CSWIP 3.1 – Welding Inspector

WIS5

Training and Examination Services
Granta Park, Great Abington
Cambridge CB21 6AL
United Kingdom

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CSWIP 3.1 – Welding Inspector

Contents

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Examination Contents

30 General multiple choice questions
45 minutes

60 Technology questions
90 minutes

20 Macroscopic questions
45 minutes

20 Plate Butt questions
75 minutes

20 Pipe Butt questions
105 minutes

70% is required in each section

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CSWIP 3.1 Welding Inspector

WIS5

Materials Joining and Engineering Technologies

Training and Examination Services

WIS5-90516b

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CSWIP 3.1 Welding Inspector

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CSWIP 3.1 Welding Inspector

Introduction

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Course Objectives

- To understand factors which influence the quality of fusion welds in steels.
- To recognise characteristics of commonly used welding processes in relation to quality control.
- To interpret drawing instructions and symbols to ensure that specifications are met.
- To set up and report on inspection of welds, macrosections and other mechanical tests.
- To assess and report on welds to acceptance levels.
- To confirm that incoming material meets stipulated requirements and recognise the effects on weld quality of departure from specification.
- To be in a position to pass the Welding Inspector - Level 2 examinations.

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The Course

The CSWIP 3.1 Welding Inspector course provides an introduction to a wide range of topics related to Welding Inspection and Quality.

- What does it contains?

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Course Contents

- Roles and duties of a Welding Inspector.
- Welding defects.
- Mechanical testing.
- Main welding processes.
- Welding symbols.
- Non-destructive testing.
- Inspection reporting.
- Welding terminology.
- Welding safety.
- Heat treatments.
- Weldability of steels.
- Joint design.
- Welding procedures.
- Welder qualification.
- Stress and distortion.
- Macro examination.
- Codes and standards.
- Welding consumables.
- Thermal cutting.

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Course Assessment

- Exam after completion of course
- No continuous assessment

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CSWIP 3.1 Examination

Before attempting the examination, you MUST provide the following:

- Two passport size photographs, with your name and signature on reverse side of both.
- Eye test certificate, the certificate must show near vision and colour tests (N4.5 or Times Roman numerals standard) and verified enrolment.
- Completed examination form, you can print from the website www.twitraining.com
- It is the sole responsibility of the candidate to provide the above. Failure to do so will delay results and certification being issued.

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CSWIP 3.1 Examination

Multiple Choice Examination

- 30 x General Multiple Choice Questions 45 Minutes
- 60 x Technology Questions 90 Minutes
- 24 x Macroscopic Questions 45 Minutes
- 20 x Plate Butt Questions 75 Minutes
- 20 x Pipe Butt Questions 105 Minutes

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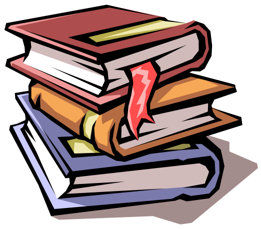
CSWIP 3.1 Examination



Closed book exam

- Any standard/code required for the examinations will be provided on the examination day.

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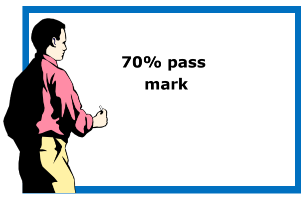
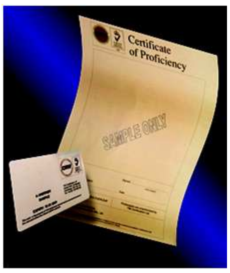
Notification of Examination Results





For every section to be awarded the certificate

2 copies of certificates and an identity card sent to delegates sponsor.

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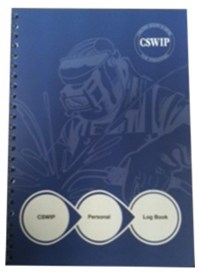
CSWIP 3.1 - 5 Year Prolongation



It is a mandatory requirement to keep an up to date log book as documentary evidence of your activities.

This will be required to be presented to CSWIP after 5 years to prolong your qualification.

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CSWIP 3.1 - 10 Year Renewals

- 10 years Renewal examination.
- 30 General multiple choice questions.
- Assessment of a welded sample.

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CSWIP Certification Scheme

- 3.0 Visual Welding Inspector.
- 3.1 Welding Inspector.
- 3.2 Senior Welding Inspector.
- Welding Quality Control Coordinator.

CERTIFICATION SCHEME CSWIP FOR PERSONNEL

For further information please see website www.cswip.com

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CSWIP Certificate Scheme

Certificate Scheme for Personnel

CERTIFICATION SCHEME CSWIP FOR PERSONNEL

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Section 1

Typical Duties of Welding Inspectors

1 Typical Duties of Welding Inspectors

1.1 General

Welding inspectors are employed to assist with the quality control (QC) activities necessary to ensure that welded items meet specified requirements and are fit for their application.

For employers to have confidence in their work, welding inspectors need to to understand/interpret the various QC procedures and also have a sound knowledge of welding technology.

Visual inspection is one of the non-destructive examination (NDE) disciplines and for some applications may be the only form.

For more demanding service conditions, visual inspection is usually followed by one or more of the other non-destructive testing (NDT) techniques - surface crack detection and volumetric inspection of butt welds.

Application Standards/Codes usually specify (or refer to other standards) that give the acceptance criteria for weld inspection and may be very specific about the particular techniques to be used for surface crack detection and volumetric inspection; they do not usually give any guidance about basic requirements for visual inspection.

Guidance and basic requirements for visual inspection are given by:

ISO 17637 (Non-destructive examination of fusion welds - visual Examination)

1.1.1 Basic requirements for visual inspection (to ISO 17637)

ISO 17637 provides the following:

- Requirements for welding inspection personnel.
- Recommendations about conditions suitable for visual examination.
- Advice on the use of gauges/inspection aids that may be needed/helpful for inspection.
- Guidance about information that may need to be in the inspection records.
- Guidance about when inspection may be required during fabrication.

A summary of each of these topics is given in the following sections.

1.1.2 Welding inspection personnel

Before starting work on a particular contract, ISO 17637 states that welding inspectors should:

- Be familiar with relevant standards, rules and specifications for the fabrication work to be undertaken.
- Be informed about the welding procedure(s) to be used.
- Have good vision – in accordance with EN 473 and checked every 12 months.

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ISO 17637 does not give or make any recommendation about a formal qualification for visual inspection of welds. However, it has become industry practice for inspectors to have practical experience of welding inspection together with a recognised qualification in welding inspection – such as a CSWIP qualification.

1.1.3 Conditions for visual inspection

Illumination

ISO 17637 states that the minimum illumination shall be 350 lux but recommends a minimum of 500 lux (normal shop or office lighting).

Access

Access to the surface for direct inspection should enable the eye to be:

- Within 600mm of the surface being inspected.
- In a position to give a viewing angle of not less than 30°.

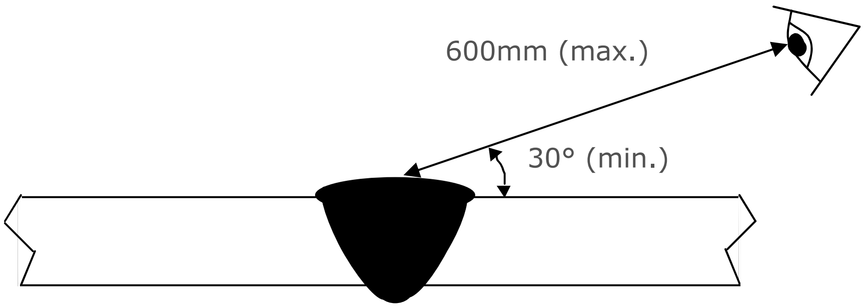

Figure 1.1 Access for visual inspection.

1.1.4 Aids to visual inspection

Where access for direct visual inspection is restricted, a mirrored boroscope or a fibre optic viewing system, may be used – usually by agreement between the contracting parties.

It may also be necessary to provide auxiliary lighting to give suitable contrast and relief effect between surface imperfections and the background.

Other items of equipment that may be appropriate to facilitate visual examination are:

- Welding gauges (for checking bevel angles and weld profile, fillet sizing, measuring undercut depth).
- Dedicated weld gap gauges and linear misalignment (hi-lo) gauges.
- Straight edges and measuring tapes.
- Magnifying lens (if a magnification lens is used it should be X2 to X5).

ISO 17637 shows a range of welding gauges together with details of what they can be used for and the precision of the measurements.

1.1.5 Stages when inspection may be required

ISO 17637 states that examination is normally performed on welds in the as-welded condition. This means that visual inspection of the finished weld is a minimum requirement.

However, ISO 17637 says that the extent of examination and the stages when inspection activity is required should be specified by the Application Standard or by agreement between client and fabricator.

For fabricated items that must have high integrity, such as pressure vessels and piping or large structures inspection, activity will usually be required throughout the fabrication process:

- Before welding.
- During welding.
- After welding.

Inspection activities at each of these stages of fabrication can be considered the duties of the welding inspector and typical inspection checks that may be required are described in the following section.

1.1.6 Typical duties of a welding inspector

The relevant standards, rules and specifications that a welding inspector should be familiar with at the start of a new contract are all the documents he will need to refer to during the fabrication sequence in order to make judgements about particular details.

Typical documents that may need to be referred to are:

- **The Application Standard (or Code)**: For visual acceptance criteria: Although most of the requirements for the fabricated item should be specified by National Standards, client standards or various QC procedures, some features are not easy to define precisely and the requirement may be given as to good workmanship standard.
- **Quality plans or inspection check lists**: For the type and extent of inspection.
- **Drawing:** For assembly/fit-up details and dimensional requirements.
- **QC procedures**: Company QC/QA procedures such as those for document control, material handling, electrode storage and issue, Welding Procedure Specifications, etc.

Examples of requirements difficult to define precisely are some shape tolerances, distortion, surface damage or the amount of weld spatter.

Good workmanship is the standard that a competent worker should be able to achieve without difficulty when using the correct tools in a particular working environment.

In practice the application of the fabricated item will be the main factor that influences what is judged to be good workmanship or the relevant client specification will determine what the acceptable level of workmanship is.

Reference samples are sometimes needed to give guidance about the acceptance standard for details such as weld surface finish and toe blend, weld root profile and finish required for welds that need to be dressed, by grinding or finishing.

A welding inspector should also ensure that any inspection aids that will be needed are:

- In good condition.
- Calibrated as appropriate/as specified by QC procedures.

Safety consciousness is a duty of all employees and a welding inspector should:

- Be aware of all safety regulations for the workplace.
- Ensure that safety equipment that will be needed is available and in suitable condition.

Duties before welding

Check	Action
Material	In accordance with drawing/WPS. Identified and can be traced to a test certificate. In suitable condition (free from damage and contamination).
WPSs	Approved and available to welders (and inspectors).
Welding equipment	In suitable condition and calibrated as appropriate.
Weld preparations	In accordance with WPS (and/or drawings).
Welder qualifications	Identification of welders qualified for each WPS to be used. All welder qualification certificates are valid (in date).
Welding consumables	Those to be used are as specified by the WPSs, are stored/controlled as specified by the QC procedure.
Joint fit-ups	In accordance with WPS/drawings tack welds are to good workmanship standard and to code/WPS.
Weld faces	Free from defects, contamination and damage.
Preheat (if required)	Minimum temperature is in accordance with WPS.

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Duties during welding

Check	Action
Site/field welding	Ensure weather conditions are suitable/comply with Code (conditions will not affect welding).
Welding process	In accordance with WPS.
Preheat (if required)	Minimum temperature is being maintained in accordance with WPS.
Interpass temperature	Maximum temperature is in accordance with WPS.
Welding consumables	In accordance with WPS and being controlled as procedure.
Welding parameters	Current, volts, travel speed are in accordance with WPS.
Root run	Visually acceptable to Code before filling the joint (for single sided welds).
Gouging/grinding	By an approved method and to good workmanship standard.
Inter-run cleaning	To good workmanship standard.
Welder	On the approval register/qualified for the WPS being used.

Duties after welding

Check	Action
Weld identification	Each weld is marked with the welder's identification and is identified in accordance with drawing/weld map.
Weld appearance	Ensure welds are suitable for all NDT (profile, cleanness, etc). Visually inspect welds and sentence in accordance with Code.
Dimensional survey	Check dimensions are in accordance with drawing/Code.
Drawings	Ensure any modifications are included on as-built drawings.
NDT	Ensure all NDT is complete and reports are available for records.
Repairs	Monitor in accordance with the procedure.
PWHT (if required)	Monitor for compliance with procedure (check chart record).
Pressure/load test (if required)	Ensure test equipment is calibrated. Monitor test to ensure compliance with procedure/Code. Ensure reports/records are available.
Documentation records	Ensure all reports/records are completed and collated as required.

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1.1.7 Examination records

The requirement for examination records/inspection reports varies according to the contract and type of fabrication and there is frequently no requirement for a formal record.

When an inspection record is required it may be necessary to show that items have been checked at the specified stages and have satisfied the acceptance criteria.

The form of this record will vary, possibly a signature against an activity on an inspection checklist or quality plan, or it may be an individual inspection report for each item.

For individual inspection reports, ISO 17637 lists typical details for inclusion such as:

- Name of manufacturer/fabricator.
- Identification of item examined.
- Material type and thickness.
- Type of joint.
- Welding process.
- Acceptance standard/criteria.
- Locations and types of all imperfections not acceptable (when specified, it may be necessary to include an accurate sketch or photograph).
- Name of examiner/inspector and date of examination.

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Typical Duties of Welding Inspectors

Section 1

Materials Joining and Engineering Technologies
Training and Examination Services

Duties of a WI Objectives

When this presentation has been completed you will have a greater understanding of the requirements of a Welding inspector before, during, and after welding. Where he/she stands in the hierarchy and the core competencies and skills required in his/her duties and obligations to quality whilst trying to facilitate, and not hold up production.

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Main Responsibilities

- Code compliance.
- Workmanship control.
- Documentation control.

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Personal Attributes

Important qualities that good Inspectors are expected to have are:

- Honesty.
- Integrity.
- Knowledge.
- Good communicator.

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Standard for Visual Inspection Basic Requirements

BS EN ISO 17637 - Non-destructive examination of fusion welds - Visual examination.

Welding Inspection Personnel should:

- Be familiar with relevant standards, rules and specifications applicable to the fabrication work to be undertaken.
- Be informed about the welding procedures to be used.
- Have good vision (which should be checked every 12 months).

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Welding Inspection

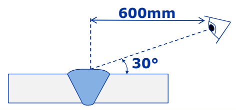
Conditions for Visual Inspection (to BS EN ISO 17637)

Illumination:

- 350 lux minimum required.
- (recommends 500 lux - normal shop or office lighting).

Vision access:

- Eye should be within 600mm of the surface.
- Viewing angle (line from eye to surface) to be not less than 30°.



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Welding Inspection

Aids to Visual Inspection (to BS EN ISO 17637)

- When access is restricted may use:
- A mirrored borescope.
- A fibre optic viewing system.

} **usually by agreement**

Other aids:

- Welding gauges (for checking bevel angles, weld profile, fillet sizing, undercut depth).
- Dedicated weld-gap gauges and linear misalignment (high-low) gauges.
- Straight edges and measuring tapes.
- Magnifying lens (if magnification lens used it should have magnification between X2 to X5).

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Welding Inspectors Equipment

Measuring devices:

- Flexible tape, steel rule.
- Temperature indicating crayons.
- Welding gauges.
- Voltmeter.
- Ammeter.
- Magnifying glass
- Torch/flash light.
- Gas flowmeter.

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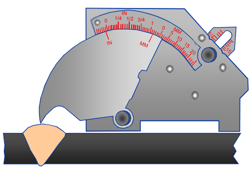
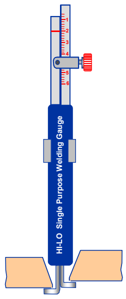
Welding Inspectors Gauges



TWI Multi-purpose Welding Gauge



Misalignment Gauges

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Welding Inspectors Equipment

Multi-meter capable of measuring amperage and voltage.

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Welding Inspection

Stages of Visual Inspection (to BS EN ISO 17637)

Extent of examination and when required should be defined in the application standard or by agreement between the contracting parties.

For high integrity fabrications inspection required throughout the fabrication process:

- Before welding.
- During welding.
- After welding.

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Duties of a Welding Inspector

- Before welding:
  - (before assembly).
  - (after assembly).
- During welding.
- After welding.

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Typical Duties of a Welding Inspector

Before welding

Preparation:

Familiarisation with relevant documents…

- Application standard/code - for visual acceptance requirements.
- Drawings - item details and positions/tolerances etc.
- Quality Control Procedures - for activities such as material handling, documentation control, storage and issue of welding consumables.
- Quality Plan/Inspection and Test Plan/Inspection Checklist - details of inspection requirements, inspection procedures and records required.

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Typical Duties of a Welding Inspector

Before welding

Welding procedures:
- Are applicable to joints to be welded and approved.
- Are available to welders and inspectors.

Welder qualifications:
- List of available qualified welders related to WPS's.
- Certificates are valid and in-date.

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Typical Duties of a Welding Inspector

Before welding

Equipment:
- All inspection equipment is in good condition and calibrated as necessary.
- All safety requirements are understood and necessary equipment available.

Materials:
- Can be identified and related to test certificates.
- Are of correct dimensions.
- Are in suitable condition (no damage/contamination).

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Typical Duties of a Welding Inspector

Before welding

Consumables:
- In accordance with WPS's.
- Are being controlled in accordance with procedure.

Weld preparations:
- Comply with WPS/drawing.
- Free from defects and contamination.

Welding equipment:
- In good order and calibrated as required by procedure.

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Typical Duties of a Welding Inspector

Before welding

Fit-up
- Complies with WPS.
- Number/size of tack welds to code/good workmanship.

Pre-heat
- If specified.
- Minimum temperature complies with WPS.

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Typical Duties of a Welding Inspector

During welding

Weather conditions
- Suitable if site/field welding.

Welding process(es)
- In accordance with WPS.

Welder
- Is approved to weld the joint.
- Pre-heat (if required).
- Minimum temperature as specified by WPS.
- Maximum interpass temperature as WPS.

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Typical Duties of a Welding Inspector

During welding

Welding consumables
- In accordance with WPS.
- In suitable condition.
- Controlled issue and handling.

Welding parameters
- Current, voltage and travel speed – as WPS.
- Root runs.
- If possible, visually inspect root before single-sided welds are filled up.

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Typical Duties of a Welding Inspector

During welding

Inter-run dressing
- In accordance with an approved method (and back gouging) to good workmanship standard.
- Distortion control.
- Welding is balanced and over-welding is avoided.

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Typical Duties of a Welding Inspector

After welding

Weld identification
- Identified/numbered as required.
- Is marked with welder's identity.

Visual inspection
- Ensure weld is suitable for **all** NDT.
- Visually inspect and sentence to code requirements.

Dimensional survey
- Ensure dimensions comply with code/drawing.

Other NDT
- Ensure all NDT is completed and reports available.

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Typical Duties of a Welding Inspector

After welding

Repairs
- Monitor repairs to ensure compliance with procedure PWHT.
- Monitor for compliance with procedure.
- Check chart records confirm procedure compliance.

Pressure/load test
- Ensure test equipment is suitably calibrated.
- Monitor to ensure compliance with procedure.
- Ensure all records are available.

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Typical Duties of a Welding Inspector

After welding

Documentation
- Ensure any modifications are on as-built drawings.
- Ensure all required documents are available.
- Collate/file documents for manufacturing records.
- Sign all documentation and forward it to QC department.

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WI Duties Before Welding

Resume:
- Check all documentation.
- Check all consumables.
- Check materials, dimensions and condition.
- Preheating, method and temperature.
- Check fit and set-up.
- Ensure no undue stress is applied to the joint.
- Check welding equipment.

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WI Duties During Welding

Resume:
- Check amperage, voltage, polarity.
- Ensure the correct technique, run sequence.
- Check run out lengths, time lapses.
- Cleaning between passes.
- Interpass temperatures.
- Consumable control.
- Maintenance of records and reports.

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WI Duties After Welding

Resume:
- Post cleaning.
- Visual inspection of completed welded joint.
- Check weld contour and width.
- PWHT.
- Dimensional accuracy.
- Weld reports.
- Tie up with NDT.
- Monitor any repairs.

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Summary of Duties

It is the duty of a Welding Inspector to ensure all the welding and associated actions are carried out in accordance with the specification and any applicable procedures.

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Summary of Duties

A Welding Inspector must:

Observe
- To observe all relevant actions related to weld quality throughout production.

Record
- To record, or log all production inspection points relevant to quality, including a final report showing all identified imperfections.

Compare
- To compare all recorded information with the acceptance criteria and any other relevant clauses in the applied application standard.

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Any Questions

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Section 2

Terms and Definitions

2 Terms and Definitions

The following definitions are taken from BS 499-1: Welding terms and symbols – Glossary for welding, brazing and thermal cutting.

Brazing

A process of joining generally applied to metals in which, during or after heating, molten filler metal is drawn into or retained in the space between closely adjacent surfaces of the parts to be joined by capillary attraction. In general, the melting point of the filler metal is above 450°C but always below the melting temperature of the parent material.

Braze welding

The joining of metals using a technique similar to fusion welding and a filler metal with a lower melting point than the parent metal, but neither using capillary action as in brazing nor intentionally melting the parent metal.

Joint

A connection where the individual components, suitably prepared and assembled, are joined by welding or brazing.

Weld

A union of pieces of metal made by welding.

Welding

An operation in which two or more parts are united by means of heat, pressure or both, in such a way that there is continuity in the nature of the metal between these parts.

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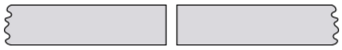
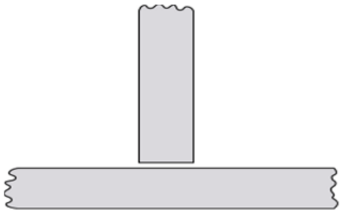
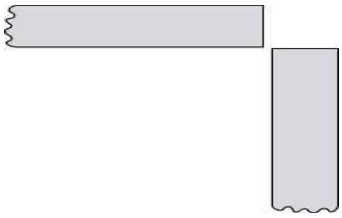
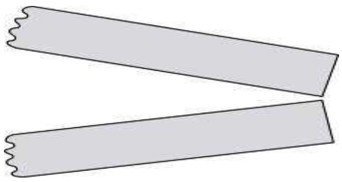
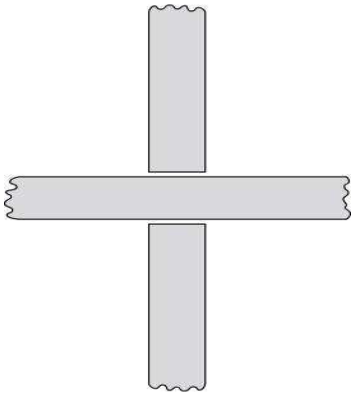
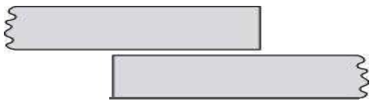
Table 2.1 Joint types, sketches and definitions.

Type of joint	Sketch	Definition
Butt		Connection between the ends or edges of two parts making an angle to one another of 135-180° inclusive in the region of the joint.
T		Connection between the end or edge of one part and the face of the other part, the parts making an angle to one another of more than 5 up to and including 90° in the region of the joint.
Corner		Connection between the ends or edges of two parts making an angle to one another of more than 30 but less than 135° in the region of the joint.
Edge		A connection between the edges of two parts making an angle to one another of 0-30° inclusive in the region of the joint.
Cruciform		A connection in which two flat plates or two bars are welded to another flat plate at right angles and on the same axis.
Lap		Connection between two overlapping parts making an angle to one another of 0-5° inclusive in the region of the weld or welds.

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2.1 Types of weld

2.1.1 From the configuration point of view (as per 2.2)

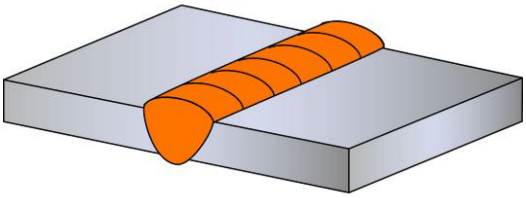

Figure 2.1 Butt weld.

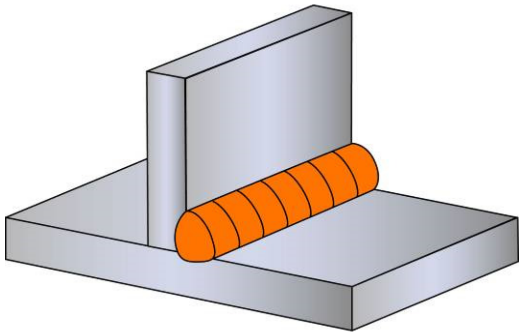

Figure 2.2 Fillet weld.

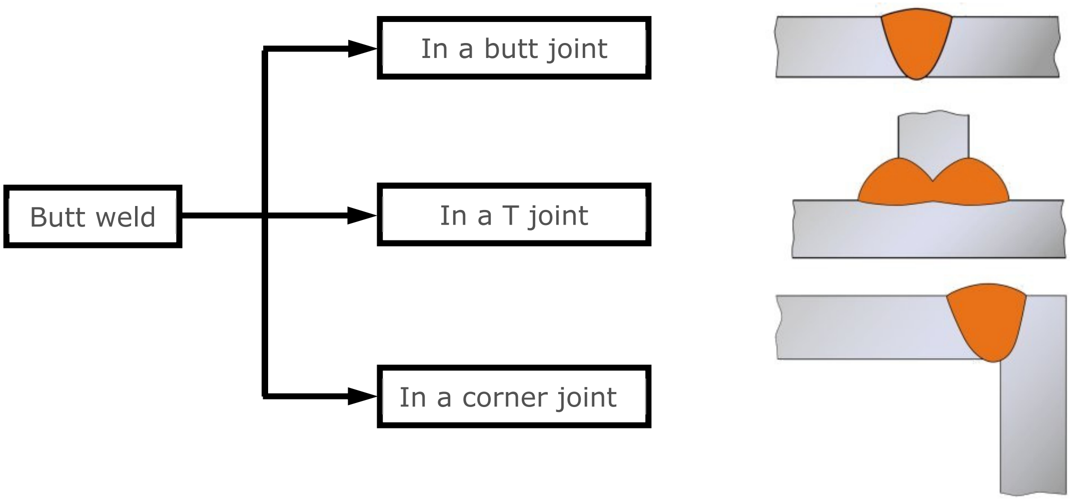

Figure 2.3 Configurations of a butt weld.

Autogenous weld

A fusion weld made without filler metal by TIG, plasma, electron beam, laser or oxy-fuel gas welding.

Slot weld

A joint between two overlapping components made by depositing a fillet weld round the periphery of a hole in one component so as to join it to the surface of the other component exposed through the hole.

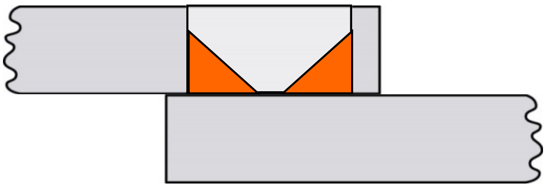

Figure 2.4 Slot weld.

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Plug weld

A weld made by filling a hole in one component of a workpiece with filler metal so as to join it to the surface of an overlapping component exposed through the hole (the hole can be circular or oval).

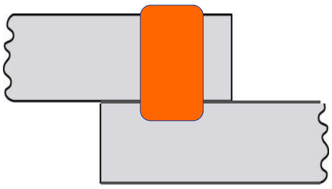

Figure 2.5 A plug weld.

2.1.2 From the penetration point of view

Full penetration weld

A welded joint where the weld metal fully penetrates the joint with complete root fusion. In the US the preferred term is complete joint penetration (CJP) weld (see AWS D1.1.).

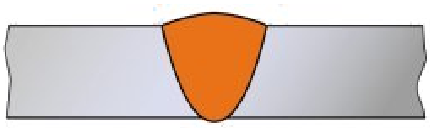

Figure 2.6 A full penetration weld.

Partial penetration weld

A welded joint without full penetration. In the US the preferred term is partial joint penetration (PJP) weld.

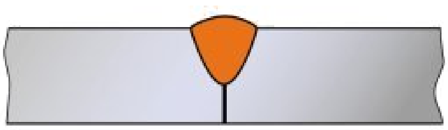

Figure 2.7 A partial penetration weld.

2.2 Types of joints (see BS EN ISO 15607)

Homogeneous

Welded joint in which the weld metal and parent material have no significant differences in mechanical properties and/or chemical composition. Example: Two carbon steel plates welded with a matching carbon steel electrode.

Heterogeneous

Welded joint in which the weld metal and parent material have significant differences in mechanical properties and/or chemical composition. Example: A repair weld of a cast iron item performed with a nickel-based electrode.

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Dissimilar/Transition

Welded joint in which the parent materials have significant differences in mechanical properties and/or chemical composition. Example: A carbon steel lifting lug welded onto an austenitic stainless steel pressure vessel.

2.3 Features of the completed weld

- **Parent metal**
  Metal to be joined or surfaced by welding, braze welding or brazing.

- **Filler metal**
  Metal added during welding, braze welding, brazing or surfacing.

- **Weld metal**
  All metal melted during the making of a weld and retained in the weld.

- **Heat-affected zone (HAZ)**
  The part of the parent metal metallurgically affected by the heat of welding or thermal cutting but not melted.

- **Fusion line**
  Boundary between the weld metal and the HAZ in a fusion weld.

- **Weld zone**
  Zone containing the weld metal and the HAZ.

- **Weld face**
  The surface of a fusion weld exposed on the side from which the weld has been made.

- **Root**
  Zone on the side of the first run furthest from the welder.

- **Toe**
  Boundary between a weld face and the parent metal or between runs. This is a very important feature of a weld since toes are points of high stress concentration and often are initiation points for different types of cracks (eg fatigue and cold cracks). To reduce the stress concentration, toes must blend smoothly into the parent metal surface.

- **Excess weld metal**
  Weld metal lying outside the plane joining the toes. Other non-standard terms for this feature are reinforcement and overfill.

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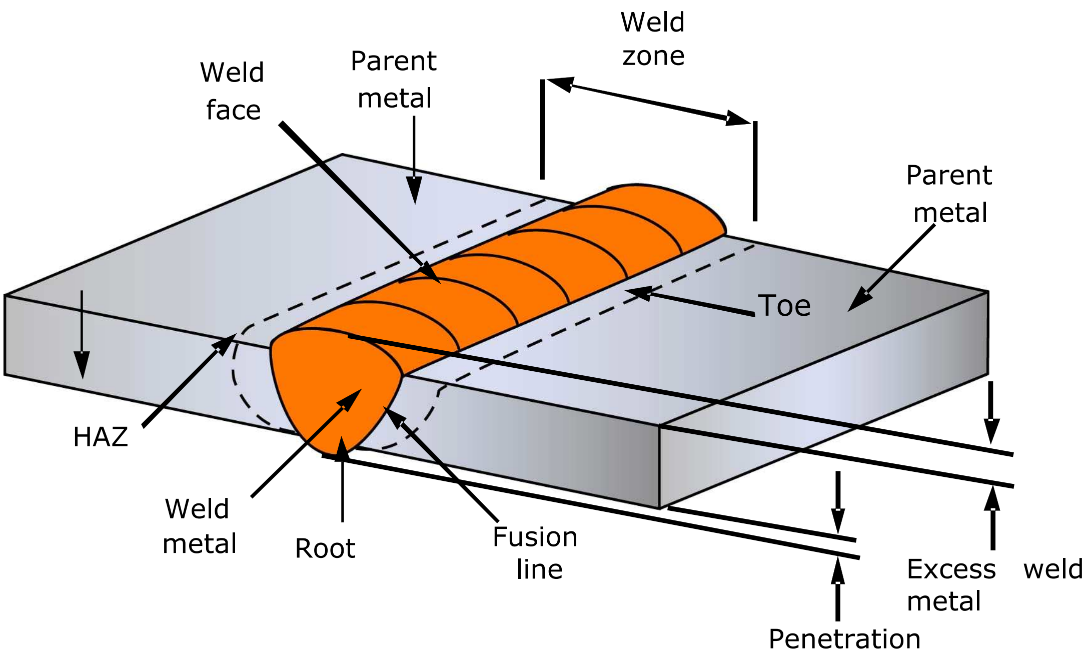

Figure 2.8 Labelled features of a butt weld.

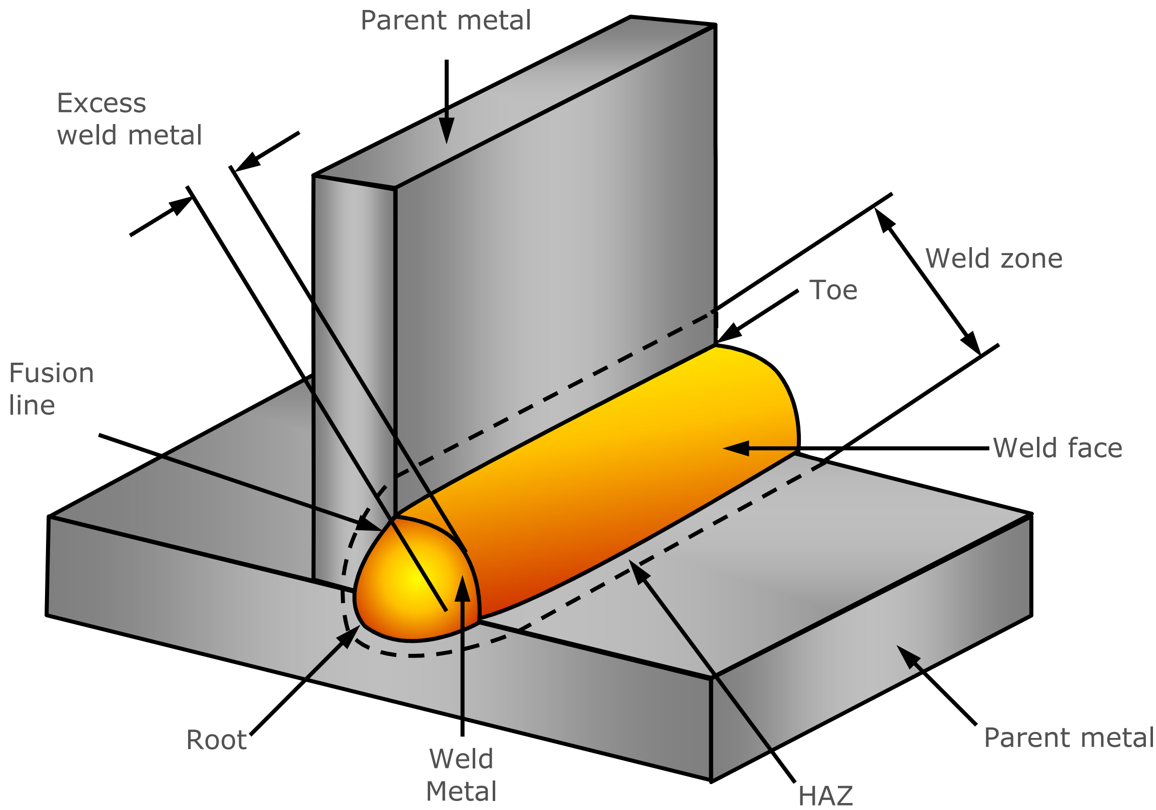

Figure 2.9 Labelled features of a fillet weld.

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2.4 Weld preparation

A preparation for making a connection where the individual components, suitably prepared and assembled, are joined by welding or brazing. The dimensions below can vary depending on WPS.

2.4.1 Features of the weld preparation

Angle of bevel

The angle at which the edge of a component is prepared for making a weld.

For an MMA weld on carbon steel plates, the angle is:

- 25-30° for a V preparation.
- 8-12° for a U preparation.
- 40-50° for a single bevel preparation.
- 10-20° for a J preparation.

Included angle

The angle between the planes of the fusion faces of parts to be welded. For single and double V or U this angle is twice the bevel angle. In the case of single or double bevel, single or double J bevel, the included angle is equal to the bevel angle.

Root face

The portion of a fusion face at the root that is not bevelled or grooved. Its value depends on the welding process used, parent material to be welded and application; for a full penetration weld on carbon steel plates, it has a value of 1-2mm (for the common welding processes).

Gap

The minimum distance at any cross-section between edges, ends or surfaces to be joined. Its value depends on the welding process used and application; for a full penetration weld on carbon steel plates, it has a value of 1-4mm.

Root radius

The radius of the curved portion of the fusion face in a component prepared for a single or double J or U, weld.

Land

Straight portion of a fusion face between the root face and the radius part of a J or U preparation can be 0. Usually present in weld preparations for MIG welding of aluminium alloys.

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2.4.2 Types of preparation

Open square butt preparation

Used for welding thin components from one or both sides. If the root gap is zero (ie if components are in contact), this preparation becomes a closed square butt preparation (not recommended due to problems caused by lack of penetration)!

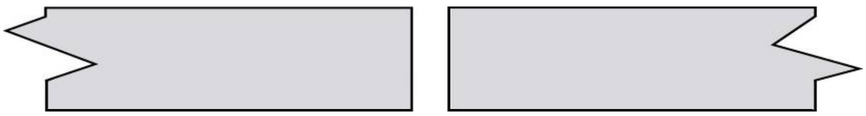

Figure 2.10 Open square butt preparation.

Single V preparation

One of the most common preparations used in welding and can be produced using flame or plasma cutting (cheap and fast). For thicker plates a double V preparation is preferred since it requires less filler material to complete the joint and the residual stresses can be balanced on both sides of the joint resulting in lower angular distortion.

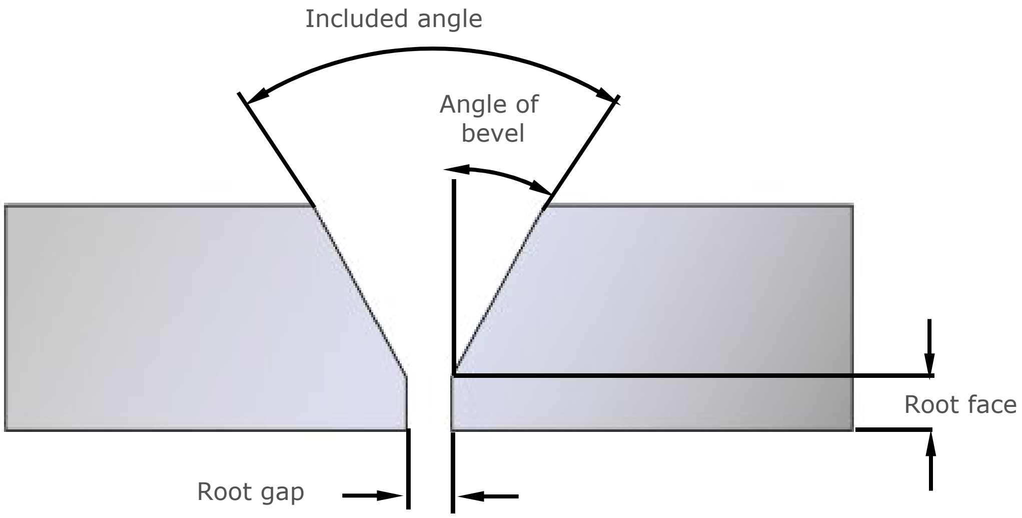

Figure 2.11 Single V preparation.

Double V preparation

The depth of preparation can be the same on both sides (symmetric double V preparation) or deeper on one side (asymmetric double V preparation). Usually, in this situation the depth of preparation is distributed as 2/3 of the thickness of the plate on the first side with the remaining 1/3 on the backside. This asymmetric preparation allows for a balanced welding sequence with root back gouging, giving lower angular distortions. Whilst a single V preparation allows welding from one side, double V preparation requires access to both sides (the same applies for all double sided preparations).

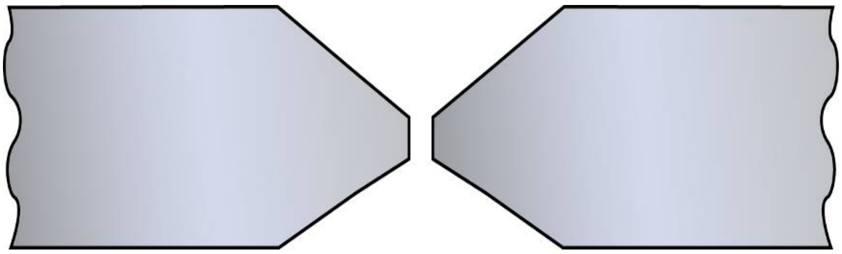

Figure 2.12 Symmetric double V preparation.

Single U preparation

U preparations can be produced only by machining (slow and expensive), however, tighter tolerances give a better fit-up than with V preparations. Usually applied to thicker plates compared with single V preparation as it requires less filler material to complete the joint, lower residual stresses and distortions. Like for V preparations, with very thick sections a double U preparation can be used.

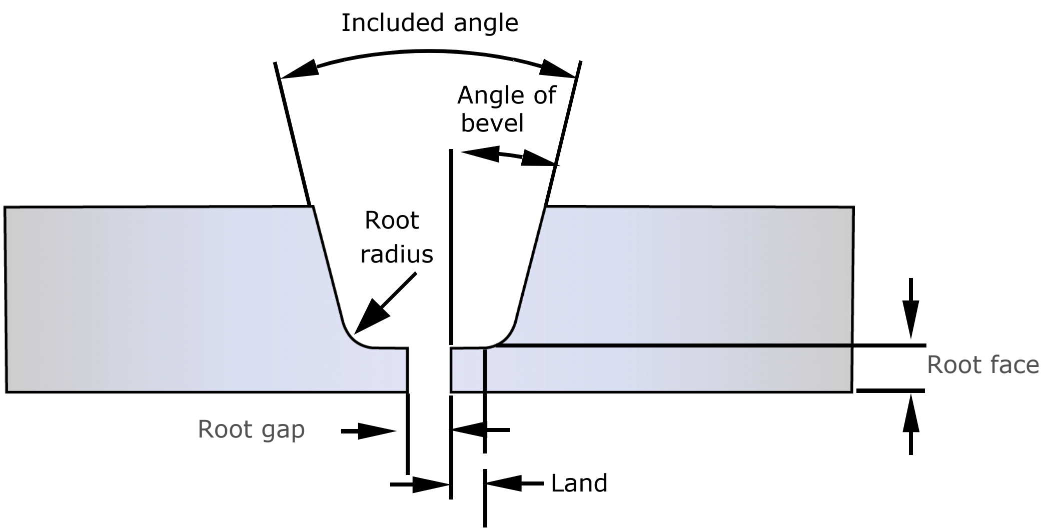

Figure 2.13 Single U preparation.

Double U preparation

Usually this type of preparation does not require a land, (except for aluminium alloys).

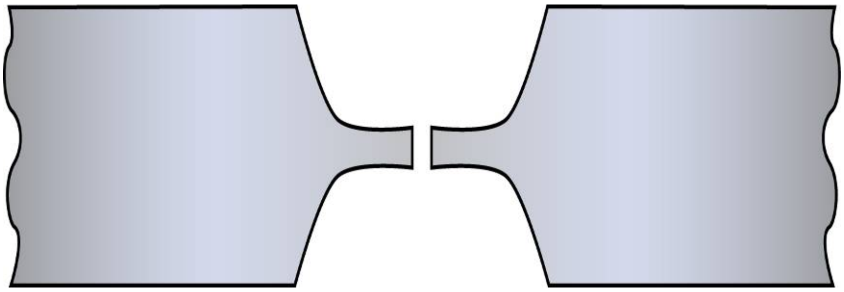

Figure 2.14 Double U preparation.

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Single V preparation with backing strip

Backing strips allow production of full penetration welds with increased current and hence increased deposition rates/productivity without the danger of burn-through. Backing strips can be permanent or temporary.

Permanent types are made of the same material as being joined and are tack welded in place. The main problems with this type of weld are poor fatigue resistance and the probability of crevice corrosion between the parent metal and the backing strip.

It is also difficult to examine by NDT due to the built-in crevice at the root of the joint. Temporary types include copper strips, ceramic tiles and fluxes.

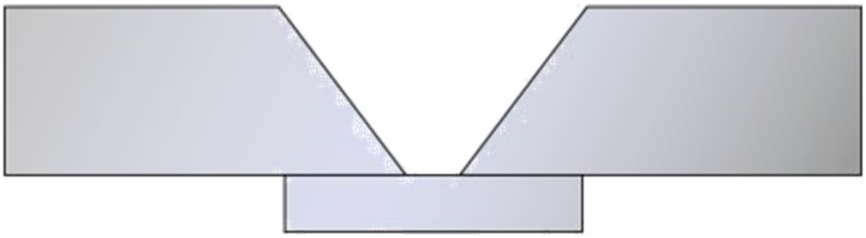

Figure 2.15 Single V preparation with backing strip.

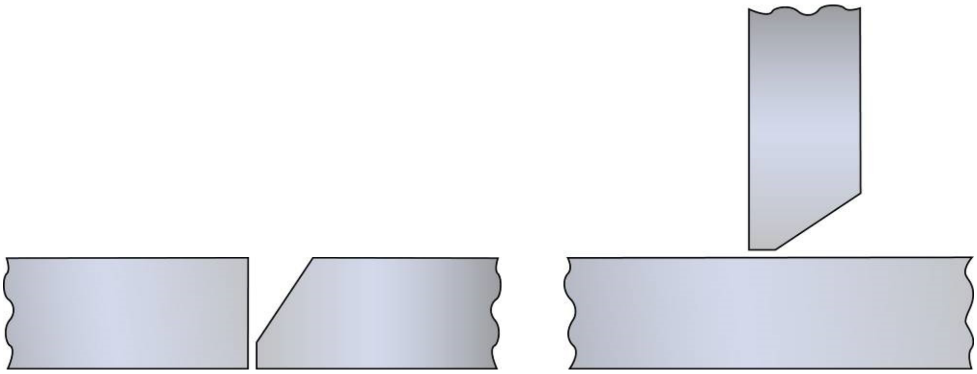

Figure 2.16 Single bevel preparation.

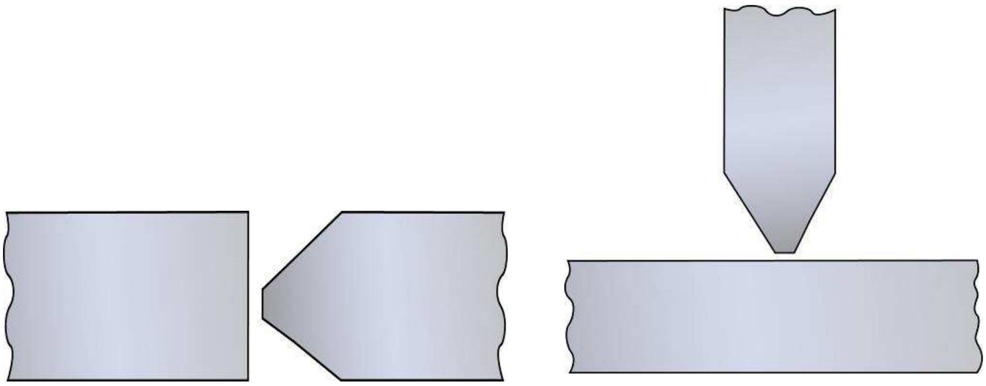

Figure 2.17 Double bevel preparation.

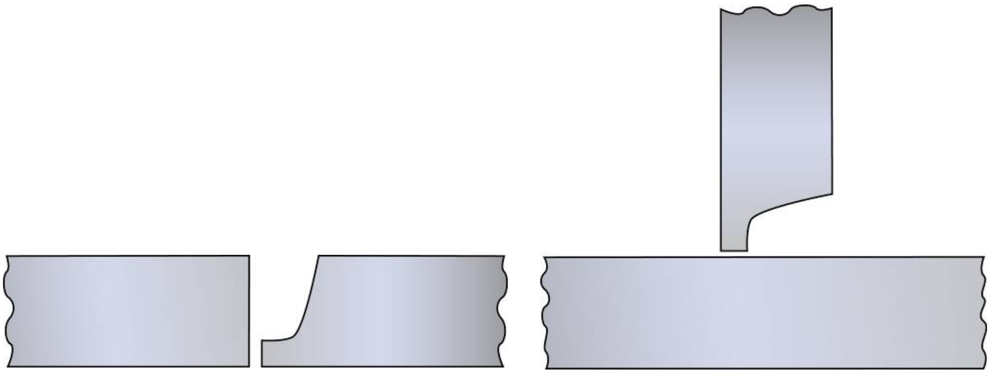

Figure 2.18 Single J preparation.

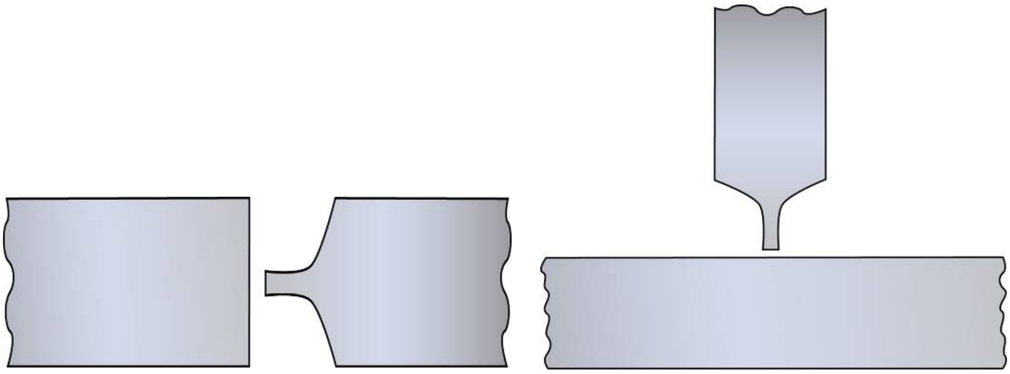

Figure 2.19 Double J preparation.

All these preparations (single/double bevel and J) can be used on T joints as well. Double preparations are recommended for thick sections. The main advantage of these preparations is that only one component is prepared (cheap, can allow for small misalignments).

For further details regarding weld preparations, please refer to Standard BS EN ISO 9692.

2.5 Size of butt welds

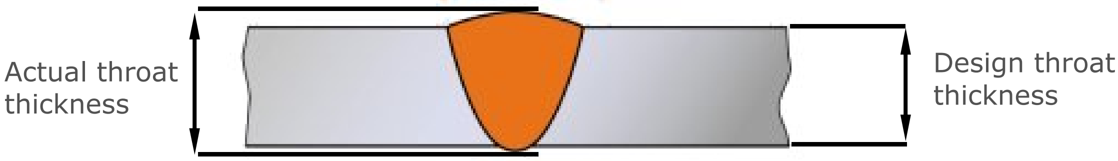

Figure 2.20 Full penetration butt weld.

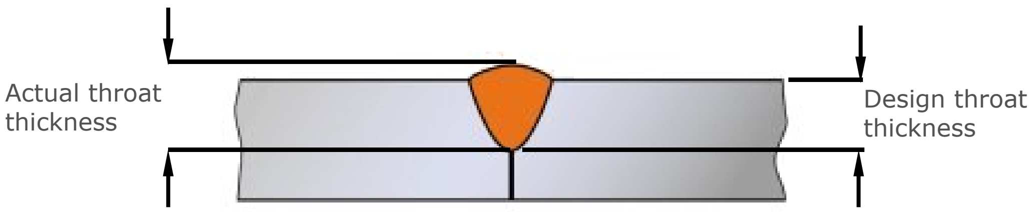

Figure 2.21 Partial penetration butt weld.

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As a general rule:

Actual throat thickness = design throat thickness + excess weld metal.

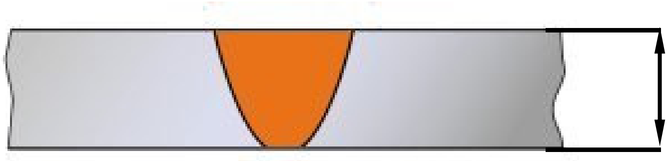

Figure 2.22 Full penetration butt weld ground flush.

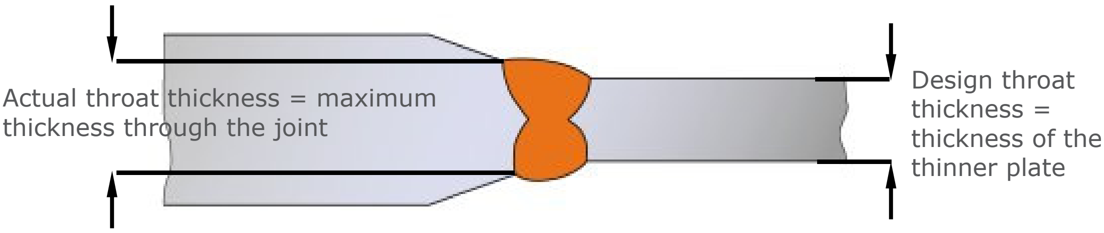

Figure 2.23 Butt weld between two plates of different thickness.

Run (pass)
The metal melted or deposited during one pass of an electrode, torch or blowpipe.

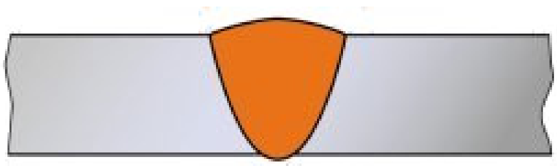

Figure 2.24 Single run weld.

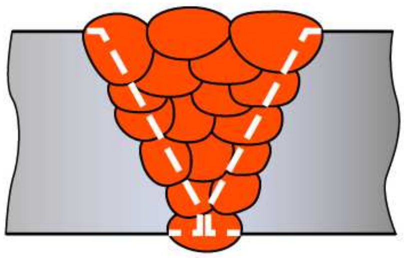

Figure 2.25 Multi-run weld.

Layer
A stratum of weld metal consisting of one or more runs.

Types of butt weld (from accessibility point of view)

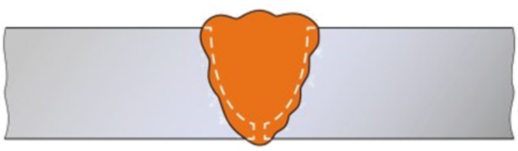

Figure 2.26Single side weld.

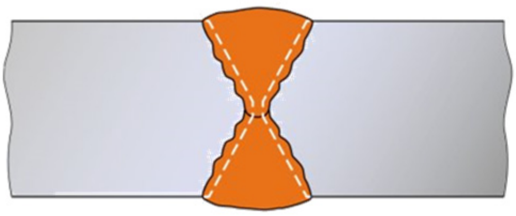

Figure 2.27 Double side weld.

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2.6 Fillet weld

A fusion weld, other than a butt, edge or fusion spot weld, which is approximately triangular in transverse cross-section.

2.6.1 Size of fillet welds

Unlike butt welds, fillet welds can be defined using several dimensions.

Actual throat thickness

Perpendicular distance between two lines, each parallel to a line joining the outer toes, one being a tangent at the weld face and the other being through the furthermost point of fusion penetration.

Design throat thickness

The minimum dimension of throat thickness used for design purposes, also known as effective throat thickness. (a on drawings).

Leg length

Distance from the actual or projected intersection of the fusion faces and the toe of a fillet weld, measured across the fusion face (z on drawings).

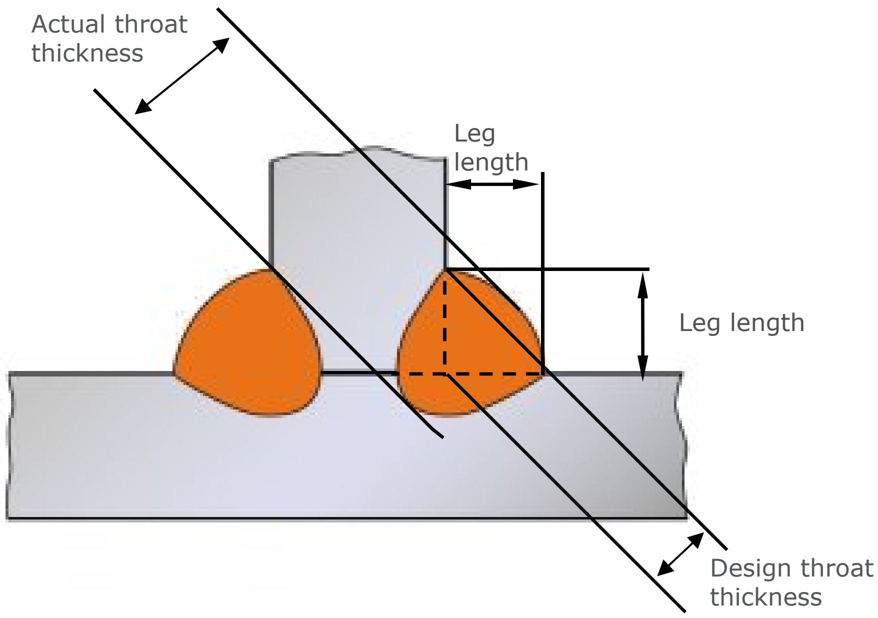

Figure 2.28 Fillet weld.

2.6.2 Shape of fillet welds

Mitre fillet weld

A flat face fillet weld in which the leg lengths are equal within the agreed tolerance. The cross-section area of this type of weld can be considered to be a right angle isosceles triangle with design throat thickness a and leg length z. The relation between design throat thickness and leg length is:

$$a = 0.707 \times z \quad \text{or} \quad z = 1.41 \times a$$

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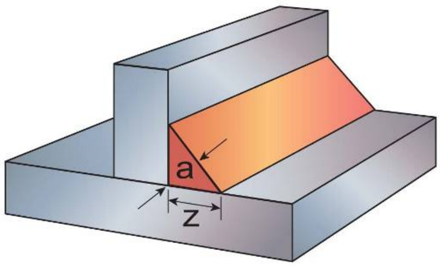

Figure 2.29 Mitre fillet weld.

Convex fillet weld

A fillet weld in which the weld face is convex. The above relation between leg length and design throat thickness for mitre fillet welds is also valid for this type of weld. Since there is excess weld metal present, the actual throat thickness is bigger than the design throat thickness.

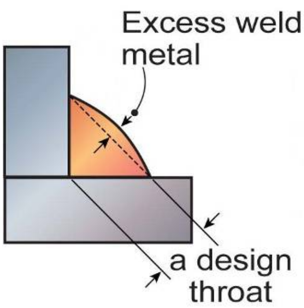

Figure 2.30 Convex fillet weld

Concave fillet weld

A fillet weld in which the weld face is concave. The relation between leg length and design throat thickness specified for mitre fillet welds is not valid for this type of weld. Also, the design throat thickness is equal to the actual throat thickness.

Due to the smooth blending between the weld face and the surrounding parent material, the stress concentration effect at the toes of the weld is reduced compared with the previous type. This is why this type of weld is highly desired in applications subjected to cyclic loads where fatigue phenomena might be a major cause for failure.

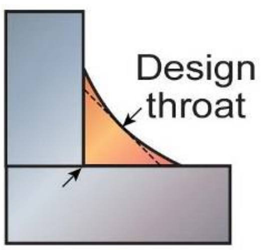

Figure 2.31 Concave fillet weld.

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Asymmetrical fillet weld

A fillet weld in which the vertical leg length is not equal to the horizontal leg length. The relation between leg length and design throat thickness is not valid for this type of weld because the cross-section is not an isosceles triangle.

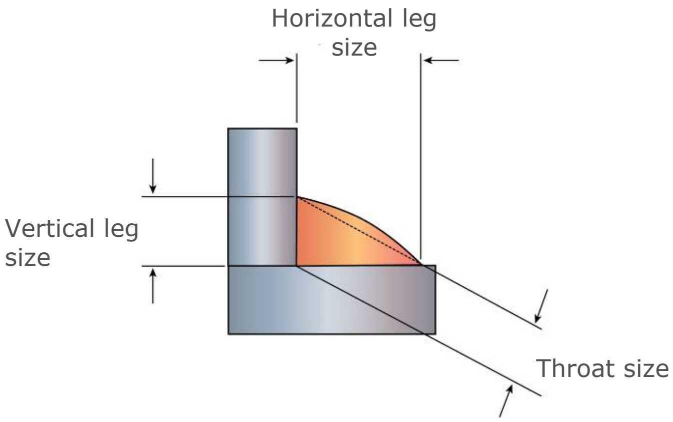

Figure 2.32 Asymmetrical fillet weld.

Deep penetration fillet weld

A fillet weld with a deeper than normal penetration. It is produced using high heat input welding processes (ie SAW or MAG with spray transfer). This type of weld uses the benefits of greater arc penetration to obtain the required throat thickness whilst reducing the amount of deposited metal needed thus leading to a reduction in residual stress level.

To produce consistent and constant penetration, the travel speed must be kept constant at a high value. Consequently this type of weld is usually produced using mechanised or automatic welding processes. Also, the high depth-to-width ratio increases the probability of solidification centreline cracking. To differentiate this type of weld from the previous types, the throat thickness is symbolised with s instead of a.

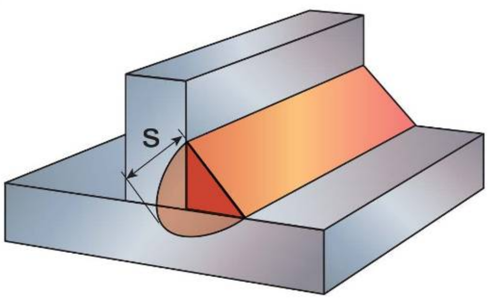

Figure 2.33 Deep penetgration fillet weld.

2.6.3 Compound of butt and fillet welds

A combination of butt and fillet welds used for T joints with full or partial penetration or butt joints between two plates with different thickness. Fillet welds added on top of the groove welds improve the blending of the weld face towards the parent metal surface and reduce the stress concentration at the toes of the weld.

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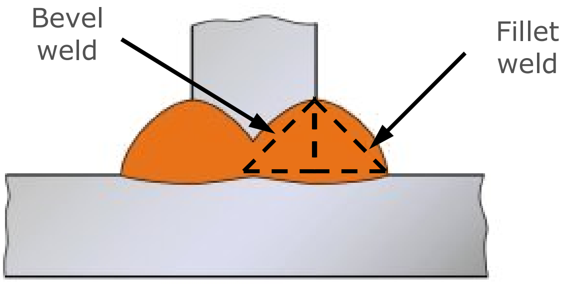

Figure 2.34 Double bevel compound weld.

2.7 Welding position, slope and rotation

Welding position

Orientation of a weld expressed in terms of working position, weld slope and weld rotation (for further details see ISO 6947).

Weld slope

Angle between root line and the positive X axis of the horizontal reference plane, measured in mathematically positive direction (ie counter-clockwise).

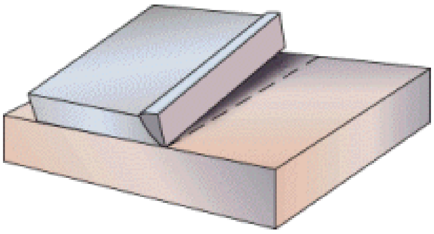

Figure 2.35 Weld slope.

Weld rotation

Angle between the centreline of the weld and the positive Z axis or a line parallel to the Y axis, measured in the mathematically positive direction (ie counter-clockwise) in the plane of the transverse cross-section of the weld in question.

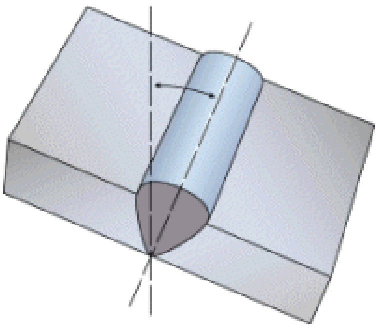

Figure 2.36 Weld rotation.

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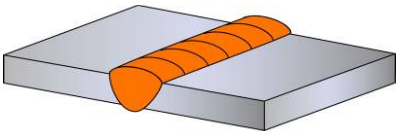
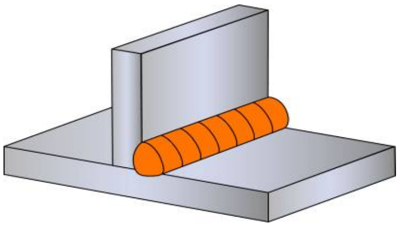
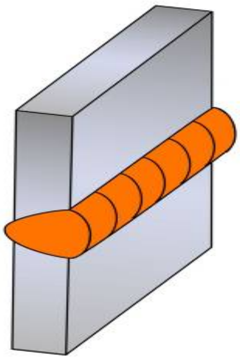
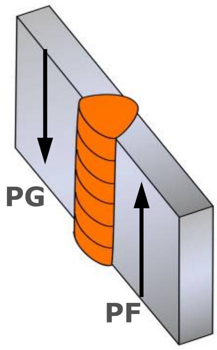
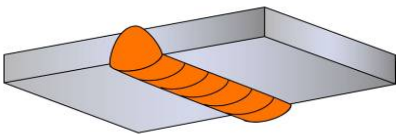
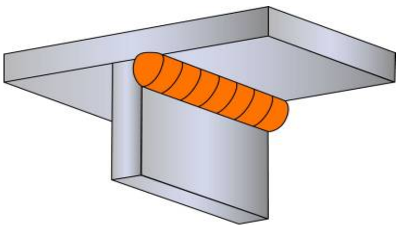
Table 2.2 Welding position, sketches and definition.

Welding position	Sketch	Definition and symbol according to ISO 6947
Flat		Welding position in which the welding is horizontal with the centreline of the weld vertical. PA.
Horizontal-vertical		Welding position in which the welding is horizontal (applicable in case of fillet welds). PB.
Horizontal		Welding position in which the welding is horizontal, with the centreline of the weld horizontal. PC.
Vertical-up		Welding position in which the welding is upwards. PF.
Vertical-down		Welding position in which the welding is downwards. PG.
Overhead		A welding position in which the welding is horizontal and overhead (applicable in fillet welds). PE.
Horizontal-overhead		Welding position in which the welding is horizontal and overhead with the centreline of the weld horizontal. PD.

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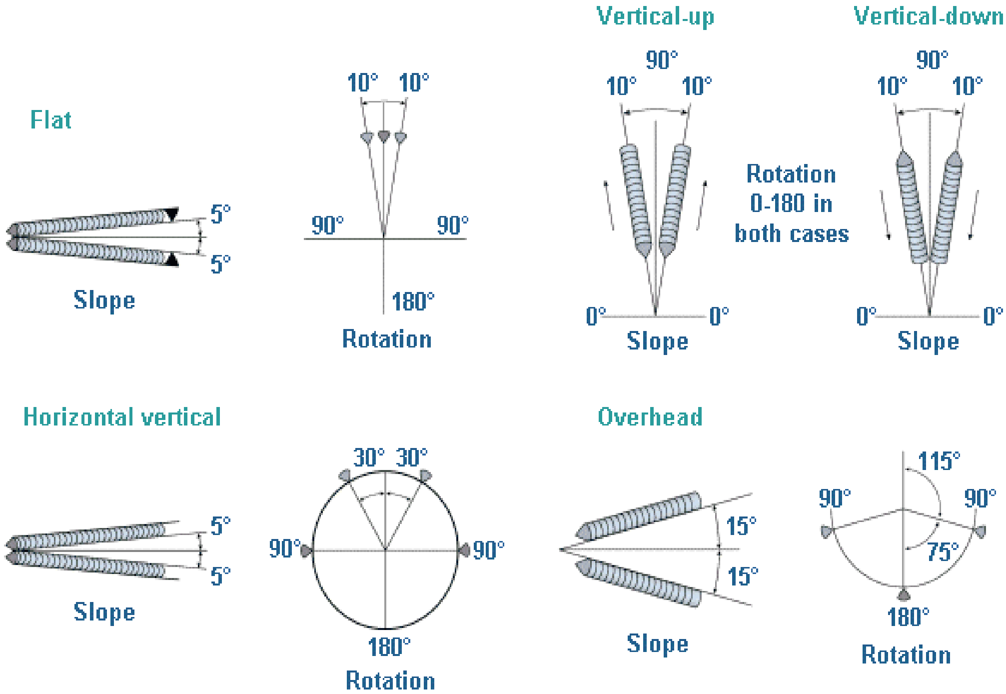

Figure 2.37 Tolerances for the welding positions.

2.8 Weaving

Transverse oscillation of an electrode or blowpipe nozzle during the deposition of weld metal, generally used in vertical-up welds.

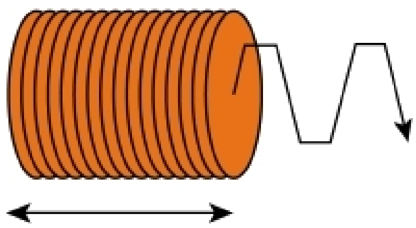

Figure 2.38 Weaving.

Stringer bead

A run of weld metal made with little or no weaving motion.

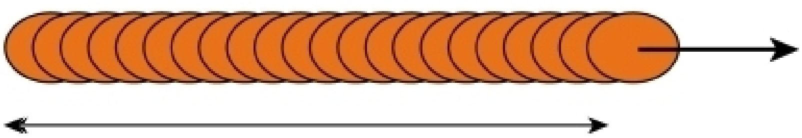

Figure 2.39 Stringer bead.

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Welding Terminology and Definitions

Section 2

Materials Joining and Engineering Technologies
Training and Examination Services

Terminology Objective

When this presentation has been completed you will have a greater understanding of typical international language used in joint design and compilation of welding documentation.

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Welding Terminology and Definitions

What is a Weld?

- A localised coalescence of metals or non-metals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone (AWS).
- A permanent union between materials caused by heat, and or pressure BS EN.

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Welding Terminology and Definitions

What is a Joint?

- The junction of members or the edges of members that are to be joined or have been joined (AWS).
- A configuration of members (BS EN).

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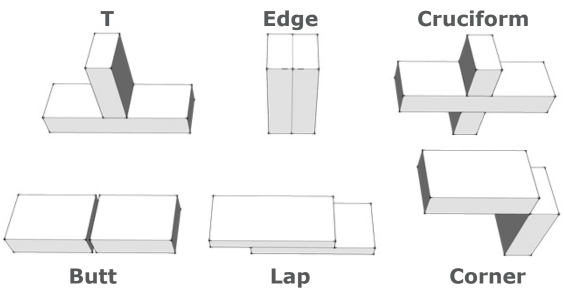
Joint Terminology



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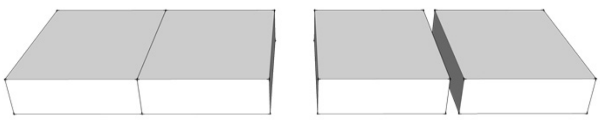
Butt Preparations



Square Edge Closed Butt

Square Edge Open Butt

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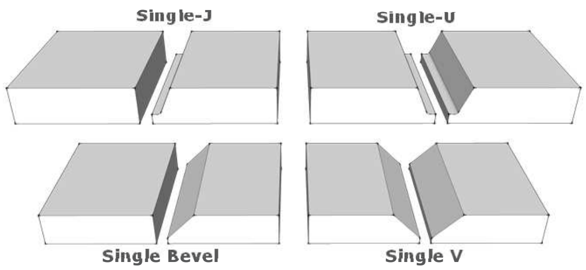
Single Sided Butt Preparations

Single sided preparations are normally made on thinner materials, or when access form both sides is restricted.



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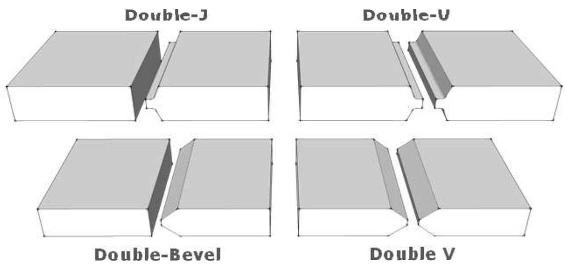
Double Sided Butt Preparations

Double sided preparations are normally made on thicker materials, or when access form both sides is unrestricted.



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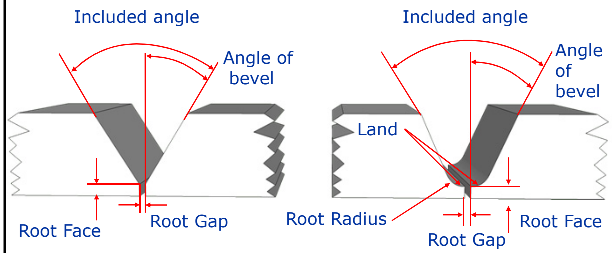
Joint Preparation Terminology



Single-V butt

Single-U butt

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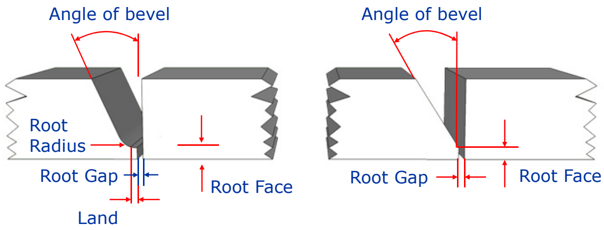
Joint Preparation Terminology



Single-J Butt

Single Bevel Butt

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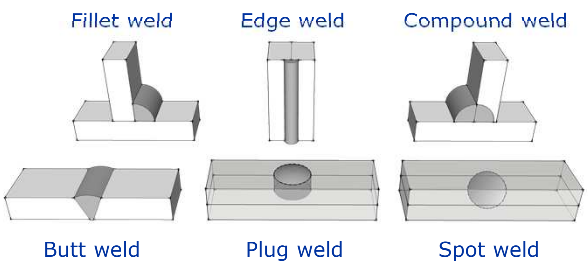
Weld Terminology



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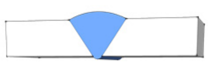
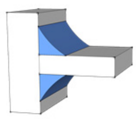
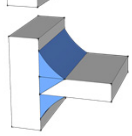
Welded Butt Joints



A butt welded butt joint



A fillet welded joint



A compound welded butt joint

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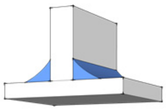
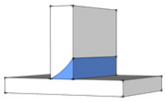
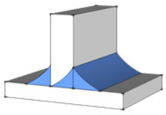
Welded T Joints



A fillet welded T joint



A butt welded T joint



A compound welded T joint

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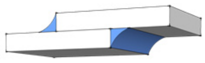
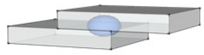
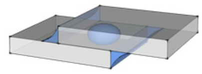
Welded Lap Joints



A fillet welded lap joint



A spot welded lap joint



A compound welded lap joint

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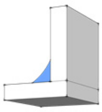
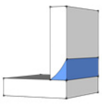
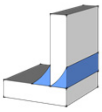
Welded Closed Corner Joints



A fillet welded closed corner joint



A butt welded closed corner joint



A compound welded closed corner joint

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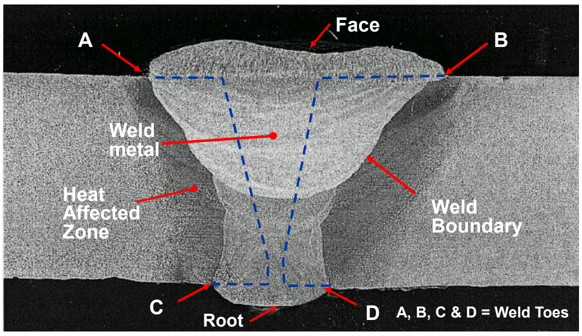
Weld Zone Terminology



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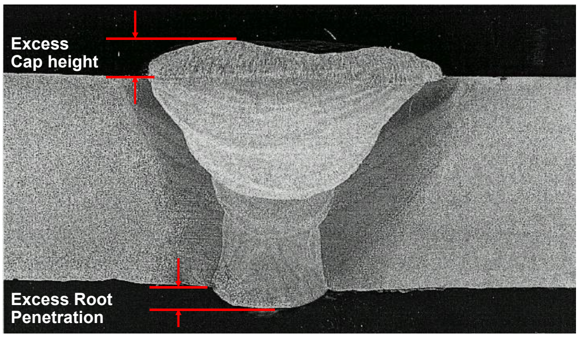
Weld Zone Terminology



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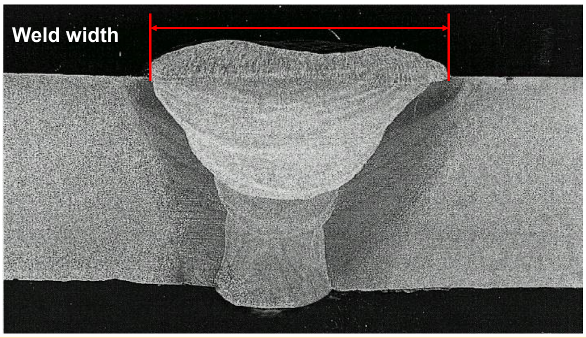
Weld Zone Terminology



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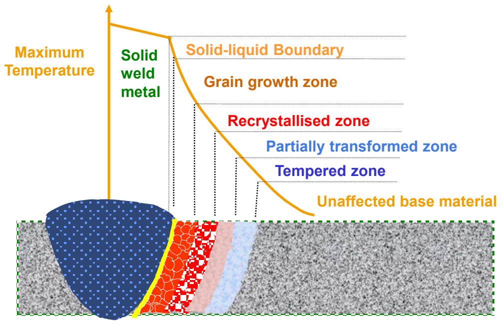
Heat Affected Zone (HAZ)



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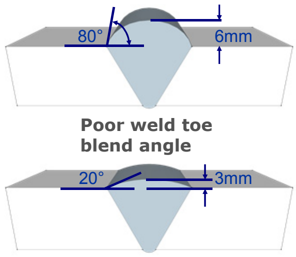
Toe Blend



Improved weld toe blend angle

- Most codes quote the weld toes shall blend smoothly.
- This statement is not quantitative and therefore open to individual interpretation.
- The higher the toe blend angle the greater the amount of stress concentration.
- The toe blend angle ideally should be between 20-30°.

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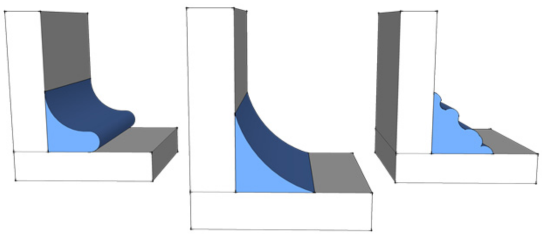
Features to Consider

Fillet welds - toe blend



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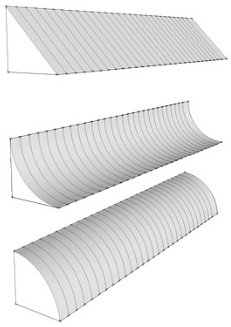
Fillet Weld Profiles

Mitre fillet

Concave fillet

A concave profile is preferred for joints subjected to fatigue loading.

Convex fillet



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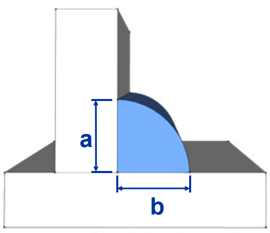
Fillet Weld Leg Length



a = Vertical leg length
b = Horizontal leg length

Note: The leg length should be approximately equal to the material thickness.

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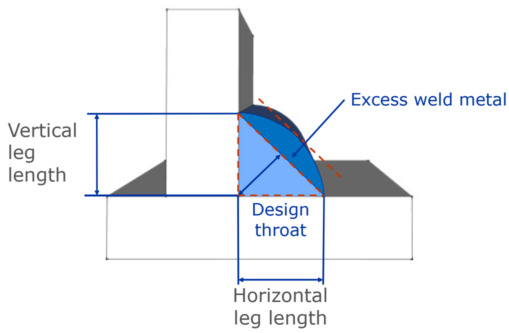
Fillet Weld Features



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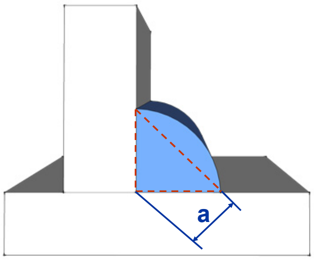
Deep Penetration Fillet Weld Features



a = Design throat thickness

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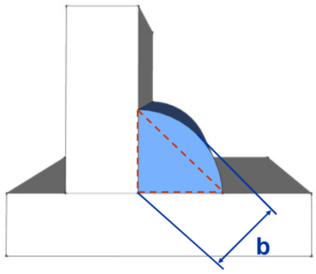
Deep Penetration Fillet Weld Features



b = Actual throat thickness

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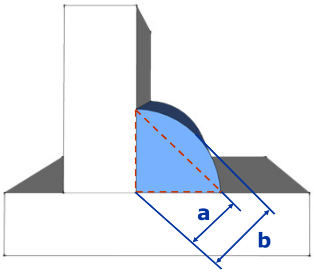
Deep Penetration Fillet Weld Features



a = Design throat thickness
b = Actual throat thickness

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Fillet Weld Sizes

Calculating **throat thickness** from a known leg length:

Design throat thickness = leg length x 0.7

- **Question:** The leg length is 14mm.
  What is the design throat?
- **Answer:** 14mm x 0.7 = 10mm **throat thickness**.

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Fillet Weld Sizes

Calculating **leg length** from a known design throat thickness:

Leg length = design throat thickness x 1.4

- **Question:** The design throat is 10mm.
  What is the leg length?
- **Answer:** 10mm x 1.4 = 14mm **leg length**.

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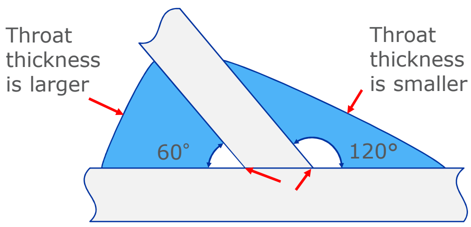
Features to Consider



Fillet welds connecting parts with fusion faces with an angle more than 120° or less than 60° should not use the previous calculations.

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Features to Consider

The design throat thickness of a flat or convex fillet weld connecting parts with the fusion faces which form an angle between 600 and 1200 may be calculated by multiplying the leg length by the appropriate factors as given below:

Angle between fusion faces in degrees	Factor
60 to 90	0.7
91 to 100	0.65
101 to 106	0.6
107 to 113	0.55
114 to 120	0.5

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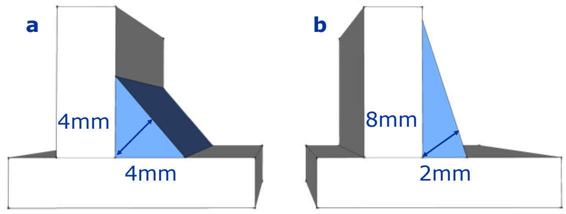
Features to Consider

Importance of fillet weld leg length size



Approximately the same weld volume in both Fillet Welds but the effective throat thickness has been altered, reducing considerably the strength of weld B.

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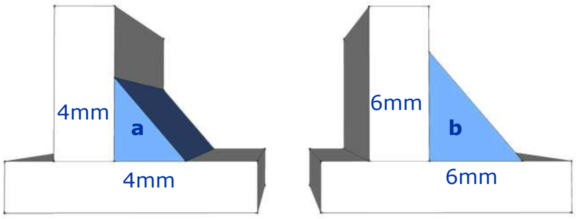
Fillet Weld Sizes

Importance of fillet weld leg length size



Cross Sectional Area

Question: How much larger is the CSA **b** comparable to **a**?

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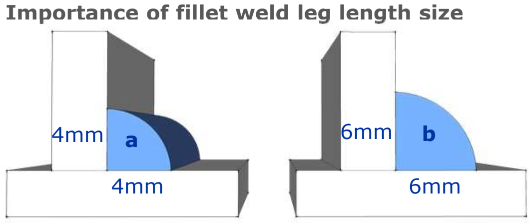
Fillet Weld Sizes

Importance of fillet weld leg length size



Area = $\frac{4 \times 4}{2}$ = **8mm²**　　**Area** = $\frac{6 \times 6}{2}$ = **18mm²**

The CSA of **b** is over **double** the area of **a** without the extra excess weld metal being added.

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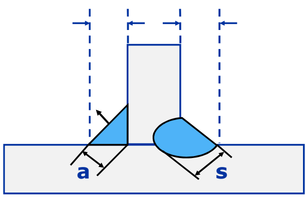
Features to Consider

Effective Throat Thickness

a = Nominal throat thickness　　s = Effective throat thickness



Deep throat fillet welds from FCAW and SAW etc.

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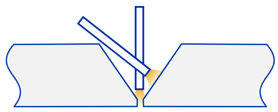
Joint Design and Weld Preparation

Bevel angle



Bevel angle must allow:

- Good access to the root.
- Manipulation of electrode to ensure sidewall fusion.

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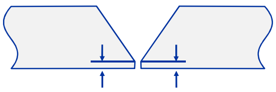
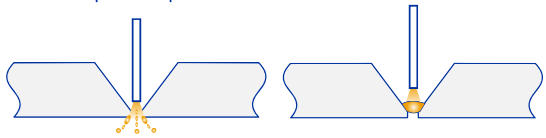
Joint Design and Weld Preparation

Root face



Root face size set to:
- Allow controlled root fusion.
- Reduce the risk of burn-through.



Too small = burn-through

Too large = lack of root penetration

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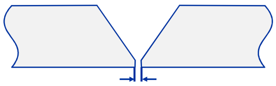
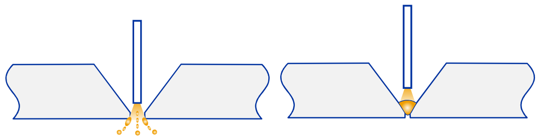
Joint Design and Weld Preparation

Root gap



Root gap set to:
- Allow controlled root fusion.
- Reduce the risk of burn-through.



Too large = burn-through

Too small = lack of root penetration

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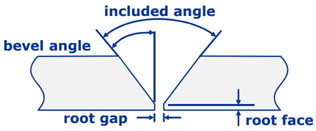
Weld Preparation

Terminology and typical dimensions: V joints



Typical dimensions

Bevel angle	30 to 35°
Root face	~1.5 to ~2.5mm
Root gap	~2 to ~4mm

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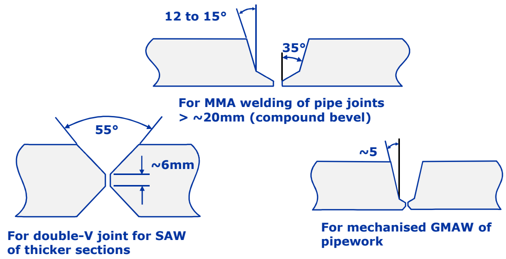
Weld Preparation

Joint design/weld preparation to reduce weld volumes



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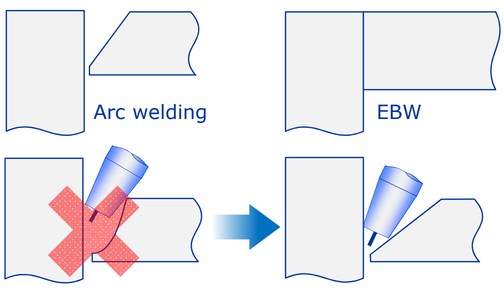
Weld Preparation

Welding process impacts upon weld preparation



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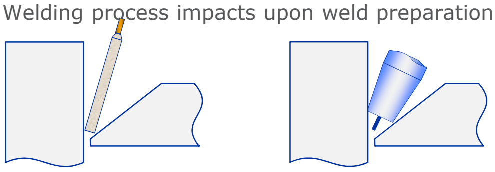
Weld Preparation

Welding process impacts upon weld preparation



MMA **MAG**

High heat input process allow a larger root face, less weld metal required, less distortions, higher productivity.

If the gap is too big risk of possible burn-through, if gap is too small risk of lack of penetration.

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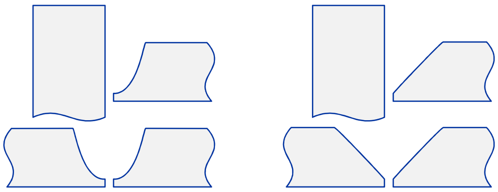
Weld Preparation

Preparation method impacts upon weld preparation



- Requires machining slow and expensive.
- Tight tolerance easier set-up.

- Can be flame/plasma cut fast and cheap.
- Large tolerance set-up can be difficult.

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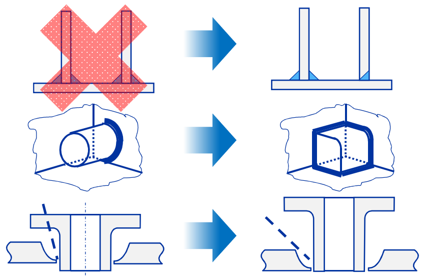
Weld Preparations

Access impacts upon weld preparation



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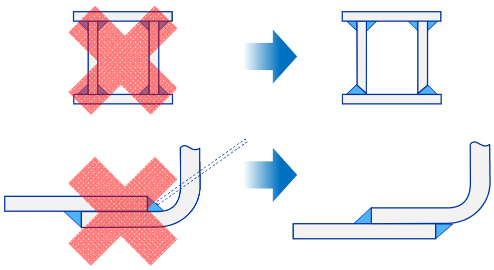
Weld Preparations

Access impacts upon weld preparation



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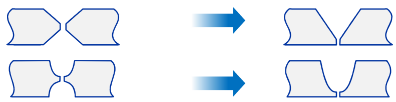
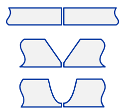
Weld Preparations

Access impacts upon weld preparation

Pipe weld preparation - one side access only!





for wall thickness up to 3mm
for wall thickness 3-20mm
for wall thickness over 20mm

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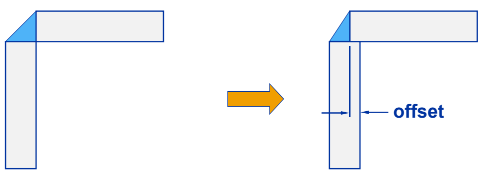
Weld Preparations

Type of joint impacts upon weld preparation

Corner joints require offset



Danger of burn-through difficult to set-up

Easy set-up no risk of burn-through

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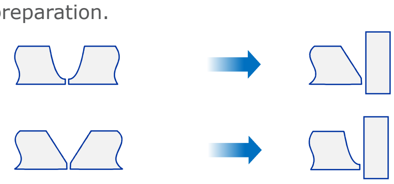
Weld Preparations

Type of joint impacts upon weld preparation

Lap and square edge butt joints do not require preparation.



Bevel angle = 30°
Included angle = 60°

Included angle =
Bevel angle = 50°

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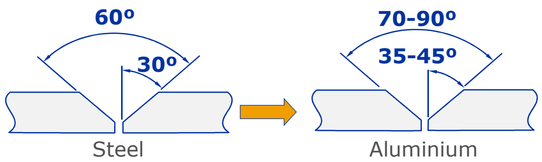
Weld Preparations

Type of parent material impacts upon weld preparation

To reduce distortions on stainless steels welds, reduce included angle and increase root face.

To avoid lack of side wall fusion problems aluminium require larger included angles than steel.



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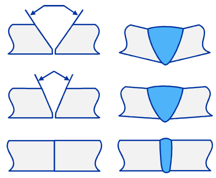
Weld Preparations

Thickness of parent material impacts upon weld preparation

A single bevel groove requires a volume of weld metal proportional to the square of plate thickness

Its lack of symmetry lead to distortions



Reduce shrinkage by:
- Reducing weld volume.
- Using single pass welding.

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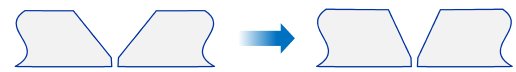
Weld Preparations

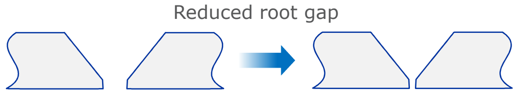
Thickness of parent material impacts upon weld preparation

Reduce weld volume by:

Reduced included angle



Reduced root gap



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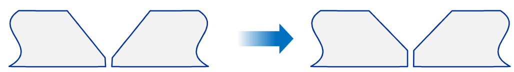
Weld Preparations

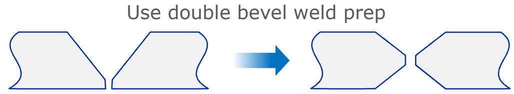
Thickness of parent material impacts upon weld preparation

Reduce weld volume by:

Increase root face



Use double bevel weld prep



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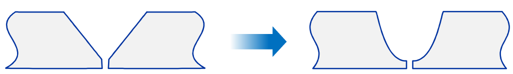
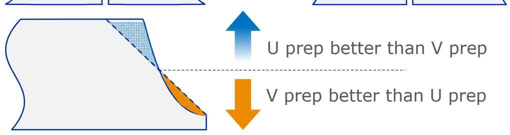
Weld Preparations

Thickness of parent material impacts upon weld preparation

Reduce weld volume by:

Use U prep instead V prep





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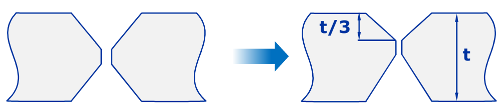
Weld Preparations

Thickness of parent material impacts upon weld preparation

Reduce distortions by using an asymmetric V prep instead of a symmetric V prep.



Weld first into the deeper side after welding to half of the depth, back gouge the root. Complete welding on the shallow side first.

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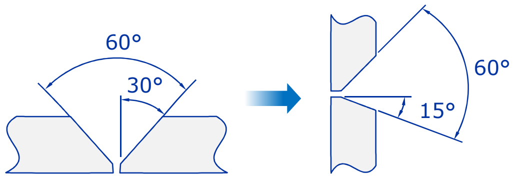
Weld Preparation

Welding position impacts upon weld preparation



PF symmetric preparation

PC asymmetric preparation

If symmetric preparation is used in the PC position the weld may spill out of the groove.

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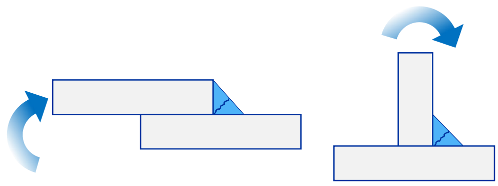
Weld Preparation

Type of loading impacts upon weld preparation

Static loads - prohibited application of one sided fillet weld.



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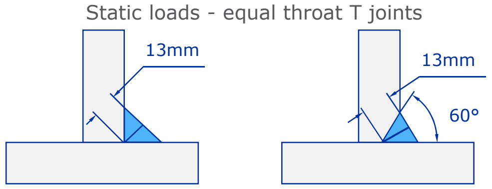
Weld Preparation

Type of loading impacts upon weld preparation

Static loads - equal throat T joints



Weld area = $160mm^2$

- No preparation required.
- Danger of lamellar tearing.

Weld area = $90mm^2$

- Preparation required.
- Reduced distortions.

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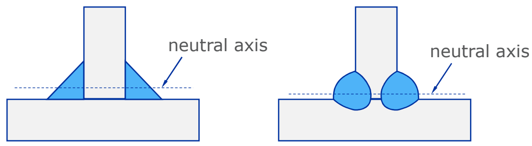
Weld Preparation

Type of loading impacts upon weld preparation

Static loads - equal throat T beams in bending



Normal fillet welds

Deep penetration fillet welds

Lower neutral axis is more advantageous (also helps to reduce residual distortions!)

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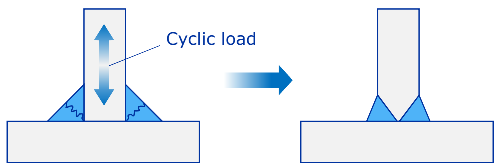
Weld Preparation

Type of loading impacts upon weld preparation

Dynamic loads - full vs. partial penetration welds



Fillet welds

Double bevel weld

Lack of penetration promotes cracking!

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Any Questions

?

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Section 3

Welding Imperfections and Materials Inspection

3 Welding Imperfections and Materials Inspection

3.1 Definitions (see BS EN ISO 6520-1)

Imperfection Any deviation from the ideal weld.
Defect An unacceptable imperfection.

Classification of imperfections according to BS EN ISO 6520-1:

This standard classifies the geometric imperfections in fusion welding dividing them into six groups:

1 Cracks.
2 Cavities.
3 Solid inclusions.
4 Lack of fusion and penetration.
5 Imperfect shape and dimensions.
6 Miscellaneous imperfections.

It is important that an imperfection is correctly identified so the cause can be established and actions taken to prevent further occurrence.

3.2 Cracks

Definition

Imperfection produced by a local rupture in the solid state, which may arise from the effect of cooling or stresses. Cracks are more significant than other types of imperfection as their geometry produces a very large stress concentration at the crack tip making them more likely to cause fracture.

Types of crack:

- Longitudinal.
- Transverse.
- Radiating (cracks radiating from a common point).
- Crater.
- Branching (group of connected cracks originating from a common crack).

These cracks can be situated in the:

- Weld metal.
- HAZ.
- Parent metal.

Exception: Crater cracks are found only in the weld metal.

Depending on their nature, these cracks can be:

- Hot (ie solidification or liquation cracks).
- Precipitation induced (ie reheat cracks present in creep resisting steels).
- Cold (ie hydrogen induced cracks).
- Lamellar tearing.

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3.2.1 Hot cracks

Depending on their location and mode of occurrence, hot cracks can be:

- **Solidification cracks:** Occur in the weld metal (usually along the centreline of the weld) as a result of the solidification process.
- **Liquation cracks:** Occur in the coarse grain HAZ, in the near vicinity of the fusion line as a result of heating the material to an elevated temperature, high enough to produce liquation of the low melting point constituents placed on grain boundaries.

3.2.2 Solidification cracks

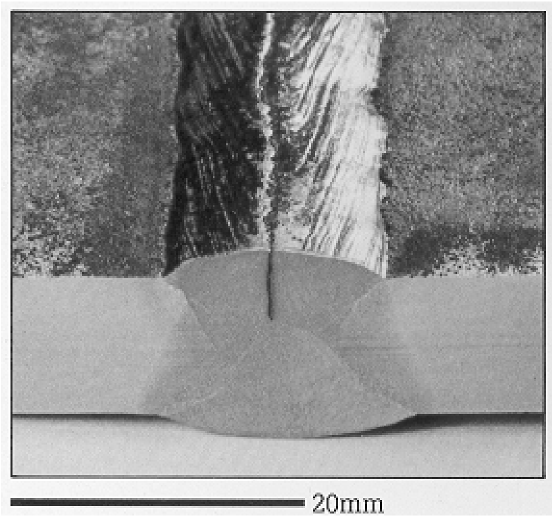

Figure 3.1 Solidification crack.

Generally, solidification cracking can occur when:

- Weld metal has a high carbon or impurity (sulphur, etc) content.
- The depth-to-width ratio of the solidifying weld bead is large (deep and narrow).
- Disruption of the heat flow condition occurs, eg stop/start condition.

The cracks can be wide and open to the surface like shrinkage voids or sub-surface and possibly narrow.

Solidification cracking is most likely to occur in compositions and result in a wide freezing temperature range. In steels this is commonly created by a higher than normal content of carbon and impurity elements such as sulphur and phosphorus.

These elements segregate during solidification, so that intergranular liquid films remain after the bulk of the weld has solidified. The thermal shrinkage of the cooling weld bead can cause these to rupture and form a crack.

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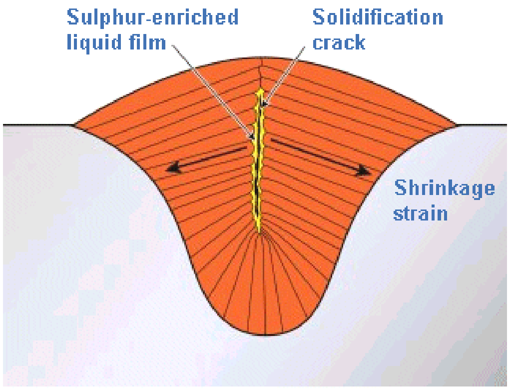
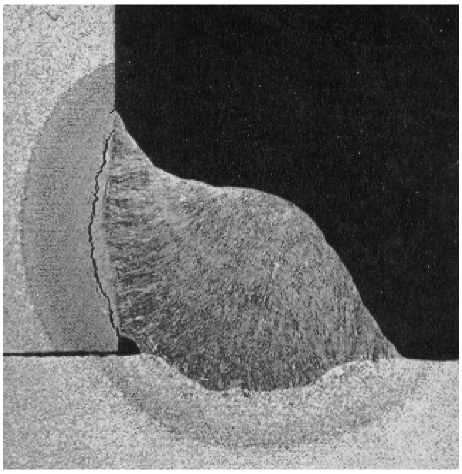


Figure 3.2 Diagram of a solidification crack.

It is important that the welding fabricator does not weld on or near metal surfaces covered with scale or contaminated with oil or grease. Scale can have a high sulphur content and oil and grease can supply both carbon and sulphur. Contamination with low melting point metals such as copper, tin, lead and zinc should also be avoided.

Hydrogen induced cracks



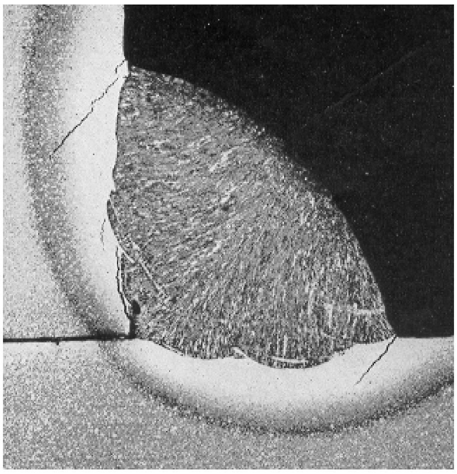


Figure 3.3 Root (underbead) crack. Figure 3.4 Toe crack.

Hydrogen induced cracking occurs primarily in the grain coarsened region of the HAZ and is also known as cold, delayed or underbead/toe cracking. It lies parallel to the fusion boundary and its path is usually a combination of inter and transgranular cracking.

The direction of the principal residual tensile stress can in toe cracks cause the crack path to grow progressively away from the fusion boundary towards a region of lower sensitivity to hydrogen cracking. When this happens, the crack growth rate decreases and eventually arrests.

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Four factors are necessary to cause HAZ hydrogen cracking:

Hydrogen level	> 15ml/100g of weld metal deposited
Stress	> 0.5 of the yield stress
Temperature	< 300°C
Susceptible microstructure	> 400HV hardness

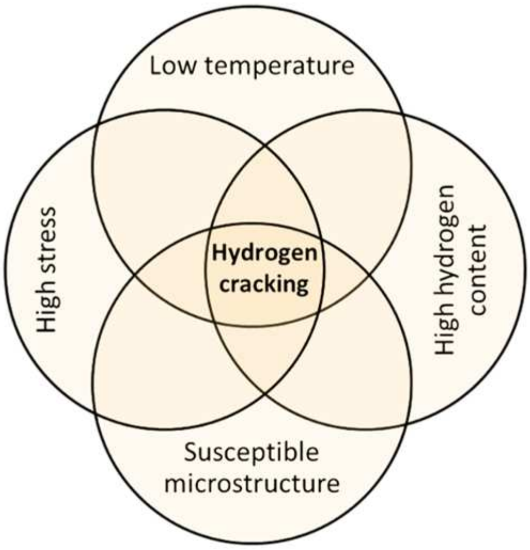

Figure 3.5 Factors susceptibility to hydrogen cracking.

If any one factor is not satisfied, cracking is prevented, so can be avoided through control of one or more factors:

- Apply preheat slow down the cooling rate and thus avoid the formation of susceptible microstructures.
- Maintain a specific interpass temperature (same effect as preheat).
- Postheat on completion of welding to reduce the hydrogen content by allowing hydrogen to diffuse from the weld area.
- Apply PWHT to reduce residual stress and eliminate susceptible microstructures.
- Reduce weld metal hydrogen by proper selection of welding process/consumable (eg use TIG welding instead of MMA, basic covered electrodes instead of cellulose).
- Use a multi-run instead of a single run technique and eliminate susceptible microstructures by the self-tempering effect, reduce hydrogen content by allowing hydrogen to diffuse from the weld area.
- Use a temper bead or hot pass technique (same effect as above).
- Use austenitic or nickel filler to avoid susceptible microstructure formation and allow hydrogen to diffuse out of critical areas).
- Use dry shielding gases to reduce hydrogen content.
- Clean rust from joint to avoid hydrogen contamination from moisture present in the rust.
- Reduce residual stress.
- Blend the weld profile to reduce stress concentration at the toes of the weld.

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Lamellar tearing

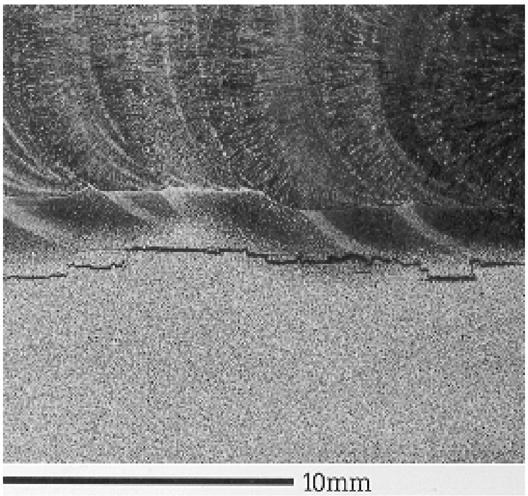

Figure 3.6 Lamellar tearing.

Lamellar tearing occurs only in rolled steel products (primarily plates) and its main distinguishing feature is that the cracking has a terraced appearance.

Cracking occurs in joints where:

- A thermal contraction strain occurs in the through-thickness direction of steel plate.
- Non-metallic inclusions are present as very thin platelets, with their principal planes parallel to the plate surface.

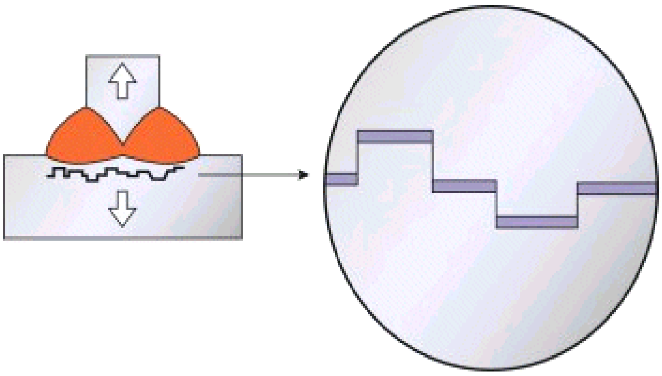

Figure 3.7 Diagram of lamellar tearing.

Contraction strain imposed on the planar non-metallic inclusions results in progressive decohesion to form the roughly rectangular holes which are the horizontal parts of the cracking, parallel to the plate surface. With further strain the vertical parts of the cracking are produced, generally by ductile shear cracking. These two stages create the terraced appearance of these cracks.

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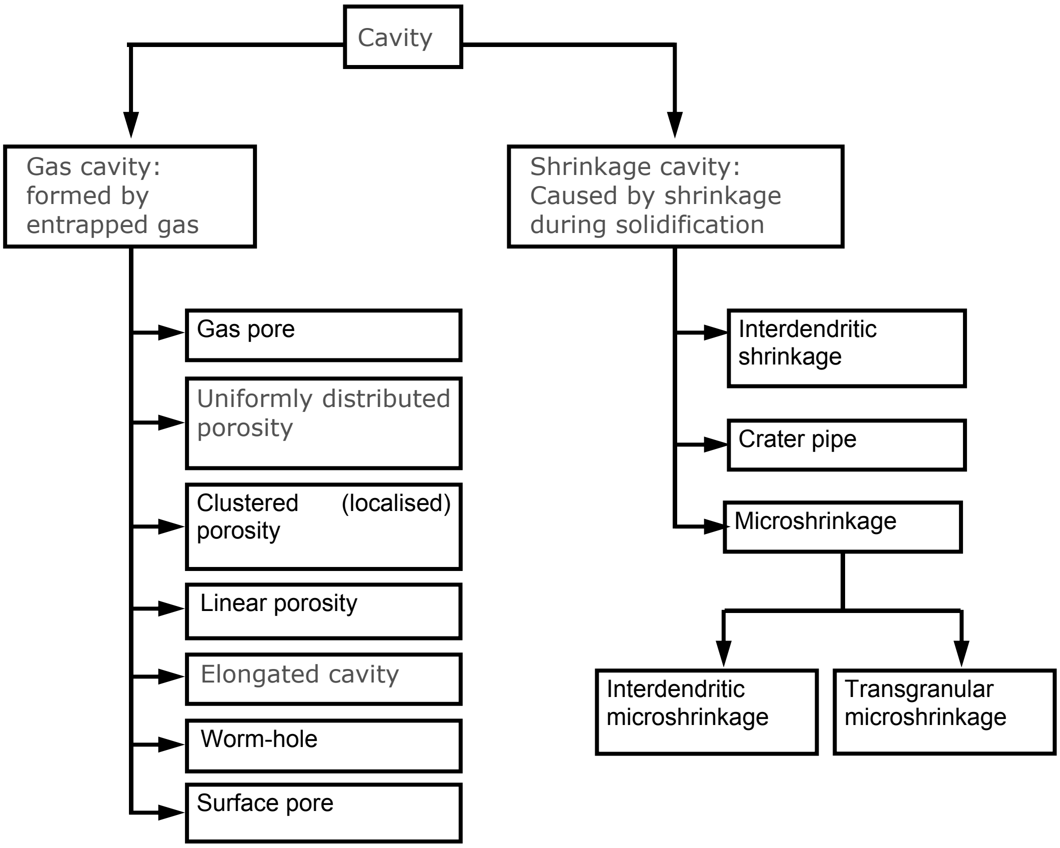
Two main options are available to control the problem in welded joints liable to lamellar tearing:

- Use a clean steel with guaranteed through-thickness properties (Z grade).
- A combination of joint design, restraint control and welding sequence to minimise the risk of cracking.

3.3 Cavities



3.3.1 Gas pore

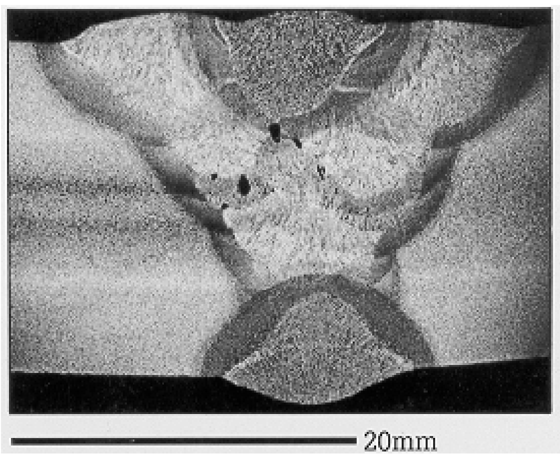


Figure 3.8 Gas pores.

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Description

A gas cavity of essentially spherical shape trapped within the weld metal.

Gas cavities can be present in various forms:

- Isolated.
- Uniformly distributed porosity.
- Clustered (localised) porosity.
- Linear porosity.
- Elongated cavity.
- Surface pore.

Causes	Prevention
Damp fluxes/corroded electrode (MMA)	Use dry electrodes in good condition
Grease/hydrocarbon/water contamination of prepared surface	Clean prepared surface
Air entrapment in gas shield (MIG/MAG, TIG)	Check hose connections
Incorrect/insufficient deoxidant in electrode, filler or parent metal	Use electrode with sufficient deoxidation activity
Too great an arc voltage or length	Reduce voltage and arc length
Gas evolution from priming paints/surface treatment	Identify risk of reaction before surface treatment is applied
Too high a shielding gas flow rate results in turbulence (MIG/MAG, TIG)	Optimise gas flow rate

Comment

Porosity can be localised or finely dispersed voids throughout the weld metal.

3.3.2 Worm holes

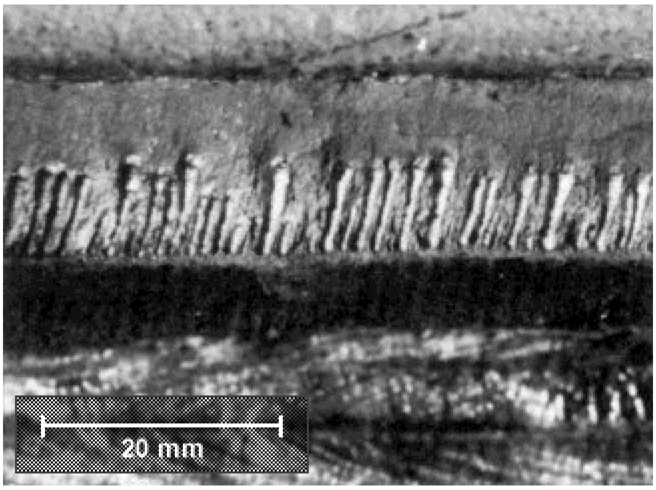

Figure 3.9 Worm holes.

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Description

Elongated or tubular cavities formed by trapped gas during the solidification of the weld metal which can occur singly or in groups.

Causes	Prevention
Gross contaminated of preparation surface.	Introduce preweld cleaning procedures.
Laminated work surface.	Replace parent material with an unlaminated piece.
Crevices in work surface due to joint geometry.	Eliminate joint shapes which produce crevices.

Comments

Worm holes are caused by the progressive entrapment of gas between the solidifying metal crystals (dendrites) producing characteristic elongated pores of circular cross-section. These can appear as a herringbone array on a radiograph and some may break the surface of the weld.

3.3.3 Surface porosity

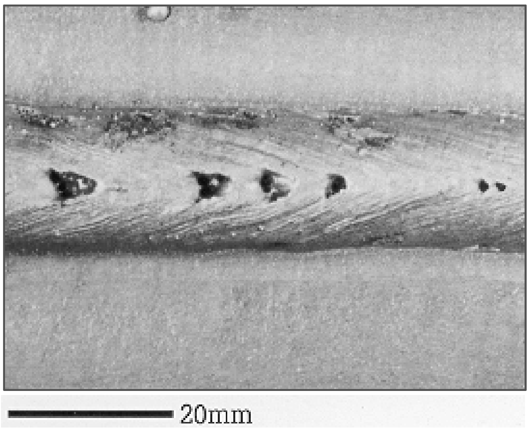

Figure 3.10 Surface porosity.

Description

A gas pore that breaks the surface of the weld.

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Causes	Prevention
Damp or contaminated surface or electrode	Clean surface and dry electrodes
Low fluxing activity (MIG/MAG)	Use a high activity flux
Excess sulphur (particularly free-cutting steels) producing sulphur dioxide	Use high manganese electrodes to produce MnS. Note free-cutting steels (high sulphur) should not normally be welded
Loss of shielding gas due to long arc or high breezes (MIG/MAG)	Improve screening against draughts and reduce arc length
A shielding gas flow rate that is too high results in turbulence (MIG/MAG,TIG)	Optimise gas flow rate

Comments

The origins of surface porosity are similar to those for uniform porosity.

3.3.4 Crater pipe

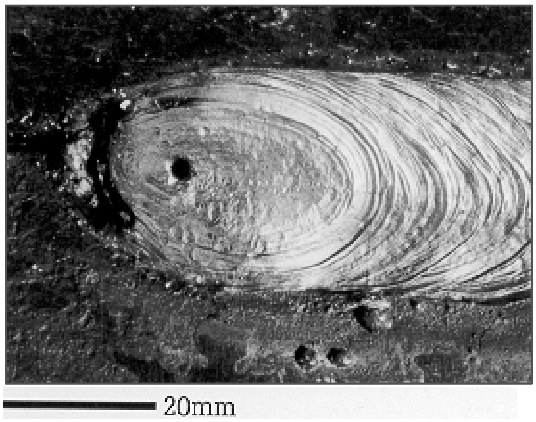

Figure 3.11 Crater pipe.

Description

A shrinkage cavity at the end of a weld run usually caused by shrinkage during solidification.

Causes	Prevention
Lack of welder skill due to using processes with too high a current.	Retrain welder.
Inoperative crater filler (slope out) (TIG).	Use correct crater filling techniques.

Comments

Crater filling is a particular problem in TIG welding due to its low heat input. To fill the crater for this process it is necessary to reduce the weld current (slope out) in a series of descending steps until the arc is extinguished.

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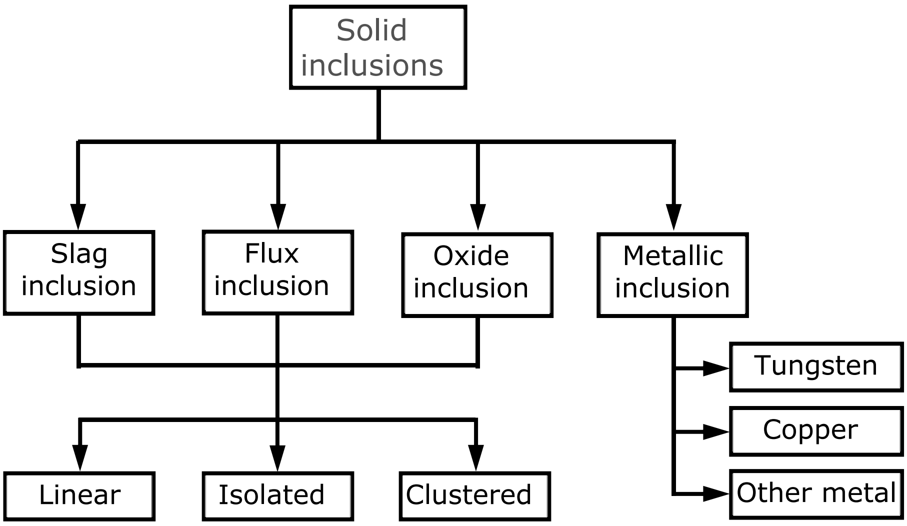
3.4 Solid inclusions

Definition

Solid foreign substances trapped in the weld metal.



3.4.1 Slag inclusions

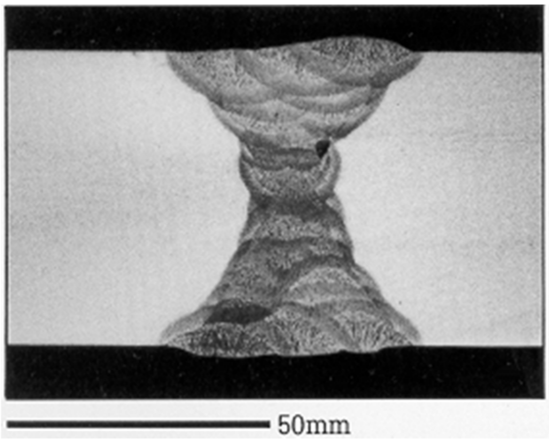


Figure 3.12 Slag inclusions.

Description

Slag trapped during welding which is an irregular shape so differs in appearance from a gas pore.

Causes	Prevention
Incomplete slag removal from underlying surface of multi-pass weld	Improve inter-run slag removal
Slag flooding ahead of arc	Position work to gain control of slag. Welder needs to correct electrode angle
Entrapment of slag in work surface	Dress/make work surface smooth

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Comments

A fine dispersion of inclusions may be present within the weld metal, particularly if the MMA process is used. These only become a problem when large or sharp-edged inclusions are produced.

3.4.2 Flux inclusions

Flux trapped during welding which is an irregular shape so differs in appearance from a gas pore. Appear only in flux associated welding processes (ie MMA, SAW and FCAW).

Causes	Prevention
Unfused flux due to damaged coating	Use electrodes in good condition
Flux fails to melt and becomes trapped in the weld (SAW or FCAW)	Change the flux/wire. Adjust welding parameters ie current, voltage etc to produce satisfactory welding conditions

3.4.3 Oxide inclusions

Oxides trapped during welding which is an irregular shape so differs in appearance from a gas pore.

Cause	Prevention
Heavy millscale/rust on work surface	Grind surface prior to welding

A special type of oxide inclusion is puckering, which occurs especially in the case of aluminium alloys. Gross oxide film enfoldment can occur due to a combination of unsatisfactory protection from atmospheric contamination and turbulence in the weld pool.

3.4.4 Tungsten inclusions

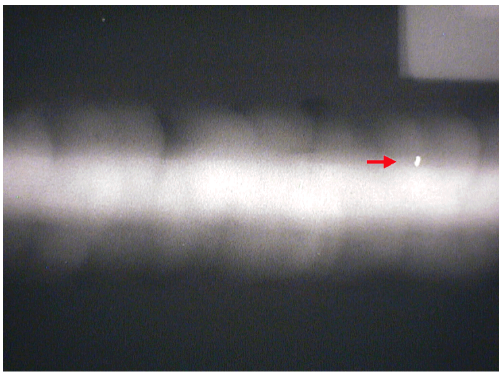

Figure 3.13 Tungsten inclusions

Particles of tungsten can become embedded during TIG welding appears as a light area on radiographs as tungsten is denser than the surrounding metal and absorbs larger amounts of X-/gamma radiation.

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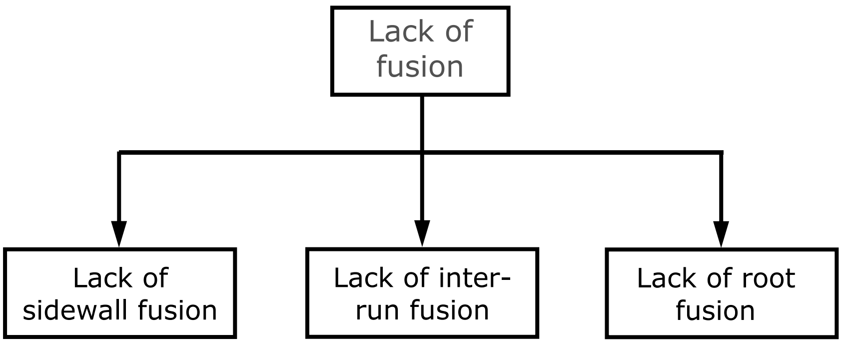
Causes	Prevention
Contact of electrode tip with weld pool	Keep tungsten out of weld pool; use HF start
Contact of filler metal with hot tip of electrode	Avoid contact between electrode and filler metal
Contamination of the electrode tip by spatter from the weld pool	Reduce welding current; adjust shielding gas flow rate
Exceeding the current limit for a given electrode size or type	Reduce welding current; replace electrode with a larger diameter one
Extension of electrode beyond the normal distance from the collet, resulting in overheating of the electrode	Reduce electrode extension and/or welding current
Inadequate tightening of the collet	Tighten the collet
Inadequate shielding gas flow rate or excessive draughts resulting in oxidation of the electrode tip	Adjust the shielding gas flow rate; protect the weld area; ensure that the post gas flow after stopping the arc continues for at least five seconds
Splits or cracks in the electrode	Change the electrode, ensure the correct size tungsten is selected for the given welding current used
Inadequate shielding gas (eg use of argon-oxygen or argon-carbon dioxide mixtures that are used for MAG welding)	Change to correct gas composition

3.5 Lack of fusion and penetration

3.5.1 Lack of fusion

Lack of union between the weld metal and the parent metal or between the successive layers of weld metal.



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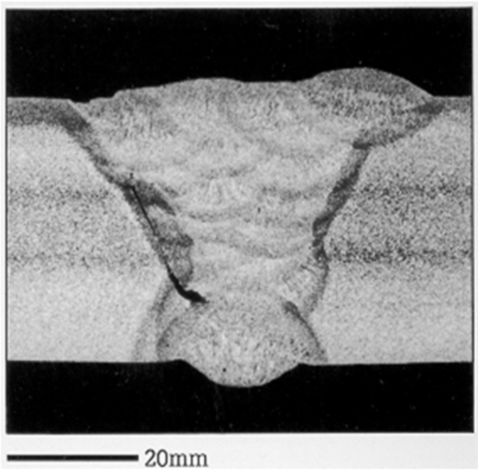

Figure 3.14 Lack of sidewall fusion.

Lack of union between the weld and parent metal at one or both sides of the weld.

Causes	Prevention
Low heat input to weld	Increase arc voltage and/or welding current; decrease travel speed
Molten metal flooding ahead of arc	Improve electrode angle and work position; increase travel speed
Oxide or scale on weld preparation	Improve edge preparation procedure
Excessive inductance in MAG dip transfer welding	Reduce inductance, even if this increases spatter

During welding sufficient heat must be available at the edge of the weld pool to produce fusion with the parent metal.

Lack of inter-run fusion

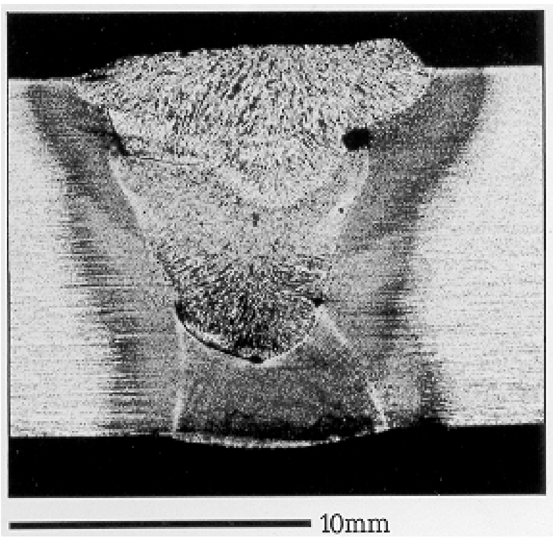

Figure 3.15 Lack of inter-run fusion.

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Lack of union along the fusion line between the weld beads.

Causes	Prevention
Low arc current resulting in low fluidity of weld pool	Increase current
Too high a travel speed	Reduce travel speed
Inaccurate bead placement	Retrain welder

Lack of inter-run fusion produces crevices between the weld beads and causes local entrapment of slag.

Lack of root fusion

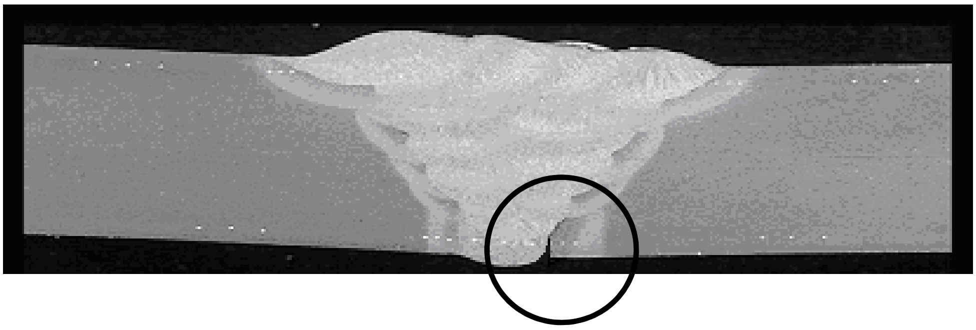

Figure 3.16 Lack of root fusion.

Lack of fusion between the weld and parent metal at the root of a weld.

Causes	Prevention
Low heat input	Increase welding current and/or arc voltage; decrease travel speed
Excessive inductance in MAG dip transfer welding,	Use correct induction setting for the parent metal thickness
MMA electrode too large (low current density)	Reduce electrode size
Use of vertical-down welding	Switch to vertical-up procedure
Large root face	Reduce root face
Small root gap	Ensure correct root opening
Incorrect angle or electrode manipulation	Use correct electrode angle. Ensure welder is fully qualified and competent
Excessive misalignment at root	Ensure correct alignment

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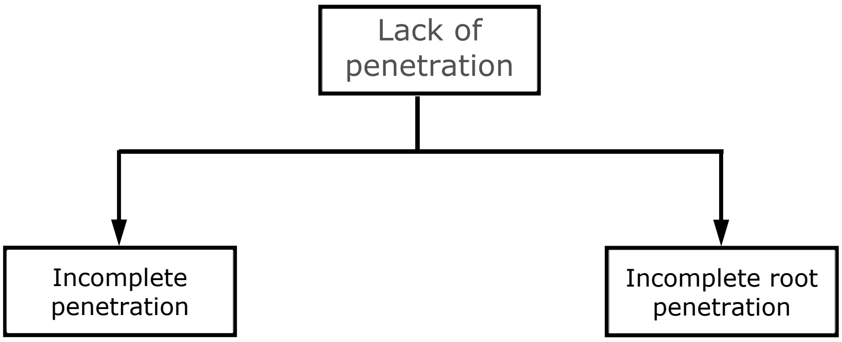
3.5.2 Lack of penetration



Incomplete penetration

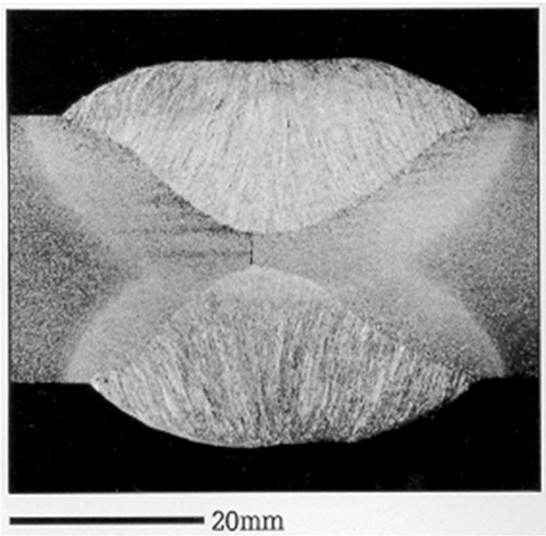


Figure 3.17 Incomplete penetration.

The difference between actual and nominal penetration.

Causes	Prevention
Excessively thick root face, insufficient root gap or failure to cut back to sound metal when back gouging	Improve back gouging technique and ensure the edge preparation is as per approved WPS
Low heat input	Increase welding current and/or arc voltage; decrease travel speed
Excessive inductance in MAG dip transfer welding, pool flooding ahead of arc	Improve electrical settings and possibly switch to spray arc transfer
MMA electrode too large (low current density)	Reduce electrode size
Use of vertical-down welding	Switch to vertical-up procedure

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If the weld joint is not of a critical nature, ie the required strength is low and the area is not prone to fatigue cracking, it is possible to produce a partial penetration weld. In this case incomplete root penetration is considered part of this structure and not an imperfection This would normally be determined by the design or code requirement.

Incomplete root penetration

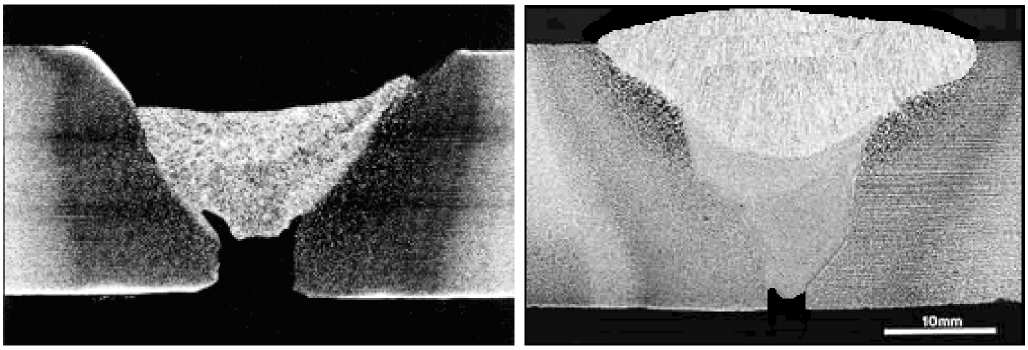

Figure 3.18 Incomplete root penetration.

Both fusion faces of the root are not melted. When examined from the root side, you can clearly see both of the root edges unmelted.

Causes and prevention

Same as for lack of root fusion.

3.6 Imperfect shape and dimensions

3.6.1 Undercut

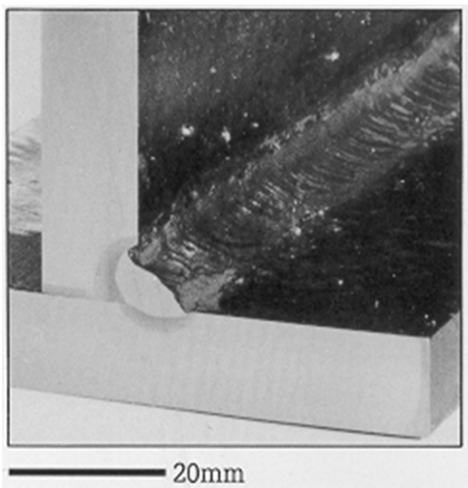

Figure 3.19 Undercut.

An irregular groove at the toe of a run in the parent metal or previously deposited weld metal due to welding. Characterised by its depth, length and sharpness.

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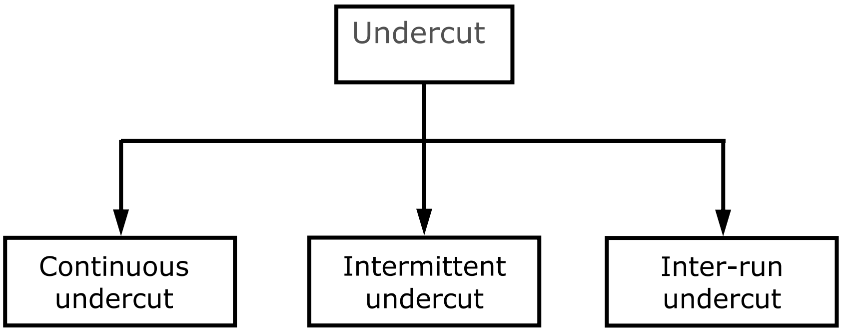

Causes	Prevention
Melting of top edge due to high welding current (especially at the free edge) or high travel speed	Reduce power input, especially approaching a free edge where overheating can occur
Attempting a fillet weld in horizontal-vertical (PB) position with leg length >9mm	Weld in the flat position or use multi-run techniques
Excessive/incorrect weaving	Reduce weaving width or switch to multi-runs
Incorrect electrode angle	Direct arc towards thicker member
Incorrect shielding gas selection (MAG)	Ensure correct gas mixture for material type and thickness (MAG)

Care must be taken during weld repairs of undercut to control the heat input. If the bead of a repair weld is too small, the cooling rate following welding will be excessive and the parent metal may have an increased hardness and the weld susceptible to hydrogen cracking.

3.6.2 Excess weld metal

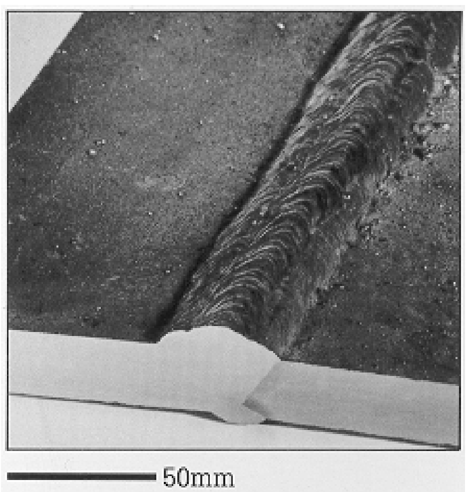

Figure 3.20 Excess weld metal.

Excess weld metal is the extra metal that produces excessive convexity in fillet welds and a weld thickness greater than the parent metal plate in butt welds. It is regarded as an imperfection only when the height of the excess weld metal is greater than a specified limit.

Causes	Prevention
Excess arc energy (MAG, SAW)	Reduction of heat input
Shallow edge preparation	Deepen edge preparation
Faulty electrode manipulation or build-up sequence	Improve welder skill
Incorrect electrode size	Reduce electrode size
Travel speed too slow	Ensure correct travel speed is used
Incorrect electrode angle	Ensure correct electrode angle is used
Wrong polarity used (electrode polarity DC-ve (MMA, SAW)	Ensure correct polarity ie DC+ve Note DC-ve must be used for TIG

The term reinforcement used to designate this feature of the weld is misleading since the excess metal does not normally produce a stronger weld in a butt joint in ordinary steel. This imperfection can become a problem, as the angle of the weld toe can be sharp leading to an increased stress concentration at the toes of the weld and fatigue cracking.

3.6.3 Excess penetration

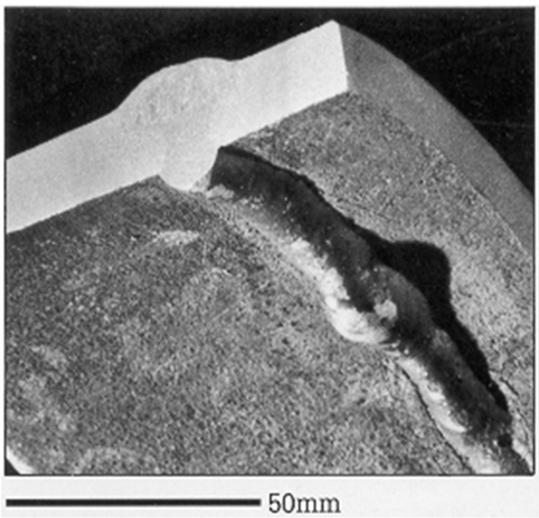

Figure 3.21 Excess penetration.

Projection of the root penetration bead beyond a specified limit, local or continuous.

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Causes	Prevention
Weld heat input too high	Reduce arc voltage and/or welding current; increase welding speed
Incorrect weld preparation ie excessive root gap, thin edge preparation, lack of backing	Improve workpiece preparation
Use of electrode unsuited to welding position	Use correct electrode for position
Lack of welder skill	Retrain welder

The maintenance of a penetration bead of uniform dimensions requires a great deal of skill, particularly in pipe butt welding. This can be made more difficult if there is restricted access to the weld or a narrow preparation. Permanent or temporary backing bars can assist in the control of penetration.

3.6.4 Overlap

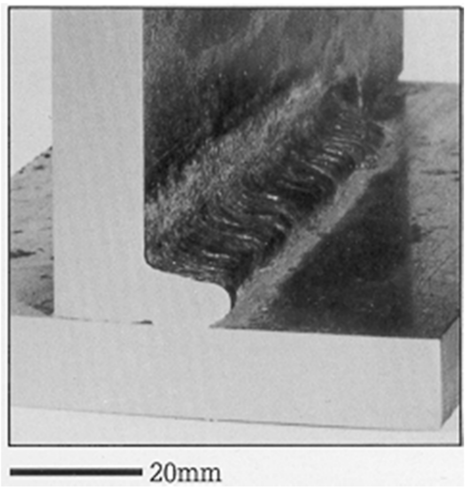

Figure 3.22 Overlap.

Imperfection at the toe of a weld caused by metal flowing on to the surface of the parent metal without fusing to it.

Causes	Prevention
Poor electrode manipulation (MMA)	Retrain welder
High heat input/low travel speed causing surface flow of fillet welds	Reduce heat input or limit leg size to 9mm maximum for single pass fillets
Incorrect positioning of weld	Change to flat position
Wrong electrode coating type resulting in too high a fluidity	Change electrode coating type to a more suitable fast freezing type which is less fluid

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For a fillet weld overlap is often associated with undercut, as if the weld pool is too fluid the top of the weld will flow away to produce undercut at the top and overlap at the base. If the volume of the weld pool is too large in a fillet weld in horizontal-vertical (PB) position, weld metal will collapse due to gravity, producing both defects (undercut at the top and overlap at the base), this defect is called sagging.

3.6.5 Linear misalignment

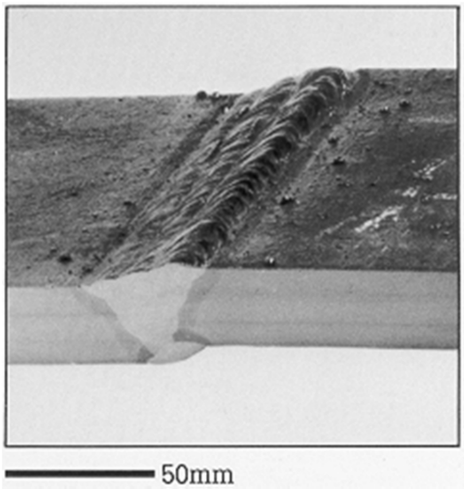

Figure 3.23 Linear misalignment.

Misalignment between two welded pieces such that while their surface planes are parallel, they are not in the required same plane.

Causes	Prevention
Inaccuracies in assembly procedures or distortion from other welds	Adequate checking of alignment prior to welding coupled with the use of clamps and wedges
Excessive out of flatness in hot rolled plates or sections	Check accuracy of rolled section prior to welding

Misalignment is not a weld imperfection but a structural preparation problem. Even a small amount of misalignment can drastically increase the local shear stress at a joint and induce bending stress.

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3.6.6 Angular distortion

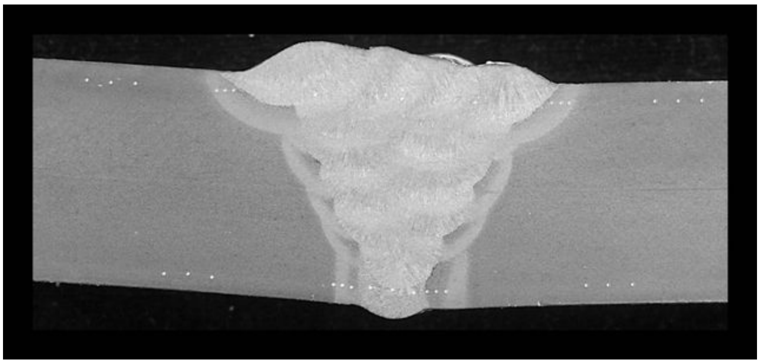

Figure 3.24 Angular distortion.

Misalignment between two welded pieces such that their surface planes are not parallel or at the intended angle.

Causes and prevention are the same as for linear misalignment.

3.6.7 Incompletely filled groove

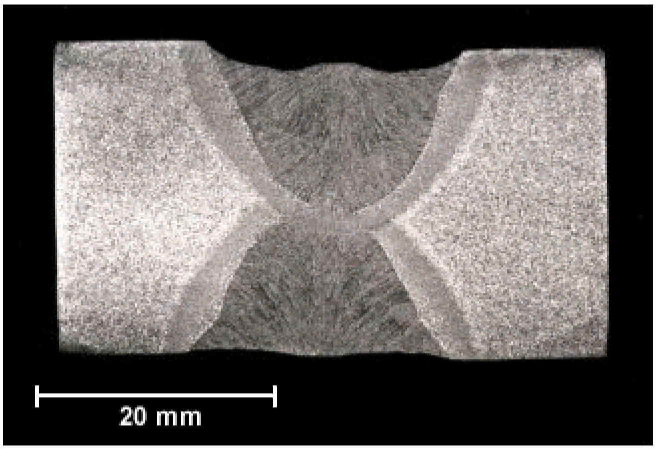

Figure 3.25 Incompletely filled groove.

Continuous or intermittent channel in the weld surface due to insufficient deposition of weld filler metal.

Causes	Prevention
Insufficient weld metal	Increase the number of weld runs
Irregular weld bead surface	Retrain welder

This imperfection differs from undercut, as it reduces the load-bearing capacity of a weld, whereas undercut produces a sharp stress-raising notch at the edge of a weld.

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3.6.8 Irregular width

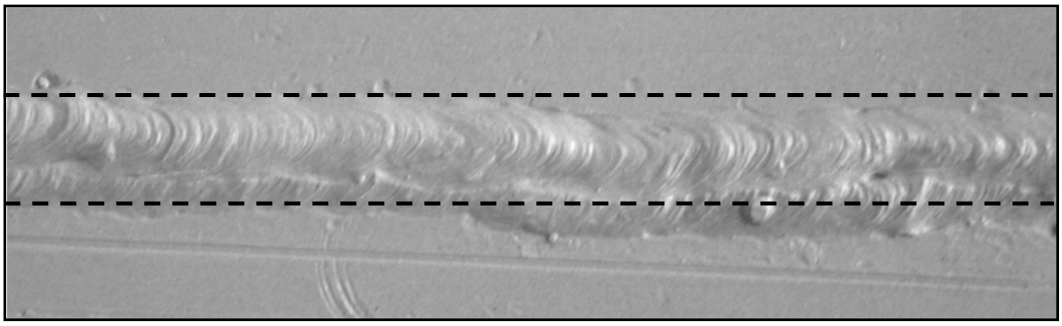

Figure 3.26 Irregular width.

Excessive variation in width of the weld.

Causes	Prevention
Severe arc blow	Switch from DC to AC, keep arc length as short as possible
Irregular weld bead surface	Retrain welder

Although this imperfection may not affect the integrity of the completed weld, it can affect the width of HAZ and reduce the load-carrying capacity of the joint (in fine-grained structural steels) or impair corrosion resistance (in duplex stainless steels).

3.6.9 Root concavity

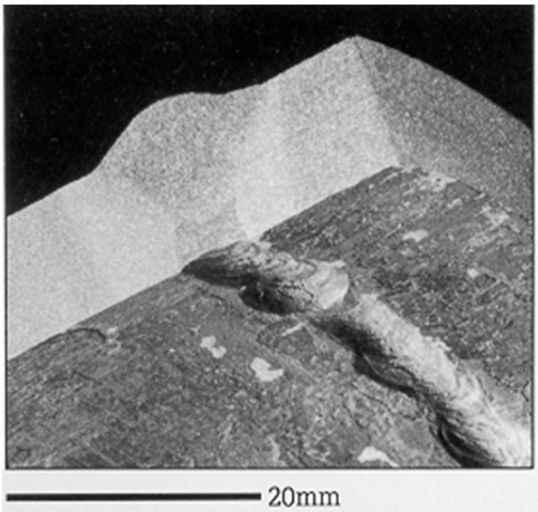

Figure 3.27 Root concavity.

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A shallow groove that occurs due to shrinkage at the root of a butt weld.

Causes	Prevention
Insufficient arc power to produce positive bead	Raise arc energy
Incorrect preparation/fit-up	Work to WPS
Excessive backing gas pressure (TIG)	Reduce gas pressure
Lack of welder skill	Retrain welder
Slag flooding in backing bar groove	Tilt work to prevent slag flooding

A backing strip can be used to control the extent of the root bead.

3.6.10 Burn-through

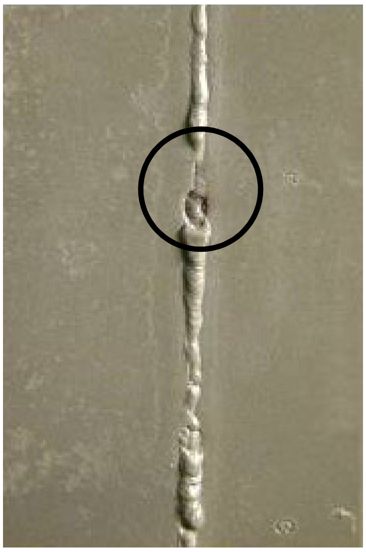

Figure 3.28 Burn-through.

A collapse of the weld pool resulting in a hole in the weld.

Causes	Prevention
Insufficient travel speed	Increase the travel speed
Excessive welding current	Reduce welding current
Lack of welder skill	Retrain welder
Excessive grinding of root face	More care taken, retrain welder
Excessive root gap	Ensure correct fit-up

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This is a gross imperfection which occurs due to lack of welder skill but can be repaired by bridging the gap formed into the joint, but requires a great deal of attention.

3.7 Miscellaneous imperfections

3.7.1 Stray arc

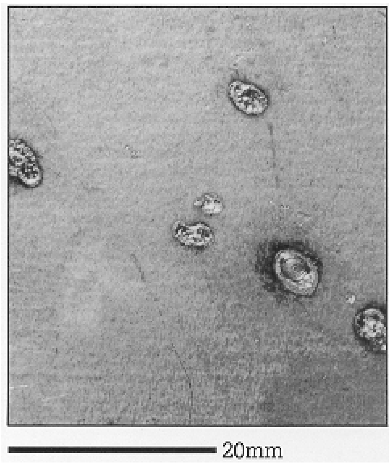

Figure 3.29 Stray arc.

Local damage to the surface of the parent metal adjacent to the weld, resulting from arcing or striking the arc outside the weld groove. This results in random areas of fused metal where the electrode, holder or current return clamp have accidentally touched the work.

Causes	Prevention
Poor access to the work	Improve access (modify assembly sequence)
Missing insulation on electrode holder or torch	Institute a regular inspection scheme for electrode holders and torches
Failure to provide an insulated resting place for the electrode holder or torch when not in use	Provide an insulated resting place
Loose current return clamp	Regularly maintain current return clamps
Adjusting wire feed (MAG welding) without isolating welding current	Retrain welder

An arc strike can produce a hard HAZ which may contain cracks, possibly leading to serious cracking in service. It is better to remove an arc strike by grinding than weld repair.

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3.7.2 Spatter

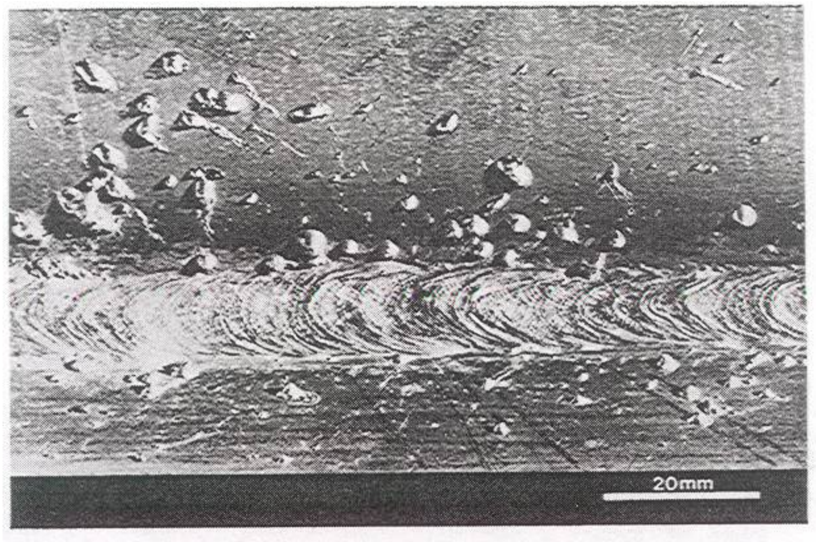

Figure 3.30 Splatter.

Globules of weld or filler metal expelled during welding adhering to the surface of parent metal or solidified weld metal.

Causes	**Prevention**
High arc current	Reduce arc current
Long arc length	Reduce arc length
Magnetic arc blow	Reduce arc length or switch to AC power
Incorrect settings for GMAW process	Modify electrical settings (but be careful to maintain full fusion!)
Damp electrodes	Use dry electrodes
Wrong selection of shielding gas (100%CO_2)	Increase argon content if possible, however if too high may lead to lack of penetration

Spatter is a cosmetic imperfection and does not affect the integrity of the weld. However as it is usually caused by an excessive welding current, it is a sign that the welding conditions are not ideal so there are usually other associated problems within the structure, ie high heat input.

Some spatter is always produced by open arc consumable electrode welding processes. Anti-spatter compounds can be used on the parent metal to reduce sticking and the spatter can then be scraped off.

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3.7.3 Torn surface

Surface damage due to the removal by fracture of temporary welded attachments. The area should be ground off, subjected to a dye penetrant or magnetic particle examination then restored to its original shape by welding using a qualified procedure.

Some applications do not allow the presence of any overlay weld on the surface of the parent material.

3.7.4 Additional imperfections

Grinding mark

Local damage due to grinding.

Chipping mark

Local damage due to the use of a chisel or other tools.

Underflushing

Lack of thickness of the workpiece due to excessive grinding.

Misalignment of opposite runs

Difference between the centrelines of two runs made from opposite sides of the joint.

Temper colour (visible oxide film)

Lightly oxidised surface in the weld zone, usually occurs in stainless steels.

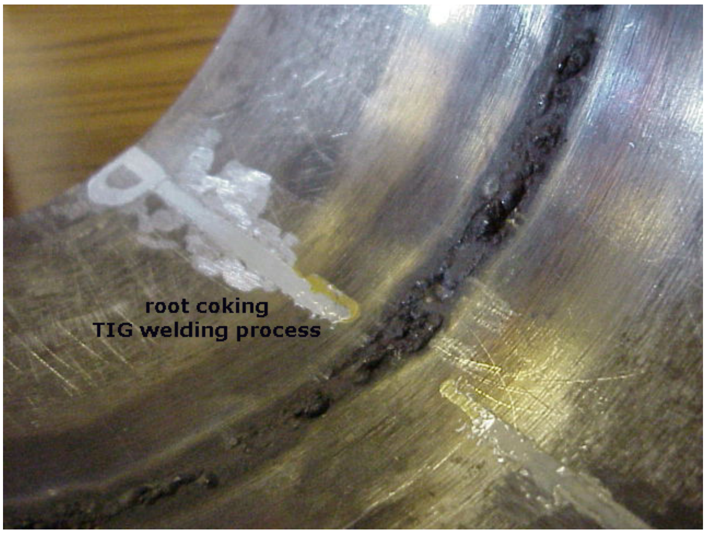

Figure 3.31 Temper colour of stainless steel.

3.8 Acceptance standards

Weld imperfections can seriously reduce the integrity of a welded structure. Prior to service of a welded joint, it is necessary to locate them using NDE techniques, assess their significance and take action to avoid their reoccurrence.

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The acceptance of a certain size and type of defect for a given structure is normally expressed as the defect acceptance standard, usually incorporated in application standards or specifications.

All normal weld imperfection acceptance standards totally reject cracks. In exceptional circumstances and subject to the agreement of all parties, cracks may remain if it can be demonstrated beyond doubt that they will not lead to failure. This can be difficult to establish and usually involves fracture mechanics measurements and calculations.

It is important to note that the levels of acceptability vary between different applications and in most cases vary between different standards for the same application. Consequently, when inspecting different jobs it is important to use the applicable standard or specification quoted in the contract.

Once unacceptable weld imperfections have been found they have to be removed. If the weld imperfection is at the surface, the first consideration is whether it is of a type shallow enough to be repaired by superficial dressing. Superficial implies that after removal of the defect the remaining material thickness is sufficient not to require the addition of further weld metal.

If the defect is too deep it must be removed and new weld metal added to ensure a minimum design throat thickness.

Replacing removed metal or weld repair (as in filling an excavation or re-making a weld joint) has to be done in accordance with an approved procedure. The rigour with which this procedure is qualified depends on the application standard for the job.

In some cases it will be acceptable to use a procedure qualified for making new joints whether filling an excavation or making a complete joint. If the level of reassurance required is higher, the qualification will have to be made using an exact simulation of a welded joint, which is excavated then refilled using a specified method. In either case, qualification inspection and testing will be required in accordance with the application standard.

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Welding Imperfections and Materials Inspection

Section 3

Materials Joining and Engineering Technologies
Training and Examination Services

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Welding Imperfections Objective

When this presentation has been completed you will have a greater understanding of the types of defects during visual inspection. You should be able to asses the defect against an acceptance criteria and accept or reject accordingly.

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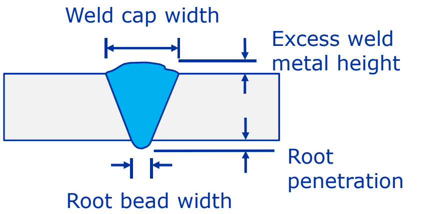
Features to Consider

Butt welds - size



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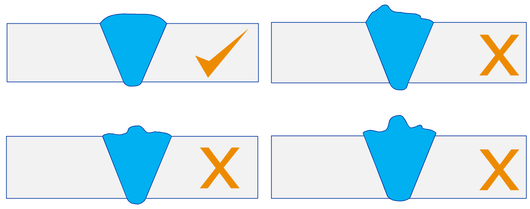
Features to Consider

Butt welds - toe blend



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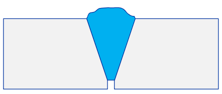
Welding Defects

Incomplete root penetration



Causes

- Too small a root gap.
- Arc too long.
- Wrong polarity.
- Electrode too large for joint preparation.
- Incorrect electrode angle.
- Too fast a speed of travel for current.

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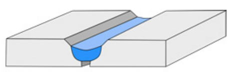
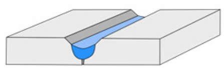
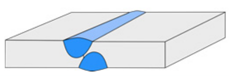
Welding Defects



a. Excessively thick root face.



b. Too small a root gap.



c. Misplaced welds.

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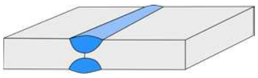
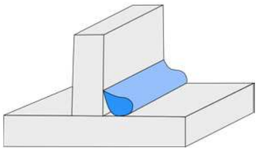
Welding Defects





d. Power input too low.

e. Arc (heat) input too low.

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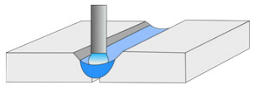
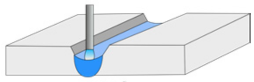
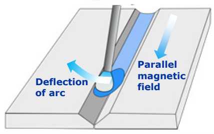
Welding Defects



Too large diameter electrode.



Smaller (correct) diameter electrode.



Lack of sidewall fusion due to arc deflection.

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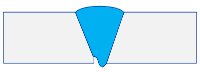
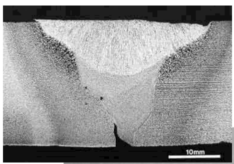
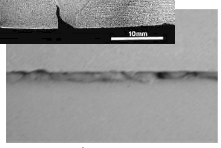
Welding Defects

Incomplete root fusion







Causes
- Too small a root gap.
- Arc too long.
- Wrong polarity.
- Electrode too large for joint preparation.
- Incorrect electrode angle.
- Too fast a speed of travel for current.

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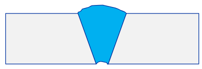
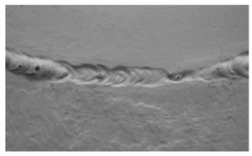
Welding Defects

Root concavity





Causes
- Root gap too large.
- Insufficient arc energy.
- Excessive back purge TIG.

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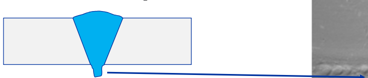
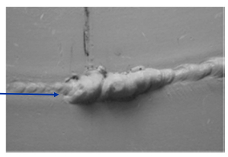
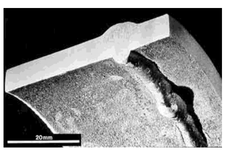
Welding Defects

Excess root penetration







Causes
- Excessive amperage during welding of root.
- Excessive root gap.
- Poor fit up.
- Excessive root grinding.
- Improper welding technique.

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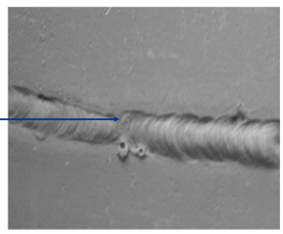
Welding Defects

Root undercut



Causes
- Root gap too large.
- Excessive arc energy.
- Small or no root face.

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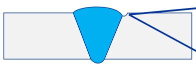
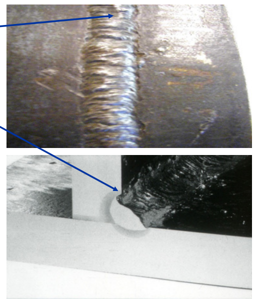
Welding Defects

Cap undercut





Causes

- Excessive welding current.
- Welding speed too high.
- Incorrect electrode angle.
- Excessive weave.
- Electrode too large.

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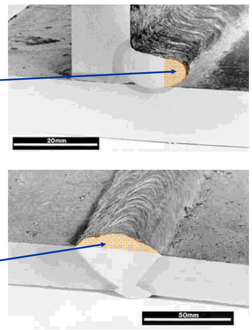
Welding Defects

Overlap

Excess weld metal



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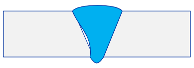
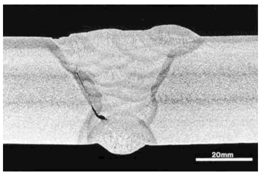
Welding Defects

Lack of fusion





Causes

- Contaminated weld preparation.
- Amperage too low.
- Amperage too high (welder increases speed of travel).

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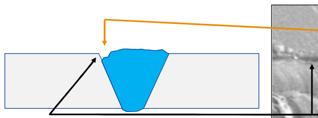
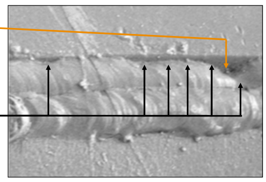
Welding Defects

Incompletely filled groove

and lack of side wall fusion





Causes

- Insufficient weld metal deposited.
- Improper welding technique.

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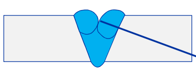
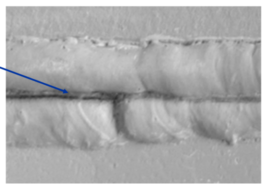
Welding Defects

Inter run incompletely filled groove





Causes

- Insufficient weld metal deposited.
- Improper welding technique.

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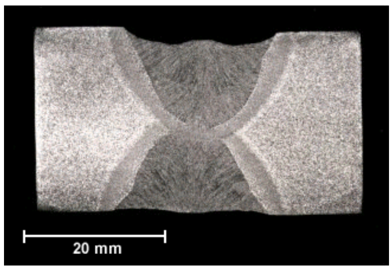
Welding Defects

Incompletely filled groove



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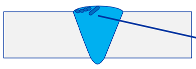
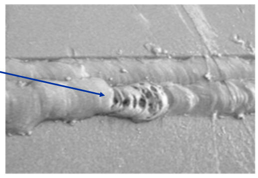
Welding Defects

Gas pores/porosity





Causes

- Excessive moisture in flux or preparation.
- Contaminated preparation.
- Low welding current.
- Arc length too long.
- Damaged electrode flux.
- Removal of gas shield.

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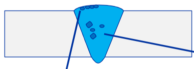
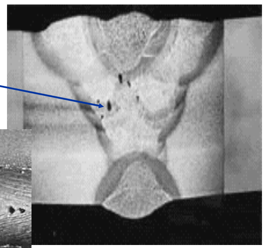
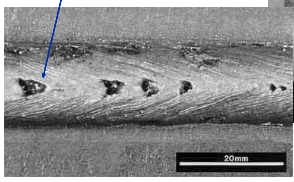
Welding Defects

Gas pores/porosity







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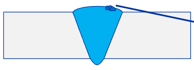
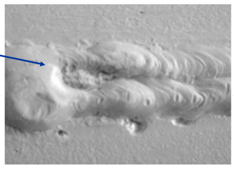
Welding Defects

Inclusions - slag





Causes

- Insufficient cleaning between passes.
- Contaminated weld preparation.
- Welding over irregular profile.
- Incorrect welding speed.
- Arc length too long.

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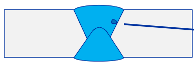
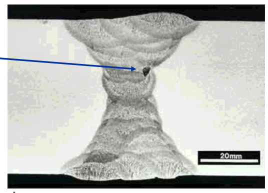
Welding Defects

Inclusions - slag





Causes

- Insufficient cleaning between passes.
- Contaminated weld preparation.
- Welding over irregular profile.
- Incorrect welding speed.
- Arc length too long.

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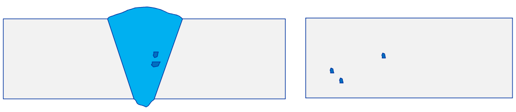
Welding Defects

Inclusions - tungsten



Causes

Contamination of weld caused by excessive current through electrode, tungsten touching weld metal or parent metal during welding using the TIG welding process.

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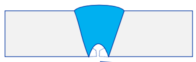
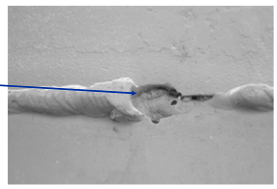
Welding Defects

Burn through





Causes

- Excessive amperage during welding of root.
- Excessive root grinding.
- Improper welding technique.

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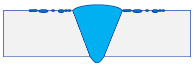
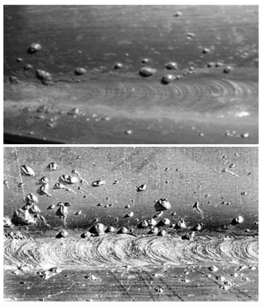
Welding Defects

Spatter





Causes
- Excessive arc energy.
- Excessive arc length.
- Damp electrodes.
- Arc blow.

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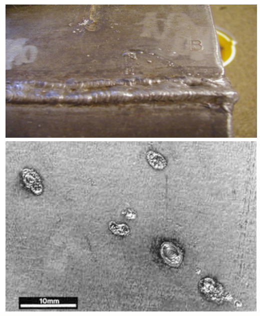
Welding Defects

Arc strikes

Causes
- Electrode straying onto parent metal.
- Electrode holder with poor insulation.
- Poor contact of earth clamp.



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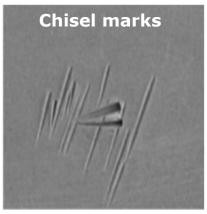
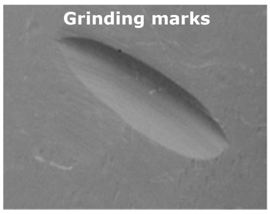
Welding Defects

Mechanical damage





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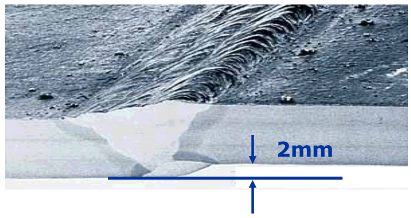
Welding Defects

Non-alignment of two abutting edges



Also known as: Hi low, mismatch or misalignment.

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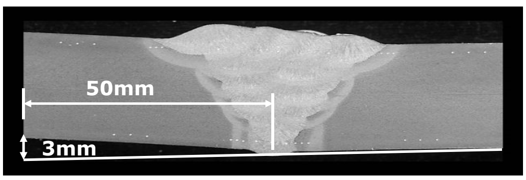
Welding Defects



Angular distortion
- Measure the distance to the edge of the plate (50mm).
- Use a straight edge (rule) to find the amount of distortion then measure the space (3mm).
- This is reported as angular distortion 3mm in 50mm.

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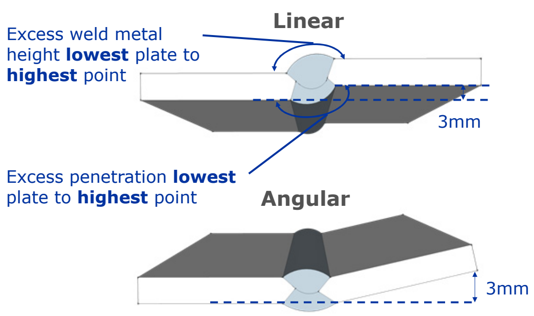
Welding Defects



Angular misalignment measured in mm.

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Any Questions

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Section 4

Destructive Testing

4 Destructive Testing

Introduction

European Welding Standards require test coupons made for welding procedure qualification testing to be subjected to non-destructive and then destructive testing.

The tests are called destructive tests because the welded joint is destroyed when various types of test piece are taken from it.

Destructive tests can be divided into two groups, those used to:

- Measure a mechanical property – **quantitative tests.**
- Assess the joint quality – **qualitative tests.**

Mechanical tests are quantitative because a quantity is measured, a mechanical property such as tensile strength, hardness or impact toughness.

Qualitative tests are used to verify that the joint is free from defects, of sound quality and examples of these are bend tests, macroscopic examination and fracture tests (fillet fracture and nick-break).

4.1 Test types, pieces and objectives

Various types of mechanical test are used by material manufacturers/ suppliers to verify that plates, pipes, forgings, etc have the minimum property values specified for particular grades.

Design engineers use the minimum property values listed for particular grades of material as the basis for design and the most cost-effective designs are based on an assumption that welded joints have properties that are no worse than those of the base metal.

The quantitative (mechanical) tests carried out for welding procedure qualification are intended to demonstrate that the joint properties satisfy design requirements.

The emphasis in the following sub-sections is on the destructive tests and test methods widely used for welded joints.

4.1.1 Transverse tensile tests

Test objective

Welding procedure qualification tests always require transverse tensile tests to show that the strength of the joint satisfies the design criterion.

Test specimens

A transverse tensile test piece typical of the type specified by European Welding Standards is shown below.

Standards, such as EN 895, that specify dimensions for transverse tensile test pieces require all excess weld metal to be removed and the surface to be free from scratches.

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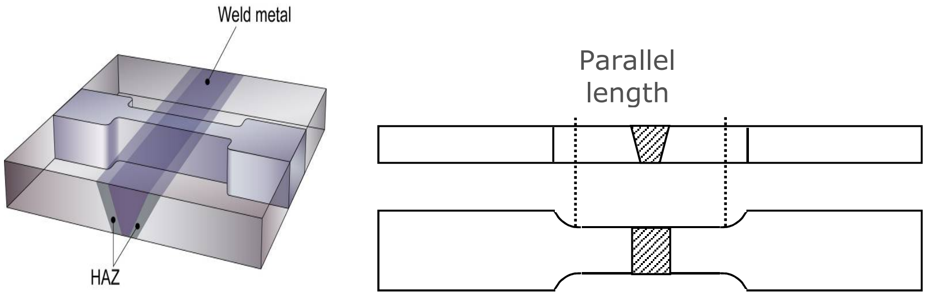

Figure 4.1 Transverse tensile test piece.

Test pieces may be machined to represent the full thickness of the joint but for very thick joints it may be necessary to take several transverse tensile test specimens to be able to test the full thickness.

Method

Test specimens are accurately measured before testing, then fitted into the jaws of a tensile testing machine and subjected to a continually increasing tensile force until the specimen fractures.

The tensile strength (R_m) is calculated by dividing the maximum load by the cross-sectional area of the test specimen, measured before testing.

The test is intended to measure the tensile strength of the joint and thereby show that the basis for design, the base metal properties, remain the valid criterion.

Acceptance criteria

If the test piece breaks in the weld metal, it is acceptable provided the calculated strength is not less than the minimum tensile strength specified, which is usually the minimum specified for the base metal material grade.

In the ASME IX code, if the test specimen breaks outside the weld or fusion zone at a stress above 95% of the minimum base metal strength the test result is acceptable.

4.1.2 All-weld tensile tests

Objective

On occasion it is necessary to measure the weld metal strength as part of welding procedure qualification, particularly for elevated temperature designs.

The test is to measure tensile strength and also yield (or proof strength) and tensile ductility.

All-weld tensile tests are regularly carried out by welding consumable manufacturers to verify that electrodes and filler wires satisfy the tensile properties specified by the standard to which the consumables are certified.

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Specimens

Machined from welds parallel with their longitudinal axis and the specimen gauge length must be 100% weld metal.

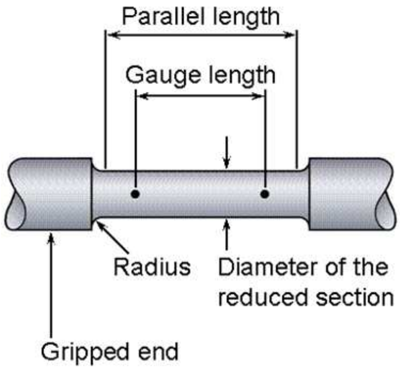
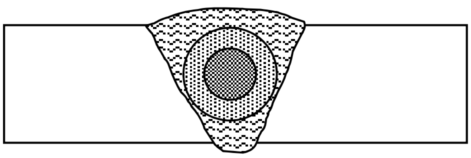
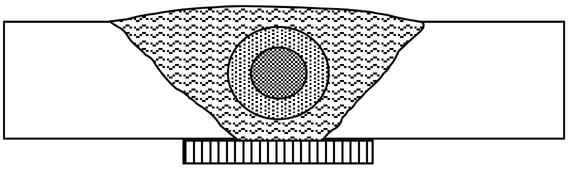


Figure 4.2 Diagram of a tensile specimen.



Round tensile specimen from a welding procedure qualification test piece.



Round tensile specimen from an electrode classification test piece.

Figure 4.3 Round cross-section tensile specimens.

Method

Specimens are subjected to a continually increasing force in the same way that transverse tensile specimens are tested.

Yield (R_e) or proof stress (R_p) are measured by an extensometer attached to the parallel length of the specimen that accurately measures the extension of the gauge length as the load is increased.

Typical load extension curves and their principal characteristics are shown below.

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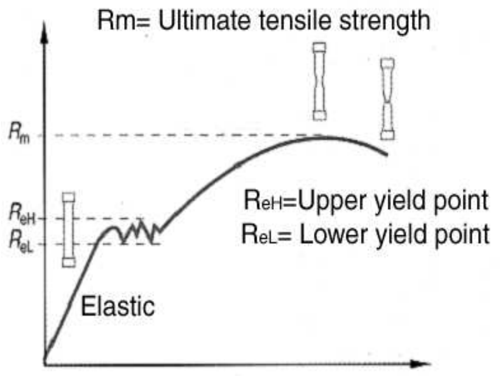
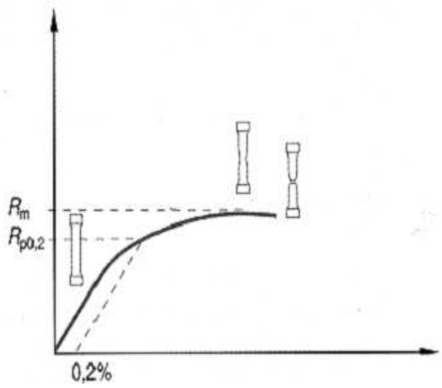


Load extension curve for a steel that shows a distinct yield point at the elastic limit.



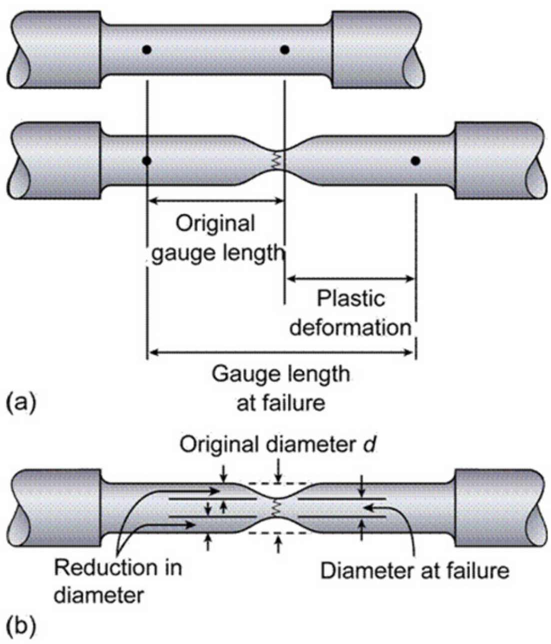
Load-extension curve for a steel (or other metal) that does not show a distinct yield point; proof stress is a measure of the elastic limit.

Figure 4.4 Typical load extension curves.

Tensile ductility is measured in two ways:

- Percent elongation of the gauge length.
- Percent reduction of area at the point of fracture.

The figure below illustrates these two ductility measurements.



Note: The term necking is often used to describe reduction in diameter.

Figure 4.5 Two ductility measurements.

To calculate elongation: $\frac{Change\ in\ length}{Original\ length}\ X\ \ 100\ elongation\ as\ a\ \%$

To calculate UTS: $\frac{Load}{CSA} = Ulimate\ tensile\ strength$

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4.1.3 Impact toughness tests

Objective

Charpy V notch test pieces are the internationally accepted method for assessing resistance to brittle fracture by measuring the energy to initiate and propagate a crack from a sharp notch in a standard sized specimen subjected to an impact load.

Design engineers need to ensure that the toughness of the steel used for a particular item will be sufficient to avoid brittle fracture in service and so impact specimens are tested at a temperature related to the design temperature for the fabricated component.

C-Mn and low alloy steels undergo a sharp change in their resistance to brittle fracture as their temperature is lowered so that a steel that may have very good toughness at ambient temperature may show extreme brittleness at sub-zero temperatures, as illustrated below.

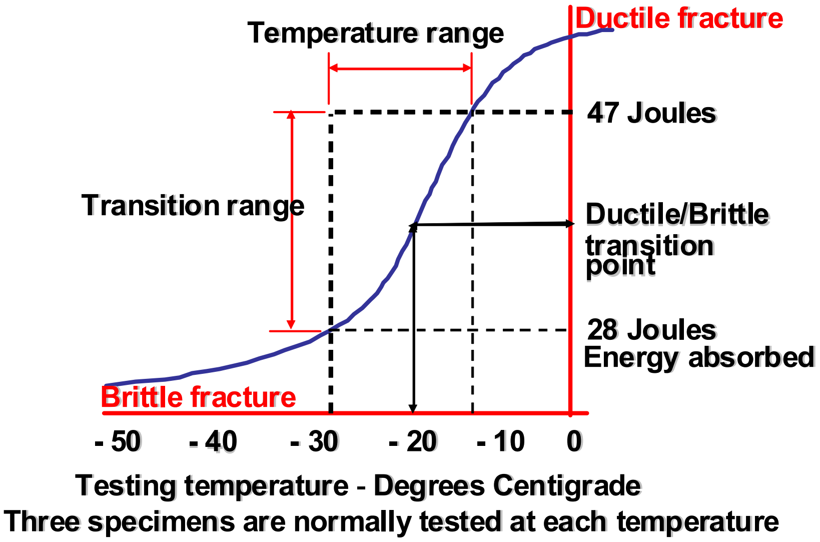

Figure 4.6 Impact toughness tests.

The transition temperature is defined as the temperature midway between the upper shelf (maximum toughness) and lower shelf (completely brittle). In the above the transition temperature is -20°C.

Specimens

Test specimen dimensions have been standardised internationally and are shown below for **full size specimens**. There are also standard dimensions for smaller sized specimens, for example 10 x 7.5mm and 10 x 5mm.

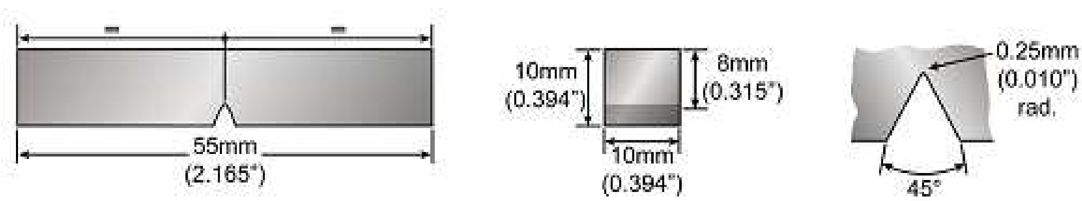

Figure 4.7 Charpy V notch test piece dimensions for full size specimens.

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Specimens are machined from welded test plates with the notch position located in different positions according to the testing requirements but typically in the centre of the weld metal and at positions across the HAZ, as shown below.

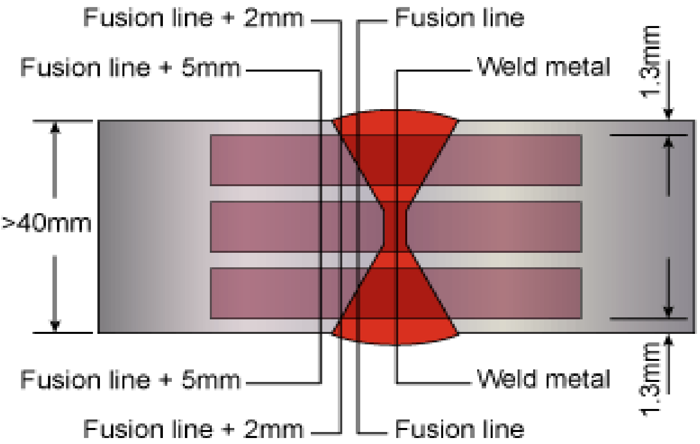

Figure 4.8 Typical notch positions for Charpy V notch test specimens from double V butt welds.

Method

Test specimens are cooled to the specified test temperature by immersion in an insulated bath containing a liquid held at the test temperature.

After allowing the specimen temperature to stabilise for a few minutes it is quickly transferred to the anvil of the test machine and a pendulum hammer quickly released so that the specimen experiences an impact load behind the notch.

The main features of an impact test machine are shown below.

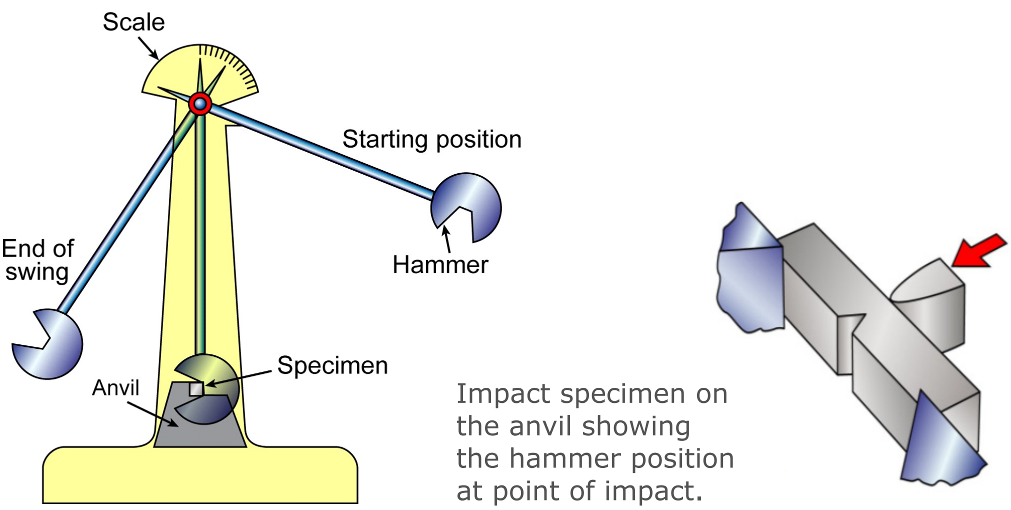

Figure 4.9 Impact testing machine.

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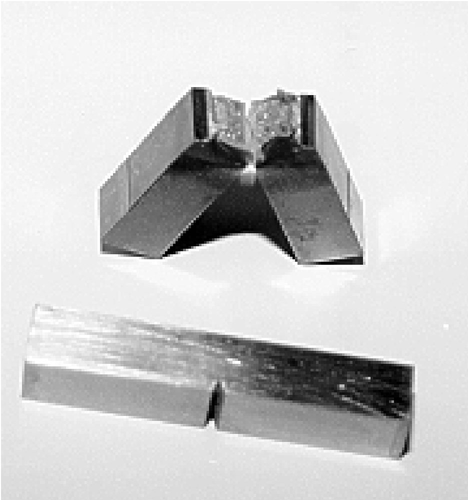


Figure 4.10 Charpy V notch test pieces after and before testing.

The energy absorbed by the hammer when it strikes each test specimen is shown by the position of the hammer pointer on the scale of the machine. Energy values are given in Joules (or ft-lbs in US specifications).

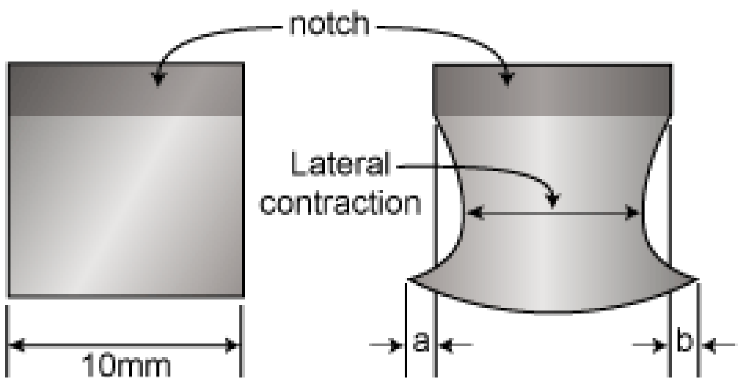
Three Impact test specimens are taken for each notch position as there is always some degree of scatter in the results, particularly for weldments.

Acceptance criteria

Each test result is recorded and an average value calculated for each set of three tests. These values are compared with those specified by the application standard or client to establish whether specified requirements have been met.

After impact testing, examination of the test specimens provides additional information about their toughness characteristics and may be added to the test report:

- Percent crystallinity: % of the fracture face that has crystalline appearance which indicates brittle fracture; 100% indicates completely brittle fracture.
- Lateral expansion: Increase in width of the back of the specimen behind the notch, as indicated below; the larger the value the tougher the specimen.



Non lateral expansion
brittle fracture

a + b = lateral expansion
ductile fracture

Figure 4.11 After impact testing.

A specimen that exhibits extreme brittleness will show a clean break, both halves of the specimen having a completely flat fracture face with little or no lateral expansion.

A specimen that exhibits very good toughness will show only a small degree of crack extension, without fracture and a high value of lateral expansion.

4.1.4 Hardness testing

Objective

The hardness of a metal is its' resistance to plastic deformation, determined by measuring the resistance to indentation by a particular type of indenter.

A steel weldment with hardness above a certain maximum may be susceptible to cracking, either during fabrication or in-service and welding procedure qualification testing for certain steels and applications requires the test weld to be hardness surveyed to ensure no regions exceed the maximum specified hardness.

Specimens prepared for macroscopic examination can also be used for taking hardness measurements at various positions of the weldments, referred to as a hardness survey.

Methods

There are three widely used methods:

- Vickers - uses a square-based diamond pyramid indenter.
- Rockwell - uses a diamond cone indenter or steel ball.
- Brinell - uses a ball indenter.

The hardness value is given by the size of the indentation produced under a standard load, the smaller the indentation, the harder the metal.

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The Vickers method of testing is illustrated below.

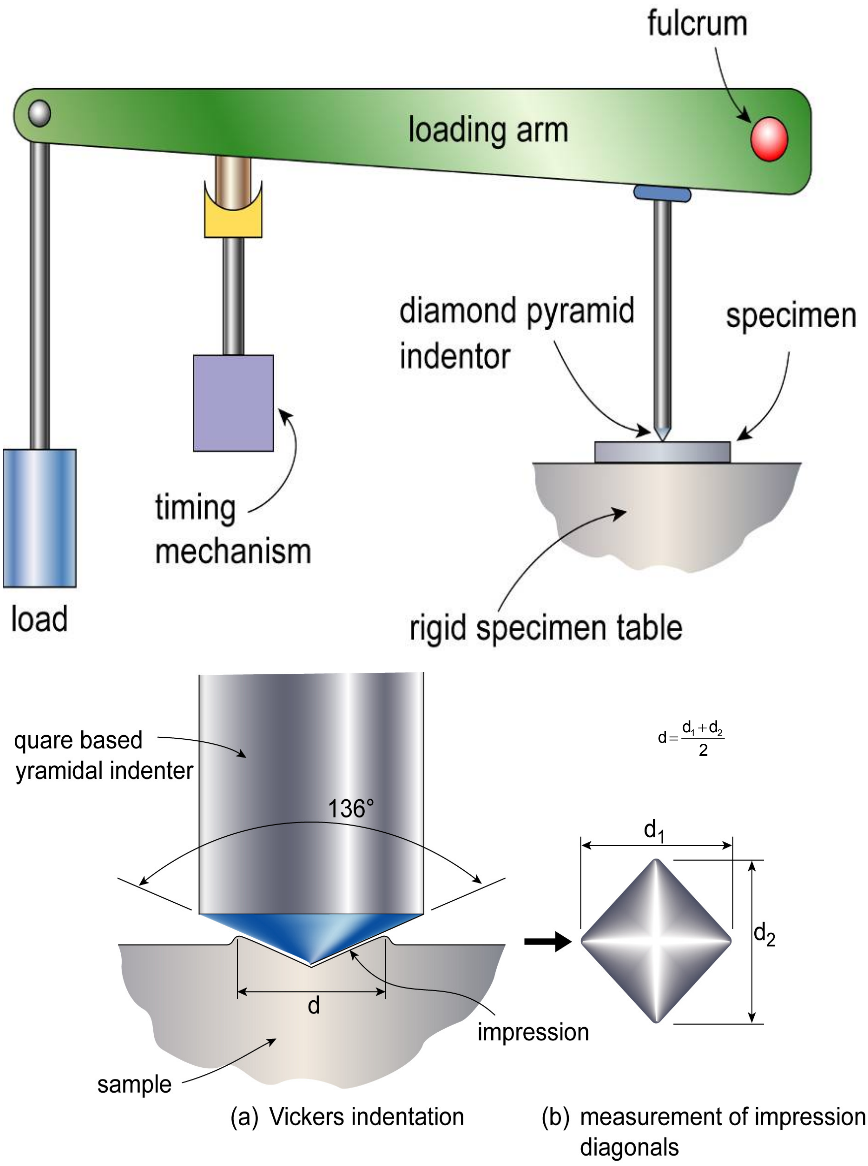

Figure 4.12 The Vickers method of testing.

Both the Vickers and Rockwell methods are suitable for carrying out hardness surveys on specimens prepared for macroscopic examination of weldments.

A typical hardness survey requires the indenter to measure the hardness in the base metal (on both sides of the weld), the weld metal and across the HAZ (on both sides of the weld).

The Brinell method gives an indentation too large to accurately measure the hardness in specific regions of the HAZ and is mainly used to measure the hardness of base metals.

A typical hardness survey (using Vickers hardness indenter) is shown below:

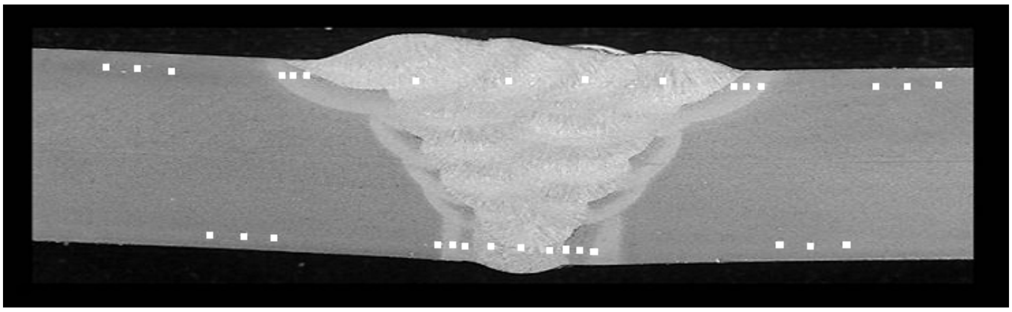

Figure 4.13 Typical hardness survey.

Hardness values are shown on test reports as a number followed by letters indicating the test method, for example:

240HV10 = hardness 240, Vickers method, 10kg indenter load.

22HRC = hardness 22, Rockwell method, diamond cone indenter (scale C).

238HBW = hardness 238, Brinell method, tungsten ball indenter.

4.1.5 Crack tip opening displacement (CTOD) testing.

Objective

Charpy V notch testing enables engineers **to make judgements** about the risk of brittle fracture occurring in steels, but a CTOD test **measures a material property - fracture toughness**.

Fracture toughness data enables engineers to carry out fracture mechanics analyses such as:

- Calculating the size of a crack that would initiate a brittle fracture under certain stress conditions at a particular temperature.
- The stress that would cause a certain sized crack to give a brittle fracture at a particular temperature.

This data is essential for making an appropriate decision when a crack is discovered during inspection of equipment that is in-service.

Specimens

A CTOD specimen is prepared as a rectangular or square shaped bar cut transverse to the axis of the butt weld. A V notch is machined at the centre of the bar, which will be coincident with the test position, weld metal or HAZ.

A shallow saw cut is made at the bottom of the notch and the specimen put into a machine that induces a cyclic bending load until a shallow fatigue crack initiates from the saw cut.

The specimens are relatively large, typically having a cross-section B x 2B and length ~10B (B = full thickness of the weld). The test piece details are shown below.

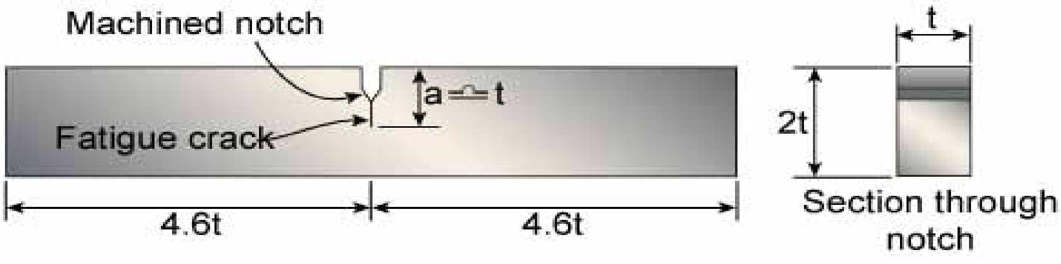

Figure 4.14 A CTOD specimen.

Method

CTOD specimens are usually tested at a temperature below ambient and the specimen temperature is controlled by immersion in a bath of liquid cooled to the required test temperature.

A load is applied to the specimen to cause bending and induce a concentrated stress at the tip of the crack and a clip gauge, attached to the specimen across the mouth of the machined notch, gives a reading of the increase in width of the crack mouth as the load is gradually increased.

For each test condition (position of notch and test temperature) it is usual to carry out three tests.

The figures below illustrate the main features of the CTOD test.

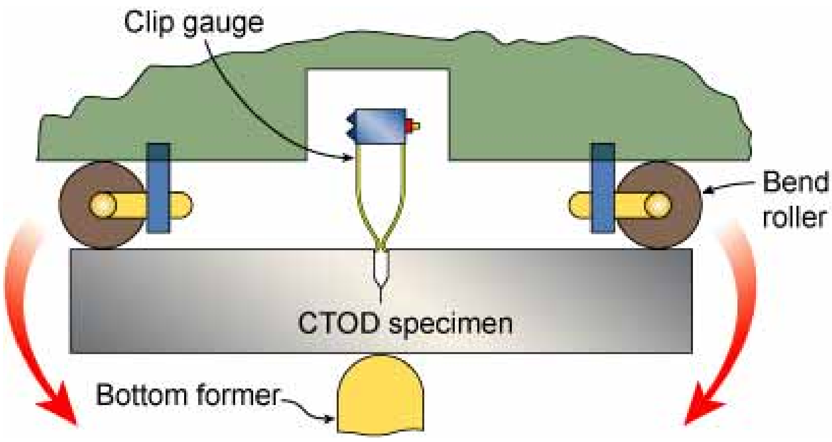

Figure 4.15 The main features of the CTOD test.

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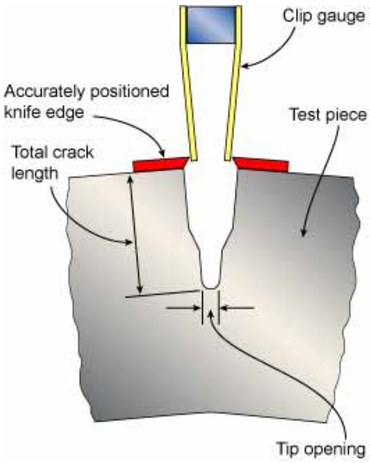

Figure 4.15 Cross section of specimen.

Fracture toughness is expressed as the distance the crack tip opens without initiation of a brittle crack.

The clip gauge enables a chart to be generated showing the increase in width of the crack mouth against applied load from which a CTOD value is calculated.

Acceptance criteria

An application standard or client may specify a minimum CTOD value that indicates ductile tearing. Alternatively, the test may be for information so that a value can be used for an engineering critical assessment (ECA).

A very tough steel weldment will allow the mouth of the crack to open widely by ductile tearing at the tip of the crack whereas a very brittle weldment will tend to fracture when the applied load is quite low and without any extension at the tip of the crack.

CTOD values are expressed in millimetres - typical values might be <<~0.1mm = brittle behaviour; >~1mm = very tough behaviour.

4.1.6 Bend testing

Objective

Bend tests routinely taken from welding procedure qualification test pieces and sometimes welder qualification test pieces.

Subjecting specimens to bending is a simple way of verifying there are no significant flaws in the joint. Some degree of ductility is also demonstrated, it is not measured but shown to be satisfactory if test specimens can withstand being bent without fracture or fissures above a certain length.

Specimens

There are four types of bend specimen:

- **Face**
  Taken with axis transverse to butt welds up to ~12mm thickness and bent so that the face of the weld is on the outside of the bend (face in tension).

- **Root**
  Taken with axis transverse to butt welds up to ~12mm thickness and bent so that the root of the weld is on the outside of the bend (root in tension).

- **Side**
  Taken as a transverse slice (~10mm) from the full thickness of butt welds >~12mm and bent so that the full joint thickness is tested (side in tension).

- **Longitudinal bend**
  Taken with axis parallel to the longitudinal axis of a butt weld; specimen thickness is ~12mm and the face or root of weld may be tested in tension.

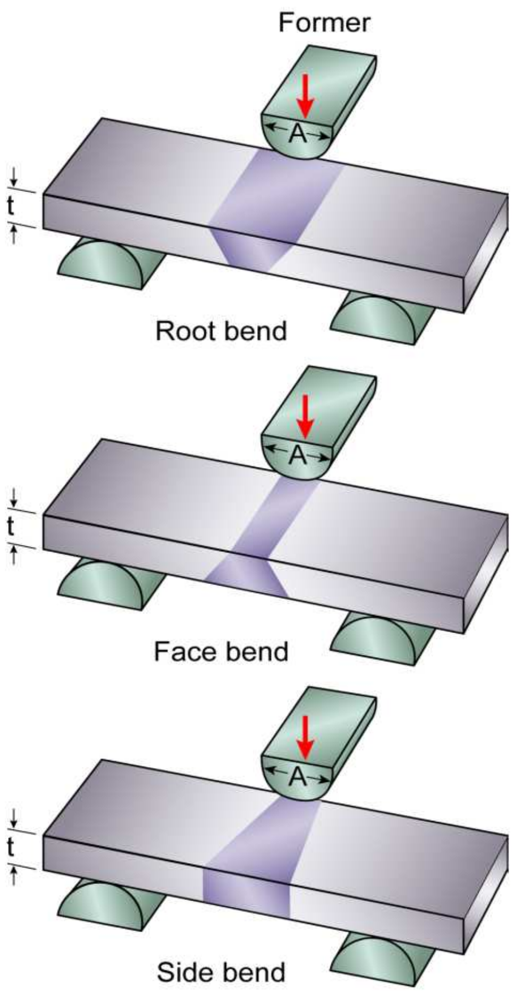

Figure 4.16 Four types of bend specimens.

Method

Guided bend tests are usually used for welding procedure and welder qualification.

Guided means that the strain imposed on the specimen is uniformly controlled by being bent around a former with a certain diameter.

The diameter of the former used for a particular test is specified in the code, having been determined by the type of material being tested and the ductility that can be expected from it after welding and any PWHT.

The diameter of the former is usually expressed as a multiple of the specimen thickness (t) and for C-Mn steel is typically 4t but for materials that have lower tensile ductility the radius of the former may be greater than 10t.

The standard that specifies the test method will specify the minimum bend angle the specimen must experience and is typically 120-180°.

Acceptance criteria

Bend tests pieces should exhibit satisfactory soundness by not showing cracks or any signs of significant fissures or cavities on the outside of the bend.

Small indications less than about 3mm in length may be allowed by some standards.

4.1.7 Fracture tests

Fillet weld fractures

Objective

The quality/soundness of a fillet weld can be assessed by fracturing test pieces and examining the fracture surfaces.

This method for assessing the quality of fillet welds may be specified by application standards as an alternative to macroscopic examination.

It is a test method that can be used for welder qualification testing according to European Standards but is not used for welding procedure qualification.

Specimens

A test weld is cut into short (typically ≥50mm) lengths and a longitudinal notch machined into the specimen as shown below. The notch profile may be square, V or U shape.

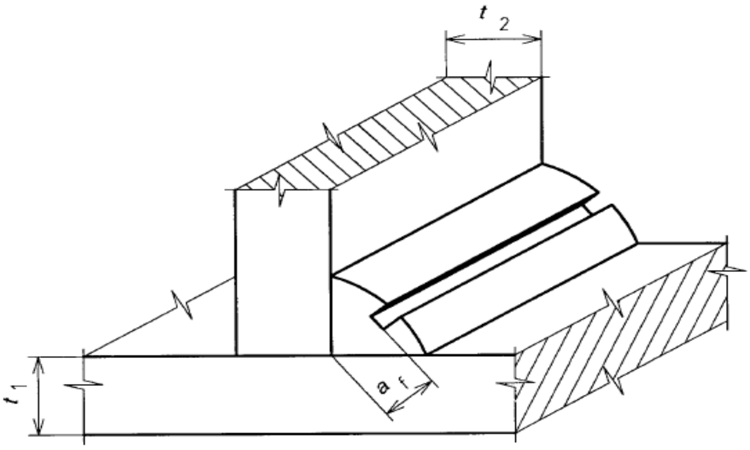

Figure 4.17 Longitudinal notch in fillet welds.

Method

Specimens are made to fracture through their throat by dynamic strokes (hammering) or by pressing, as shown below. The welding standard or application standard will specify the number of tests (typically four).

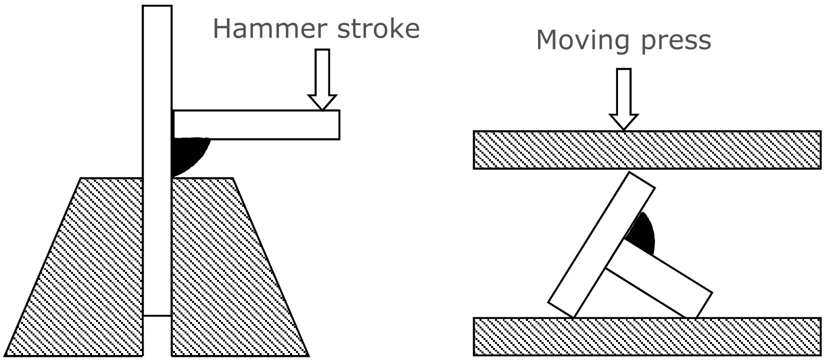

Figure 4.18 Hammer stroke and pressing specimens.

Acceptance criteria

The standard for welder qualification, or application standard, will specify the acceptance criteria for imperfections such as lack of penetration into the root of the joint and solid inclusions and porosity that are visible on the fracture surfaces.

Test reports should also give a description of the appearance of the fracture and location of any imperfection.

Butt weld fractures (nick-break tests)

Objective

The same as for fillet fracture tests.

These tests are specified for welder qualification testing to European Standards as an alternative to radiography and are not used for welding procedure qualification testing.

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Specimens

Taken from a butt weld and notched so that the fracture path will be in the central region of the weld. Typical test piece types are shown below.

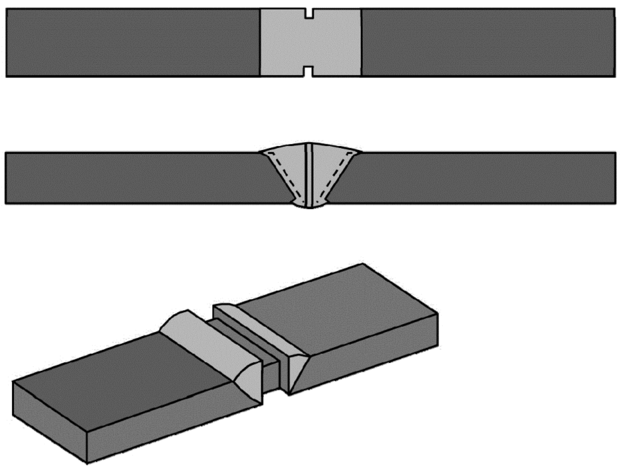

Figure 4.19 Notched butt weld.

Method

Test pieces are made to fracture by hammering or three-point bending.

Acceptance criteria

The standard for welder qualification or application standard will specify the acceptance criteria for imperfections such as lack of fusion, solid inclusions and porosity that are visible on the fracture surfaces.

Test reports should also give a description of the appearance of the fracture and location of any imperfection.

4.2 Macroscopic examination

Transverse sections from butt and fillet welds are required by the European Standards for welding procedure qualification testing and may be required for some welder qualification testing for assessing the quality of the welds.

This is considered in detail in a separate section of these course notes.

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4.2.1 European Standards for destructive test methods

The following Standards are specified by the European Welding Standards for destructive testing of welding procedure qualification test welds and for some welder qualification test welds.

BS EN ISO 9016	Destructive tests on welds in metallic materials - impact tests - test specimen location, notch orientation and examination.
BS EN ISO 4136	Destructive tests on welds in metallic materials - transverse tensile test.
BS EN ISO 5173 +A1	Destructive tests on welds in metallic materials - bend tests.
BS EN ISO 17639	Destructive tests on welds in metallic materials - macro and microscopic examination of welds.
BS EN ISO 6892-1	Metallic materials - Tensile testing. Part 1: Method of test at ambient temperature.
BS EN ISO 6892-2	Tensile testing of metallic materials. Part 5: Method of test at elevated temperatures.

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Destructive Testing

Section 4

Materials Joining and Engineering Technologies
Training and Examination Services

Destructive testing Objective

When this presentation has been completed you should be able to recognise a wide range of mechanical tests and their purpose. You should also be able to make calculations using formulae and tables to determine various values of strength, toughness, hardness and ductility.

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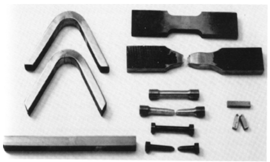
Destructive Testing Definitions

What is destructive testing?

The destruction of a welded unit or by cutting out selected specimens from the weld, is carried out to check the mechanical properties of the joint materials.



They can be produced to

- Approve welding procedures (BS EN 15614).
- Approve welders (BS EN ISO 9606).
- Production quality control.

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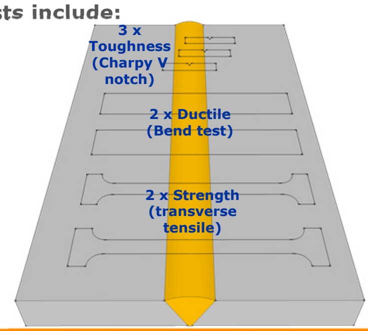
Destructive Tests

Destructive tests include:

- Bend test.
- Impact test.
- Tensile test.
- Hardness test.
- Macro/micro examination.



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Qualitative and Quantitative Tests

The following mechanical tests have units and are termed **quantitative** tests to measure **mechanical properties** of the joint.

- Tensile tests (transverse welded joint, all weld metal).
- Toughness testing (Charpy, Izod, CTOD).
- Hardness tests (Brinell, Rockwell, Vickers).

The following mechanical tests have no units and are termed **qualitative** tests for assessing **weld quality**.

- Macro testing.
- Bend testing.
- Fillet weld fracture testing.
- Butt weld nick-break testing.

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Definitions

Mechanical properties of metals are related to the amount of deformation which metals can withstand under different circumstances of force application.

- Malleability.
- Ductility.
- Toughness.
- Hardness.
- Tensile Strength.

Ability of a material to withstand deformation under static compressive loading without rupture.

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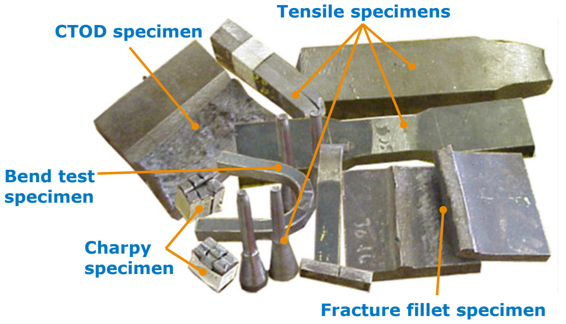
Mechanical Test Samples



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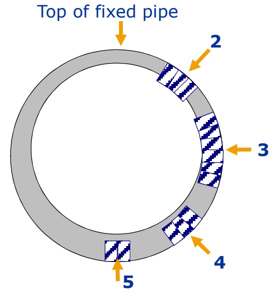
Destructive Testing

Welding procedure qualification testing



Typical positions for test pieces and specimen type position

- Macro + hardness. 5
- Transverse tensile. 2, 4
- Bend tests. 2, 4
- Charpy impact tests. 3
- Additional tests. 3

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Mechanical Testing

Hardness Testing

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Hardness Testing

Definition

- Measurement of resistance of a material against penetration of an indenter under a constant load.
- There is a direct correlation between UTS and hardness.

Hardness tests:

- Brinell.
- Vickers.
- Rockwell.

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Hardness Testing

Objectives:

- Measuring hardness in different areas of a welded joint.
- Assessing resistance toward brittle fracture, cold cracking and corrosion sensitivity.

Information to be supplied on the test report:

- Material type.
- Location of indentation.
- Type of hardness test and load applied on the indenter.
- Hardness value.

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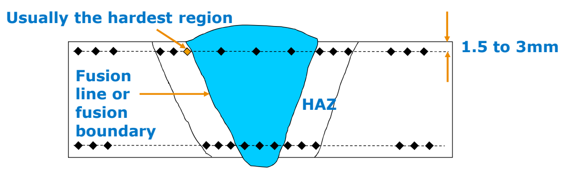
Hardness Testing



Hardness test methods	Typical designations
Vickers	240 HV10
Rockwell	Rc 22
Brinell	200 BHN-W

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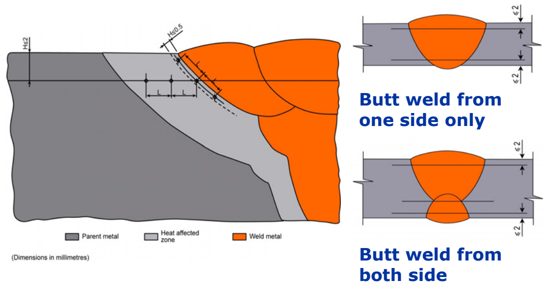
Vickers Hardness Test

Typical location of the indentations



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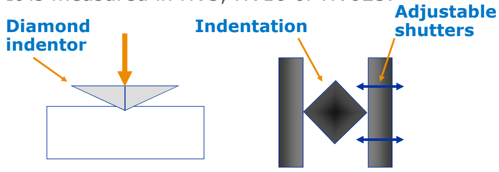
Vickers Hardness Test

Vickers hardness tests:

- Indentation body is a square based diamond pyramid (136° included angle).
- The average diagonal (d) of the impression is converted to a hardness number from a table.
- It is measured in HV5, HV10 or HV025.



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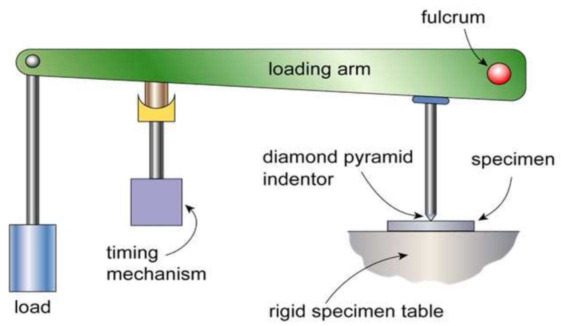
Vickers Hardness Test Machine



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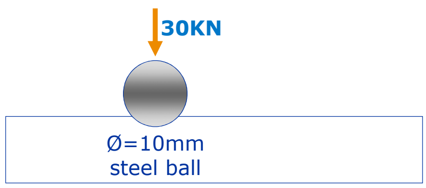
Brinell Hardness Test

- Hardened steel ball of given diameter is subjected for a given time to a given load.
- Load divided by area of indentation gives Brinell hardness in kg/mm^2.
- More suitable for on site hardness testing.



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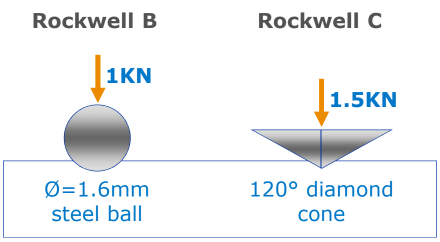
Rockwell Hardness Test



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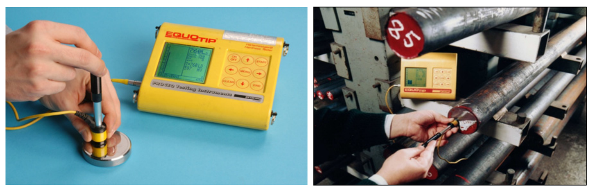
Portable Hardness Test



- Dynamic and very portable hardness test.
- Accuracy depends on the the condition of the test/support surfaces and the support of the test piece during the test.
- For more details, see ASTM E448.

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Mechanical Testing

Impact Testing

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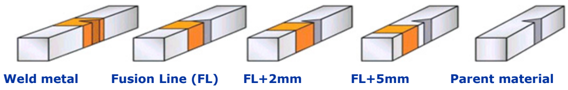
Charpy V-Notch Impact Test



Objectives:
- Measuring impact strength in different weld joint areas.
- Assessing resistance toward brittle fracture.

Information to be supplied on the test report:
- Material type.
- Notch type.
- Specimen size.
- Test temperature.
- Notch location.
- Impact strength value.

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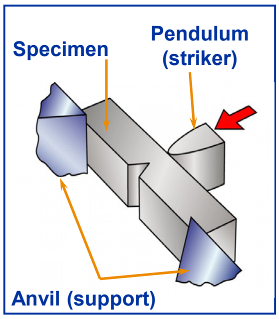
Charpy V-Notch Impact Test



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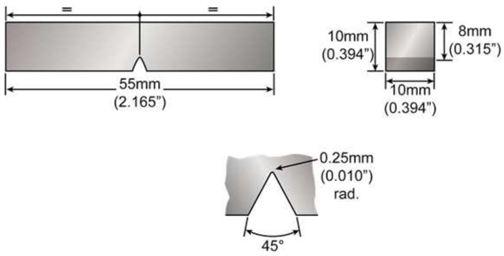
Charpy V-Notch Impact Test Specimen

Specimen dimensions according ASTM E23



ASTM: American **Society of Testing Materials.**

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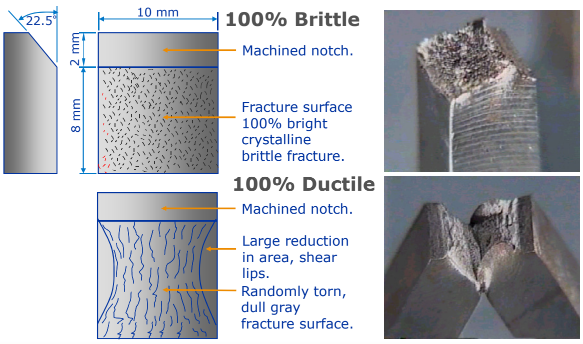
Charpy Impact Test



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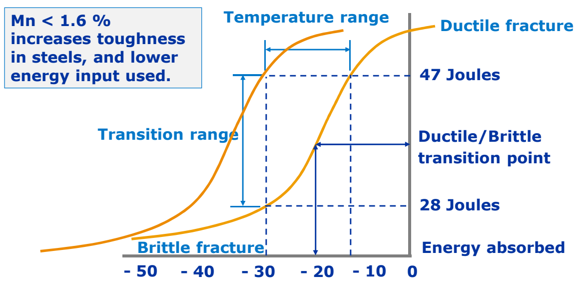
Ductile/Brittle Transition Curve



Testing temperature - Degrees centigrade

Three specimens are normally tested at each temperature

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Comparison Charpy Impact Test Results

Impact energy joules

Room Temperature	-20°C Temperature
1. 197 Joules	1. 49 Joules
2. 191 Joules	2. 53 Joules
3. 186 Joules	3. 51 Joules
Average = 191 Joules	Average = 51 Joules

The test results show the specimens carried out at room temperature absorb more energy than the specimens carried out at -20°C.

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Charpy Impact Test

Reporting results

- Location and orientation of notch.
- Testing temperature.
- Energy absorbed in joules.
- Description of fracture (brittle or ductile).
- Location of any defects present.
- Dimensions of specimen.

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Mechanical Testing

Tensile Testing

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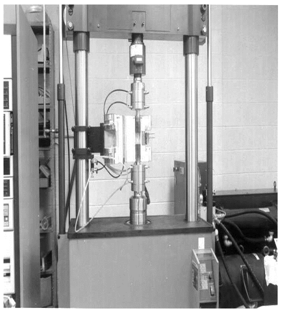
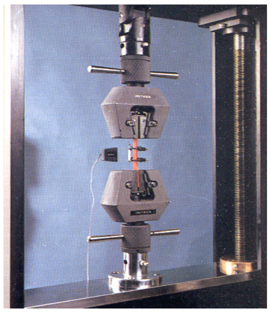
Tensile Testing





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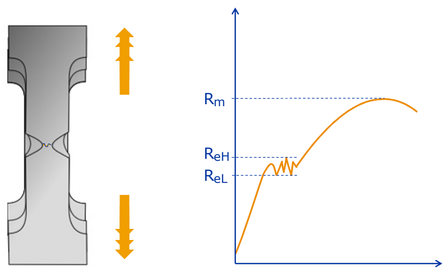
UTS Tensile Test



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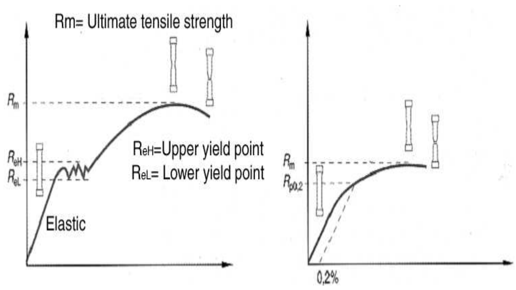
Tensile Tests



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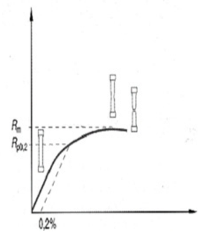
Tensile Test

Rp 0.2% - Proof stress. Refers to materials which do not have a defined yielding such as aluminium and some steels.



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Tensile Tests

Different tensile tests:

- Transverse tensile.
- All-weld metal tensile test.
- Cruciform tensile test.
- Short tensile test (through thickness test).

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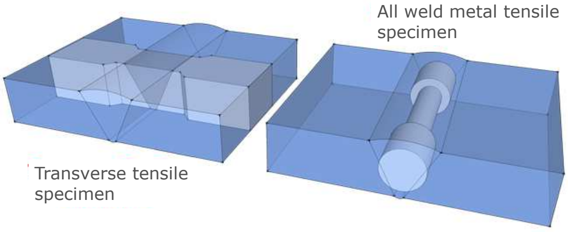
Tensile Test



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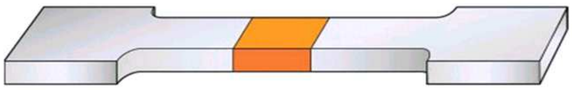
Transverse Joint Tensile Test



Objective:
Measuring the overall strength of the weld joint.

Information to be supplied on the test report:

- Material type.
- Specimen type
- Specimen size (see QW-462.1).
- UTS.
- Location of final rupture.

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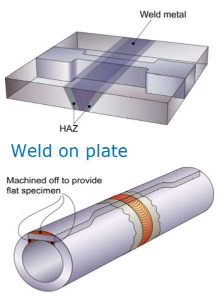
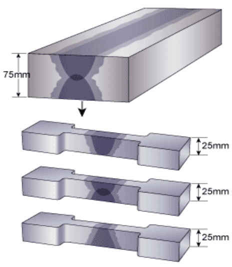
Transverse Joint Tensile Test



Weld on plate

Weld on pipe



Multiple cross joint specimens

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Transverse Tensile Test

Maximum load applied = 220 kN

Cross sectional area = 25 mm X 12 mm

$$UTS = \frac{\text{Maximum load applied}}{\text{csa}}$$

$$UTS = \frac{220\ 000}{25\text{mm X } 12\text{mm}}$$

UTS = 733.33 N/mm²

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Transverse Tensile Test

Reporting results:

- Type of specimen eg reduced section.
- Whether weld reinforcement is removed.
- Dimensions of test specimen.
- The ultimate tensile strength in N/mm^2, psi or Mpa.
- Location of fracture.
- Location and type of any flaws present if any.

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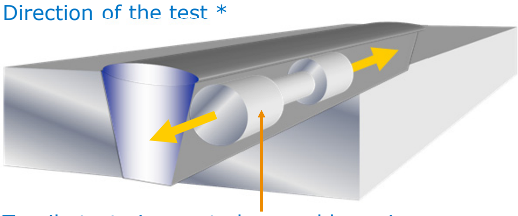
All-Weld Metal Tensile Test

BS 709/BS EN 10002

All Weld Metal Tensile Testing

Direction of the test *



Tensile test piece cut along weld specimen.

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All-Weld Metal Tensile Test

Original gauge length = 50mm

Increased gauge length = 64

$$\text{Elongation \%} = \frac{\text{Increase of gauge length}}{\text{Original gauge length}} \times 100$$

$$\text{Elongation \%} = \frac{14}{50} \times 100$$

Elongation = 28%

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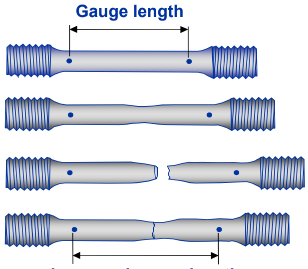
All-Weld Metal Tensile Test



Object of test:

- Ultimate tensile strength.
- Yield strength.
- Elongation %(ductility).

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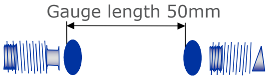
All-Weld Metal Tensile Test

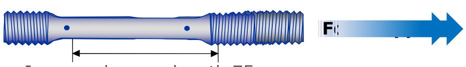
Two marks are made

Gauge length 50mm



During the test, yield and tensile strength are recorded

The specimen is joined and the marks are re-measured



Increased gauge length 75mm

A measurement of 75mm will give Elongation of 50%.

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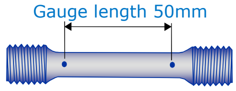
All-Weld Metal Tensile Test

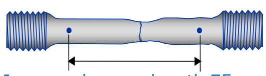
Two marks are made

Gauge length 50mm



During the test, yield and tensile strength are recorded

The specimen is joined and the marks are re-measured



Increased gauge length 75mm

A measurement of 75mm will give Elongation of 50%.

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All-Weld Metal Tensile Test

Reporting results:

- Type of specimen eg reduced section.
- Dimensions of test specimen.
- The UTS, yield strength in N/mm², psi or Mpa.
- Elongation %.
- Location and type of any flaws present if any.

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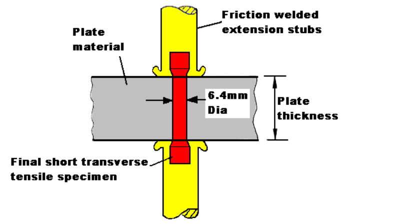
STRA (Short Transverse Reduction Area)



Short transverse tensile test specimen with friction welded extensions

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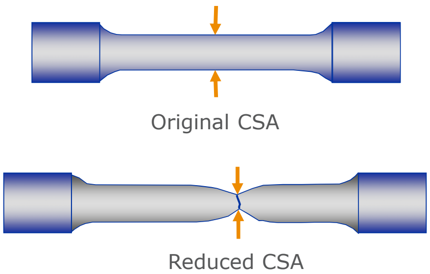
STRA Test



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UTS Calculation

A welded sample has undergone a transverse tensile test. The specimen before testing 120mm long and after testing had a length 150mm, the maximum load applied was 140Kn. The cross sectional area before testing was 10mm in depth and 40mm in width.

Please calculate the elongation % and UTS.

$$\frac{\text{Change in length}}{\text{Original length}} \quad \frac{(150 - 120) = 30}{120} \quad = 0.25 \times 100 = 25\%$$

$$\frac{\text{Load}}{\text{CSA}} \quad \frac{140 \text{ Kn}}{10 \times 40} \quad \frac{14{,}000 \text{ n}}{400} \quad = 350 \text{ n/mm}^2$$

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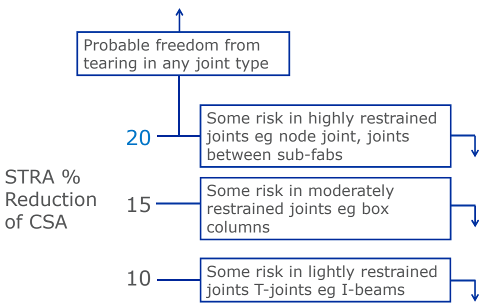
STRA Test



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Mechanical Testing

Macro/Micro Examination

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Macro Preparation

Purpose

To examine the weld cross-section to give assurance that:

- The weld has been made in accordance with the WPS.
- The weld is free from defects.

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Macro Preparation

Specimen preparation

- Full thickness slice taken from the weld (typically ~10mm thick).
- Width of slice sufficient to show all the weld and HAZ on both sides plus some unaffected base material.
- One face ground to a progressively fine finish (grit sizes 120 to ~400).
- Prepared face heavily etched to show all weld runs and all HAZ.
- Prepared face examined at up to x10 (and usually photographed for records).
- Prepared face may also be used for a hardness survey.

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Macro Preparation

Purpose

To examine a particular region of the weld or HAZ in order to:

- To examine the microstructure.
- Identify the nature of a crack or other imperfection.

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Macro Preparation

Specimen preparation

- A small piece is cut from the region of interest (typically up to ~20mm x 20mm).
- The piece is mounted in plastic mould and the surface of interest prepared by progressive grinding (to grit size 600 or 800).
- Surface polished on diamond impregnated cloths to a mirror finish.
- Prepared face may be examined in as-polished condition and then lightly etched.
- Prepared face examined under the microscope at up to ~100 – 1000X.

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Macro/Micro Examination

Object:

- Macro/microscopic examinations are used to give a visual evaluation of a cross-section of a welded joint.
- Carried out on full thickness specimens.
- The width of the specimen should include HAZ, weld and parent plate.
- They maybe cut from a stop/start area on a welders approval test.

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Macro/Micro Examination

Will reveal:

- Weld soundness.
- Distribution of inclusions.
- Number of weld passes.
- Metallurgical structure of weld, fusion zone and HAZ.
- Location and depth of penetration of weld.
- Fillet weld leg and throat dimensions.

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Macro/Micro Examination

Macro
- Visual examination for defects.
- Cut transverse from the weld.
- Ground and polished P400 grit paper.
- Acid etch using 5-10% nitric acid solution.
- Wash and dry.
- Visual evaluation under 5x magnification.
- Report on results.

Micro
- Visual examination for defects and grain structure.
- Cut transverse from a weld.
- Ground and polished P1200 grit paper, 1μm paste.
- Acid etch using 1-5% nitric acid solution.
- Wash and dry.
- Visual evaluation under 100-1000x magnification.
- Report on results.

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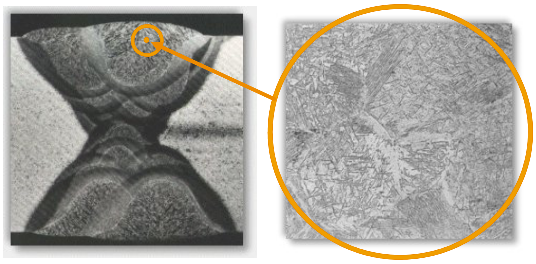
Metallographic Examination



Macro examination Micro examination

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Metallographic Examination

Objectives:
- Detecting weld defects (macro).
- Measuring grain size (micro).
- Detecting brittle structures, precipitates, etc.
- Assessing resistance toward brittle fracture, cold cracking and corrosion sensitivity.

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Metallographic Examination

Information to be supplied on the test report:
- Material type.
- Etching solution.
- Magnification.
- Grain size.
- Location of examined area.
- Weld imperfections (macro).
- Phase, constituents, precipitates (micro).

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Mechanical Testing

Bend Testing

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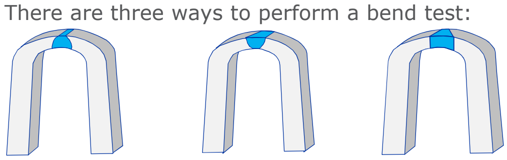
Bend Tests

Object of test:
To determine the soundness of the weld zone. Bend testing can also be used to give an assessment of weld zone ductility.

There are three ways to perform a bend test:



Root bend Face bend Side bend

Side bend tests are normally carried out on welds over 12mm in thickness.

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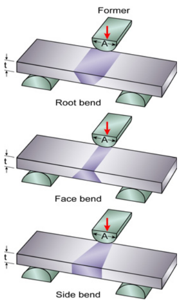
Bending Test

Types of bend test for welds (acc BS EN ISO 5173+A1):

- **Thickness of material - t**
  - **t up to 12 mm** → **Root/face bend**
  - **t over 12 mm** → **Side bend**



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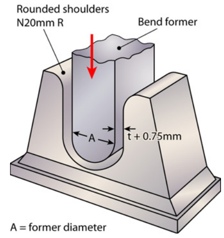
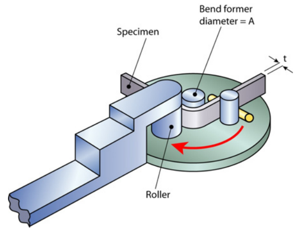
Bending Test Methods



Guided bend test



Wrap around bend test

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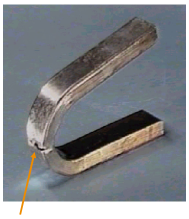
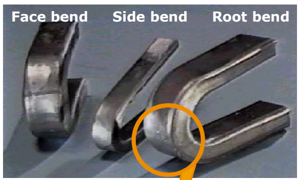
Bend Testing





Defect indication generally this specimen would be unacceptable.

Acceptance for minor ruptures on tension surface depends upon code requirements.

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Bend Tests

Reporting results:

- Thickness and dimensions of specimen.
- Direction of bend (root, face or side).
- Angle of bend (90°, 120°, 180°).
- Diameter of former (typical 4T).
- Appearance of joint after bending eg type and location of any flaws.

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Bend Testing

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Mechanical Testing

Fillet Weld Fracture Testing

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Fillet Weld Fracture Tests

Object of test:
- To break open the joint through the weld to permit examination of the fracture surfaces.
- Specimens are cut to the required length.
- A saw cut approximately 2mm in depth is applied along the fillet welds length.
- Fracture is usually made by striking the specimen with a single hammer blow.
- Visual inspection for defects.

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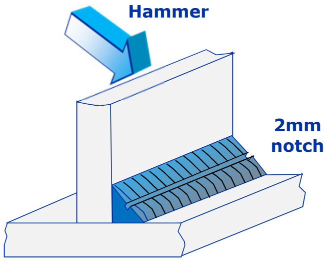
Fillet Weld Fracture Tests



Fracture **should** break weld saw cut to root

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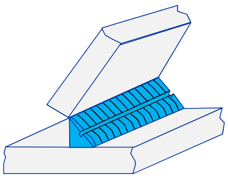
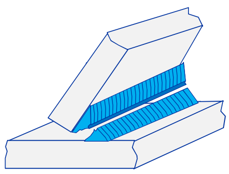
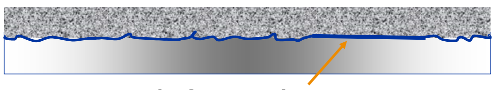
Fillet Weld Fracture Tests



This fracture indicates lack of fusion



This fracture has occurred saw cut to root



Lack of penetration

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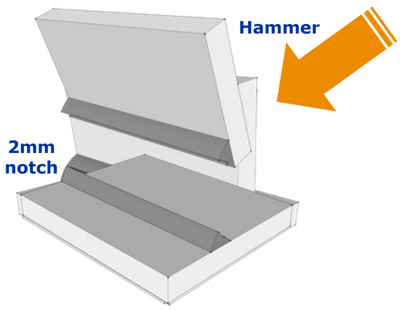

Fracture should break weld saw cut to root

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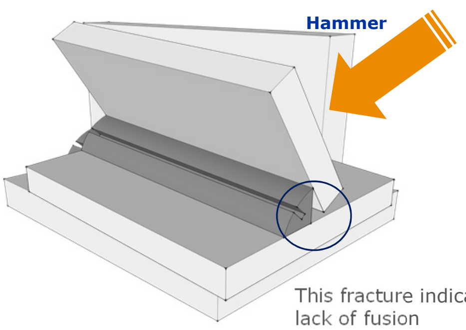

This fracture indicates lack of fusion

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Fillet Weld Fracture Tests

Reporting results:
- Thickness of parent material.
- Throat thickness and leg lengths.
- Location of fracture.
- Appearance of joint after fracture.
- Depth of penetration.
- Defects present on fracture surfaces.

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Mechanical Testing

Nick-Break Testing

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Nick-Break Test

Object of test:

- To permit evaluation of any weld defects across the fracture surface of a butt weld.
- Specimens are cut transverse to the weld.
- A saw cut approximately 2mm in depth is applied along the welds root and cap.
- Fracture is usually made by striking the specimen with a single hammer blow.
- Visual inspection for defects.

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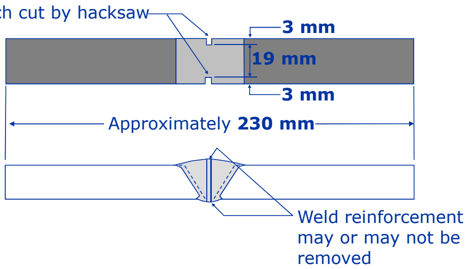
Nick-Break Test



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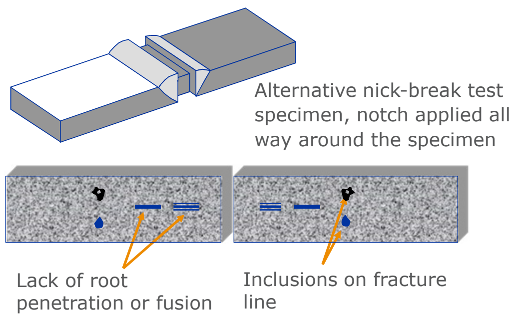
Nick-Break Test



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Nick-Break Test

Reporting results:

- Thickness of parent material.
- Width of specimen.
- Location of fracture.
- Appearance of joint after fracture.
- Depth of penetration.
- Defects present on fracture surfaces.

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Summary of Mechanical Testing

We test welds to establish minimum levels of mechanical properties, and soundness of the welded joint

We divide tests into qualitative and quantitative methods:

Quantitative: (Have units)

- Hardness (VPN & BHN).
- Toughness (Joules & ft.lbs).
- Strength (N/mm² & PSI, MPa).
- Ductility/Elongation (E%).

Qualitative: (Have no units)

- Macro tests.
- Bend tests.
- Fillet weld fracture tests.
- Butt Nick break tests.

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Hydrostatic Test

Under pressure leakage proof test

Vessel configuration:

- The test should be done after any stress relief.
- Components that will not stand the pressure test (eg flexible pipes, diaphragms) must be removed.
- The ambient temperature MUST be above 0°C (preferably 15-20°C).

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Hydrostatic Test

Test procedure:

- Blank off all openings with solid flanges.
- Use correct nuts and bolts, **not** G clamps.
- Two pressure gauges on independent tapping points should be used.
- For safety purposes bleed all the air out.
- Pumping should be done slowly (no dynamic pressure stresses).
- Test pressure - see relevant standards (PD 5500, ASME VIII). Usually 150% design pressure.
- Hold the pressure for minimum 30 minutes.

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Hydrostatic Test

What to look for:

- Leaks (check particularly around seams and nozzle welds)!
- Dry off any condensation.
- Watch the gauges for pressure drop.
- Check for distortion of flange faces, etc.

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Any Questions

?

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Section 5

Non-destructive Testing

5 Non-destructive Testing

5.1 Introduction

Radiographic, ultrasonic, dye penetrant and magnetic particle methods are briefly described below. Their relative advantages and limitations are discussed in terms of their applicability to the examination of welds.

5.2 Radiographic methods

In all cases radiographic methods as applied to welds involve passing a beam of penetrating radiation through the test object. The transmitted radiation is collected by some form of sensor, capable of measuring the relative intensities of penetrating radiations impinging upon it. In most cases this sensor is radiographic film; however the use of various electronic devices is on the increase. These devices facilitate so-called real-time radiography and examples may be seen in the security check area at airports. Digital technology has enabled the storing of radiographs using computers. The present discussion is confined to film radiography since this is still the most common method applied to welds.

5.2.1 Sources of penetrating radiation

Penetrating radiation may be generated from high energy electron beams and (X-rays), or from nuclear disintegrations (atomic fission), in which case they are termed gamma rays. Other forms of penetrating radiation exist but are of limited interest in weld radiography.

5.2.2 X-rays

X-rays used in the industrial radiography of welds generally have photon energies in the range 30keV up to 20MeV. Up to 400keV they are generated by conventional X-ray tubes which, dependent upon output may be suitable for portable or fixed installations. Portability falls off rapidly with increasing kilovoltage and radiation output. Above 400keV X-rays are produced using devices such as betatrons and linear accelerators, not generally suitable for use outside of fixed installations.

All sources of X-rays produce a continuous spectrum of radiation, reflecting the spread of kinetic energies of electrons within the electron beam. Low energy radiations are more easily absorbed and the presence of low energy radiations within the X-ray beam, gives rise to better radiographic contrast and therefore better radiographic sensitivity than is the case with gamma-rays which are discussed below. Conventional X-ray units are capable of performing high quality radiography on steel of up to 60mm thickness, betatrons and linear accelerators in excess of 300mm.

5.2.3 Gamma rays

Early sources of gamma rays used in industrial radiography were in generally composed of naturally occurring radium. The activity of these sources was not very high so they were large by modern standards even for quite modest outputs of radiation and the radiographs produced were not of a particularly high standard.

Radium sources were also extremely hazardous to the user due to the production of radioactive radon gas as a product of the fission reaction. Since the advent of the nuclear age it has been possible to artificially produce isotopes of much higher specific activity than those occurring naturally which do not produce hazardous fission products.

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Unlike X-ray sources gamma sources do not produce a continuous distribution of quantum energies. Gamma sources produce a number of specific quantum energies unique for any particular isotope. Four isotopes in common use for the radiography of welds; are in ascending order of radiation energy: Thulium 90, ytterbium 169, iridium 192 and cobalt 60.

In terms of steel thulium 90 is useful up to a thickness of about 7mm, it's energy is similar to that of 90keV X-rays and due to it's high specific activity useful sources can be produced with physical dimensions of less than 0.5mm.

Ytterbium 169 has only fairly recently become available as an isotope for industrial use, it's energy is similar to that of 120keV X-rays and is useful for the radiography of steel up to approximately 12mm thickness.

Iridium 192 is probably the most commonly encountered isotopic source of radiation used in the radiographic examination of welds. It has a relatively and high specific activity and output sources with physical dimensions of 2-3mm in common usage, it's energy is approximately equivalent to that of 500keV X-rays and is useful for the radiography of steel of 10-75mm thickness.

Cobalt 60 has an energy approximating that of 1.2MeV X-rays, so suitable source containers are large and heavy so Cobalt 60 sources are not fully portable. They are useful for the radiography of steel in 40-150mm of thickness. The major advantages of using isotopic sources over X-rays are:

- Increased portability.
- No need for a power source.
- Lower initial equipment costs.

Against this the quality of radiographs produced by gamma ray techniques is inferior to those produced by X-ray the hazards to personnel may be increased (if the equipment is not properly maintained or if the operating personnel have insufficient training) and due to their limited useful lifespan new isotopes have to be purchased on a regular basis so that the operating costs may exceed those of an X-ray source.

5.2.4 Radiography of welds

Radiographic techniques depend on detecting differences in absorption of the beam, ie changes in the effective thickness of the test object, to reveal defective areas. Volumetric weld defects such as slag inclusions (except in special cases where the slag absorbs radiation to a greater extent than does the weld metal) and various forms of gas porosity are easily detected by radiographic techniques due to the large negative absorption difference between the parent metal and the slag or gas.

Planar defects such as cracks or lack of sidewall or inter-run fusion are much less likely to be detected by radiography since they may cause little or no change in the penetrated thickness. Where defects of this type are likely to occur other NDE techniques such as ultrasonic testing are preferable.

This lack of sensitivity to planar defects makes radiography unsuitable where a fitness-for-purpose approach is taken when assessing the acceptability of a weld. However, film radiography produces a permanent record of the weld condition which can be archived for future reference and provides an excellent means of assessing the welder's performance so it is often still the preferred method for new construction.

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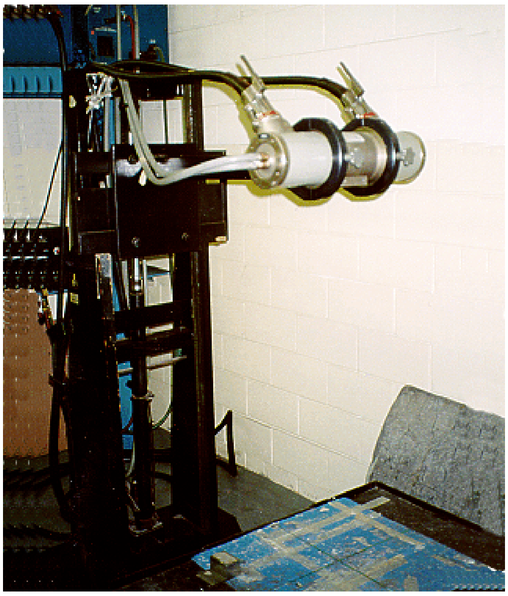

Figure 5.1 X-ray equipment.

Figure 5.2 Gamma ray equipment.

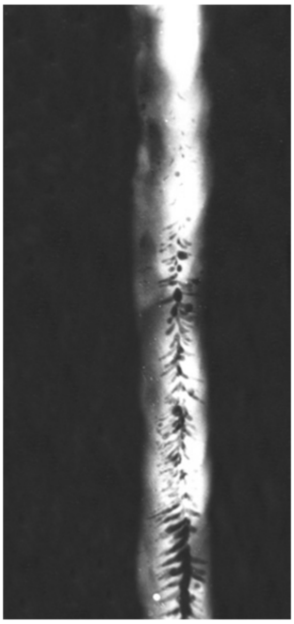

Figure 5.3 X-ray of a welded seam showing porosity.

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5.2.5 Radiographic testing

Advantages	Limitations
Permanent record	Health hazard. Safety (important)
Good for sizing non-planar defects/ flaws	Classified workers, medicals required
Can be used on all materials	Sensitive to defect orientation
Direct image of defect/flaws	Not good for planar defect detection
Real-time imaging	Limited ability to detect fine cracks
Can be positioned inside pipe (productivity)	Access to both sides required
Very good thickness penetration	Skilled interpretation required
No power required with gamma	Relatively slow
	High capital outlay and running costs Isotopes have a half-life (cost)

5.3 Ultrasonic methods

The velocity of ultrasound in any given material is a constant for that material and ultrasonic beams travel in straight lines in homogeneous materials. When ultrasonic waves pass from a given material with a given sound velocity to a second material with different velocity, refraction and a reflection of the sound beam will occur at the boundary between the two materials. The same laws of physics apply to ultrasonic waves as to light waves.

Ultrasonic waves are refracted at a boundary between two materials having different acoustic properties so probes may be constructed which can beam sound into a material at (within certain limits) any given angle. Because sound is reflected at a boundary between two materials having different acoustic properties ultrasound is a useful tool for the detection of weld defects.

Since velocity is a constant for any given material and sound travels in a straight line (with the right equipment) ultrasound can also be used to give accurate positional information about a given reflector.

Careful observation of the echo pattern of a given reflector and its behaviour as the ultrasonic probe is moved together with the positional information obtained above and knowledge of the component history enables the experienced ultrasonic operator to classify the reflector as slag, lack of fusion or a crack.

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5.3.1 Equipment for ultrasonic testing

Equipment for manual ultrasonic testing consists of:

A flaw detector:

- Pulse generator.
- Adjustable time base generator with an adjustable delay control.
- Cathode ray tube with fully rectified display.
- Calibrated amplifier with a graduated gain control or attenuator.

An ultrasonic probe:

- Piezo-electric crystal element capable of converting electrical vibrations into mechanical vibrations and vice versa.
- Probe shoe, normally a Perspex block to which the crystal is firmly attached using suitable adhesive.
- Electrical and/or mechanical crystal damping facilities to prevent excessive ringing.

Such equipment is lightweight and extremely portable. Automated or semi-automated systems for ultrasonic testing the same basic use equipment although since in general this will be multi-channel it is bulkier and less portable.

Probes for automated systems are set in arrays and some form of manipulator is necessary to feed positional information about them to the computer. Automated systems generate very large amounts of data and make large demands upon the RAM of the computer. Recent advances in automated UT have led to a reduced amount of data being recorded for a given length of weld.

Simplified probe arrays have greatly reduced the complexity of setting-up the automated system to carry out a particular task. Automated UT systems now provide a serious alternative to radiography on such constructions as pipelines where a large number of similar inspections allow the unit cost of system development to be reduced to a competitive level.

Figure 5.4 Ultrasonic equipment.

Figure 5.5 Compression and a shear wave probe.

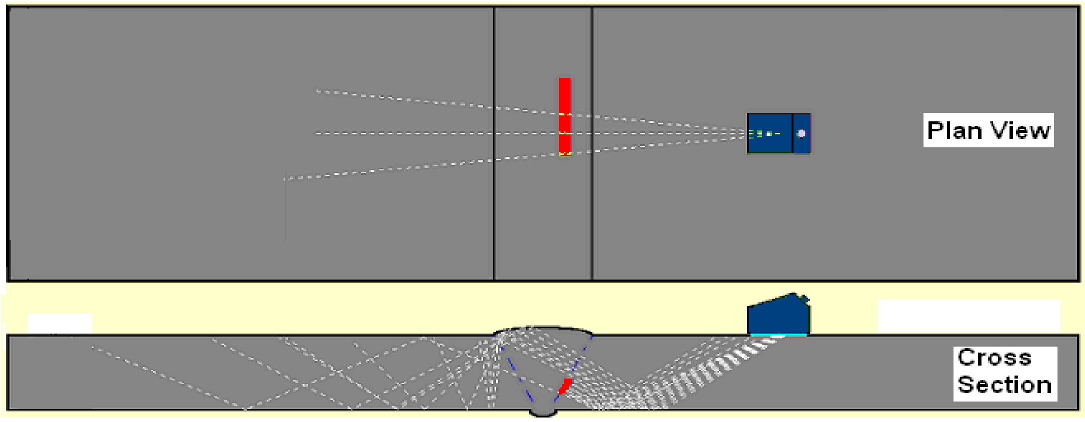

Figure 5.6 Example of a scanning technique with a shear wave probe.

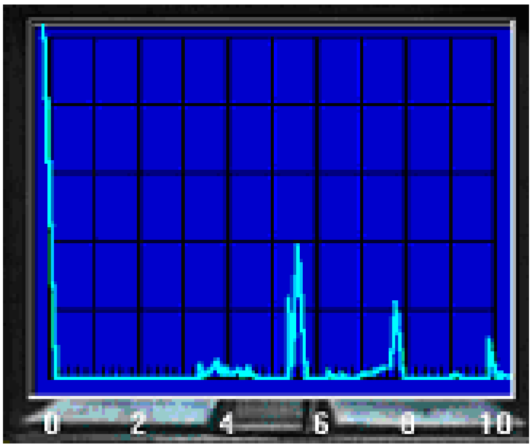

Figure 5.7 Typical screen display when using a shear wave probe.

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5.3.2 Ultrasonic testing

Advantages	Limitations
Portable (no mains power) battery	No permanent record
Direct location of defect (3 dimensional)	Only ferritic materials (mainly)
Good for complex geometry	High level of operator skill required
Safe operation (can be done next to someone)	Calibration of equipment required
Instant results	Special calibration blocks required
High penetrating capability	No good for pin pointing porosity
Can be done from one side only	Critical of surface conditions (clean smooth)
Good for finding planar defects	Will not detect surface defects
	Material thickness >8mm due to dead zone

5.4 Magnetic particle testing

Surface breaking or very near surface discontinuities in ferromagnetic materials give rise to leakage fields when high levels of magnetic flux are applied. These leakage fields attract magnetic particles (finely divided magnetite) to themselves leading to the formation of an indication.

The magnetic particles may be visibly or fluorescently pigmented to provide contrast with the substrate or conversely the substrate may be lightly coated with a white background lacquer to contrast with the particles.

Fluorescent magnetic particles normally provide the greatest sensitivity in a liquid suspension, usually applied by spraying. In certain cases dry particles may be applied by a gentle jet of air. The technique is applicable only to ferromagnetic materials at a temperature below the Curie point (about 650°C).

The leakage field will be greatest for linear discontinuities at right angles to the magnetic field so for a comprehensive test the magnetic field must normally be applied in two directions, mutually perpendicular. The test is economical to carry out in terms of equipment cost and rapidity of inspection and the level of operator training required is relatively low.

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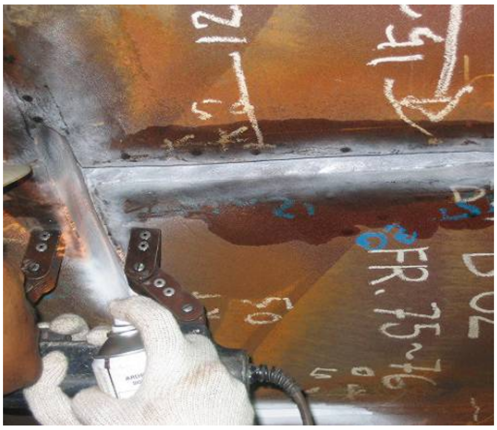

Figure 5.8 Magnetic particle inspection using a yoke.

Figure 5.9 Crack found using magnetic particle inspection.

Advantages	Limitations
Inexpensive equipment	Only magnetic materials
Direct location of defect	May need to demagnetise components
Surface conditions not critical	Access may be a problem for the yoke
Can be applied without power	Need power if using a yoke
Low skill level	No permanent record
Sub-surface defects found 1-2mm	Calibration of equipment
Quick, instant results	Testing in two directions required
Hot testing (using dry powder)	Need good lighting - 500 lux minimum
Can be used in the dark (UV light)	

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5.5 Dye penetrant testing

Any liquid with good wetting properties will act as a penetrant, which is attracted into surface-breaking discontinuities by capillary forces. Penetrant which has entered a tight discontinuity will remain even when the excess is removed.

Application of a suitable developer will encourage the penetrant within discontinuities to bleed out. If there is a suitable contrast between the penetrant and the developer an indication visible to the eye will be formed. Provided by either visible or fluorescent dyes.

Use of fluorescent dyes considerably increases the sensitivity of the technique. The technique is not applicable at extremes of temperature as at below 5°C the penetrant vehicle, normally oil, will become excessively viscous causing an increase in the penetration time with a consequent decrease in sensitivity.

Above 60°C the penetrant will dry out and the technique will not work.

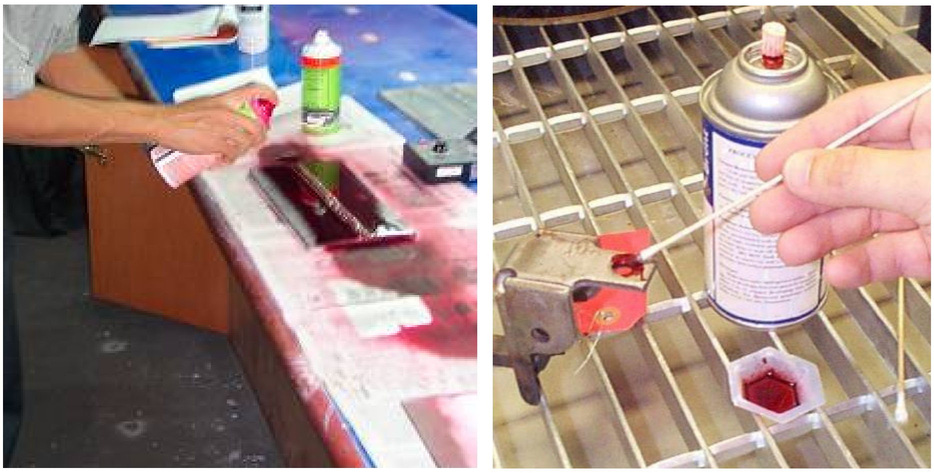

Figure 5.10 Methods of applying the red dye during dye penetrant inspection.

Figure 5.11 Crack found using dye penetrant inspection.

5.5.1 Dye penetrant

Advantages	Limitations
All non porous materials	Will only detect defects open to the surface
Portable	Requires careful space preparation
Applicable to small parts with complex geometry	Not applicable to porous surfaces
Simple	Temperature dependent
Inexpensive	Cannot retest indefinitely
Sensitive	Potentially hazardous chemicals
Relatively low skill level (easy to interpret)	No permanent record
	Time lapse between application and results
	Messy

5.5.2 Surface crack detection (magnetic particle/dye penetrant)

When considering the relative value of NDE techniques it should not be forgotten that most catastrophic failures initiate from the surface of a component, so the value of the magnetic particle and dye penetrant techniques should not be under-estimated.

Ultrasonic inspection may not detect near-surface defects easily since the indications may be masked by echoes arising from the component geometry and should therefore be supplemented by an appropriate surface crack detection technique for maximum test confidence.

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Non-Destructive Testing

Section 5

Materials Joining and Engineering Technologies
Training and Examination Services

Non Destructive Testing Objective

When this presentation has been completed you will have a greater understanding of and recognise various NDT methods and their differences ,capabilities and why one particular method may be chosen based on the advantages and disadvantages over other methods. Why we choose or don't choose a particular method for a certain material and the potential risks in safety and production issues.

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Non-Destructive Testing

A welding inspector should have a working knowledge of NDT methods and their applications, advantages and disadvantages.

Four basic NDT methods

1. Magnetic particle inspection (MT).
2. Dye penetrant inspection (PT).
3. Radiographic inspection (RT).
4. Ultrasonic inspection (UT).

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Non-Destructive Testing

Surface crack detection

- Liquid penetrant (PT or dye-penetrant).
- Magnetic particle inspection (MT or MPI).

Volumetric inspection

- Ultrasonics (UT).
- Radiography (RT).

Each technique has advantages and disadvantages with respect to:

- Technical capability and cost.

Note: The choice of NDT techniques is based on consideration of these advantages and disadvantages.

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Penetrant Testing (PT)

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Penetrant Testing

Main features:

- Detection of surface breaking defects only.
- This test method uses the forces of capillary action.
- Applicable on any material type, as long they are non porous.
- Penetrants are available in many different types:
  - Water washable contrast.
  - Solvent removable contrast.
  - Water washable fluorescent.
  - Solvent removable fluorescent.
  - Post-emulsifiable fluorescent.

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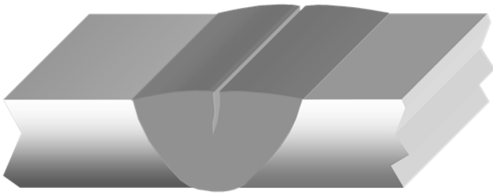
Penetrant Testing

Step 1: Pre-cleaning
- Ensure surface is very clean normally with the use of a solvent.



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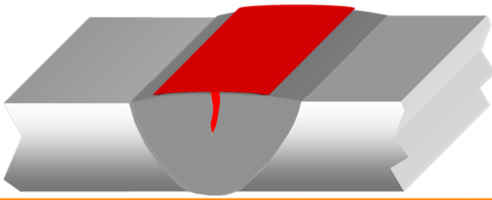
Penetrant Testing

Step 2: Apply penetrant
- After the application, the penetrant is normally left on the components surface for approximately 15-20 minutes (dwell time).
- The penetrant enters any defects that may be present by capillary action.



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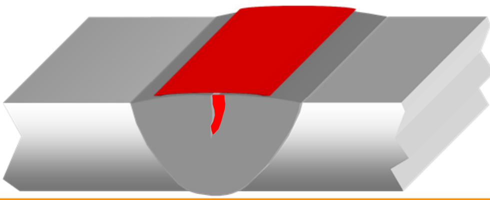
Penetrant Testing

Step 3: Clean off penetrant
- The penetrant is removed after sufficient penetration time (dwell time).
- Care must be taken not to wash any penetrant out off any defects present.



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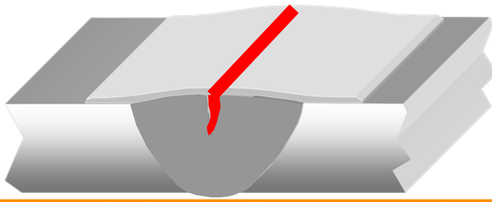
Penetrant Testing

Step 3: Apply developer
- After the penetrant has be cleaned sufficiently, a thin layer of developer is applied.
- The developer acts as a contrast against the penetrant and allows for reverse capillary action to take place.



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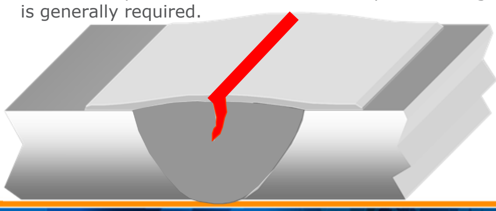
Penetrant Testing

Step 4: Inspection/development time
- Inspection should take place immediately after the developer has been applied.
- any defects present will show as a bleed out during development time.
- After full inspection has been carried out post cleaning is generally required.



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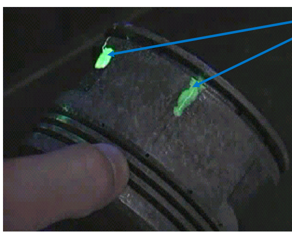
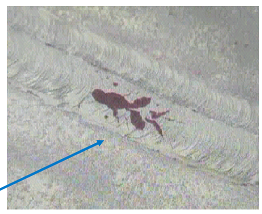
Penetrant Testing

Fluorescent penetrant



Bleed out viewed under a UV-A light source



Bleed out viewed under white light

Colour contrast Penetrant

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Penetrant Testing

Advantages
- Simple to use.
- Inexpensive.
- Quick results.
- Can be used on any non-porous material.
- Portability.
- Low operator skill required.

Disadvantages
- Surface breaking defect only.
- Little indication of depths.
- Penetrant may contaminate component.
- Surface preparation critical.
- Post cleaning required.
- Potentially hazardous chemicals.
- Can not test unlimited times.
- Temperature dependant.

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Penetrant Testing

Comparison with magnetic particle inspection

Advantages
- Easy to interpret results.
- No power requirements.
- Relatively little training required.
- Can use on all materials.

Disadvantages
- Good surface finish needed.
- Relatively slow.
- Chemicals - health and safety issue.

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Any Questions

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Magnetic Particle Testing (MT)

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Magnetic Particle Testing

Main features:
- Surface and slight sub-surface detection.
- Relies on magnetization of component being tested.
- Only ferro-magnetic materials can be tested.
- A magnetic field is introduced into a specimen being tested.
- Methods of applying a magnetic field, yoke, permanent magnet, prods and flexible cables.
- Fine particles of iron powder are applied to the test area.
- Any defect which interrupts the magnetic field, will create a leakage field, which attracts the particles.
- Any defect will show up as either a dark indication or in the case of fluorescent particles under UV-A light a green/yellow indication.

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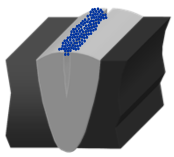
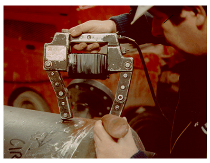
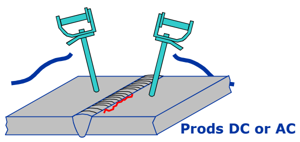
Magnetic Particle Testing

Collection of ink particles due to leakage field





Electro-magnet (yoke) DC or AC



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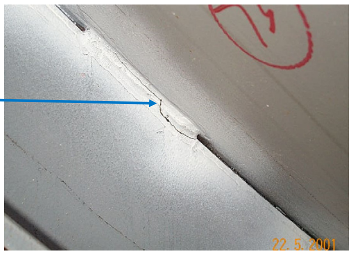
Magnetic Particle Testing

A crack like indication



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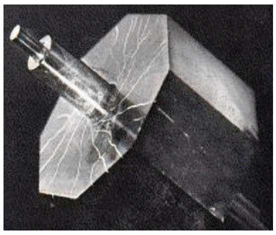
Magnetic Particle Testing



Alternatively to contrast inks, fluorescent inks may be used for greater sensitivity. These inks require a UV-A light source and a darkened viewing area to inspect the component.

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Magnetic Particle Testing

Typical sequence of operations to inspect a weld

- Clean area to be tested.
- Apply contrast paint.
- Apply magnetisism to the component.
- Apply ferro-magnetic ink to the component during magnatising.
- Iterpret the test area.
- Post clean and de-magnatise if required.

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Magnetic Particle Testing

Advantages

- Simple to use.
- Inexpensive.
- Rapid results.
- Little surface preparation required.
- Possible to inspect through thin coatings.

Disadvantages

- Surface or slight sub-surface detection only.
- Magnetic materials only.
- No indication of defects depths.
- Only suitable for linear defects.
- Detection is required in two directions.

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Magnetic Particle Testing

Comparison with penetrant testing

Advantages

- Much quicker than PT.
- Instant results.
- Can detect near-surface imperfections (by current flow technique).
- Less surface preparation needed.

Disadvantages

- Only suitable for ferromagnetic materials.
- Electrical power for most techniques.
- May need to de-magnetise (machine components).

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Any Questions

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Ultrasonic Testing (UT)

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Ultrasonic Testing

Main features:

- Surface and sub-surface detection.
- This detection method uses high frequency sound waves, typically above 2MHz to pass through a material.
- A probe is used which contains a piezo electric crystal to transmit and receive ultrasonic pulses and display the signals on a cathode ray tube or digital display.
- The actual display relates to the time taken for the ultrasonic pulses to travel the distance to the interface and back.
- An interface could be the back of a plate material or a defect.
- For ultrasound to enter a material a couplant must be introduced between the probe and specimen.

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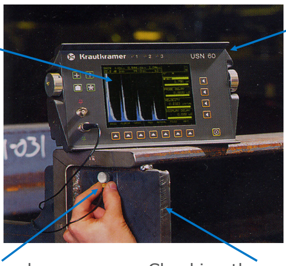
Ultrasonic Testing

Pulse echo signals A scan display

Digital UT Set,



Compression probe

Checking the material Thickness

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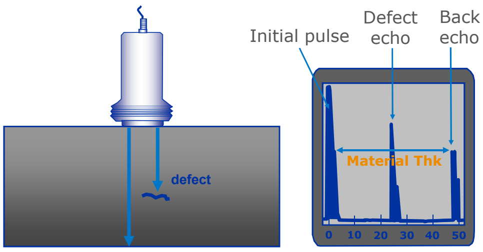
Ultrasonic Testing



Compression probe

CRT Display

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Ultrasonic Testing

A scan display

UT set

Angle probe

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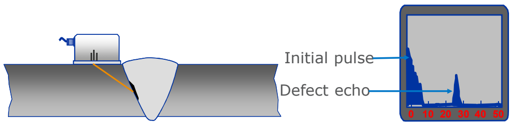
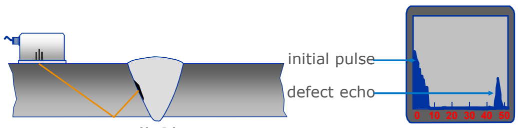
Ultrasonic Testing



½ Skip

CRT Display



Full Skip

CRT Display

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Ultrasonic Testing

Advantages
- Rapid results.
- Both surface and sub-surface detection.
- Safe.
- Capable of measuring the depth of defects.
- May be battery powered.
- Portable.

Disadvantages
- Trained and skilled operator required.
- Requires high operator skill.
- Good surface finish required.
- Defect identification.
- Couplant may contaminate.
- No permanent record.
- Calibration required.
- Ferritic Material (mostly).

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Ultrasonic Testing

Comparison with radiography

Advantages
- Good for planar defects.
- Good for thick sections.
- Instant results.
- Can use on complex joints.
- Can automate.
- Very portable.
- No safety problems (parallel working is possible).
- Low capital and running costs.

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Ultrasonic Testing

Comparison with radiography

Disadvantages
- No permanent record (with standard equipment).
- Not suitable for very thin joints <8mm.
- Reliant on operator interpretation.
- Not good for sizing porosity.
- Good/smooth surface profile needed.
- Not suitable for coarse grain materials (eg, castings).
- Ferritic materials (with standard equipment).

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Any Questions

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Radiographic Testing (RT)

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Radiographic Testing

The principles of radiography
- X or Gamma radiation is imposed upon a test object.
- Radiation is transmitted to varying degrees dependant upon the density of the material through which it is travelling.
- Thinner areas and materials of a less density show as darker areas on the radiograph.
- Thicker areas and materials of a greater density show as lighter areas on a radiograph.
- Applicable to metals, non-metals and composites.

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Radiographic Testing

X–rays
Electrically generated.

Gamma rays
Generated by the decay of unstable atoms.

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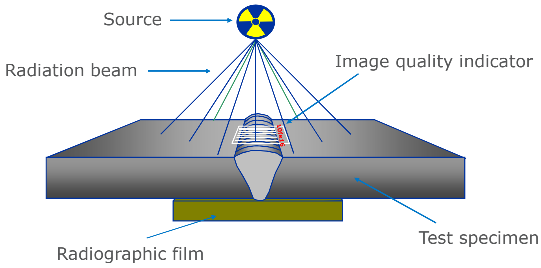
Radiographic Testing



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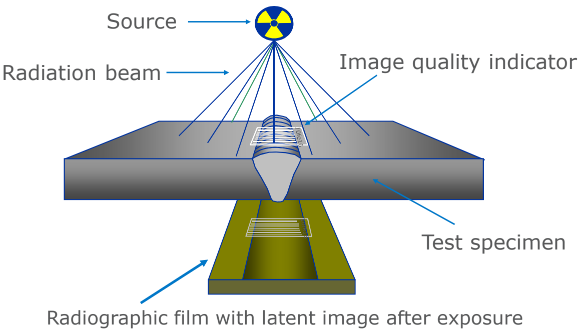
Radiographic Testing



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Radiographic Testing

Density - relates to the degree of darkness.

Densitometer

Contrast - relates to the degree of difference.

Definition - relates to the degree of sharpness.

Sensitivity - relates to the overall quality of the radiograph.

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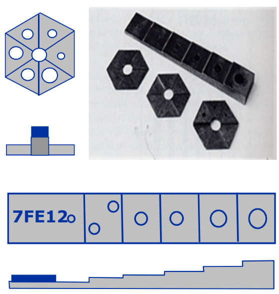
Radiographic Sensitivity



Step/Hole type IQI

Wire type IQI

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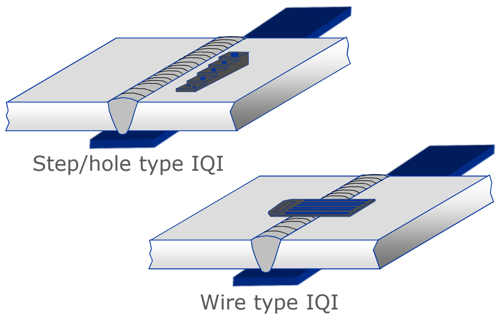
Radiographic Sensitivity



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Radiographic Techniques

Single Wall Single Image (SWSI)
- Film inside, source outside.

Single Wall Single Image (SWSI) panoramic
- Film outside, source inside (internal exposure).

Double Wall Single Image (DWSI)
- Film outside, source outside (external exposure).

Double Wall Double Image (DWDI)
- Film outside, source outside (elliptical exposure).

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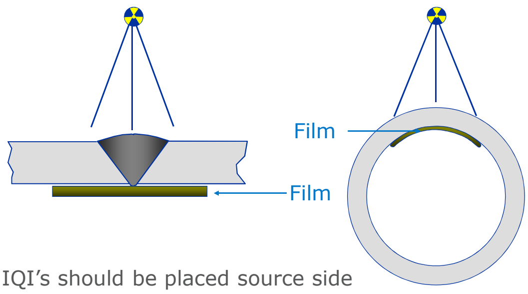
Single Wall Single Image (SWSI)



IQI's should be placed source side

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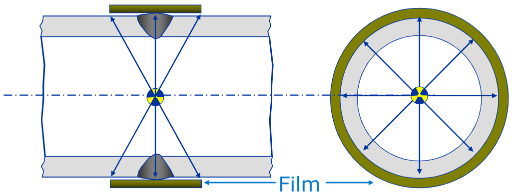
Single Wall Single Image Panoramic



- IQI's are placed on the film side.
- Source inside film outside (single exposure).

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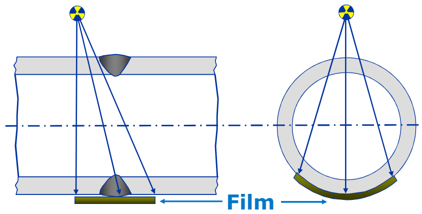
Double Wall Single Image (DWSI)



- IQI's are placed on the film side.
- Source outside film outside (multiple exposure).
- This technique is intended for pipe diameters over 100mm.

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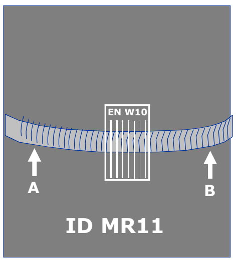
Double Wall Single Image (DWSI)

Identification
- Unique identification.
- IQI placing.
- Pitch marks indicating readable film length.



Radiograph

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Double Wall Single Image (DWSI)

Radiograph

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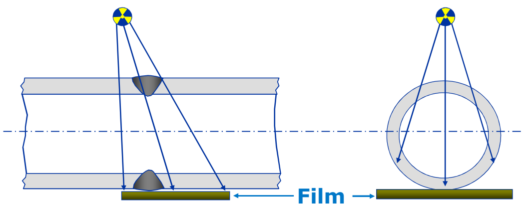
Double Wall Double Image (DWDI)



- IQI's are placed on the source or film side.
- Source outside film outside (multiple exposure).
- A minimum of two exposures.
- This technique is intended for pipe diameters less than 100mm.

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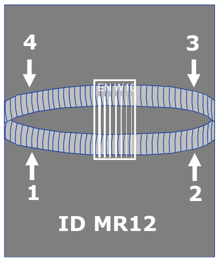
Double Wall Double Image (DWDI)

Identification

- Unique identification.
- IQI placing.
- Pitch marks indicating readable film length.



Shot A Radiograph

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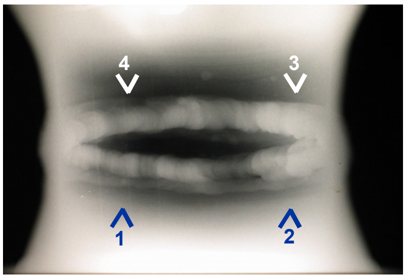
Double Wall Double Image (DWDI)



Elliptical radiograph

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Radiography

Penetrating power

Question: What determines the penetrating power of an X-ray?

- The kilo-voltage applied (between anode and cathode).

Question: What determines the penetrating power of a gamma ray?

- The type of isotope (the wavelength of the gamma rays).

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Radiography

Gamma sources

Isotope	Typical thickness range
Iridium 192	10 to 50 mm (mostly used)
Cobalt 60	> 50mm
Ytterbium	< 10mm
Thulium	< 10mm
Caesium	< 10mm

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Radiographic Testing

Advantages

- Permanent record.
- Little surface preparation.
- Defect identification.
- No material type limitation.
- Not so reliant upon operator skill.
- Thin materials.

Disadvantages

- Expensive consumables.
- Bulky equipment.
- Harmful radiation.
- Defect require significant depth in relation to the radiation beam (not good for planar defects).
- Slow results.
- Very little indication of depths.
- Access to both sides required.

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Radiographic Testing

Comparison with ultrasonic examination

Advantages

- Good for non-planar defects.
- Good for thin sections.
- Gives permanent record.
- Easier for 2nd party interpretation.
- Can use on all material types.
- High productivity.
- Direct image of imperfections.

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Radiographic Testing

Comparison with ultrasonic examination

Disadvantages

- Health and safety hazard.
- Not good for thick sections.
- High capital and relatively high running costs.
- Not good for planar defects.
- X-ray sets not very portable.
- Requires access to both sides of weld.
- Frequent replacement of gamma source needed (half life).

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Any Questions

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Section 6

WPS/Welder Qualifications

6 WPS/Welder Qualifications

6.1 General

When structures and pressurised items are fabricated by welding, it is essential that all the welded joints are sound and have suitable properties for their application.

Control of welding is by WPSs that give detailed written instructions about the welding conditions that must be used to ensure that welded joints have the required properties.

Although WPSs are shopfloor documents to instruct welders, welding inspectors need to be familiar with them because they will refer to them when checking that welders are working within the specified requirements.

Welders need to be able to understand WPSs, make non-defective welds and demonstrate these abilities before being allowed to make production welds.

6.2 Qualified welding procedure specifications

It is industry practice to use **qualified WPSs** for most applications.

A welding procedure is usually qualified by making a test weld to demonstrate that the properties of the joint satisfy the requirements specified by the application standard and the client/end user.

Demonstrating the mechanical properties of the joint is the principal purpose of qualification tests, but showing that a defect-free weld can be produced is also very important.

Production welds made in accordance with welding conditions similar to those used for a test weld should have similar properties and therefore be fit for their intended purpose.

Table 6.1 is a typical WPS written in accordance with the European Welding Standard format giving details of all the welding conditions that need to be specified.

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Table 6.1 Typical sequence for welding procedure qualification by means of a test weld.

The welding engineer writes a **preliminary** Welding Procedure Specification (pWPS) for each test coupon to be welded.

↓

- A welder makes the test coupon in accordance with the pWPS.
- A welding inspector records all the welding conditions used to make the test coupon (the **as-run conditions**).

An independent examiner/examining body/third party inspector **may be** requested to monitor the procedure qualification.

↓

The test coupon is subjected to **NDT** in accordance with the methods specified by the Standard – visual inspection, MT **or** PT and RT **or** UT.

↓

- The test coupon is **destructively tested** (tensile, bend, macro tests).
- The code/application standard client may require additional tests such as hardness, impact or corrosion tests – depending on the material and application.

↓

- A WPQR is prepared by the welding engineer giving details of:
  - As run welding conditions.
  - Results of the NDT.
  - Results of the destructive tests.
  - Welding conditions allowed for production welding.
- If a third party inspector is involved he will be requested to sign the WPQR as a true record of the test.

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6.2.1 Welding standards for procedure qualification

European and American Standards have been developed to give comprehensive details about:

- How a welded test piece must be made to demonstrate joint properties.
- How the test piece must be tested.
- Which welding details need to be included in a WPS.
- The range of production welding allowed by a particular qualification test weld.

The principal **European Standards** that specify these requirements are:

EN ISO 15614
Specification and qualification of welding procedures for metallic materials, welding procedure test.

Part 1

Arc and gas welding of steels and arc welding of nickel and nickel alloys.

Part 2

Arc welding of aluminium and its alloys.

The principal **American Standards** for procedure qualification are:

ASME Section IX

Pressurised systems (vessels and pipework).

AWS D1.1

Structural welding of steels.

AWS D1.2

Structural welding of aluminium.

6.2.2 The qualification process for welding procedures

Although qualified WPSs are usually based on test welds made to demonstrate weld joint properties; welding standards also allow qualified WPSs for some applications to be written based on other data.

Some alternative ways that can be used for writing qualified WPSs for some applications are:

- Qualification by adoption of a standard welding procedure - test welds previously qualified and documented by other manufacturers.
- Qualification based on previous welding experience - weld joints that have been repeatedly made and proved to have suitable properties by their service record.

Procedure qualification to European Standards by a test weld (similar in ASME Section IX and AWS) requires a sequence of actions typified by those shown by Table 6.1.

A successful procedure qualification test is completed by the production of a WPQR, an example of which is shown in Figure 6.1.

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Weldspec

PQR record number Date	WIS 5-002 27/03/2006	Revision 0	pWPS record number	WIS 5 - p002	Revision 0

Examiner/examining body Reference number Code/Testing standard	Third Party Ltd TPL/TWI/WIS5-002 EN 15614-1: 2004	Manufacturer Address	TWI Ltd

EXTENT OF APPROVAL (JOINT/WELDING CONDITIONS)

Joint type	Butt plate ss mb nb, bs gg ng : T-Butt ss bs : Fillet plate : Fillet pipe
Parent metal(s)	Groups 1-1
Coupon thickness (mm)	17.5 - 70.0
Coupon outside diameter (mm)	Greater than 500.0
Fillet throat thickness (mm)	No Restriction
Branch angle (deg.)	n/a
Preheat (°C)	50
Interpass temperature (°C)	200
PWHT and/or ageing	-

EXTENT OF APPROVAL (PROCESS)

Welding process	111:MMA
Welding process type	Manual
Welded thickness (mm)	17.5 – 70.0
Welded outside diameter (mm)	Greater than 500.0
Filler metal type	BS EN ISO 2560 46 6 mn 1 ml b12 h5
Shielding gas/flux	none
Welding positions	PA,FC,PE,PF
Preheat temperature (°C)	50
Interpass temperature (°C)	200
Current/polarity	DC +VE
Multi/Single pass per side	Multi-pass only
Heat input (kJ/mm)	Max 3.2
Metal transfer mode	n/a
Backing gas	n/a

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Catalog n° PQR00012 Page 1 of 3

Figure 6.1 Example of WPQR (qualification range) to EN15614 format.

6.2.3 Relationship between a WPQR and a WPS

Once a WPQR has been produced, the welding engineer can write **qualified WPSs** for the various production weld joints that need to be made.

The welding conditions that are allowed to be written on a qualified WPS are referred to as the qualification range and depend on the welding conditions used for the test piece (as-run details) and form part of the WPQR.

Welding conditions are referred to as welding variables by European and American Welding Standards and are classified as either essential or non-essential variables and can be defined as:

- **Essential variable**
  Variable that has an effect on the mechanical properties of the weldment and if changed beyond the limits specified by the standard will require the WPS to be re-qualified.

- **Non-essential variable**
  Variable that must be specified on a WPS but does not have a significant effect on the mechanical properties of the weldment and can be changed without the need for re-qualification but will require a new WPS to be written.

Because essential variables can have a significant effect on mechanical properties they are the controlling variables that govern the qualification range and determine what can be written in a WPS.

If a welder makes a production weld using conditions outside the range given on a particular WPS there is a danger that the welded joint will not have the required properties and there are two options:

1 Make another test weld using similar welding conditions to those used for the affected weld and subject this to the same tests used for the relevant WPQR to demonstrate that the properties still satisfy specified requirements.

2 Remove the affected weld and re-weld the joint strictly in accordance with the designated WPS.

Most of the welding variables classed as essential are the same in both the European and American Welding Standards but their qualification ranges may differ.

Some application standards specify their own essential variables and it is necessary to ensure these are considered when procedures are qualified and WPSs written.

Examples of essential variables (according to European Welding Standards) are given in Table 6. 2.

Table 6.2 Typical examples of WPS essential variables according to EU Welding Standards.

Variable	Range for procedure qualification
Welding process	No range – process qualified must be used in production.
PWHT	Joints tested after PWHT only qualify PWHT production joints. Joints tested as-welded only qualify as-welded production joints.
Parent material type	Parent materials of similar composition and mechanical properties are allocated the same Material Group No; qualification only allows production welding of materials with the same Group No.
Welding consumables	Consumables for production welding must have the same European designation –general rule.
Material thickness	A thickness range is allowed – below and above the test coupon thickness.
Type of current	AC only qualifies for AC; DC polarity (+ve or -ve) cannot be changed; pulsed current only qualifies for pulsed current production welding.
Preheat temperature	The preheat temperature used for the test is the minimum that must be applied.
Interpass temperature	The highest interpass temperature reached in the test is the maximum allowed.
Heat input (HI)	When impact requirements apply the maximum HI allowed is 25% above test HI. When hardness requirements apply the minimum HI allowed is 25% below test HI.

6.3 Welder qualification

The use of qualified WPSs is the accepted method for controlling production welding but will only be successful if the welders understand and work in accordance with them.

Welders also need to have the skill to consistently produce sound (defect-free) welds.

Welding Standards have been developed to give guidance on which test welds are required to show that welders have the required skills to make certain types of production welds in specified materials.

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6.3.1 Welding standards for welder qualification

The principal EU Standards that specify requirements are:

BS EN ISO 9606-1

Qualification test of welders – Fusion welding.
Part 1: Steels.

EN ISO 9606-2

Qualification test of welders – Fusion welding.
Part 2: Aluminium and aluminium alloys.

EN 1418

Welding personnel – Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanised and automatic welding of metallic materials.

The principal **American Standards** that specify requirements for welder qualification are:

ASME Section IX

Pressurised systems (vessels & pipework).

AWS D1.1

Structural welding of steels.

AWS D1.2

Structural welding of aluminium.

6.3.2 The qualification process for welders

Qualification testing of welders to European Standards requires test welds to be made and subjected to specified tests to demonstrate that the welder is able to understand the WPS and produce a sound weld.

For manual and semi-automatic welding tests demonstrate the ability to manipulate the electrode or welding torch.

For mechanised and automatic welding the emphasis is on demonstrating the ability to control particular types of welding equipment.

American Standards allow welders to demonstrate they can produce sound welds by subjecting their first production weld to NDT.

Table 6.3 shows the steps required for qualifying welders in accordance with EU Standards.

Table 6.3 The stages for qualification of a welder.

The welding engineer writes a WPS for a welder qualification test piece.

- The welder makes the test weld in accordance with the WPS.
- A welding inspector monitors the welding to ensure that the welder is working in accordance with the WPS.

An independent examiner/examining body/third party inspector **may be** requested to monitor the test.

- The test coupon is subjected to **NDT** in accordance with the methods specified by the Standard (visual inspection, MT **or** PT and RT **or** UT).
- For certain materials, and welding processes, some destructive testing may be required (bend tests or macros).

- A welder's Qualification Certificate is prepared showing the welding conditions used for the test piece and the range of qualification allowed by the Standard for production welding.
- If a third party is involved they would endorse the Qualification Certificate as a true record of the test.

Figure 6.2 shows a typical welder qualification certificate in accordance with EU Standards.

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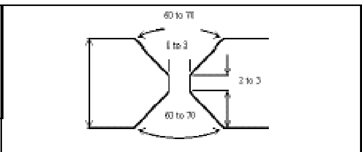
PQR record number Date	WIS 5-002 27/03/2006	Revision 0	pWPS record number	WIS 5 - p002	Revision 0

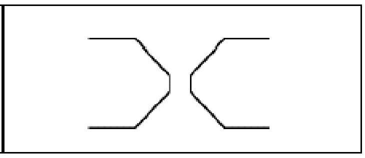
TEST PIECE MATERIAL SPECIFICATION

	Product form	Specification (type or grade)	Grp-no.	Size	Sch.	Thick. (mm)	Dia.(mm)
Welded to:	Plate	BS 10025	1.1	-	-	35	-
	Plate	BS 10025	1.1	-	-	35	-
and tested: Notes	Without PWHT, With Impacts						

TEST PIECE JOINT SPECIFICATION

Joint design		Butt-plate bs gg
Backing:		gg: gouging or grinding
Retainers		
Groove angle	(deg.)	60
Root opening	(mm)	2.5
Root face	(mm)	2





WELDING PROCESSES

Welding process	111: MMA
Type	Manual

FILLER METALS

Filler metal manufacturer, trade name		ESAB OK 53.08 Hytuf 1NI
Filler metal designation type		Yield strength
Filler metal designation		BS EN ISO 2560 E 46 6 Mln 1 NI B 12 H5
Filler metal size	(mm)	3.25 & 4.0
Deposited thickness	(mm)	35
MMA Electrode coating		B basic

POSITION

Position of groove	PF

PREHEAT

Preheat temperature	(°C)	50
Maximum interpass temperature	(°C)	200

ELECTRICAL

Filler metal size	(mm)	3.25 & 4.0
Amperes		3.25mm = 110; 4.0mm = 130
Volts		23 to 25
Electrode run out length	(mm)	3.25mm=75mln.; 4.0mm=125mln.
Travel speed	(mm/min)	60 to 70
Maximum heat input	(kJ/mm)	2.6
Current/polarity		DC +ve

TECHNIQUE

String or weave		Stringer and Weave
Maximum width of run	(mm)	8
Multi/Single pass per side		Multi-pass
Surface preparation		ground
Initial/interpass cleaning		Brushing and Grinding
Back gouging method		arc-air

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Figure 6.2 Example of a WPQR document (test weld details) to EN15614 format.

6.3.3 Welder qualification and production welding allowed

The welder is allowed to make production welds within the range of qualification recorded on his Welder Qualification Certificate.

The range of qualification is based on the limits specified by the Welding Standard for welder qualification essential variables - defined as:

A variable that if changed beyond the limits specified by the Welding Standard may require greater skill than has been demonstrated by the test weld.

Some welding variables classed as essential for welder qualification are the same types as those classified as essential for welding procedure qualification, but the range of qualification may be significantly wider.

Some essential variables are specific to welder qualification.

Examples of welder qualification essential variables are given in Table 6.4.

Table 6.4 Typical examples of welder qualification essential variables according to EU Welding Standards.

Variable	Range for welder qualification
Welding process	No range – process qualified is the process that a welder can use in production.
Type of weld	Butt welds cover any type of joint except branch welds. Fillet welds only qualify fillets.
Parent material type	Parent materials of similar composition and mechanical properties are allocated the same Material Group No; qualification only allows production welding of materials with the same Group No. but the Groups allow much wider composition ranges than the procedure Groups.
Filler material	Electrodes and filler wires for production welding must be within the range of the qualification of the filler material.
Material thickness	A thickness range is allowed; for test pieces above 12mm allow ≥ 5mm.
Pipe diameter	Essential and very restricted for small diameters: Test pieces above 25mm allow ≥ 0.5 x diameter used (minimum 25mm).
Welding positions	Position of welding very important; H-L045 allows all positions except PG.

6.3.4 Period of validity for a Welder Qualification Certificate

A welder's qualification begins from the date of welding the test piece.

- The welding co-ordinator or other responsible person can confirm that the welder has been working within the initial range of qualification.
- The Certificate needs to be confirmed every 6 months otherwise the Certificate(s) become(s) invalid.
- The validity of the Certificate may be extended.
- The chosen method of extension must be stated on the Certificate at the time of issue.
  - Retest every three years.
  - Valid for two years provided that:
    - The welder is working for the same manufacturer.
    - The manufacturer has a quality system to ISO 3834-2 or ISO 3834-3.

6.3.5 Prolongation of welder qualification

A welder's qualification certificate can be prolonged by an examiner/examining body but certain conditions need to be satisfied:

- Records/evidence are available that can be traced to the welder and the WPSs used for production welding.
- Supporting evidence must relate to volumetric examination of the welder's production welds (RT or UT) on two welds made during the six months prior to the extension date.
- Supporting evidence welds must satisfy the acceptance levels for imperfections specified by the EU welding standard and have been made under the same conditions as the original test weld.

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PQR record number	WIS 5-002	Revision 0	pWPS record number	WIS 5 - p002	Revision 0
Date	27/03/2006				

TENSILE TESTS

Type/Number	Re (N/mm²)	Rm (N/mm²)	A% on	Z%	Fracture location	Remarks
transverse	480	610	32	35	Ductile-Base Metal	
transverse	473	598	33	35	Ductile-Base Metal	
Comments	2 Transverse tensile tests according to EN 895					

GUIDED BEND TESTS

Type/Number	Bend angle	Elongation*	Results
4 Side bend tests as per 7.4.3 and EN 910	EN 25817		Acceptable
Comments			

TOUGHNESS TESTS

Notch location/direction	Temperature (°C)	Values (J)	(J)	(J)	Average (J)	Remarks
weld metal (surface)	-46	157	146	149	150.67	
weld metal (root)	-46	127	136	132	131.67	
FL (surface)	-46	67	78	63	69.33	
FL + 2 (surface)	-46	105	113	143	120.33	
FL + 5 (surface)	-46	216	203	215	211.33	
Comments						

CERTIFICATION

Welder's name	ID Number	Stamp number		
R.A.T. Catcher			Mechanical testing by	The Test House
			Laboratory test number	TTH - 1341-2006
			Test file number	1341-2006
			Tests conducted by	I. A. M. Tougher

Certified that test welds were performed, welded and tested satisfactorily in accordance with the requirements of the code/testing standard indicated above.

Examiner or examining body		Manufacturer	
Name	Signature	Name	Signature
Date		Date	

Signature 3		Signature 4	
Name	Signature	Name	Signature
Date		Date	

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Figure 6.3 Example of WPQR document (details of weld test) to EN15614 format.

TWI

Welderqual

EN DESIGNATION

Designation	EN287-1, 111, T, BW, 1.1, B, t14.27, D168.28, H-L045, ss, nb

Welder's name	A. Weaver	Test date	06/07/2005
ID Number	AW-3463	WPQ record number	3463-001
Date of birth	12.3.79	Standard test number	n/a Rev. 0
Stamp number	3463	pWPS record number	WPS – 013 Rev. 0
Company name	XYZ Fabrications	Qualification code	BS EN ISO 9606-1
Division	North East	Examining body	Third Party Ltd
Job knowledge	Not tested	Reference no.	TPL/XYZ/3463-1
		Expiry date	05/07/2007

BASE METALS

	Product form	Specification (type or grade)	Grp-no.	Size	Sch.	Thick(mm)	Dia(mm)
Welded to:	Pipe	BS 10025 (50-B)	1.1	152.40	120	14.27	168.28
	Pipe	BS 10025 (50-B)	1.1	152.40	120	14.27	168.28
Joint type	Butt						

VARIABLES	Actual values	RANGE QUALIFIED
Type of weld joint	Pipe - Butt	Butt, Fillet welds and Branch welds where angle >= 60°
Base metal	1.1 to 1.1	1.1, 1.2, 1.4

BASE METAL THICKNESS	Butt	Fillet	Butt	Fillet
Plate thickness (mm)	14.27	-	5.00 min	5.00 min
Pipe/tube thickness (mm)	14.27	-	5.00 min	5.00 min
Pipe diameter (mm)	168.28	-	84.14 and above	84.14 and above

VARIABLES	Actual values	RANGE QUALIFIED
Welding process	111:MMA	111: MMA
Type	Manual	Manual
Backing	Nb: without backing	ss nb, ss mb, bs
Filler metal type/designation	BS EN ISO 2560 E 46 6 Min NI B	Any Similar
Filler metal group	n/a	Any Similar
Covered electrode type	B basic	B,A,RA,RB,RC,RR,R
Weld deposit thickness (mm)	12.70	5.00 min
Weld position (Actual position tested)	H-LD45	
Butt-Plate		PA,PC,PF,PE
Fillet-Plate		PA,PB,PF,PD
Butt-Pipe		PA,PF,PC,H-L045
Fillet-Pipe		PA,PB,PF,PD
Butt-Pipe Diameter (see en287 6.3 a,c)		-

TESTS

Type of test	Acceptance criteria	Result	Comments
Visual examination per Table 10 and EN 970	EN ISO 5817	Acceptable	see - EN ISO 5817
Radiographic examination per Table 10 and EN 1435	EN ISO 5817	Acceptable	see - EN ISO 5817
Notes	branch set-on; angle at smallest required		

CERTIFICATION

Tests conducted by		Laboratory test number	
Mechanical tests by		Test file number	

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of EN 287.

Signature 1 (defined using Tools-Options-Default Settings)		Signature 2 (also user defined)	
Name	Signature	Name	Signature
Date		Date	

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Catalog n° WPQ00010 Page 1 of 1

Figure 6.4 Example of a welder qualification test certificate (WPQ) to EN9606-1 format.

Welding Procedures

Section 6

Materials Joining and Engineering Technologies
Training and Examination Services

WPS Objective

When this presentation has been completed you will have a greater understanding of the terminology used in welding and welder documentation and the order in which it should be completed. This section does not state how to write a procedure to a code as this is the duty, according to international standards as the role of a qualified Welding Engineer and not the role of a WI. We will however discuss the contents of WPQR and its associated documentation.

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Welding Procedure Qualification

Question: What is the main reason for carrying out a welding procedure qualification test?
(What is the test trying to show?)

Answer: To show that the welded joint has the properties* that satisfy the design requirements (fit for purpose).

Properties*

- Mechanical properties are the main interest - always strength but toughness hardness may be important for some applications.
- Test also demonstrates that the weld can be made without defects.

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Welding Procedure Qualification

According to EN ISO 15614

Preliminary welding procedure specification (pWPS).

Welding procedure qualification record (WPQR).

Welding procedure specification (WPS).

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Welding Procedure Qualification

Preliminary welding procedure specification (pWPS)

Welding engineer writes a **preliminary** Welding Procedure Specification (pWPS) for each test weld to be made.

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Welding Procedure Qualification

Welding procedure qualification record (WPQR)

- A welder makes a test weld in accordance with the pWPS.
- A welding inspector records all the welding conditions used for the test weld (referred to as the as-run conditions).
- An independent examiner/examining body/third party inspector **may be** requested to monitor the qualification process.

The finished test weld is subjected to NDT in accordance with the methods specified by the EN ISO Standard - Visual, MT or PT and RT or UT.

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Welding Procedure Qualification

Welding procedure qualification record (WPQR)
Test weld is subjected to destructive testing (tensile, bend, macro). The application standard, or client, may require additional tests such as impact tests, hardness tests (and for some materials - corrosion tests).

Welding procedure qualification record (WPQR) details:

The welding conditions used for the test weld
- Results of the NDT.
- Results of the destructive tests.
- The welding conditions that the test weld allows for production welding.

The Third Party may be requested to sign the WPQR as a true record.

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Welding Procedure Qualification

Welding procedure specification (WPS)
The welding engineer writes qualified welding procedure specifications (WPS) for production welding.

Production welding conditions must remain within the range of qualification allowed by the WPQR.

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Welding Procedure Qualification

According to EN Standards
Welding conditions are called welding variables.

Welding variables are classified by the EN ISO Standard as:
- Essential variables.
- Non-essential variables.
- Additional variables.

Note: Additional variables = ASME supplementary essential.
The range of qualification for production welding is based on the limits that the EN ISO Standard specifies for essential variables*.

(* and when applicable - the additional variables)

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Welding Procedure Qualification

According to EN Standards
Welding essential variables

Question: Why are some welding variables classified as essential?

Answer: A variable, that if changed beyond certain limits (specified by the Welding Standard) may have **a significant effect** on the properties* of the joint.

* particularly joint strength and ductility.

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Welding Procedure Qualification

According to EN Standards
Welding additional variables

Question: Why are some welding variables classified as **additional**?

Answer: A variable, that if changed beyond certain limits (specified by the welding standard) may have **a significant effect** on the **toughness** and/or **hardness** of the joint.

Note: ASME calls variables that affect toughness as supplementary essential variables (but does not refer to hardness).

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Welding Procedure Qualification

According to EN Standards
Some typical **essential** variables
- Welding process.
- Post weld heat treatment (PWHT).
- Material type.
- Electrode type, filler wire type (classification).
- Material thickness.
- Polarity (AC, DC+ve/DC-ve).
- Pre-heat temperature.

Some typical **additional** variables
- Heat input.
- Welding position.

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Welding Procedures

Producing a welding procedure involves:

- Planning the tasks.
- Collecting the data.
- Writing a procedure for use of for trial.
- Making a test welds.
- Evaluating the results.
- Approving the procedure.
- Preparing the documentation.

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Welding Procedures

In most codes reference is made to how the procedure are to be devised and whether approval of these procedures is required.

The approach used for procedure approval depends on the code:

Example codes:

- AWS D.1.1: Structural Steel Welding Code.
- BS 2633: Class 1 Welding of Steel Pipe Work.
- API 1104: Welding of Pipelines.
- BS 4515: Welding of Pipelines over 7 Bar.

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Welding Procedures

Other codes may not specifically deal with the requirement of a procedure but may contain information that may be used in writing a weld procedure.

EN 1011 Process of Arc Welding Steels.

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Welding Procedures

Components of a welding procedure

Parent material

- Type (grouping).
- Thickness.
- Diameter (pipes).
- Surface condition.

Welding process

- Type of process (MMA, MAG, TIG, SAW).
- Equipment parameters.
- Amps, volts, travel speed.

Welding consumables

- Type of consumable/diameter of consumable.
- Brand/classification.
- Heat treatments/storage.

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Welding Procedures

Components of a welding procedure

Joint design

- Edge preparation.
- Root gap, root face.
- Jigging and tacking.
- Type of baking.

Welding Position

- Location, shop or site.
- Welding position eg 1G, 2G, 3G etc.
- Any weather precaution.

Thermal heat treatments

- Preheat, temps.
- Post weld heat treatments eg stress relieving.

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Welding Procedures

Object of a welding procedure test

To give maximum confidence that the welds mechanical and metallurgical properties meet the requirements of the applicable code/specification.

Each welding procedure will show a range to which the procedure is approved (extent of approval).

If a customer queries the approval evidence can be supplied to prove its validity.

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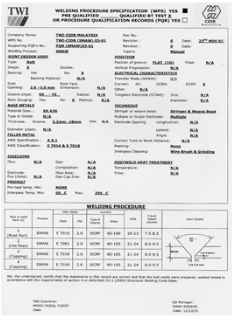
Welding Procedures



Example:
Welding procedure specification (WPS)

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Welding Procedures

Purpose of a WPS

- To achieve specific properties, mechanical strength, corrosion resistance, composition.
- To ensure freedom from defects.
- To enforce QC procedures.
- To standardise on methods and costs.
- To control production schedules.
- To form a record.
- Application standard or contract requirement.

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Welding Procedures

Monitoring heat input
As Required by BS EN ISO 15614-1:2004
In accordance with EN 1011-1:1998.

When impact and/or hardness requirements are specified, impact test shall be taken from the weld in the highest heat input position and hardness tests shall be taken from the weld in the lowest heat input position in order to qualify for all positions.

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Welding Procedures

PA	1G/1F	Flat/Downhand
PB	2F	Horizontal-Vertical
PC	2G	Horizontal
PD	4F	Horizontal-Vertical (Overhead)
PE	4G	Overhead
PF	3G/5G	Vertical-Up
PG	3G/5G	Vertical-Down
H-L045	6G	Inclined Pipe (Upwards)
J-L045	6G	Inclined Pipe (Downwards)

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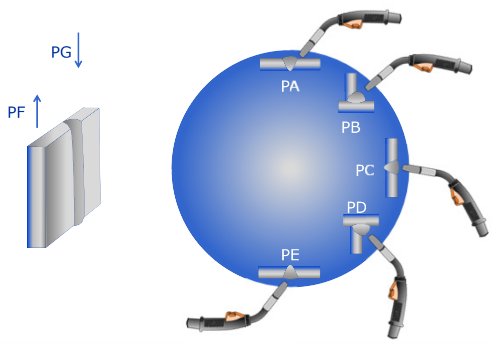

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Welding Procedures

Monitoring heat input
As Required by BS EN ISO 15614-1:2012
In accordance with EN 1011-1:1998

- When impact requirements apply, the upper limit of heat input qualified is 25% greater than that used in welding the test piece.
- When hardness requirements apply, the lower limit of heat input qualified is 25% lower than that used in welding the test piece.
- Heat input is calculated in accordance with EN1011-1.
- If welding procedure tests have been preformed at both a high and low heat input level, then all intermediate heat inputs are also qualified.

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Welding Procedures

EN 288 PART 2 15614-1-2-3

Specifies contents of WPS
Shall give details of how a welding operation is to be performed and contain all relevant information.

Definitions
- Processes to be designated in accordance with ISO 4063.
- Welding positions in accordance with ISO 6947.
- Typical WPS form.

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Welding Procedures

BS EN ISO 15614-1:2012 (Replaced BS EN 288-3)
- Does not invalidate previous … approvals made to former national standards… providing the intent of the technical requirements is satisfied… approvals are relevant.
- Where additional tests… make the approval technically equivalent… only necessary to do the additional tests….
- Approval is valid… in workshops or sites under the same technical and quality control of that manufacturer….
- Service, material or manufacturing conditions may require more comprehensive testing….
- Application standard may require more testing.

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Welding Procedures

Table 5 BS EN ISO 15614-1:2012

Thickness of test piece t	Range of qualification	
	Single run	Multi run
t≤3	0.7t to 1.3t[a]	0.7t to 2t
3<t≤12	0.5t (3 min) to 1.3t[a]	3 to 2t[a]
12<t≤100	0.5t to 1.1t	0.5t to 2t
t>100	Not applicable	50 to 2t

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Welding Procedures

Table 6 BS EN ISO 15614-1:2004

Thickness of test piece t	Range of qualification		
	Material Thickness	Throat Thickness	
		Single run	Multi run
t≤3	0.7 to 2 t	0.75 a to 1.5 a	No restriction
3<t<30	0.5t (3 min) to 2 t	0.75 a to 1.5 a	No restriction
t≥30	≥5	a	No restriction

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Welding Procedures

BS EN ISO 15614-1:2012 (Replaced BS EN 288-3)
Covers arc, gas welding of steels, arc welding of nickel and nickel alloys.

111 - MMA
12 - SAW
135 - MAG
311 – Oxy-Acetylene
15 - Plasma Arc
114 - FCAW - no gas shield
131 - MIG
136 - FCAW - active gas
141 – TIG

The principle of this European Standard may be applied to other fusion welding processes.

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Welding Procedures

BS EN ISO 15614-1:2012 (Replaced BS EN 288-3)
Range of approval

Other quirks
- Approval valid only for process used.
- Multi-process - valid for order used…during approval test.
- Processes… Processes may be approved separately or in combination….
- Cannot change multi-run to single run **or** vice versa.

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Welding Procedures

BS EN ISO 15614-1:2012
(Replaced BS EN 288-3)

Thickness definitions

- **Butt:** Parent metal thickness at the joint.
- **Fillet:** Parent metal thickness.
- **Set-on branch:** Parent metal thickness.
- **Set-in/through branch:** Parent metal thickness.
- **T-butt:** Parent metal thickness.

For branch connections and fillet welds, the range of qualification shall be applied to both parent materials independently.

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Welding Procedures

Note 1:

a is the throat as used for the test piece.

Note 2:

Where the fillet weld is qualified by means of a butt test, the throat thickness range qualified shall be based on the thickness of the deposited metal.

For special applications only. Each fillet weld shall be proofed separately by a welding procedure test.

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Welding Procedures

Table 7 **BS EN ISO 15614-1:2004**

Diameter of the test piece D[a], mm	Range of Qualification
D≤25	0.5 D to 2 D
D>25	≥0.5 D (25 mm min)
NOTE For structural hollow sections D is the dimension of the smaller side	
[a] D is the outside diameter of the pipe or outside diameter of the branch pipe	

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Welding Procedures

Monitoring Heat Input

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Monitoring Heat Input

Arc energy and heat input

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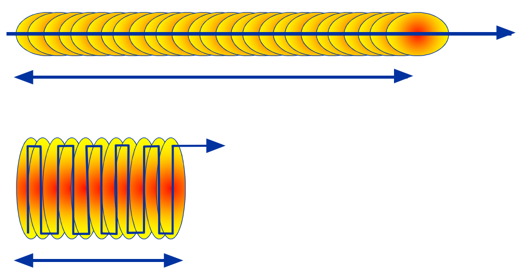
Monitoring Heat Input



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Monitoring Heat Input

Arc energy

The amount of heat generated in the welding arc per unit length of weld. Expressed in kilo Joules per millimetre length of weld (kJ/mm).

- Arc energy (kJ/mm) = Volts x Amps.
- Welding speed(mm/s) x 1000.

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Monitoring Heat Input

Heat input

- The energy supplied by the welding arc to the work piece.
- Expressed in terms of; arc energy x thermal efficiency factor.
- Thermal efficiency factor is the ratio of heat energy introduced into the weld to the electrical energy consumed by the arc.

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Monitoring Heat Input

Thermal efficiency factor k of welding processes

Process No	Process	Factor k
121	Submerged arc welding with wire	1.0
111	Metal-arc welding with covered electrodes	0.8
131	MIG welding	0.8
135	MAG welding	0.8
114	Flux-cored wire metal-arc welding without gas shield	0.8
136	Flux-cored wire metal-arc welding with active gas shield	0.8
137	Flux-cored wire metal-arc welding with inert gas shield	0.8
138	Metal-cored wire metal-arc welding with active gas shield	0.8
139	Metal-cored wire metal-arc welding with inert gas shield	0.8
141	TIG welding	0.6
15	Plasma arc welding	0.6

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Monitoring Heat Input

Abbreviations and symbols

I	Arc welding current	(Amps)
k	Thermal efficiency factor	
v	Welding speed	(mm/min)
Q	Heat input	(kJ/mm)
U	Arc voltage	(Volts)

$$Q = k\,\frac{U \times I}{v} \times 10^{-3} = \text{kJ/mm} \quad \text{or} \quad \frac{\text{Amp x volts x time}}{\text{ROL x 1000}}$$

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Monitoring Heat Input

Example

A MAG weld is made and the following conditions were recorded;

- Arc volts = 24
- Welding amperage = 240
- Travel speed = 300mm/minute.

What is the arc energy and heat input?

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Monitoring Heat Input

$$\text{AE (kJ/mm)} = \frac{\text{Volts x amps}}{\text{Travel speed(mm/ sec) x 1000}}$$

$$= \frac{24 \times 240}{(300/60) \times 1000}$$

$$= \frac{5760}{5000}$$

AE = 1.152 or 1.2kJ/mm.

HI = 1.2 x 0.8 = 0.96kJ/mm.

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Monitoring Arc Energy

Amps	Volts	Time In secs	ROL In mm		Input Kj/mm
110	26	60	100	=	1.7
220	28	90	200	=	2.8
120	12	120	90	=	1.9
300	28	60	300	=	1.7
180	12	120	90	=	2.8
110	26	60	300	=	0.57

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CSWIP 3.1 Welding Inspection

Welder Approval
Example BS EN ISO 9606

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Welder Qualification

BS EN ISO 9606

Question: What is the main reason for qualifying a welder?

Answer: To show that he has the skill to be able to make production welds that are free from defects.

Note: When welding in accordance with a Qualified WPS.

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Welder Qualification

BS EN ISO 9606
An approved WPS should be available covering the range of qualification required for the welder approval.

- The welder qualifies in accordance with an approved WPS.
- A welding inspector monitors the welding to make sure that the welder uses the conditions specified by the WPS.

EN Welding Standard states that an Independent Examiner, Examining Body or Third Party Inspector **may be** required to monitor the qualification process.

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Welder Qualification

BS EN ISO 9606
The finished test weld is subjected to NDT by the methods specified by the EN Standard - Visual, MT or PT and RT or UT.

The test weld may need to be destructively tested - for certain materials and/or welding processes specified by the EN Standard or the Client Specification.

- A Welder's Qualification Certificate is prepared showing the conditions used for the test weld and the range of qualification allowed by the EN Standard for production welding.
- The Qualification Certificate is usually endorsed by a Third Party Inspector as a true record of the test.

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Welder Qualification

BS EN ISO 9606
The welder is allowed to make production welds within the range of qualification shown on the Certificate.

The range of qualification allowed for production welding is based on the limits that the EN Standard specifies for the welder qualification essential variables.

A Welder's Qualification Certificate automatically expires if the welder has not used the welding process for 6 months or longer.

A Certificate may be withdrawn by the Employer if there is reason to doubt the ability of the welder, for example:

- A high repair rate.
- Not working in accordance with a qualified WPS.

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Welder Qualification

BS EN ISO 9606
Essential variables

Question: What is a welder qualification essential variable?
(What makes the variable essential?)

Answer: A variable, that if changed beyond the limits specified by the EN Standard, may require more skill than has been demonstrated by the test weld.

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Welder Qualification

BS EN ISO 9606
Typical Welder Essential Variables

- Welding Process.
- Material type.
- Electrode type – Filler Material Classification
- Material thickness.
- Pipe diameter
- Welding position.
- Weld Backing (an unbacked weld requires more skill).

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Welder Qualification

Numerous codes and standards deal with welder qualification, eg BS EN ISO 9606

- Once the content of the procedure is approved the next stage is to approve the welders to the approved procedure.
- A welders test know as a Welders Qualification Test (WQT).

Object of a welding qualification test:

- To give maximum confidence that the welder meets the quality requirements of the approved procedure (WPS).
- The test weld should be carried out on the same material and same conditions as for the production welds.

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Welder Qualification

Information that should be included on a welders test certificate are:

- Welders name and identification number.
- Date of test and expiry date of certificate.
- Standard/code eg BS EN ISO 9606.
- Test piece details.
- Welding process.
- Welding parameters, amps, volts.
- Consumables, flux type and filler classification details.

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Welder Qualification

Information that should be included on a welders test certificate are:

- Sketch of run sequence.
- Welding positions.
- Joint configuration details.
- Material type qualified, pipe diameter etc.
- Test results, remarks.
- Test location and witnessed by.
- Extent (range) of approval.

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Welder Qualification

The inspection of a welders qualification test

- It is normal for a qualified inspectors usually from an independent body to witness the welding.
- Under normal circumstances only one test weld per welder is permitted.
- If the welder fails the test weld and the failure is not the fault of the welder eg faulty welding equipment then a re-test would be permitted.
- The testing of the test weld is done in accordance with the applicable code.
- It is not normal to carry out tests that test for the mechanical properties of welds eg tensile, charpy and hardness tests.

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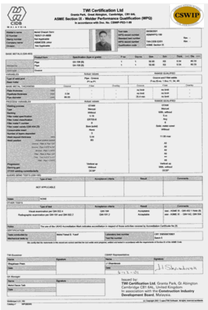
Welder Qualification



Example:
Welder
Approval
Qualification
Certification

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Any Questions

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Section 7

Materials Inspection

7 Materials Inspection

7.1 General

One of the duties of the visual/welding inspector is materials inspection and there are a number of situations where this will be required:

- At the plate or pipe mill.
- During fabrication or construction of the material.
- After installation of material, usually during a planned maintenance programme, outage or shutdown.

A wide range of materials can be used in fabrication and welding and include, but is not limited to:

- Steels.
- Stainless steels.
- Aluminium and its alloys.
- Nickel and its alloys.
- Copper and its alloys.
- Titanium and its alloys.
- Cast iron.

These materials are all widely used in fabrication, welding and construction to meet the requirements of a diverse range of applications and industry sectors.

There are three essential aspects to material inspection that the Inspector should consider:

- Material type and weldability.
- Material traceability.
- Material condition and dimensions.

7.2 Material type and weldability

A welding inspector must understand and interpret the material designation to check compliance with relevant normative documents. For example materials standards such as BS EN, API, ASTM, the WPS, purchase order, fabrication drawings, quality plan/contract specification and client requirements.

A commonly used material standard for steel designation is **BS EN 10025 – Hot rolled products of non-alloy structural steels**.

A typical steel designation to this standard, S355J2G3, would be classified as follows:

S	Structural steel.
355	Minimum yield strength: N/mm² at t ≤ 16mm.
J2	Longitudinal Charpy, 27Joules 20°C.
G3	Normalised or normalised rolled.

Commonly used materials and most of the alloys can be fusion welded using various welding processes, in a wide range of thickness and where applicable, diameters.

Reference to other standards such as ISO 15608 Welding - Guidelines for a metallic material grouping system and steel producer and welding consumable data books can also provide the inspector with guidance as to the suitability of a material and consumable type for a given application.

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7.3 Alloying elements and their effects

Iron	Fe	
Carbon	C	Strength
Manganese	Mn	Toughness
Silicon	Si	< 0.3% deoxidiser
Aluminium	Al	Grain refiner, <0.008% deoxidiser + toughness
Chromium	Cr	Corrosion resistance
Molybdenum	Mo	1% is for creep resistance
Vanadium	V	Strength
Nickel	Ni	Low temperature applications
Copper	Cu	Used for weathering steels (Corten)
Sulphur	S	Residual element (can cause hot shortness)
Phosphorus	P	Residual element
Titanium	Ti	Grain refiner, used as a micro-alloying element (strength and toughness)
Niobium	Nb	Grain refiner, used as a micro-alloying element (strength and toughness)

7.4 Material traceability

Traceability is defined as the ability to trace the history, application or location of that which is under consideration. With a welded product, traceability may require the inspector to consider the:

- Origin of both parent and filler materials.
- Processing history – for example before or after PWHT.
- Location of the product – this usually refers to a specific part or sub-assembly.

To trace the history of the material, reference must be made to the inspection documents. BS EN 10204 Metallic products – Types of inspection documents is the standard which provides guidance on these types of document. According to BS EN 10204 inspection documents fall into two types:

7.4.1 Non-specific inspection

Carried out by the manufacturer in accordance with his own procedures to assess whether products defined by the same product specification and made by the same manufacturing process, comply with the requirements of the order.

- Type 2.1 are documents in which the manufacturer declares that the products supplied comply with the requirements of the order without inclusion of test results.

- Type 2.2 are documents in which the manufacturer declares that the products supplied comply with the requirements of the order and includes test results based on non-specific inspection.

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7.4.2 Specific inspection

Inspection carried out before delivery according to the product specification on the products to be supplied or test units of which the products supplied are part, to verify that these products comply with the requirements of the order.

- Type 3.1 are certificates in which the manufacturer declares that the products supplied comply with the requirements of the order and in which test results are supplied.

- Type 3.2 are certificates prepared by both the manufacturer's authorised inspection representative independent of the manufacturing department and either the purchaser's authorised representative or the inspector designated by the official regulations and in which they declare that the products supplied comply with the requirements of the order and in which test results are supplied.

Application or location of a particular material can be carried out through a review of the WPS, fabrication drawings, quality plan or by physical inspection of the material at the point of use.

In certain circumstances the inspector may have to witness the transfer of cast numbers from the original plate to pieces to be used in production.

On pipeline work it is a requirement that the inspector records all the relevant information for each piece of linepipe. On large diameter pipes this information is usually stencilled on the inside of the pipe. On smaller diameter pipes it may be stencilled along the outside of the pipe.

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BS EN 10204: Metallic materials

Summary of types of inspection documents.

Non-specific inspection*
May be replaced by specific inspection if specified in the material standard or the order.

Inspection document Type 2.1
- Declaration of compliance with the order.
- Statement of compliance with the order.
- Validated by manufacturer.

Inspection document Type 2.2
- Test report.
- Statement of compliance with the order, with indication of results of non-specific inspection.
- Validated by manufacturer.

Specific inspection
Quality management system of the material manufacturer certified by a competent body established within the community and having undergone a specific assessment for materials.

Inspection certificate Type 3.1
- Statement of compliance with the order with indication of results of specific inspection.
- Validated by manufacturer's authorised inspection representative independent of the manufacturing department.

Inspection certificate Type 3.2
- Statement of compliance with the order with indication of results of specific inspection.
- Validated by manufacturer's authorised inspection representative independent of the manufacturing department and either the purchaser's authorised inspection representative or the inspector designated by the official regulations.

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7.5 Material condition and dimensions

The condition of the material could have an adverse effect on the service life of the component so is an important inspection point. The points for inspection must include:

- General inspection.
- Visible imperfections.
- Dimensions.
- Surface condition.

General inspection

This takes account of storage conditions, methods of handling, number of plates or pipes and distortion tolerances.

Visible imperfections

Typical visible imperfections are usually attributable to the manufacturing process and include cold laps which break the surface or laminations if they appear at the edge of the plate. Ultrasonic testing using a compression probe may be required for laminations which may be present in the body of the material.

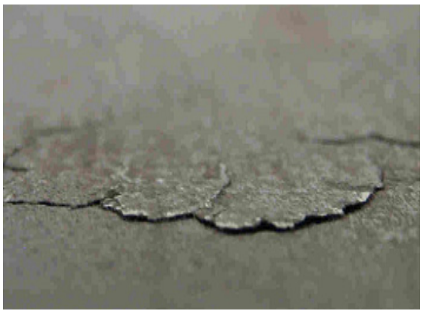

Figure 7.1 Cold lap.

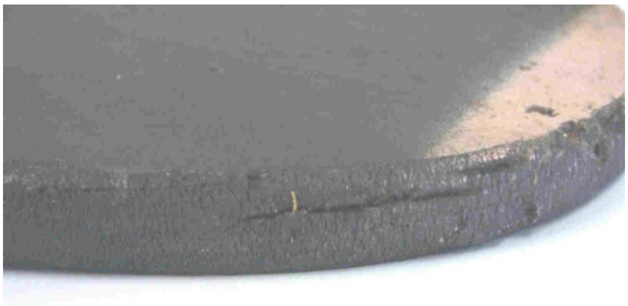

Figure 7.2 Plate lamination.

Dimensions

For plates this includes length, width and thickness.

For pipes this includes length and wall thickness and also inspection of diameter and ovality. At this stage of inspection the material cast or heat number may be recorded for validation against the material certificate.

Surface condition

The surface condition is important and must not show excessive millscale or rust, be badly pitted or have unacceptable mechanical damage.

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There are four grades of rusting which the inspector may have to consider:

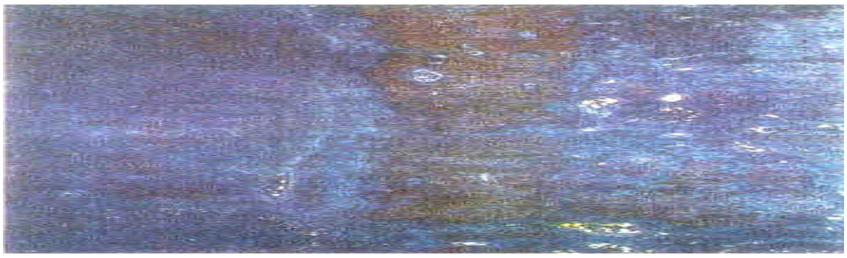

Figure 7.3 Rust Grade A.

Steel surface largely covered with adherent millscale with little or no rust.

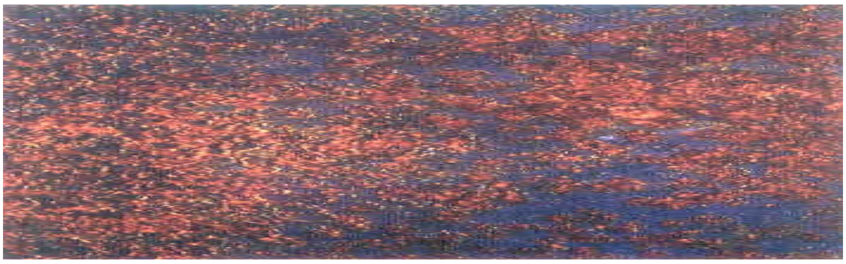

Figure 7.4 Rust Grade B.

Steel surface which has begun to rust and from which mill scale has begun to flake.

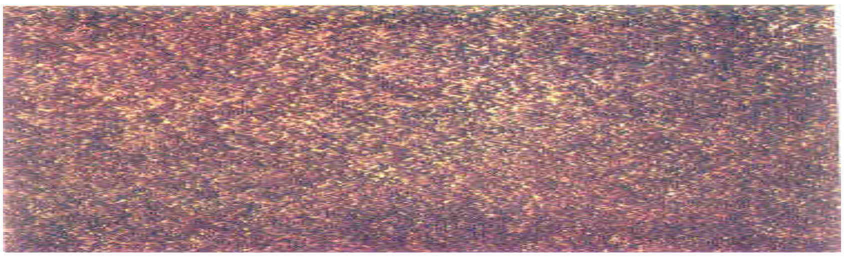

Figure 7.5 Rust Grade C.

Steel surface on which the mill scale has rusted away or from which it can be scraped. Slight pitting visible under normal vision.

Figure 7.6 Rust Grade D.

Steel surface on which mill scale has rusted away. General pitting visible under normal vision.

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7.6 Summary

Material inspection is an important part of the inspector's duties and an understanding of the documentation involved is key to success.

Material inspection must be approached in a logical and precise manner if material verification and traceability are to be achieved. This can be difficult if the material is not readily accessible, access may have to be provided, safety precautions observed and authorisation obtained before material inspection can be carried out. The quality plan should identify the level of inspection required and the point at which inspection takes place. A fabrication drawing should provide information on the type and location of the material.

If material type cannot be determined from the inspection documents available or the inspection document is missing, other methods of identifying the material may need to be used.

These methods may include but are not limited to: Spark test, spectroscopic analysis, chemical analysis, scleroscope hardness test, etc. These types of test are normally conducted by an approved test house but sometimes on- site and the inspector may be required to witness them to verify compliance with the purchase order or appropriate standard(s).

*EN ISO 9000 Quality management systems – Fundamentals and vocabulary.

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Material Inspection

Section 7

Materials Joining and Engineering Technologies
Training and Examination Services

Material Inspection Objective

When this presentation has been completed you should be able to identify key areas for visual inspection of materials and how manufacturing defects occur.

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Material Inspection

All materials arriving on site should be inspected for:

- Size/dimensions.
- Condition.
- Type/specification.

In addition other elements may need to be considered depending on the materials form or shape.

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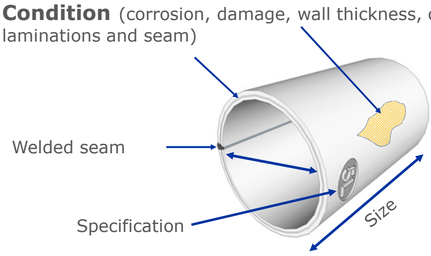
Pipe Inspection

Condition (corrosion, damage, wall thickness, ovality, laminations and seam)



Other checks may need to be made such as: distortion tolerance, number of pipes and storage*.

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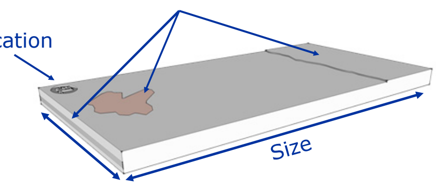
Plate Inspection

Condition (corrosion, mechanical damage, laps, bands and laminations)



Other checks may need to be made such as: distortion tolerance, number of plates and storage.

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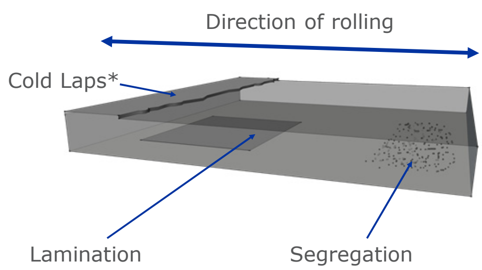
Rolling Imperfections



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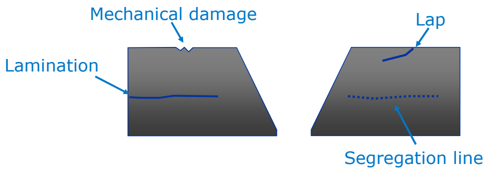
Parent Material Imperfections



Laminations are caused in the parent plate by the steel making process, originating from ingot casting defects.

Segregation bands occur in the centre of the plate and are low melting point impurities such as sulphur and phosphorous.

Laps are caused during rolling when overlapping metal does not fuse to the base material.

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Lapping

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Lapping

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Lapping

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Lamination

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Lamination

Plate lamination

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Any Questions

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Section 8

Codes and Standards

8 Codes and Standards

8.1 General

It is not necessary for the inspector to carry a range of codes and standards in the performance of his duties, normally the contract specification is the only document required. However this may reference supporting codes and standards and the inspector should know where to access these normative documents.

The following is a list of definitions relating to codes and standards the inspector may come across whilst carrying out his duties.

8.2 Definitions

Normative document

Document that provides rules, guidelines or characteristics for activities or their results. The term normative document is generic, covering documents such as standards, technical specifications, codes of practice and regulations.*

Standard

Document established by consensus and approved by a recognised body. A standard provides, for common and repeated use, guidelines, rules, characteristics for activities or their results, aimed at achieving the optimum degree of order in a given context.*

Harmonised standards

Standards on the same subject approved by different standardising bodies, that establish inter-changeability of products, processes and services, or mutual understanding of test results or information provided according to these standards.*

Code of practice

Document that recommends practices or procedures for the design, manufacture, installation, maintenance and utilisation of equipment, structures or products. A code of practice may be a standard, part of a standard or independent of a standard.*

Regulation

Document providing binding legislative rules adopted by an authority.*

Authority

A body (responsible for standards and regulations legal or administrative entity that has specific tasks and composition) that has legal powers and rights.*

Regulatory authority

Authority responsible for preparing or adopting regulations.*

Enforcement authority

Authority responsible for enforcing regulations.*

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Specification

A document stating requirements, needs or expectations. A specification could cover both physical and technical requirements ie Visual Inspection, NDT, mechanical testing etc., essentially full data and its supporting medium. Generally implied or obligatory.**

Procedure

Specified way to carry out an activity or process*. Usually a written description of all essential parameters and precautions to be observed when applying a technique to a specific application following an established standard, code or specification.

Instruction

Written description of the precise steps to be followed based on an established procedure, standard, code or specification.

Quality plan

Document specifying which procedures and associated resources shall be applied by whom and when to a specific project, product, process or contract.*

* ISO IEC Guide 2 – Standardisation and related activities – General vocabulary.

** EN ISO 9000 – 2000 – Quality management systems – Fundamentals and vocabulary.

8.3 Summary

Application standards and codes of practice ensure that a structure or component will have an acceptable level of quality and be fit-for-purpose.

Applying the requirements of a standard, code of practice or specification can be a problem for the inexperienced inspector. Confidence in applying the requirements of one or all of these documents to a specific application only comes with use.

If in doubt the inspector must always refer to a higher authority in order to avoid confusion and potential problems.

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Standard Number	Year	Status	**Comments** **AMD = amended** **COR = corrected**
BS 499-1	2009	Superseded	Superseded by: BS EN ISO 2560:2005
BS 709	1983	Superseded	Superseded by: BS EN ISO 9016:2011 BS EN ISO 5178:2011 BS EN ISO 4136:2011 BS EN ISO 5173:2010 + A1 2011 BS EN ISO 9015-1:2011 BS EN ISO 9015 -2:2011 BS EN 1320:1997 BS EN 1321:1997 AMD 14972 BS EN ISO 9018 : 2003 AMD 15061
BS 1113(1999)	1999	Superseded	Superseded By: BS EN 12952-1:2001 COR 2010 BS EN 12952-2:2011 BS EN 12952-3:2011 BS EN 12952-5:2011 BS EN 12952-6:2011 BS EN 12952-7:2010 BS EN 12952-10:2002 COR 2010 BS EN 12952-11:2002 COR 2010
BS1453 (1972)	1972 (amended 2001)	Partly Superseded	Partly superseded by: BS EN 12536:2000
BS 1821	1982 (amended 1998)	Cancelled	
BS 2493(1985)	1985	Superseded	Superseded by: BS EN ISO 18275:2012 & BS EN ISO 3580:2011
BS 2633(1987)	1987 (amended 1998)	Current	
BS 2640(1982)	1982 (amended 1998)	Cancelled	
BS 2654(1989)	1989 (amended 1997)	Superseded	Superseded by: BS EN 14015:2005
BS 2901-3(1990)	1990	Superseded	Superseded by: BS EN ISO 24373:2009
BS 2926	1984	Superseded	Superseded by: BS EN ISO 3581:2012
BS 3019	1984	Superseded	Superseded by: BS EN 1011-4:2000 AMD 2004
BS 3604-1 (1990)	1990	Superseded	Superseded by: BS EN 10216-2:2002 AMD 2007 & BS EN 10217-2:2002 AMD 2006
BS 3605	1991 AMD 1997	Superseded	Superseded by: BS EN 10216-5:2004 COR 2008

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Standard Number	Year	Status	**Comments** **AMD = amended** **COR = corrected**
BS 4515-1 (2009)	2009	Current	
BS 4570 (1985)	1985	Partly Superseded	Partly superseded by: BS EN 1011-8:2004 AMD
BS 4677 (1984)	1985	Current	
BS 4872-1 (1982)	1982	Current	
BS 4872-2 (1976)	1976	Current	
	1982	Superseded	There are multiple parts to this standard, part 1 was superseded by: BS EN 10305-5:2010 BS EN 10305-1:2010 BS EN 10305-2:2010 BS EN 10305-3:2010 BS EN 10305-4:2011 BS EN 10305-6:2005 AMD 2007 BS EN 10296-1:2003 BS EN 10296-2:2005 AMD 2007 BS EN 10297-1:2003 AMD 2003
BS 6693-1(1986)	1986	Superseded	There are multiple parts to this standard, part 1 was superseded by: BS EN ISO 3690:2012
BS 6990(1989)	1989 AMD 1998	Current	
BS 7191(1989)	1989 AMD 1991	Superseded	Superseded By: BS EN 10225:2009
BS 7570(2000)	2000	Superseded	Superseded By: BS EN 50504:2009
BS EN 287-1:2011	2011	Superseded	Superseded By: BS EN ISO 9606-1: 2013
BS EN 440:1995	1995	Superseded	Superseded By: BS EN ISO 14341:2011
BS EN 499:1995	1995	Superseded	Superseded By: BS EN ISO 2560:2009
BS EN 383			
BS EN 756:2004	2004	Superseded	Superseded By: BS EN ISO 14171:2010
BS EN 760:1996	1996	Superseded	Superseded By: BS EN ISO 14174:2012

Standard Number	**Year**	**Status**	**Comments** **AMD = amended** **COR = corrected**
BS EN 910:1996	1996	Superseded	Superseded By: BS EN ISO 5173:2010 + A1 2011
BS EN 970:1997	1997	Superseded	Superseded By: BS EN ISO 17637:2011
BS EN 12072:2000	2000	Superseded	Superseded By: BS EN ISO 14343:2009
BS EN ISO 18274:2011	2011	Current	
BS EN 1011-1:2009	2009	Current	
BS EN 1011-2:2001 AMD 2004	2001	Current	
BS EN 1011-3:2000 AMD 2004	2000	Current	
BS EN 1011-4:2000 AMD 2004	2000	Current	
BS EN 1320:1997	1997	Current	
BS EN 1435:1997 AMD 2004	1997	Current	
BS EN 10002-1:2001	2001	Superseded	There are multiple parts for this standard, part one is superseded by: BS EN ISO 6892-1:2009
BS EN 10020:2000	2000	Current	
BS EN 10027:2005	2005	Current	
BS EN 10045-1:1990	1990	Superseded	
BS EN 10204:2004	2004	Current	
BS EN 22553:1995	1995	Current	
BS EN 24063:1992	1992	Superseded	Superseded By: BS EN ISO 4063:2010
BS EN 25817:1992	1992	Superseded	Superseded By: BS EN ISO 5817:2007
BS EN 26520:1992	1992	Superseded	Superseded By: BS EN ISO 6520-1:2007
BS EN 26848:1991	1991	Superseded	Superseded By: BS EN ISO 6848:2004
ISO 857-1:1998	1998	Current	
BS EN ISO 6947:2011	2011	Current	
BS EN ISO 15607:2003	2003	Current	

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Standard Number	**Year**	**Status**	**Comments** **AMD = amended** **COR = corrected**
BS PD CR ISO 15608:2000	2000	Superseded	Superseded By: BS PD CEN ISO/TR 15608:2005
BS EN ISO 15609-1:2004	2004	Current	
BS EN ISO 15610:2003	2003	Current	
BS EN ISO 15611:2003	2003	Current	
BS EN ISO 15613:2004	2004	Current	
BS EN ISO 15614-1: 2004 A2 2012	2004	Current	
BS EN ISO 15614-2:2005	2005	Current	
BS EN ISO 15614-3:2008	2008		
BS EN ISO 15614-4:2005 COR 2008	2008		
BS EN ISO 15614-5:2004	2004		
BS EN ISO 15614-6:2006	2006		
BS EN ISO 15614-7:2007	2007		
BS EN ISO 15614-8:2002	2002		
BS EN ISO 15614-9	None available		
BS EN ISO 15614-10:2005	2005		
BS EN ISO 15614-11:2002	2002		
BS EN ISO 15614-12:2004	2004		
BS EN ISO 15614-13:2005	2005		

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Quality in Welding Codes and Standards

Section 8

Materials Joining and Engineering Technologies
Training and Examination Services

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Codes and Standards Objective

When this presentation has been completed you will be able to acknowledge what is a code and standard and recognise their purpose. You should be able to identify some commonly used ones by their unique numbers and for what they are used for in industry.

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Quality in Welding

Quality assurance manual

Essentially what the QA manual sets out to achieved is the how the company is organised, to lay down the responsibilities and authority of the various departments, how these departments interlink. The manual usually covers all aspects of the company structure, not just those aspects of manufacture.

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Quality in Welding

Quality control manual

The QC manual will be the manual most often referred to by the SWI as it will spell out in detail how different departments and operations are organised and controlled.

Typical examples would be

- Production and control of drawings, how materials and consumables are purchased, how welding procedures are produced, etc.
- Essentially all operations to be carried out within the organisation will have control procedures laid down.

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Standard/Codes/Specifications

Specifications	Codes
Examples:	**Examples:**
▪ Plate, pipe.	▪ Pressure vessels.
▪ Forgings, castings.	▪ Bridges.
▪ Valves.	▪ Pipelines.
▪ Electrodes.	▪ Tanks.

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Standard/Codes/Specifications

Standard

A document that is established by consensus and approved by a recognised body.

A standard provides, for common and repeated use, guidelines, rules, and characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.

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Standard/Codes/Specifications

Specification
A document stating requirements, needs or expectations.

A specification could cover both physical and technical requirements ie Visual Inspection, NDT, mechanical testing etc., essentially full data and its supporting medium. Generally implied or obligatory.

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Standard/Codes/Specifications

Examples of specification

BS 4515
Specification for welding of steel pipelines on land and offshore.

BS EN 26848
Specification for tungsten electrodes for inert gas shielded arc welding and for plasma cutting and welding.

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Standard/Codes/Specifications

Examples of standards

BS EN ISO 17637
Non - destructive examination of fusion welds - visual examination.

BS EN 440
Wire electrodes and deposits for gas shielded metal arc of non - alloy and fine grain steels.

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Any Questions

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Section 9

Welding Symbols

9 Welding Symbols

A weld joint can be represented on an engineering drawing by a detailed sketch showing every detail and dimension of the joint preparation, as shown below.

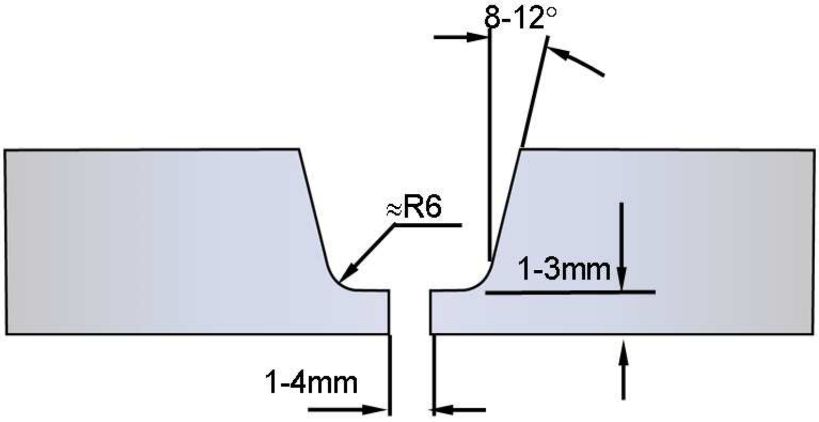

Figure 9.1 Single U preparation.

While this method of representation gives comprehensive information, it can be time-consuming and overburden the drawing.

An alternative is to use a symbolic representation to specify the required information, as shown below for the same joint detail.

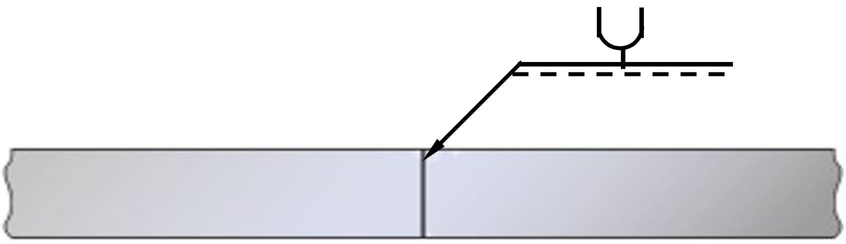

Figure 9.2 Symbolic representation of the single U preparation.

Advantages of symbolic representation:

- Simple and quick to add to the drawing.
- Does not overburden the drawing.
- No need for an additional view, all welding symbols can be put on the main assembly drawing.

Disadvantages of symbolic representation:

- Can only be used for standard joints (eg BS EN ISO 9692).
- No way of giving precise dimensions for joint details.
- Some training is necessary to correctly interpret the symbols.

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9.1 Standards for symbolic representation of welded joints on drawings

Two principal standards are used for welding symbols:

European Standard

EN 22553 – Welded, brazed & soldered joints, Symbolic representation on drawings.

American Standard

AWS A2.4, standard symbols for welding, brazing and non-destructive examination.

These standards are very similar in many respects, but there are also some major differences that need to be understood to avoid misinterpretation.

Details of the European Standard are given in the following sub-sections with only brief information about how the American Standard differs.

Elementary welding symbols

Various types of weld joint are represented by a symbol that is intended to help interpretation by being similar to the shape of the weld to be made.

Examples of symbols used by EN 22553 are shown on the following pages.

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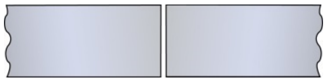
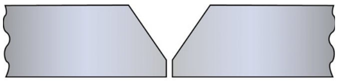
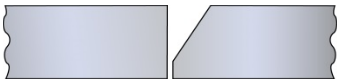
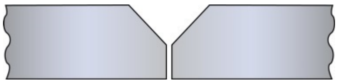
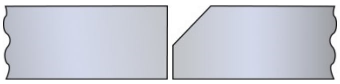
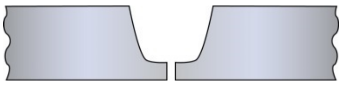
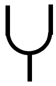
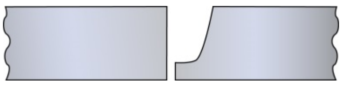
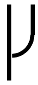
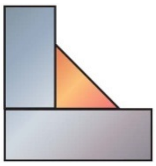
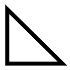
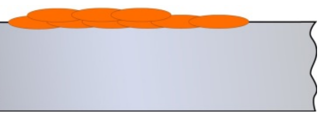
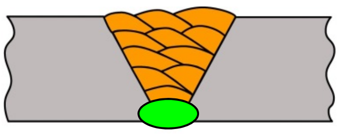
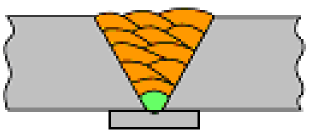
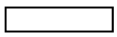
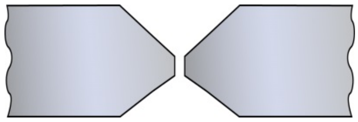
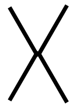
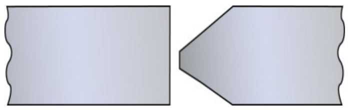
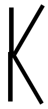
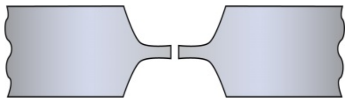
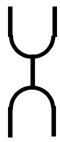
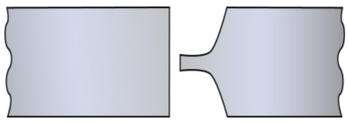
9.2 Elementary welding symbols

Designation	Illustration of joint preparation	Symbol
Square butt weld		
Single V butt weld		
Single bevel butt weld		
Single V butt weld with broad root face		
Single bevel butt weld with broad root face		
Single U butt weld		
Single J butt weld		
Fillet weld		
Surfacing (cladding)		
Backing run (back or backing weld)		
Backing bar		

9.3 Combination of elementary symbols

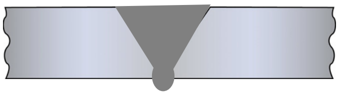
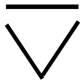
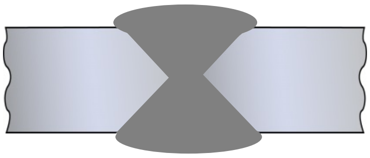
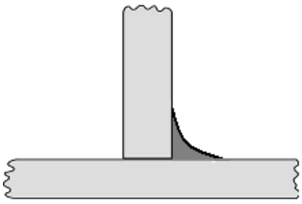
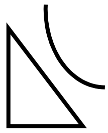
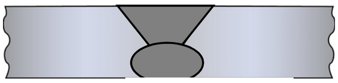
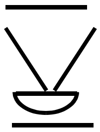
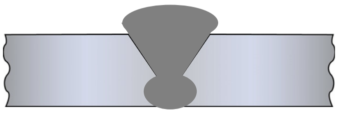
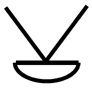
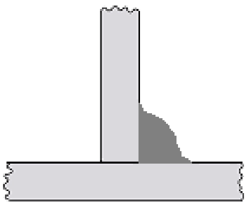
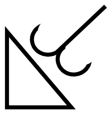
For symmetrical welds made from both sides, the applicable elementary symbols are combined, as shown below.

Designation	Illustration of joint preparation	Symbol
Double V butt weld (X weld)		
Double bevel butt weld (K weld)		
Double U butt weld		
Double J butt weld		

9.4 Supplementary symbols

Weld symbols may be complemented by a symbol to indicate the required shape of the weld.

Examples of supplementary symbols and how they are applied are given below.

Designation	Illustration of joint preparation	Symbol
Flat (flush) single V butt weld		
Convex double V butt weld		
Concave fillet weld		
Flat (flush) single V butt weld with flat (flush) backing run		
Single V butt weld with broad root face and backing run		
Fillet weld with both toes blended smoothly		

Note: If the weld symbol does not have a supplementary symbol then the shape of the weld surface does not need to be indicated precisely.

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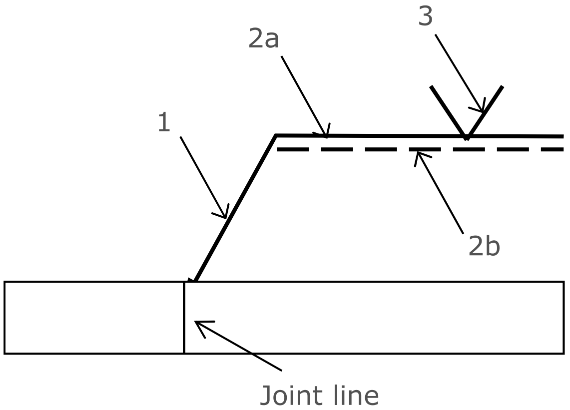
9.5 Position of symbols on drawings

To be able to provide comprehensive details for weld joints, it is necessary to distinguish the two sides of the weld joint.

This is done, according to EN 22553, by:

- An arrow line.
- A dual reference line consisting of a continuous and a dashed line.

The figure below illustrates the method of representation.



1 = Arrow line
2a = Reference (continuous line)
2b = Identification line (dashed line)
3 = Welding symbol (single V joint)

Figure 9.3 The method of representation.

9.6 Relationship between the arrow and joint lines

One end of the joint line is called the arrow side and the opposite end is called other side.

The arrow side is always the end of the joint line that the arrow line points to (and touches).

It can be at either end of the joint line and it is the draughtsman who decides which end to make the arrow side.

The figure below illustrates these principles.

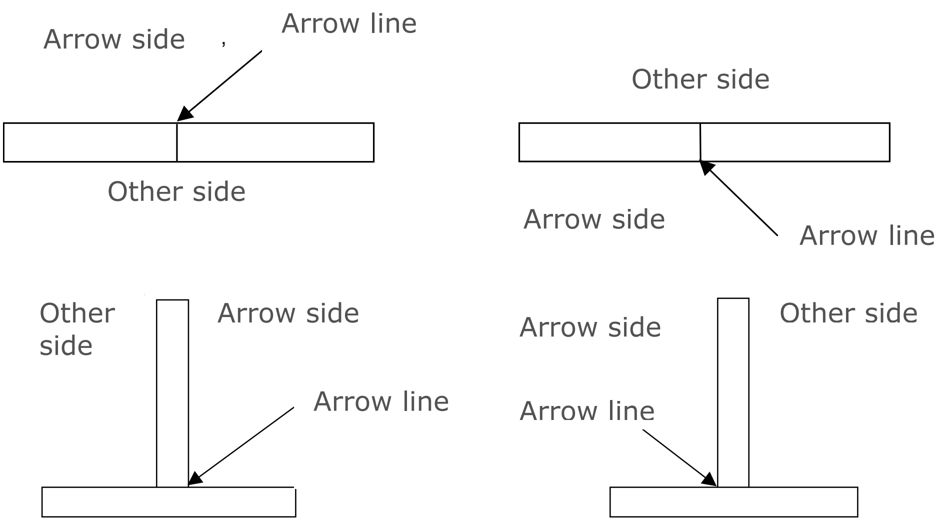


Figure 9.4 The relationship between the arrow and joint lines.

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There are some conventions about the arrow line:

- It must touch one end of the joint line.
- It joins one end of the continuous reference line.
- In case of a **non-symmetrical joint**, such as a single bevel joint, the arrow line must point towards the joint member that will have the weld preparation put on to it (as shown below).

An example of how a single bevel butt joint should be represented.

Figure 9.5 Single bevel butt joint representation.

9.7 Position of the reference line and weld symbol

The reference line should, wherever possible, be drawn parallel to the bottom edge of the drawing (or perpendicular to it).

For a non-symmetrical weld it is essential that the arrow side and other side of the weld are distinguished. The convention for doing this is:

- Symbols for the weld details required on the arrow side must be placed on the continuous line.
- Symbols for the weld details on the other side must be placed on the dashed line.

9.8 Positions of the continuous and dashed lines

EN22553 allows the dashed line to be either above or below the continuous line – as shown below.

If the weld is symmetrical it is not necessary to distinguish between the two sides and EN22553 states that the dashed line should be omitted. Thus, a single V butt weld with a backing run can be shown by any of the four symbolic representations shown below.

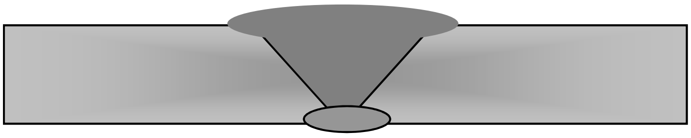

Figure 9.6 Single V weld with backing run.

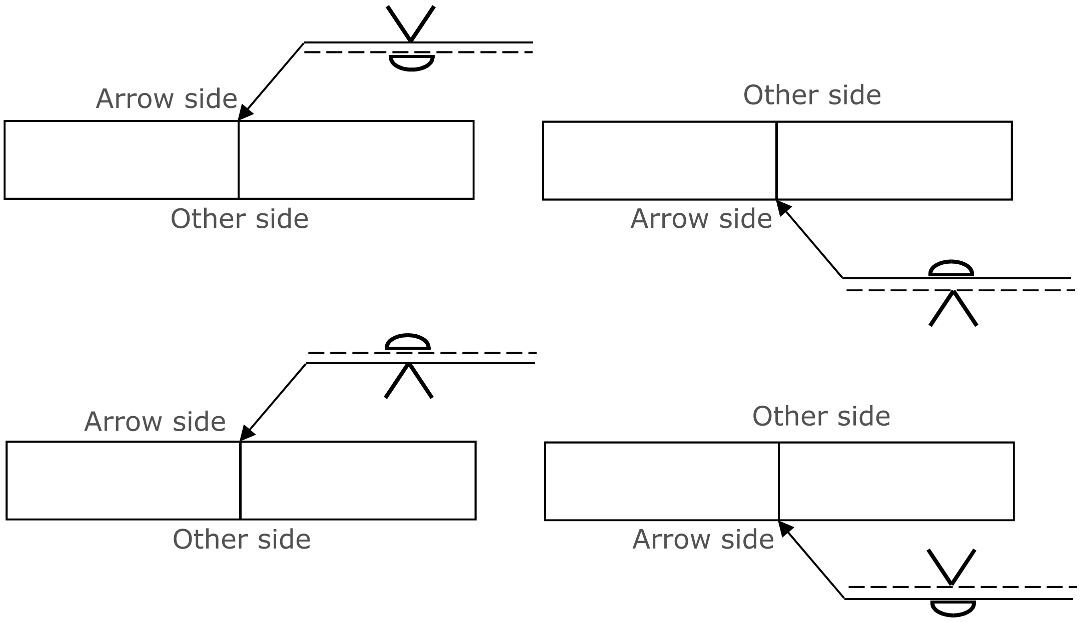

Figure 9.7 Symbolic representations of a single V weld with backing run.

This flexibility of the position of the continuous and dashed lines is an interim measure that EN22553 allows so that old drawings (to the obsolete BS 499 Part 2, for example) can be easily converted to show the EN method of representation.

9.9 Dimensioning of welds

General rules

Dimensions may need to be specified for some types of weld and EN 22553 specifies a convention for this.

- Dimensions for the cross-section of the weld are written on the lefthand side of the symbol.
- Length dimensions for the weld are written on the righthand side of the symbol.
- In the absence of any indication to the contrary, all butt welds are full penetration welds.

9.9.1 Symbols for cross-section dimensions

The following letters are used to indicate dimensions:

a Fillet weld throat thickness.
Z Fillet weld leg length.
s Penetration depth (applicable to partial penetration butt welds and deep penetration fillets).

Some examples of how these symbols are used are shown below.

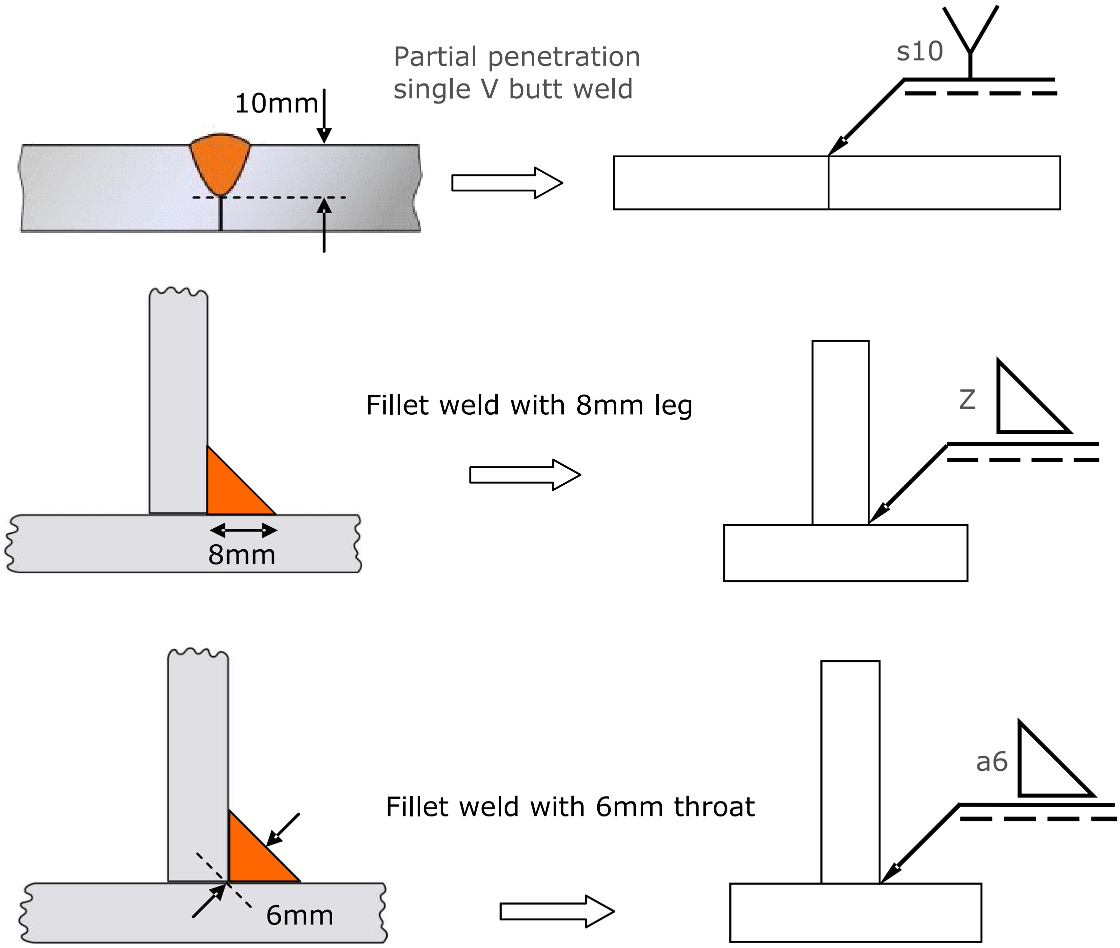

Figure 9.8 Examples of symbols for cross-section dimensions.

9.9.2 Symbols for length dimensions

To specify weld length dimensions and, for intermittent welds the number of individual weld lengths (weld elements), the following letters are used:

l Length of weld.
(e) Distance between adjacent weld elements.
n Number of weld elements.

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The use of these letters is shown for the intermittent double-sided fillet weld shown below.

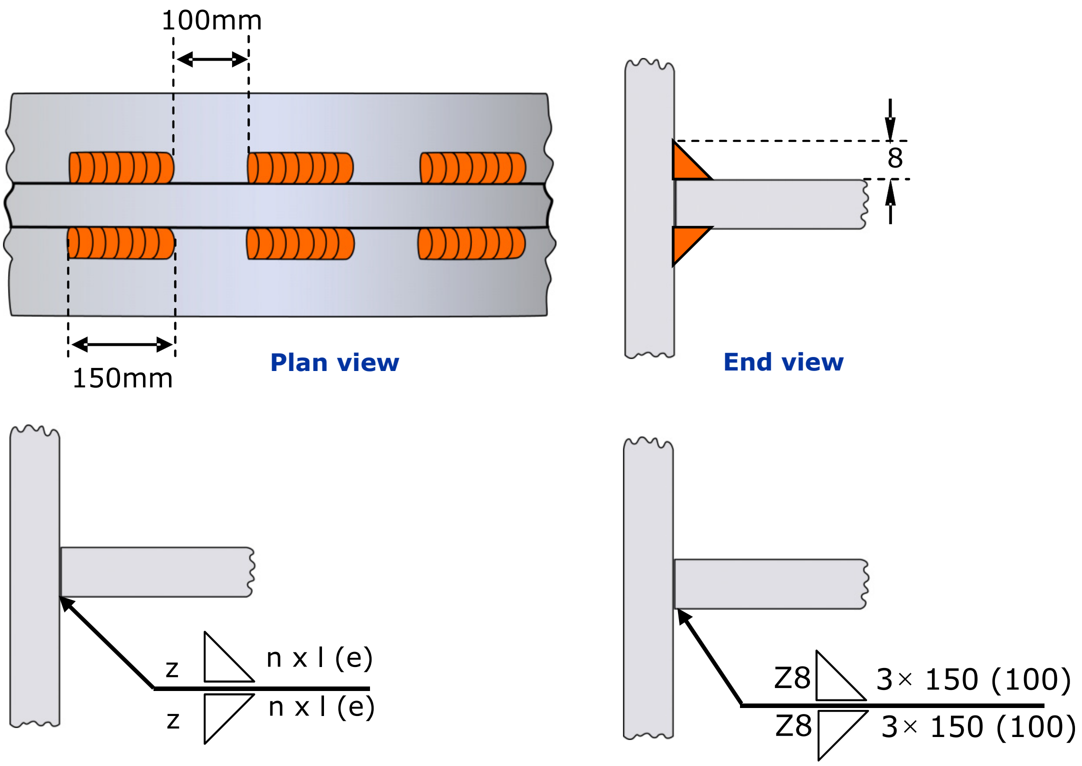

Figure 9.9 Symbols for length dimensions.

Note: Dashed line is not required because it is a symmetrical weld.

The convention for an intermittent double-sided staggered fillet weld is shown below.

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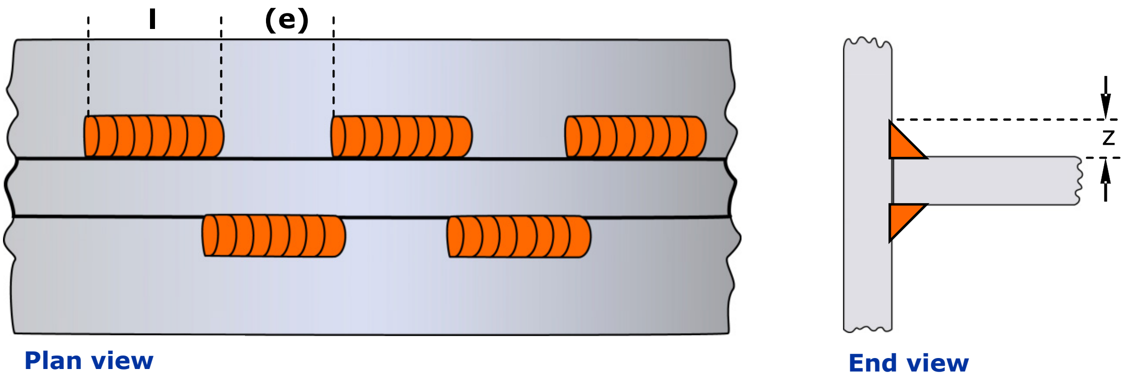

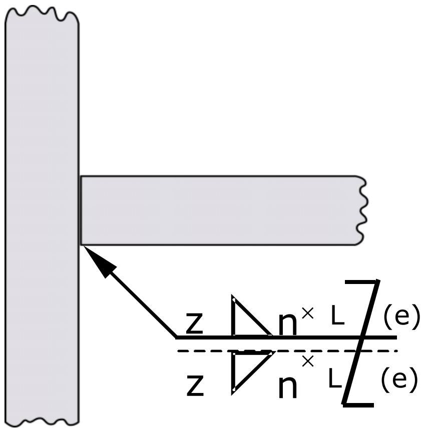

Figure 9.10 An intermittent double-sided staggered fillet weld.

9.10 Complimentary indications

Complementary indications may be needed to specify other characteristics of welds, eg:

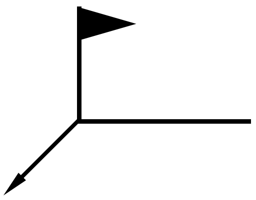

Figure 9.11 Field or site welds are indicated by a flag.

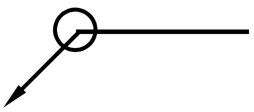

Figure 9.12 A peripheral weld to be made all around a part is indicated by a circle.

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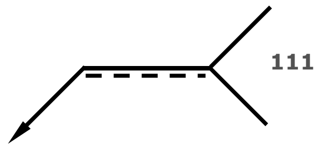
9.11 Indication of the welding process

If required, the welding process is symbolised by a number written between the two branches of a fork at the end of the reference line.

Some welding process designations:

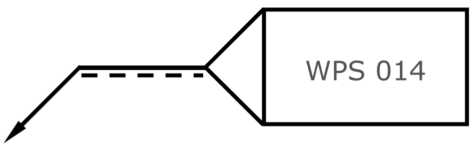
111 = MMA
121 = SAW
131 = MIG
135 = MAG



9.11.1 Other information in the tail of the reference line

Information other than the welding process can be added to an open tail such as the NDT acceptance level, the working position and filler metal type and EN22553 defines the sequence that must be used for this information.

A closed tail can also be used into which reference to a specific instruction can be added.



9.12 Weld symbols in accordance with AWS 2.4

Many of the symbols and conventions specified by EN22553 are the same as those for AWS.

The major differences are:

- Only one reference line is used (a continuous line).
- Symbols for weld details on the arrow side go underneath the reference line.
- Symbols for weld details on the other side go on top of the reference line.

These differences are illustrated by the following example.

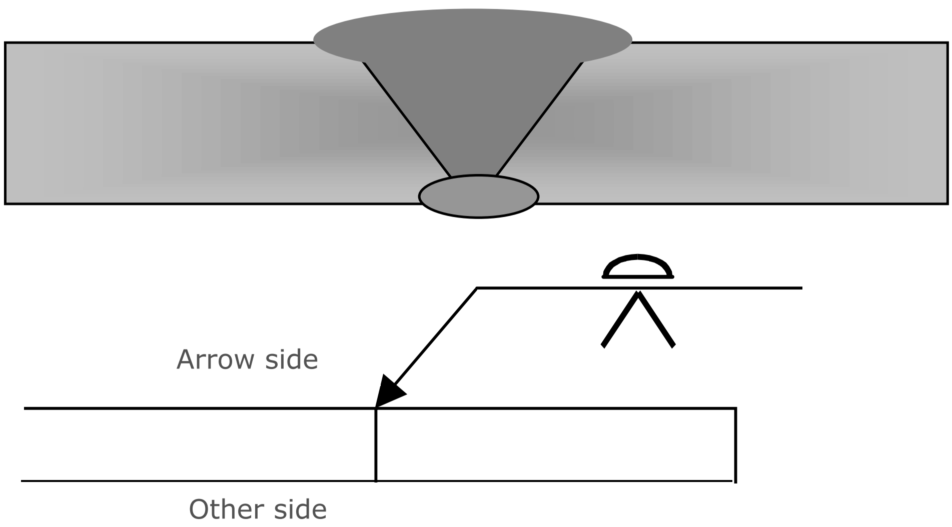


Figure 9.13 Weld symbols in accordance with AWS 2.4.

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Welding Symbols

Section 9

Materials Joining and Engineering Technologies
Training and Examination Services

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Welding Symbols Objective

When this presentation has been completed you should be able to recognise the differences in the international standards for symbols and be able to break down each element of the representation, on an engineering drawing.

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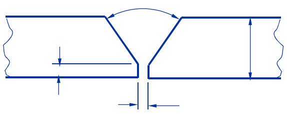
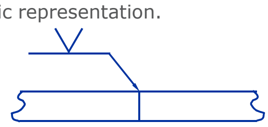
Weld Symbols on Drawings

Joints in drawings may be indicated:

By detailed sketches, showing every dimension.



By symbolic representation.



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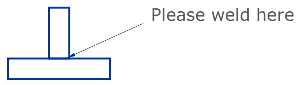
Weld Symbols on Drawings

A method of transferring information from the design office to the workshop is:



The above information does not tell us much about the wishes of the designer. We obviously need some sort of code which would be understood by everyone.

Most countries have their own standards for symbols.
Some of them are AWS A2.4 & BS EN 22553 (ISO 2553)

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Weld Symbols on Drawings

Advantages of symbolic representation:

- Simple and quick plotting on the drawing.
- Does not over-burden the drawing.
- No need for additional view.
- Gives all necessary indications regarding the specific joint to be obtained.

Disadvantages of symbolic representation:

- Used only for usual joints.
- Requires training for properly understanding of symbols.

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Weld Symbols on Drawings

The symbolic representation includes:

- An arrow line.
- A reference line.
- An elementary symbol.

The elementary symbol may be completed by:

- A supplementary symbol.
- A means of showing dimensions.
- Some complementary indications.

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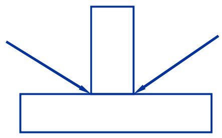
Arrow Line

(BS EN ISO 22553 and AWS A2.4):
Convention of the arrow line:

- Shall touch the joint intersection.
- Shall not be parallel to the drawing.
- Shall point towards a single plate preparation (when only one plate has preparation).



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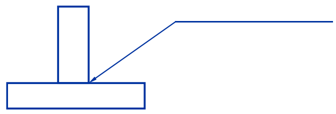
Reference Line

(AWS A2.4)
Convention of the reference line:

- **Shall** touch the arrow line.
- **Shall** be parallel to the bottom of the drawing.



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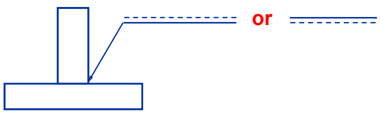
Reference Line

(BS EN ISO 22553)
Convention of the reference line:

- **Shall** touch the arrow line.
- **Shall** be parallel to the bottom of the drawing.
- **There shall** be a further broken identification line above or beneath the reference line (Not necessary where the weld is symmetrical!).



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Elementary Welding Symbols

(BS EN ISO 22553 & AWS A2.4)
Convention of the elementary symbols:

- Various categories of joints are characterised by an elementary symbol.
- The vertical line in the symbols for a fillet weld, single/double bevel butts and a J-butt welds must always be on the left side.

Weld type	Sketch	Symbol
Square edge butt weld		
Single-v butt weld		

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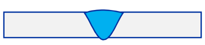
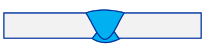
Elementary Welding Symbols

Weld type	Sketch	Symbol
Single V butt weld with broad root face.		
Single bevel butt weld.		
Single bevel butt weld with broad root face.		
Backing run.		

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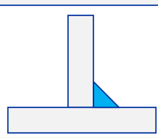
Elementary Welding Symbols

Weld type	Sketch	Symbol
Single-U butt weld.		
Single-J butt weld.		
Surfacing.		
Fillet weld.		

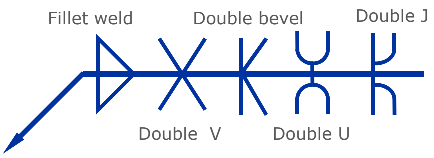
Copyright © TWI Ltd

Double Side Weld Symbols

(BS EN ISO 22553 & AWS A2.4)

Convention of the double side weld symbols:

Representation of welds done from **both sides** of the joint intersection, touched by the arrow head.



Copyright © TWI Ltd

Dimensions

Convention of dimensions

In most standards the cross sectional dimensions are given to the left side of the symbol, and all linear dimensions are give on the right side.

BS EN ISO 22553

a = Design throat thickness.
s = Depth of penetration, throat thickness.
z = Leg length (min material thickness).

AWS A2.4

- In a fillet weld, the size of the weld is the leg length.
- In a butt weld, the size of the weld is based on the depth of the joint preparation.

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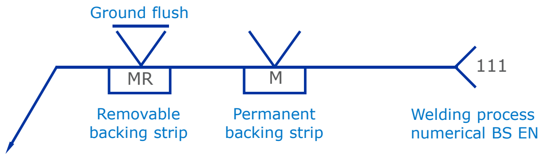
Supplementary Symbols

(BS EN ISO 22553 and AWS A2.4)
Convention of supplementary symbols

Supplementary information such as welding process, weld profile, NDT and any special instructions.



Further supplementary information, such as WPS number, or NDT may be placed in the fish tail.

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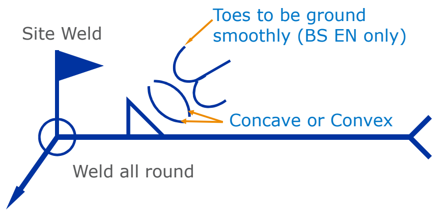
Supplementary Symbols

(BS EN ISO 22553 & AWS A2.4)
Convention of supplementary symbols

Supplementary information such as welding process, weld profile, NDT and any special instructions.



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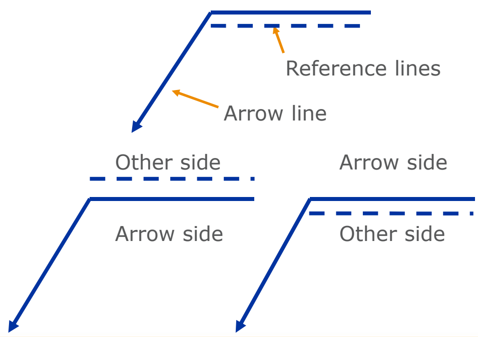
Welding Symbols

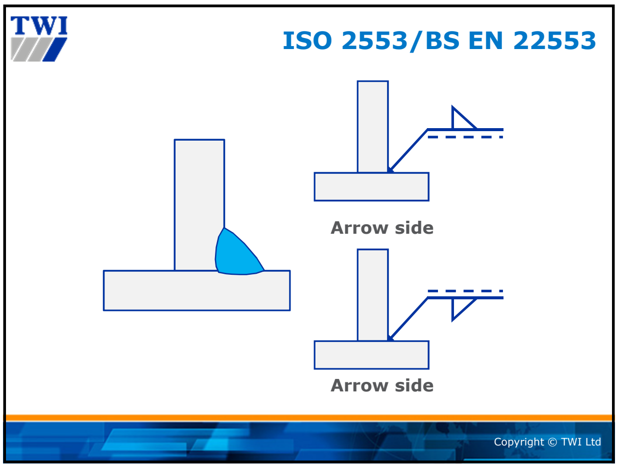
BS EN 22553 (ISO 2553)

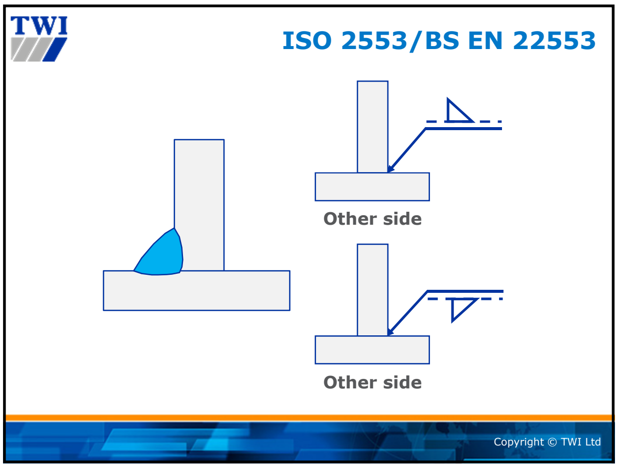
Copyright © TWI Ltd

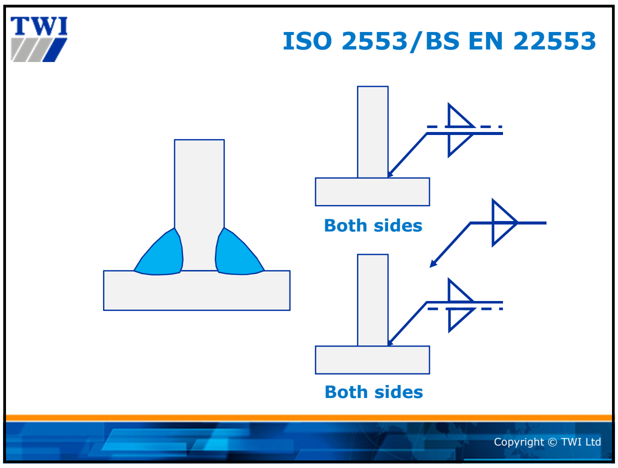
ISO 2553/BS EN 22553

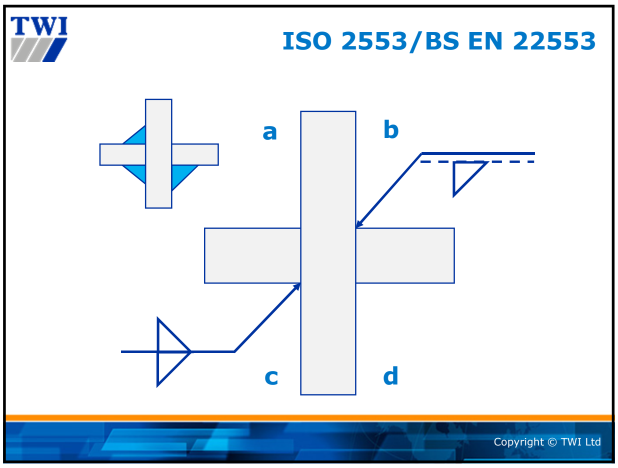


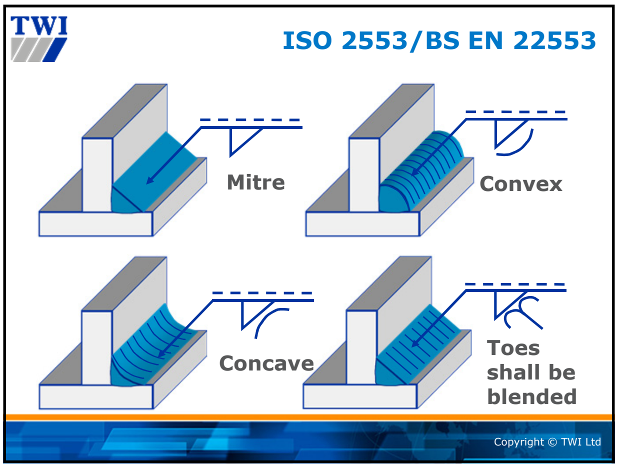
Copyright © TWI Ltd

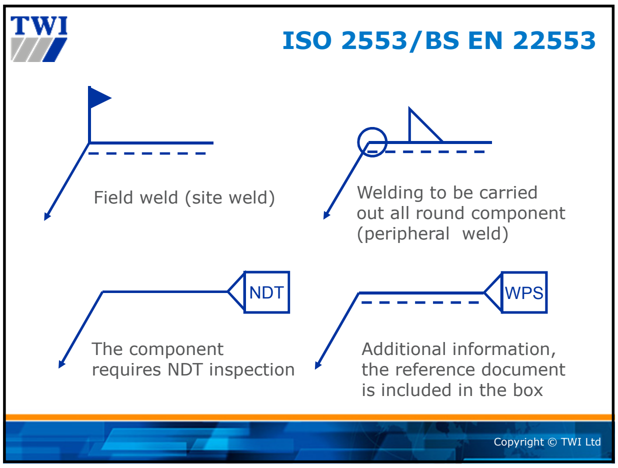

TWI
ISO 2553/BS EN 22553
Arrow side
Arrow side
Copyright © TWI Ltd

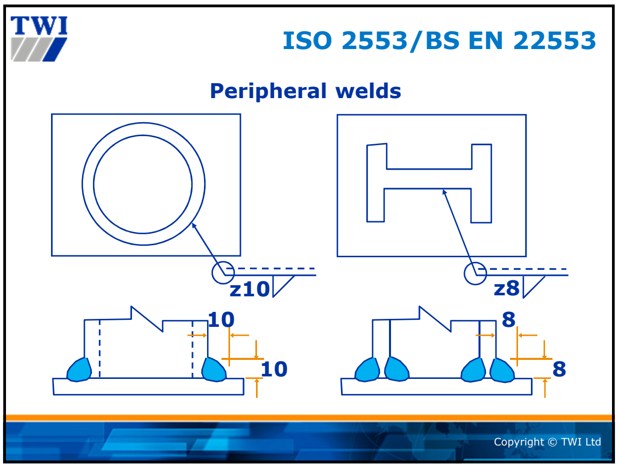

TWI
ISO 2553/BS EN 22553
Other side
Other side
Copyright © TWI Ltd

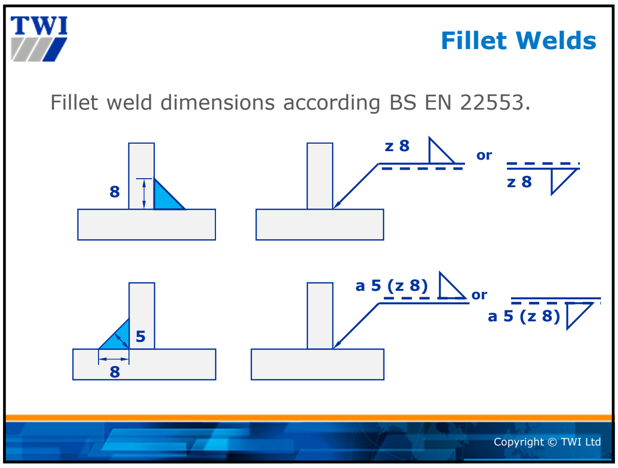

TWI
ISO 2553/BS EN 22553
Both sides
Both sides
Copyright © TWI Ltd

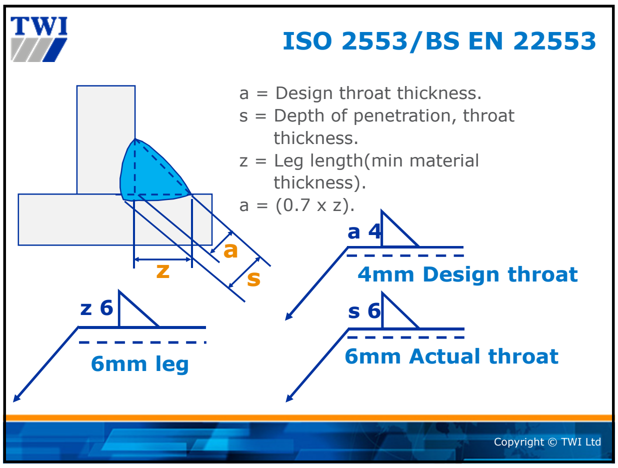

TWI
ISO 2553/BS EN 22553
a
b
c
d
Copyright © TWI Ltd

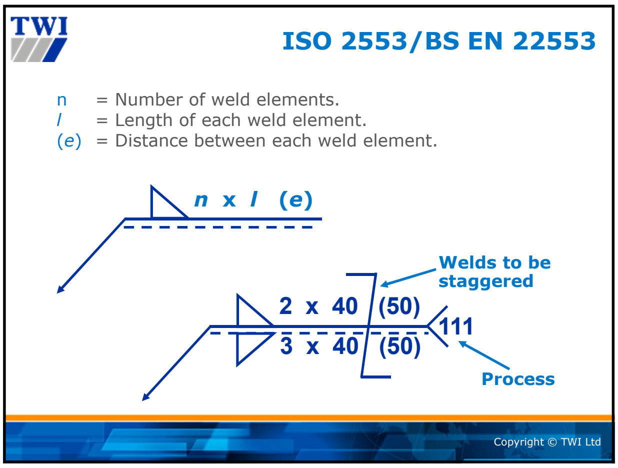

TWI
ISO 2553/BS EN 22553
Mitre
Convex
Concave
Toes shall be blended
Copyright © TWI Ltd

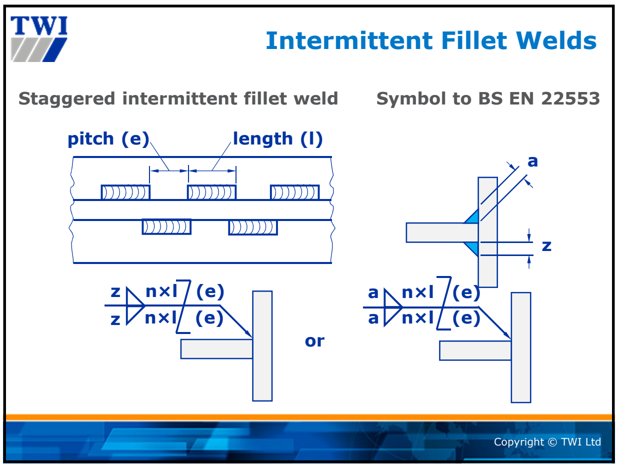

TWI
ISO 2553/BS EN 22553
Field weld (site weld)
Welding to be carried out all round component (peripheral weld)
NDT
The component requires NDT inspection
WPS
Additional information, the reference document is included in the box
Copyright © TWI Ltd

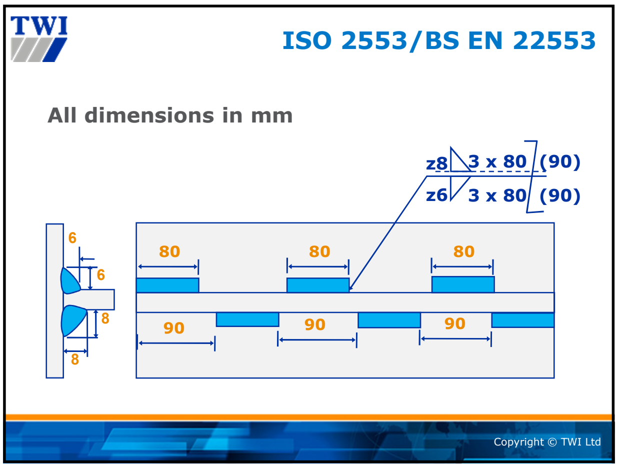

TWI
ISO 2553/BS EN 22553
Peripheral welds
z10
10
10
z8
8
8
Copyright © TWI Ltd

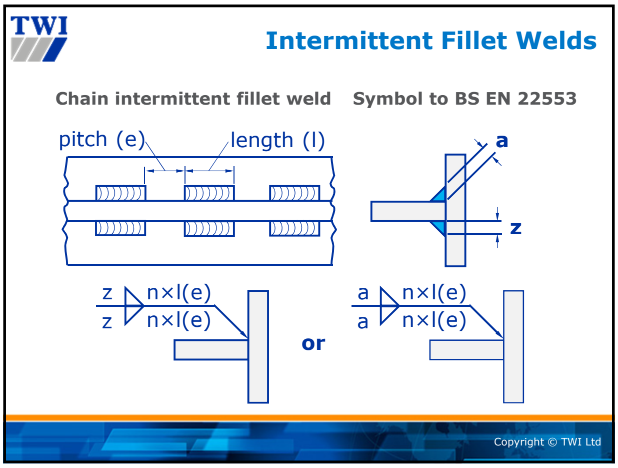

TWI
Fillet Welds
Fillet weld dimensions according BS EN 22553.
8
z 8
or
z 8
5
8
a 5 (z 8)
or
a 5 (z 8)
Copyright © TWI Ltd

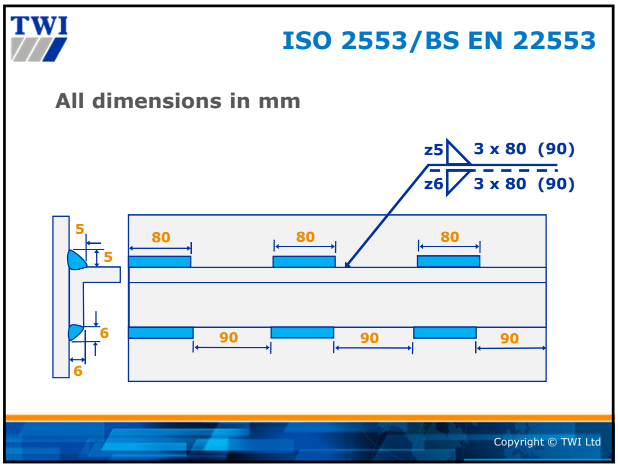

TWI
ISO 2553/BS EN 22553
a = Design throat thickness.
s = Depth of penetration, throat thickness.
z = Leg length(min material thickness).
a = (0.7 x z).
a
z
s
a 4
4mm Design throat
z 6
6mm leg
s 6
6mm Actual throat
Copyright © TWI Ltd

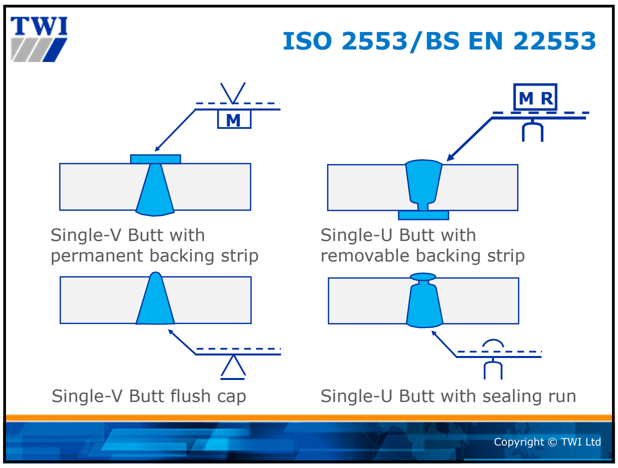

TWI
ISO 2553/BS EN 22553
n = Number of weld elements.
l = Length of each weld element.
(e) = Distance between each weld element.
n x l (e)
Welds to be staggered
2 x 40 (50)
3 x 40 (50)
111
Process
Copyright © TWI Ltd

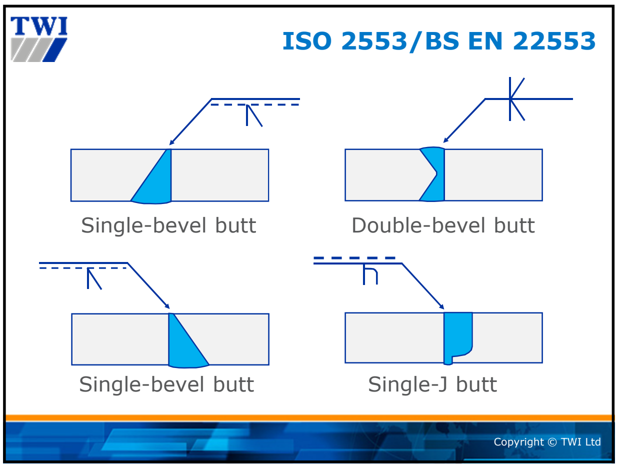

TWI
Intermittent Fillet Welds
Staggered intermittent fillet weld
Symbol to BS EN 22553
pitch (e)
length (l)
a
z
z n×l (e)
z n×l (e)
or
a n×l (e)
a n×l (e)
Copyright © TWI Ltd

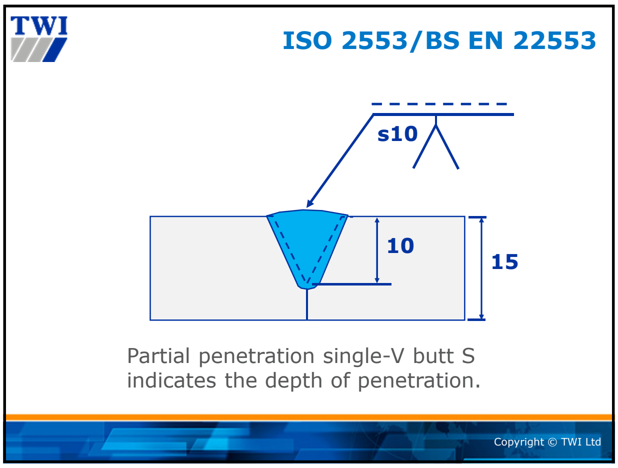

TWI
ISO 2553/BS EN 22553
All dimensions in mm
z8 3 x 80 (90)
z6 3 x 80 (90)
6
6
8
8
80
80
80
90
90
90
Copyright © TWI Ltd

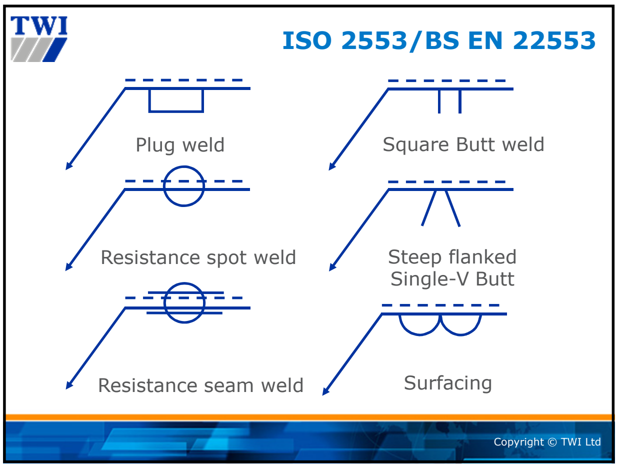

Intermittent Fillet Welds
Chain intermittent fillet weld
Symbol to BS EN 22553
pitch (e)
length (l)
a
z
z n×l(e)
z n×l(e)
or
a n×l(e)
a n×l(e)
Copyright © TWI Ltd


ISO 2553/BS EN 22553
All dimensions in mm
z5 3 x 80 (90)
z6 3 x 80 (90)
5
5
80
80
80
6
6
90
90
90
Copyright © TWI Ltd


ISO 2553/BS EN 22553
M
M R
Single-V Butt with
permanent backing strip
Single-U Butt with
removable backing strip
Single-V Butt flush cap
Single-U Butt with sealing run
Copyright © TWI Ltd


ISO 2553/BS EN 22553
Single-bevel butt
Double-bevel butt
Single-bevel butt
Single-J butt
Copyright © TWI Ltd

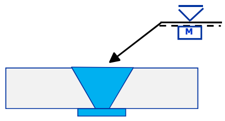

ISO 2553/BS EN 22553
s10
10
15
Partial penetration single-V butt S
indicates the depth of penetration.
Copyright © TWI Ltd


ISO 2553/BS EN 22553
Plug weld
Square Butt weld
Resistance spot weld
Steep flanked
Single-V Butt
Resistance seam weld
Surfacing
Copyright © TWI Ltd

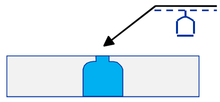
TWI

ISO 2553/BS EN 22553 Butt Weld Example

1 **Welded arrow side:** Single-V butt weld with permanent backing strip, flat weld profile.



2 **Welded other side:** Single-U butt weld, flat weld profile.



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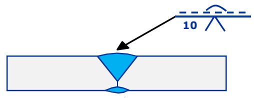
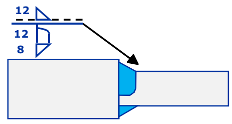
ISO 2553/BS EN 22553 Butt Weld Example

3 **Welded arrow side:** Single-V butt weld depth of preparation 10mm. **Welded other side:** Backing run. (Plate thickness 15mm.)



4 **Welded arrow side:** Single-J butt weld, depth of preparation 12mm with a 8mm fillet weld superimposed. (plate thickness 15mm. **Welded other side:** 12mm leg length fillet weld.



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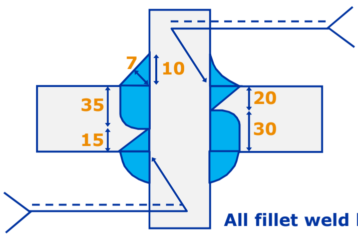
ISO 2553/BS EN 22553 Compound Weld Example

Complete the symbol drawing for the welded cruciform joint provided below. All welds are welded with the MIG process and fillet welds with the MMA process.



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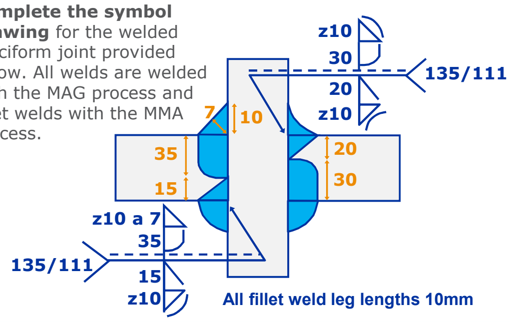
ISO 2553/BS EN 22553 Compound Weld Example

Complete the symbol drawing for the welded cruciform joint provided below. All welds are welded with the MAG process and fillet welds with the MMA process.



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BS EN 22553 Rules

Welds **this side** of joint, go on the **unbroken** reference line while welds **the other side** of the joint, go on the **broken** reference line.

Symbols with a **vertical line** component must be drawn with the vertical line to the **left** side of the symbol.

All **CSA** dimensions are shown to the **left** of the symbol.

All **linear** dimensions are shown on the **right** of the symbol ie number of welds, length of welds, length of any spaces.

Included angle and root opening are shown on **top** of the symbol.

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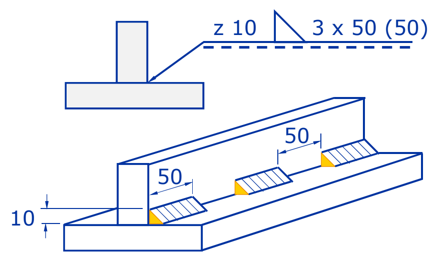
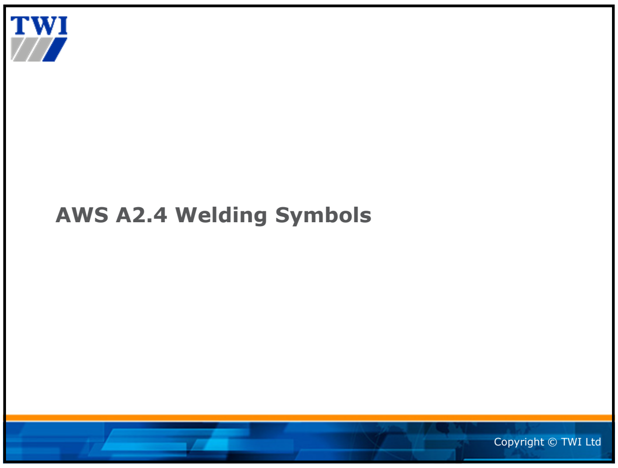
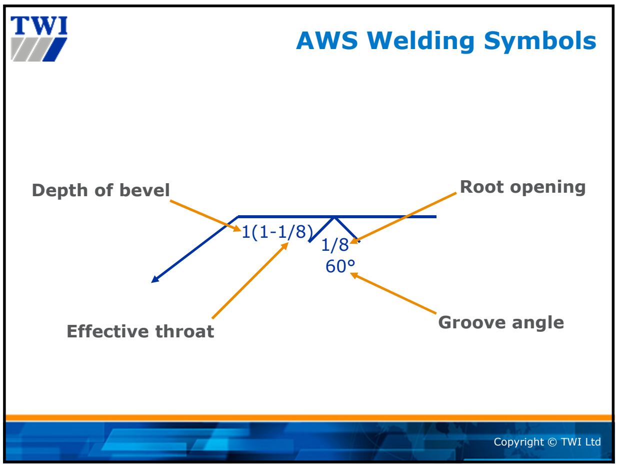
BS EN 22553 Rules - Example

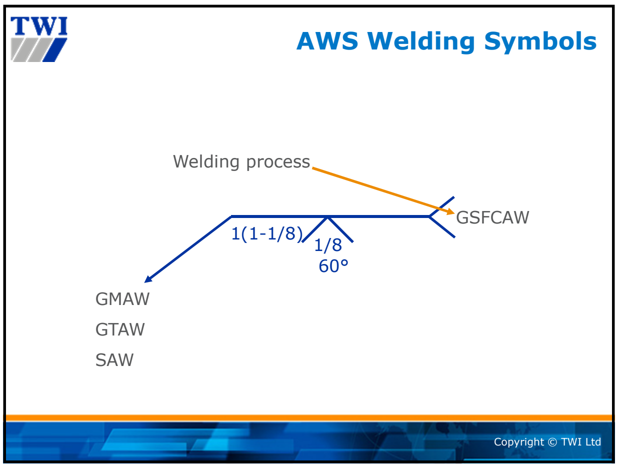
All leg lengths **shall** be preceded by z and throat by a or s (in case of deep penetration welds).

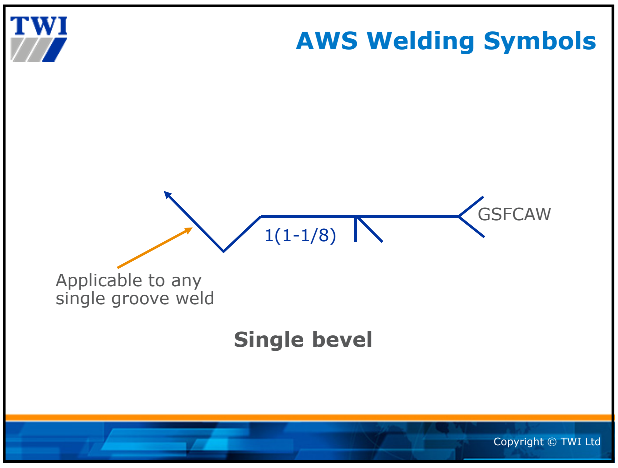


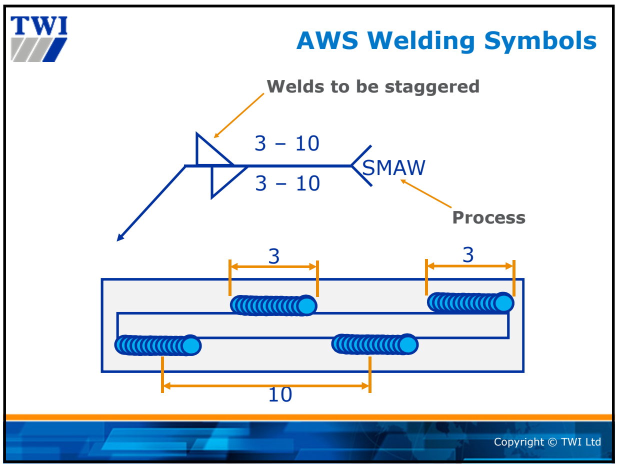
Copyright © TWI Ltd

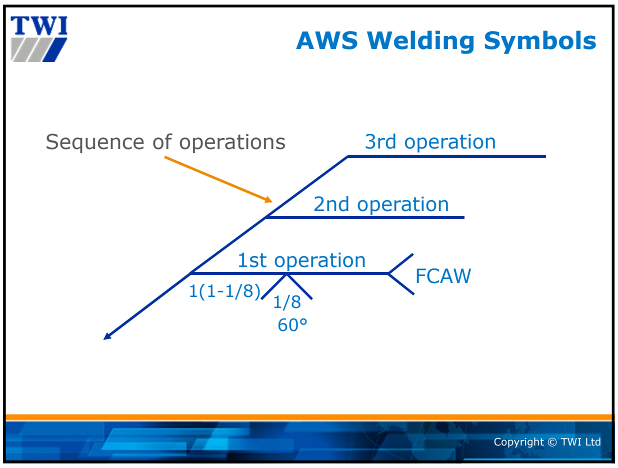

TWI
AWS A2.4 Welding Symbols
Copyright © TWI Ltd


TWI
AWS Welding Symbols
Depth of bevel
Root opening
1(1-1/8)
1/8
60°
Effective throat
Groove angle
Copyright © TWI Ltd

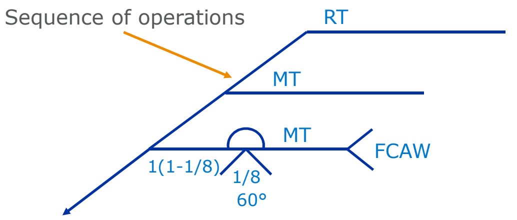

TWI
AWS Welding Symbols
Welding process
GSFCAW
1(1-1/8)
1/8
60°
GMAW
GTAW
SAW
Copyright © TWI Ltd


TWI
AWS Welding Symbols
GSFCAW
1(1-1/8)
Applicable to any
single groove weld
Single bevel
Copyright © TWI Ltd


TWI
AWS Welding Symbols
Welds to be staggered
3 – 10
SMAW
3 – 10
Process
3
3
10
Copyright © TWI Ltd


TWI
AWS Welding Symbols
Sequence of operations
3rd operation
2nd operation
1st operation
FCAW
1(1-1/8)
1/8
60°
Copyright © TWI Ltd

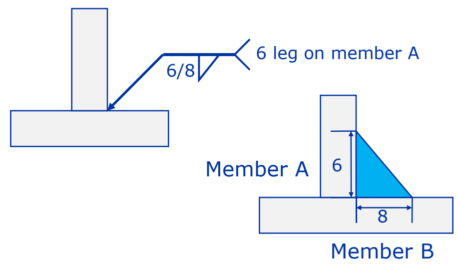
AWS Welding Symbols



Copyright © TWI Ltd

AWS Welding Symbols

Dimensions - Leg length



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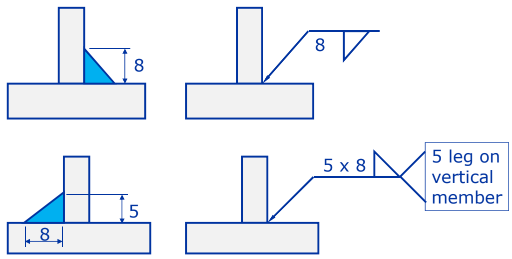
Fillet Welds

Fillet weld dimensions according AWS A 2.4



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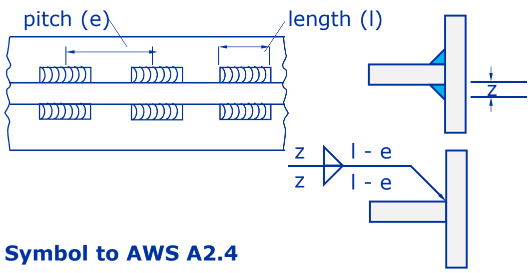
Intermittent Fillet Welds

Chain intermittent fillet weld



Symbol to AWS A2.4

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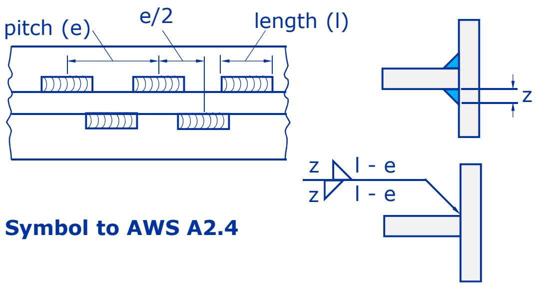
Intermittent Fillet Welds

Staggered intermittent fillet weld



Symbol to AWS A2.4

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AWS A 2.4 Rules

Welds **on arrow side** of joint go **underneath** the reference line while welds **the other side** of the joint, go **on top** of the reference line.

Symbols with a **vertical line** component must be drawn with the vertical line to the **left side** of the symbol.

All **CSA** dimensions are shown to the **left** of the symbol.

All **linear** dimensions are shown on the **right** of the symbol ie number of welds, length of welds, length of any spaces.

Included angle and root opening are shown on **top** of the symbol.

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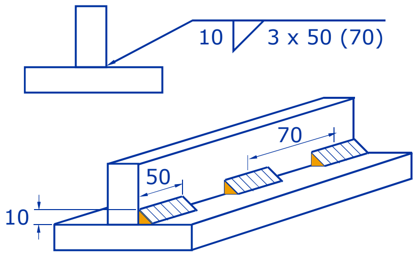
AWS A 2.4 Rules - Example



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Any Questions

?

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Section 10

Introduction to Welding Processes

10 Introduction to Welding Processes

10.1 General

Common characteristics of the four main arc welding processes, MMA, TIG, MIG/MAG and SAW are:

- An arc is created when an electrical discharge occurs across the gap between the electrode and parent metal.
- The discharge causes a spark to form causing the surrounding gas to ionise.
- The ionised gas enables a current to flow across the gap between the electrode and base metal thereby creating an arc.
- The arc generates heat for fusion of the base metal.
- With the exception of TIG welding, the heat generated by the arc also causes the electrode surface to melt and molten droplets can transfer to the weld pool to form a weld bead or run.
- Heat input to the fusion zone depends on the voltage, arc current and welding/travel speed.

10.2 Productivity

With most welding processes, welding in the PA (flat or 1G) position results in the highest weld metal deposition rate and therefore productivity.

For consumable electrode welding processes the rate of transfer of molten metal to the weld pool is directly related to the welding current density (ratio of the current to the diameter of the electrode).

For TIG welding, the higher the current, the more energy there is for fusion so the higher the rate at which filler wire can be added to the weld pool.

10.3 Heat input

Arc energy is the amount of heat generated in the welding arc per unit length of weld and is usually expressed in kilojoules per millimetre length of weld (kJ/mm) Heat input (HI) for arc welding is calculated from the following formula:

$$Arc\,energy\,(kJ\,/\,mm) = \frac{Volts\;x\;Amps}{Travel\,speed\,(mm\,/\,\mathrm{sec})\;\;x\,1000}$$

Heat input is the energy supplied by the welding arc to the workpiece and is expressed in terms of arc energy x thermal efficiency factor.

The thermal efficiency factor is the ratio of heat energy into the welding arc to the electrical energy consumed by the arc.
Heat input values into the weld for various processes can be calculated from the arc energy by multiplying by the following thermal efficiency factors:

SAW (wire electrode)	1.0
MMA (covered electrode)	0.8
MIG/MAG	0.8
FCAW (with or without gas shield)	0.8
TIG	0.6
Plasma	0.6

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Example

A weld is made using the MAG welding process and the following welding conditions were recorded:

Volts: 24
Amps: 240
Travel speed: 300mm per minute

$$Arc\,energy\,(kJ/mm) = \frac{Volts\ x\ Amps}{Travel\,speed\,(mm/\sec)\ x\,1000}$$

$$= \frac{24 \times 240}{300/60 \times 1000}$$

$$= \frac{5760}{5000}$$

Arc energy = 1.152 or 1.2kJ/mm

Heat input = 1.2 x 0.8 = 0.96kJ/mm

Heat input is mainly influenced by the travel speed.

Welding position and the process have a major influence on the travel speed that can be used.

For manual and semi-automatic welding the following are general principles:

- Vertical-up progression tends to give the highest heat input because there is a need to weave to get a suitable profile and the forward travel speed is relatively slow.
- Vertical-down welding tends to give the lowest heat input because of the fast travel speed that can be used.
- Horizontal-vertical welding is a relatively low heat input welding position because the welder cannot weave in this position.
- Overhead welding tends to give low heat input because of the need to use low current and relatively fast travel speed.
- Welding in the flat position (downhand) can be a low or high heat input position because the welder has more flexibility about the travel speed that can be used.
- Of the arc welding processes, SAW has the potential to give the highest heat input and deposition rates and TIG and MIG/MAG can produce very low heat input.
- Typical heat input values for controlled heat input welding will tend to be ~1.0-~3.5kJ/mm.

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10.4 Welding parameters

Arc voltage

Arc voltage is related to the arc length. For processes where the arc voltage is controlled by the power source (SAW, MIG/MAG and FCAW) and can be varied independently from the current, the voltage setting will affect the profile of the weld.

As welding current is raised, the voltage also needs to be raised to spread the weld metal and produce a wider and flatter deposit.

For MIG/MAG, arc voltage has a major influence on droplet transfer across the arc.

Welding current

Welding current has a major influence on the depth of fusion/penetration into the base metal and adjacent weld runs.

As a rule, the higher the current the greater the penetration depth.

Penetration depth affects dilution of the weld deposit by the parent metal and it is particularly important to control this when dissimilar metals are joined.

Polarity

Polarity determines whether most of the arc energy (heat) is concentrated at the electrode surface or at the surface of the parent material.

The location of the heat with respect to polarity is not the same for all processes and the effects/options/benefits for each of the main arc welding processes are summarised below.

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Process	Polarity		
	DC+ve	**DC-ve**	**AC**
MMA	Best penetration	Less penetration but higher deposition rate (used for root passes and weld overlaying)	Not suitable for some electrodes. Minimises arc blow
TIG	Rarely used due to tungsten overheating	Used for all metals except Al/Al alloys and Mg/Mg alloys	Required for Al/Al alloys to break-up the refractory oxide film
GMAW solid wires (MIG/MAG)	Used for all metals and virtually all situations	Rarely used	Not used
FCAW/MCAW gas-shielded and self-shielded cored wires	Most common	Some positional basic fluxed wires are designed to run on -ve; some metal cored wires may also be used on -ve particularly for positional welding	Not used
SAW	Best penetration	Less penetration but higher deposition rate (used for root passes and overlaying)	Used to avoid arc blow, particularly for multi-electrode systems

10.5 Power source characteristics

To strike an arc, a relatively high voltage is required to generate a spark between the electrode and base metal. This is known as the open circuit voltage (OCV) and is typically ~50-~90V.

Once an arc has been struck and stabilised there is a relationship between the arc voltage and current flowing through the welding circuit that depends on the electrical characteristics of the power source.

This relationship is known as the power source static characteristic and power sources are manufactured to give a constant current or voltage characteristic.

10.5.1 Constant current power source

This is the preferred type of power source for manual welding (MMA and manual TIG).

The volt-amp relationship for a constant current power source is shown in Figure 10.1 and shows the no current position (the OCV) and from this point there are arc voltage/current curves that depend on the power source for the various current settings.

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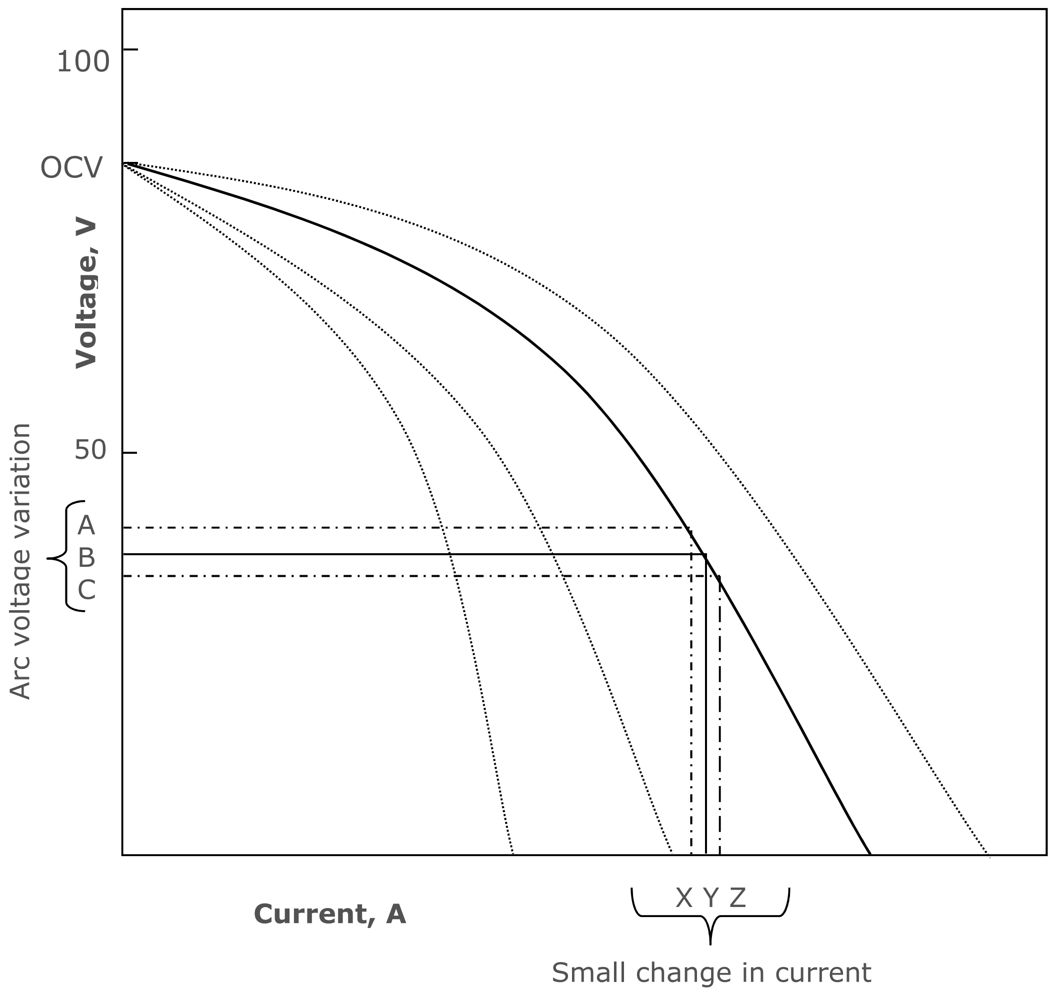

Figure 10.1 Typical volt-amp curves for a constant current power source.

For manual welding (MMA and manual TIG) the welder sets the required current on the power source but arc voltage is controlled by the arc length the welder uses.

A welder has to work within a fairly narrow range of arc length for a particular current setting, if it is too long the arc will extinguish, too short and the electrode may stub into the weld pool and the arc extinguish.

For the operating principle of this type of power source see Figure 10.1.

The welder tries to hold a fairly constant arc length (B in Figure 10.1) for the current (Y) that has been set. However, he cannot keep the arc length constant and it will vary over a small working range (A-C) due to normal hand movement during welding.

The power source is designed to ensure that these small changes in arc voltage during normal welding will give only small changes in current (X to Z). Thus the current can be considered to be essentially constant and this ensures that the welder is able to maintain control of fusion.

The drooping shape of the volt-amp curves has led to constant current power sources sometimes being said to have a **drooping characteristic.**

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10.5.2 Constant voltage power source

This is the preferred type of power source for welding processes that have a wire feeder (MIG/MAG, FCAW and SAW).

Wire feed speed and current are directly related so that as the current increases, so does the feed speed and there is a corresponding increase in the burn-off rate to maintain the arc length/voltage.

The operating principle of this type of power source is shown in Figure 10.2.

A welder sets voltage B and current Y on the power source. If the arc length is decreased to C (due to a variation in weld profile or as the welder's hand moves up and down during semi-automatic welding) there will be a momentary increase in welding current to Z. The higher current Z gives a higher burn-off rate which brings the arc length (and arc voltage) back to the pre-set value.

Similarly, if the arc length increases the current quickly falls to X and the burn-off rate is reduced so that the arc length is brought back to the pre-set level B.

Thus, although the arc voltage does vary a little during welding the changes in current that restore the voltage to the pre-set value happen extremely quickly so that the voltage can be considered constant.

The straight-line relationship between voltage and current and the relatively small gradient is why this type of power source is often referred to as having a flat characteristic.

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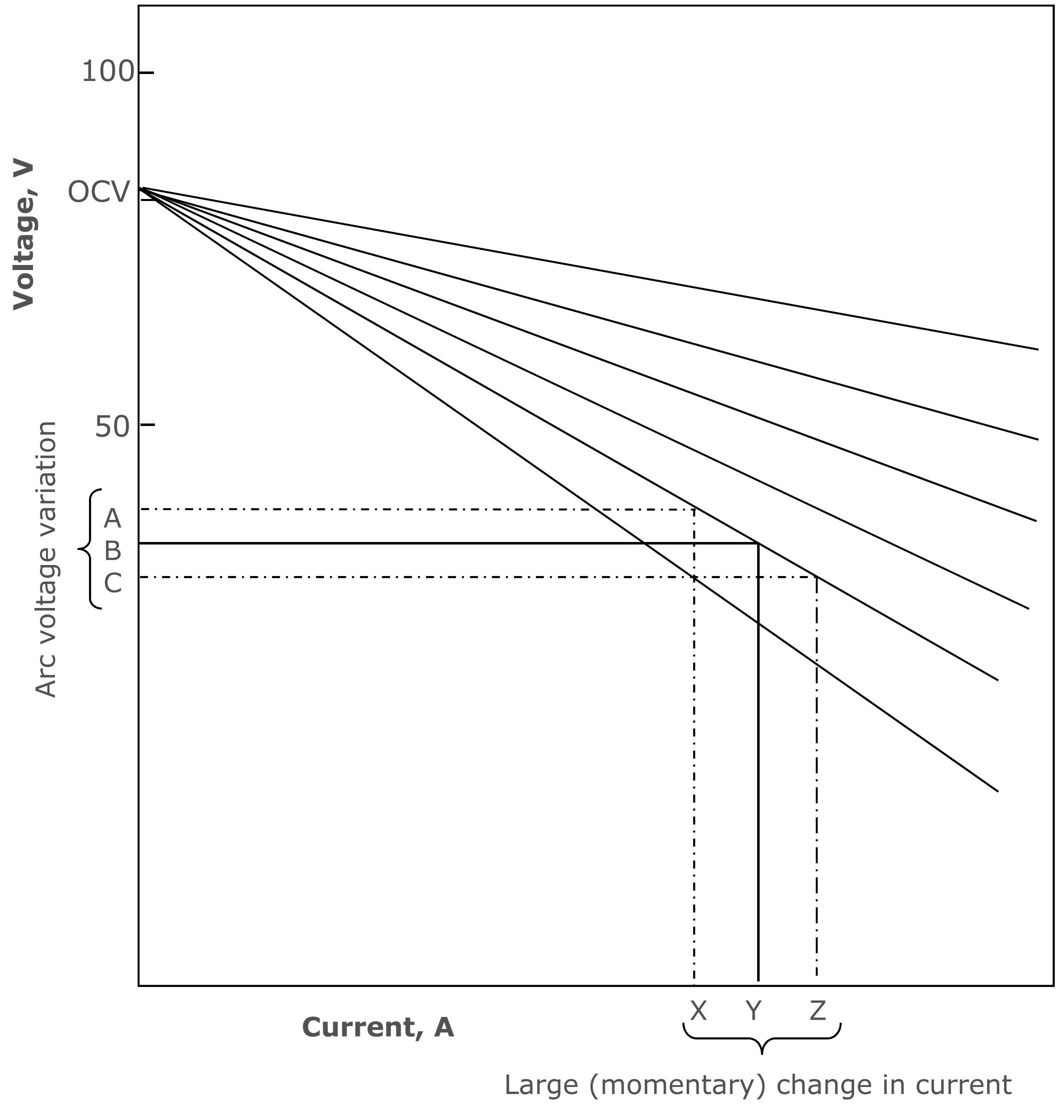

Figure 10.2 Typical volt-amp curves for a constant voltage power source.

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Introduction to Welding Processes

Section 10

Materials Joining and Engineering Technologies
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Welding Processes Objective

When this presentation has been completed you will have a greater understanding of the differences in processes and their key characteristics and why we choose one over another.

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Welding Processes

Welding is regarded as a joining process in which the work pieces are in atomic contact.

Pressure welding

- Forge welding.
- Friction welding.
- Resistance Welding.

Fusion welding

- Oxy-acetylene.
- MMA (SMAW).
- MIG/MAG (GMAW).
- TIG (GTAW).
- Sub-arc (SAW).
- Electro-slag (ESW).
- Laser Beam (LBW).
- Electron-Beam (EBW).

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Welding Processes

The four essential factors for fusion welding:

1. Fusion is achieved by melting using a high intensity heat source.
2. The welding process must be capable of removing any oxide and contamination from the joint.
3. Atmosphere contamination must be avoided.
4. The welded joint must possess the mechanical properties required by the specification being adapted.

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Welding Processes

Choice of welding process

Material Type:

Steels.	All processes.
Reactive metals (aluminium titanium).	TIG and MIG.
Nickel-based alloys	All processes for most alloys.
Copper-based alloys	Mainly TIG and MIG.

Material Thickness:

MMA	All above ~ 3mm.
TIG (low productivity)	Generally thin sections (<~ 10mm).
MIG/MAG/FCAW	Typically ~ 3 to 30mm.
SAW	Typically ~ 15 to 150mm or above.

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Welding Processes

Choice of welding process

Joint properties

Very high quality.	TIG and SAW.
Very demanding properties.	TIG usually best. (for toughness and corrosion resistance).

Welding Position

MMA, TIG, MIG/MAG.	All positions.
SAW.	Mainly flat but is used for girth seams on large diameter storage tanks.

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Welding Processes

Non-fusion welding processes

Friction welding

- Because no fusion - can join wide variety of dissimilar materials.
- Sound joints produced.
- HAZ degradation minimised.
- Many variants being developed for different shapes/applications.

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Welding Process Comparison

Process	Electrical characteristic	Electrode current type
MMA	Drooping/constant current	DC+ve, DC-ve, AC
TIG	Drooping/constant current	DC-ve, AC
MIG/MAG	Flat/constant voltage	DC+ve
MAG FCAW	Flat/constant voltage	DC+ve, DC-ve,
Sub-arc	Drooping/constant current >1000amp Flat/constant voltage <1000amp	DC+ve, DC-ve, AC
Electro-slag	Flat/constant voltage	DC+ve

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Any Questions

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Section 11

Manual Metal Arc/Shielded Metal Arc Welding

11 Manual Metal Arc/Shielded Metal Arc Welding (MMA/SMAW)

Manual metal arc (MMA) welding was invented in Russia in 1888 and involved a bare metal rod with no flux coating to give a protective gas shield. Coated electrodes weren't developed until the early 1900s when the Kjellberg process was invented in Sweden and the quasi-arc method was introduced in the UK.

The most versatile welding process, MMA is suitable for most ferrous and non-ferrous metals, over a wide range of thicknesses. It can be used in all positions, with reasonable ease of use and relatively economically. The final weld quality is primarily dependent on the skill of the welder.

When an arc is struck between the coated electrode and workpiece, both surfaces melt to form a weld pool. The average temperature of the arc is approximately 6000°C, sufficient to simultaneously melt the parent metal, consumable core wire and flux coating. The flux forms gas and slag which protect the weld pool from oxygen and nitrogen in the surrounding atmosphere. The molten slag solidifies, cools and must be chipped off the weld bead once the weld run is complete (or before the next weld pass is deposited). The process allows only short lengths of weld to be produced before a new electrode needs to be inserted in the holder.

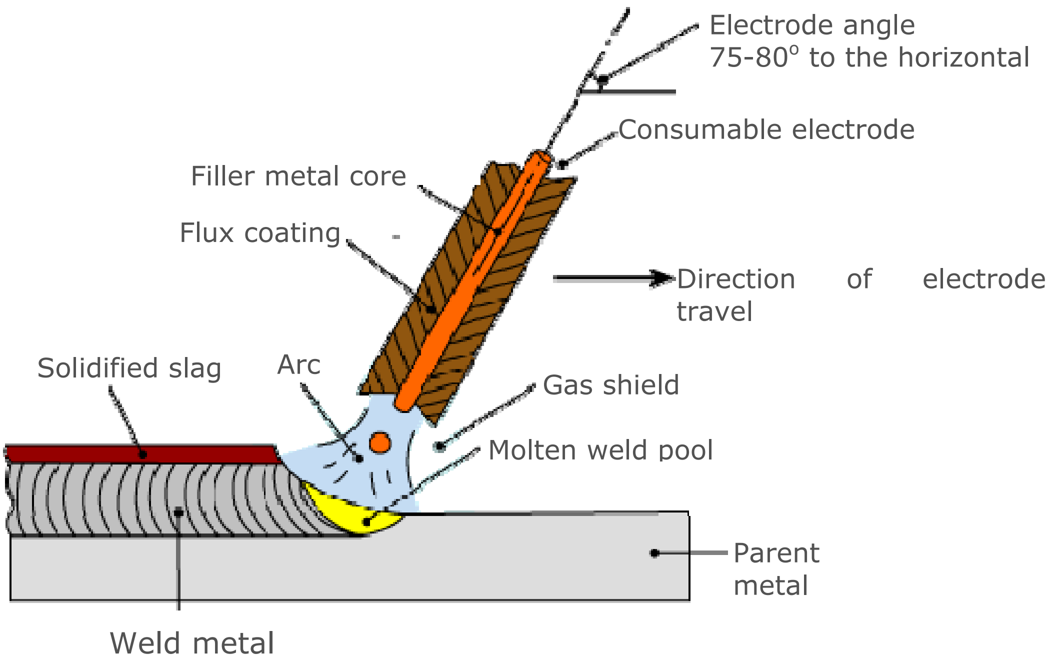

Figure 11.1 MMA welding.

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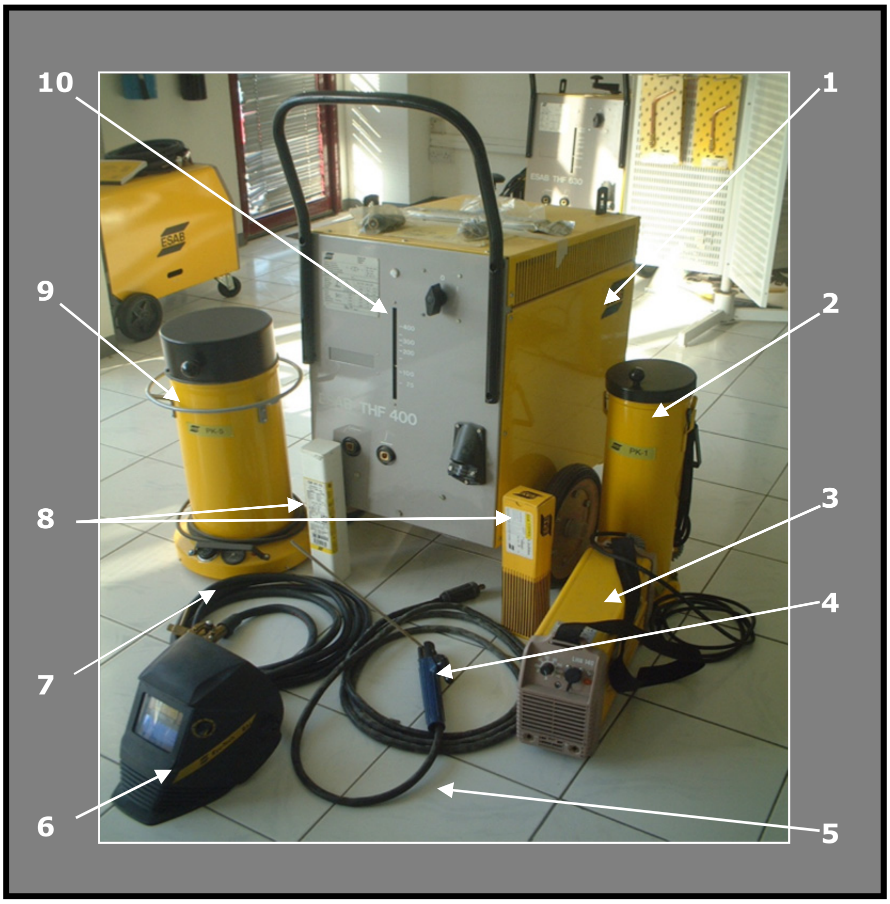
11.1 MMA basic equipment requirements



1 Power source transformer/rectifier (constant current type).
2 Holding oven (holds at temperatures up to 150°C).
3 Inverter power source (more compact and portable).
4 Electrode holder (of a suitable amperage rating).
5 Power cable (of a suitable amperage rating).
6 Welding visor (with correct rating for the amperage/process).
7 Power return cable (of a suitable amperage rating).
8 Electrodes (of a suitable type and amperage rating).
9 Electrode oven (bakes electrodes at up to 350°C).
10 Control panel (on/off/amperage/polarity/OCV).

11.2 Power requirements

MMA welding can be carried out using either DC or AC current. With DC welding current either positive (+ve) or negative (-ve) polarity can be used, so current is flowing in one direction. AC welding current flows from negative to positive and is two directional.

Power sources for MMA welding are transformers (which transform mains AC-AC suitable for welding), transformer-rectifiers (which rectify AC-DC), diesel or petrol driven generators (preferred for site work) or inverters (a more recent addition to welding power sources). A power source with a constant current (drooping) output must be used.

The power source must provide:

- An OCV.
- Initiate the arc.
- Welding voltage between 20 and 40V to maintain the arc during welding.
- Suitable current range, typically 30-350 amps.
- Stable arc-rapid arc recovery or arc re-ignition without current surge.
- Constant welding current. The arc length may change during welding but consistent electrode burn-off rate and weld penetration characteristics must be maintained.

11.3 Welding variables

Other factors or welding variables which affect the final quality of the MMA weld, are:

Current (amperage)
Voltage
Travel speed
Polarity
Type of electrode

Affects heat input

Figure 11.2 Examples of the MMA welding process.

11.3.1 Current (amperage)

The flow of electrons through the circuit is the welding current measured in amperes (I). Amperage controls burn-off rate and depth of penetration. Welding current level is determined by the size of electrode and manufacturers recommend the normal operating range and current.

Amperage too low

Poor fusion or penetration, irregular weld bead shape, slag inclusion unstable arc, arc stumble, porosity and potential arc strikes.

Amperage too high

Excessive penetration, burn-through, undercut, spatter, porosity, deep craters, electrode damage due to overheating, high deposition making positional welding difficult.

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11.3.2 Voltage

The welding potential or pressure required for current to flow through the circuit is the voltage (U). For MMA welding the voltage required to initiate the arc is OCV, the voltage measured between the output terminals of the power source when no current is flowing through the welding circuit.

For safety reasons the OCV should not exceed 90V and is usually 50-90V. Arc voltage that is required to maintain the arc during welding and is usually 20-40V and is a function of arc length. With MMA the welder controls the arc length and therefore the arc voltage which in turn controls weld pool fluidity.

Arc voltage too low

Poor penetration, electrode stubbing, lack of fusion defects, potential for arc strikes, slag inclusion, unstable arc condition, irregular weld bead shape.

Arc voltage too high

Excessive spatter, porosity, arc wander, irregular weld bead shape, slag inclusions, fluid weld pool making positional welding difficult.

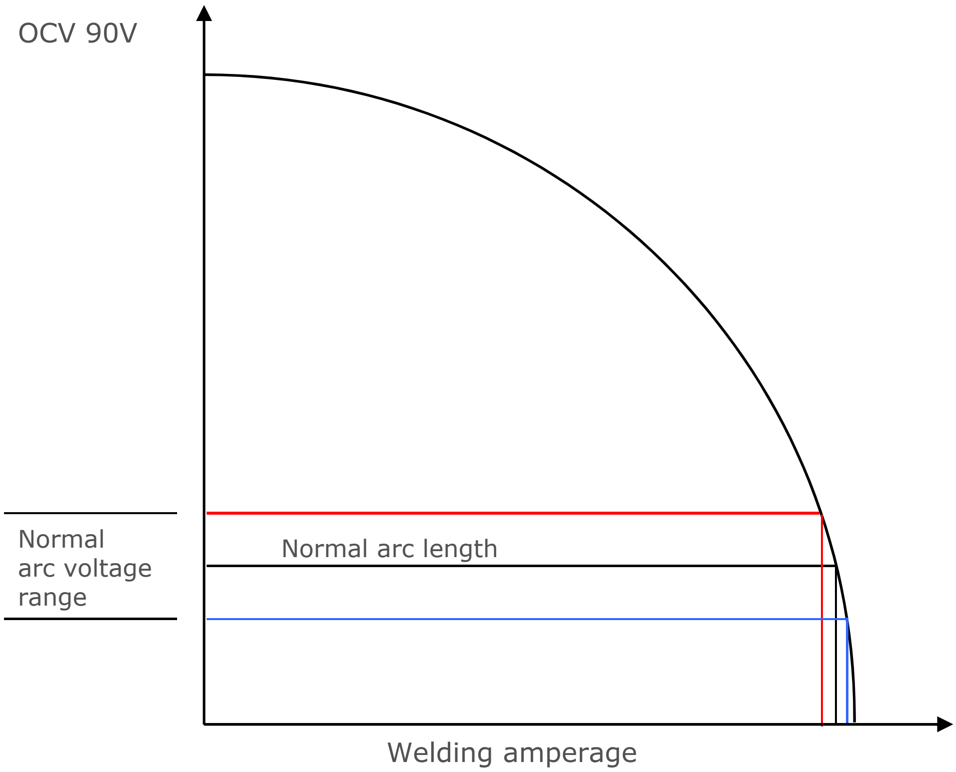

Figure 11.3 Constant current (drooping) output characteristic.

Large change in arc voltage = small change in welding amperage.

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11.3.3 Travel speed

The rate of weld progression, the third factor that affects heat input and therefore metallurgical and mechanical conditions.

Travel speed too fast

Narrow thin weld bead, fast cooling, slag inclusions, undercut, poor fusion, penetration.

Travel speed too slow

Cold lap, excess weld deposition, irregular bead shape undercut.

11.3.4 Polarity (type of current)

Polarity will determine the distribution of heat energy at the welding arc. The preferred polarity of the MMA system depends primarily on the electrode being used and the desired properties of the weld.

Direct current (DC)

Direct current is the flow of current in one direction and for MMA welding it refers to the polarity of the electrode.

Direct current/electrode positive (DCEP/DC+ve)

When the electrode is on the positive pole of the welding circuit, the workpiece becomes the negative pole. Electron flow direction is from the workpiece to the electrode.

When the electrode is positively charged (DC+ve) and the workpiece is negatively charged the two thirds of the available heat energy is at the tip of the electrode, with the remaining third being generated in the parent material, resulting in an increase in weld penetration.

Direct current/electrode negative (DCEN/DC-ve)

When the electrode is on the negative pole of the welding circuit, the workpiece becomes the positive pole, electron flow direction is from the electrode to the workpiece. The distribution of energy is now reversed. One third of the available heat energy is generated at the tip of the electrode, the remaining two thirds in the parent material.

Direct current with a negatively charged electrode (DC-ve) causes heat to build up on the electrode, increasing the electrode melting rate and decreasing the depth of the weld penetration depth.

When using DC the welding arc can be affected by arc blow, the deflection of the arc from its normal path due to magnetic forces.

Alternating current (AC)

The current alternates in the welding circuit, flowing first in one direction then the other. With AC, the direction of flow changes 100-120 times per second, 50-60 cycles per second (cps). AC is the flow of current in two directions.

Therefore, distribution of heat energy at the arc is equal, 50% at the electrode, 50% at the workpiece.

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11.3.5 Type of consumable electrode

For MMA welding there are three generic types of flux covering:

Rutile electrodes

Contain a high proportion of titanium oxide (rutile) in the coating which promotes easy arc ignition, smooth arc operation and low spatter. These electrodes are general purpose with good welding characteristics and can be used with AC and DC power sources and in all positions. The electrodes are especially suitable for welding fillet joints in the horizontal/vertical (HV) position.

Features

- Moderate weld metal mechanical properties.
- Good bead profile produced through the viscous slag.
- Positional welding possible with a fluid slag (containing fluoride).
- Easily removable slag.

Basic electrodes

Contain a high proportion of calcium carbonate (limestone) and calcium fluoride (fluorspar) in the coating, making the slag coating more fluid than rutile coatings. This is also fast freezing which assists welding in the vertical and overhead positions. These electrodes are used for welding medium and heavy section fabrications where higher weld quality, good mechanical properties and resistance to cracking due to high restraint are required.

Features

- Low hydrogen weld metal.
- Requires high welding currents/speeds.
- Poor bead profile (convex and coarse surface profile).
- Slag removal difficult.

Cellulosic electrodes

Contain a high proportion of cellulose in the coating and are characterised by a deeply penetrating arc and rapid burn-off rate giving high welding speeds. Weld deposit can be coarse and with fluid slag, deslagging can be difficult. These electrodes are easy to use in any position and are noted for their use in the stovepipe welding technique.

Features

- Deep penetration in all positions.
- Suitable for vertical-down welding.
- Reasonably good mechanical properties.
- High level of hydrogen generated, risk of cracking in the HAZ.

Within these three generic groups sub-groups of covered electrodes provide a wide range of electrode choice.

MMA electrodes are designed to operate with AC and DC power sources. Although AC electrodes can be used on DC, not all DC electrodes can be used with AC power sources.

Operating factor: (O/F) The percentage of **arc on time** in a given time.

When compared with semi-automatic welding processes MMA has a low O/F of approximately 30%. Manual semi-automatic MIG/MAG O/F is about 60% with fully automated in the region of 90%. A welding process O/F can be directly linked to **productivity**.

Operating factor should not be confused with the term **duty cycle** which is a safety value given as the % of time a conductor can carry a current and is given as a specific current at **60** and **100**% of 10 minutes, ie 350A 60% and 300A 100%.

11.4 Summary of MMA/SMAW

Equipment requirement

- Transformer/rectifier, generator, inverter (constant amperage type).
- Power and power return cable (of a suitable amperage rating).
- Electrode holder (of a suitable amperage rating).
- Electrodes (of a suitable type and amperage rating).
- Correct visor/glass, safety clothing and good extraction.

Parameters and inspection points

- Amperage.
- OCV.
- AC/DC and polarity.
- Speed of travel.
- Electrode type and diameter.
- Duty cycles.
- Electrode condition.
- Connections.
- Insulation/extraction.
- Any special electrode treatment.

Typical welding imperfections

- Slag inclusions caused by poor welding technique or insufficient inter-run cleaning.
- Porosity from using damp or damaged electrodes or when welding contaminated or unclean material.
- Lack of root fusion or penetration caused by incorrect settings of the amps, root gap or face width.
- Undercut caused by amperage too high for the position or by a poor welding technique. eg travel speed too fast or slow, arc length (therefore voltage) variations particularly during excessive weaving.
- Arc strikes caused by incorrect arc striking procedure or lack of skill. These may also be caused by incorrectly fitted/secured power return lead clamps.
- Hydrogen cracks caused by the use of incorrect electrode type or baking procedure and/or control of basic coated electrodes.

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Successful welding with the MMA process is reliant on a number of factors, not least of which is the skill required to produce a sound weld. This is dependent on the welder’s ability to match the arc length (distance from the tip of the electrode to the workpiece), to the burn-off rate (rate at which the electrode is consumed).

Advantages

- Field or shop use.
- Range of consumables.
- All positional.
- Very portable.
- Simple equipment.

Disadvantages

- High skill factor required.
- Arc strikes/slag inclusions.
- Low operating factor.
- High level of generated fumes.
- Hydrogen control.

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Welding Processes and Equipment – Power Source

Sections 11-14

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Welding Processes Objective

When this presentation has been completed you will have a greater understanding of the differences in processes and their key characteristics and why we choose one over another.

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Power Sources

Manual Metal Arc Welding

Welding Process Film

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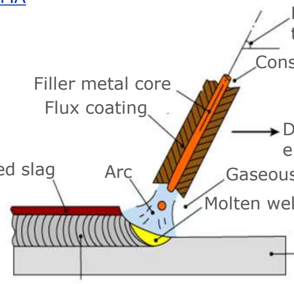
MMA - Principle of Operation

FILM MMA



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MMA Welding

Main features:

- Shielding provided by decomposition of flux.
- Consumable electrode.
- Manual process.

Welder controls:

- Arc length.
- Angle of electrode.
- Speed of travel.
- Current setting.

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MMA Basic Equipment

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MMA Welding Variables

Open circuit voltage (OCV)
- Value of potential difference delivered by set with no load. Must be enough for specific electrode.
- Electrodes labelled with min OCV, usually ~80V.

Voltage
- Measure arc voltage close to arc.
- Variable with change in arc length.
- Too low, electrode stubs into weld pool.
- Too high, spatter, porosity, excess penetration, undercut, burn-through.

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MMA Welding Parameters

Current
- Range set by electrode, diameter, material type and thickness.
- Approx 35A per mm diameter.
- Too low – poor start, lack of fusion, slag inclusions, humped bead shape.
- Too high – spatter, excess penetration, undercut, burn-through.

Polarity
- Can be DCEP, DCEN, AC.
- Determined by operation and electrode type.

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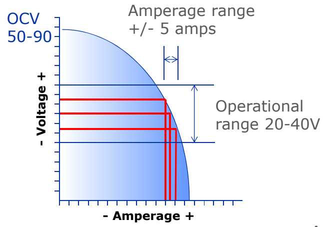
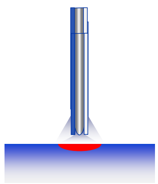
Constant/Drooping Current Characteristics





As arc length increases voltage increases and amperage decreases

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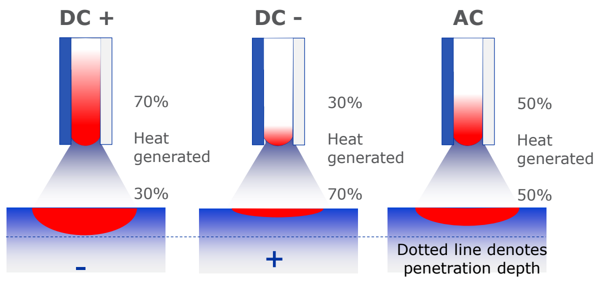
The Effects of Polarity on Penetration



= ion greater density (heavier = increased surface impact).
= electron generates greater heat.

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MMA Welding Parameters

Travel speed
- Controlled by welder.
- Often measured as run-out length as time to burn single rod fairly standard at constant current.
- Too low – wide bead, excess penetration, burn-through.
- Too high – narrow bead, lack of penetration, lack of fusion, difficult slag removal.

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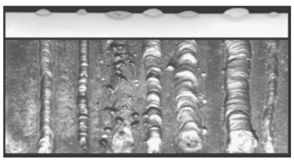
MMA – Parameter Setting

Left to right
- Good conditions.
- Current too low.
- Current too high.
- Arc length too short.
- Arc length too long.
- Travel too slow.
- Travel too fast.



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Operating Factor for MMA

- Welder needs time to change electrodes.
- Also has to de-slag weld bead and grind any imperfections.
- May be required to observe interpass temperatures.
- Inspection will be required.
- On long runs welder has to reposition.
- All reduce time weld metal is deposited.
- Arc time % to total time is operating factor. For MMA this is rarely above 30%.

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Typical Welding Defects

Most caused by:
- Lack of welder skill.
- Incorrect settings of equipment.
- Incorrect use or treatment of electrodes.

Typical defects:
- Slag inclusions.
- Arc strikes.
- Porosity.
- Undercut.
- Shape defects (overlap, excessive root penetration, etc).

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Advantages and Disadvantages

Advantages
- Field or shop use.
- Range of consumables.
- All positions.
- Portable.
- Simple equipment.

Disadvantages
- High welder skill.
- High levels of fume.
- Hydrogen control (flux).
- Stop/start problems.
- Low productivity.

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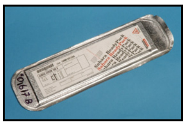
MMA Welding Consumables


Courtesy of Lincoln Electric

Plastic foil sealed cardboard box
- Rutile electrodes.
- General purpose basic electrodes.

Tin can
- Cellulosic electrodes.


Courtesy of Lincoln Electric



Vacuum sealed pack
- Extra low hydrogen electrodes.

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Cellulosic Electrodes

- Use industrially extracted cellulose powder or wood flour in the formula.
- Characteristic smell when welding.
- Slag remains thin and friable.
- Strong arc action and deep penetration.
- AWS E6010 types DC: E6011 run on AC.
- Gas shield principally hydrogen.
- Only used on C- and C-Mn steels.
- High arc force allows V-D stovepiping.

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Rutile Electrodes

- High amount of TiO_2, (rutile sand or ilmenite).
- Coatings often coloured.
- AWS type E6012 are DC: E6013 run on AC.
- Many designed for flat position.
- Fluid slag, smooth bead, easy slag removal.
- Need some moisture to give gas shield.
- Not low hydrogen.
- Available for ferritic and austenitic steels.
- Fair mechanical properties.

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Rutile High Recovery Electrodes

- High amount Fe powder added.
- More weld metal laid at the same current.
- Coating much thicker, forms deep cup.
- End of coating can rest on workpiece.
- Slag easy release, sometimes self-releasing.
- Only for flat position.
- These AWS E7024 have recovery between 150 and 180%.
- Recovery = Weld metal wt x100/core wire wt.

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Basic Electrodes

- $CaCO_3$ and CaF_2 main ingredients.
- AWS E7015 first modern basic rods. Ran DC.
- Superseded by E7016 or E7018 – AC and DC.
- E7018 has Fe powder to help stabilise arc.
- E7016 good rooting and all-positional.
- Both can give good mechanical properties.
- Often hybrid; small dia. no Fe powder, larger dia. increasing amounts.
- Used for ferritic, stainless steels, Ni and Cu.

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BS EN 2560 MMA Covered Electrodes

E 50 3 2Ni B 7 2 H10

- Covered electrode
- Yield strength N/mm²
- Toughness
- Chemical composition
- Flux covering
- Weld metal recovery and current type
- Welding position
- Hydrogen content

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BS EN 2560 MMA Covered Electrodes

Electrodes classified as follows:

- E 35 - Minimum yield strength 350 N/mm²
  Tensile strength 440-570 N/mm²
- E 38 - Minimum yield strength 380 N/mm²
  Tensile strength 470-600 N/mm²
- E 42 - Minimum yield strength 420 N/mm²
  Tensile strength 500-640 N/mm²
- E 46 - Minimum yield strength 460 N/mm²
  Tensile strength 530-680 N/mm²
- E 50 - Minimum yield strength 500 N/mm²
  Tensile strength 560-720 N/mm²

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AWS A5.1 Alloyed Electrodes

E 60 1 3

- Covered electrode
- Tensile strength (p.s.i)
- Welding position
- Flux covering

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MMA Welding Consumables

TYPES OF ELECTRODES
(for C, C-Mn Steels)

	BS EN 2560	AWS A5.1
Cellulosic	E XX X **C**	EXX1**0** EXX1**1**
Rutile	E XX X **R**	EXX1**2** EXX1**3**
Rutile heavy coated	E XX X **RR**	EXX**24**
Basic	E XX X **B**	EXX1**5** EXX1**6** EXX1**8**

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Any Questions

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TIG Welding

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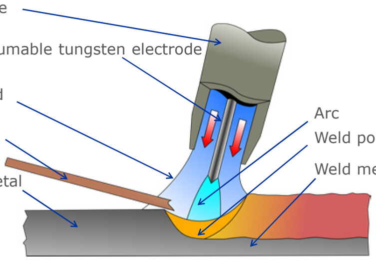
TIG Basics

Film TIG



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Equipment for TIG

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Arc Starting

Scratch start
- Tungsten touched on workpiece.
- Short-circuit starts current.
- Arc established as torch lifted.
- Can leave tungsten inclusions.

Lift Arc
- Electronic control very low short-circuit current.
- Builds to operational current as torch lifted.

HF
- Superimposition of HF high voltage spark.

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Polarity

DCEN
- Most used.
- Tungsten cooled by electron emission.
- Workpiece receives more heat.

DCEP
- Will clean oxide from Al and Mg.
- Heat tends to melt tungsten.
- Can be done with water cooled torch.

AC
- Usual way to weld Al and Mg to get cleaning.

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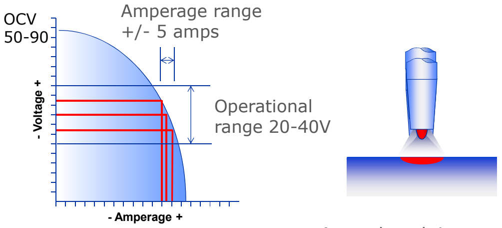
Constant/Drooping Current Characteristics



As arc length increases voltage increases and amperage decreases

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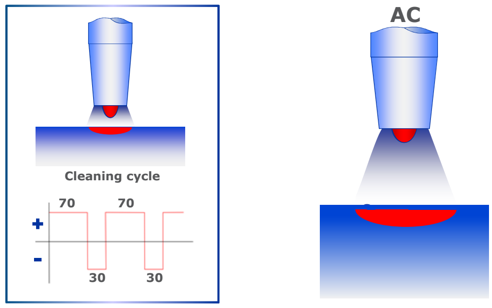
Cathodic Cleaning Square Wave Maximum



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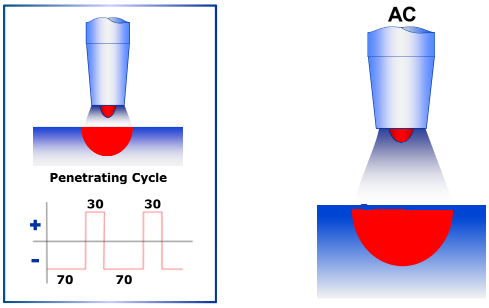
Square Wave Maximum Penetration



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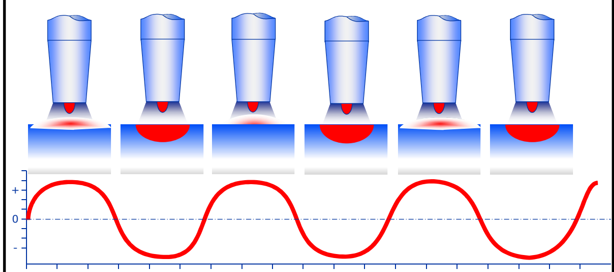

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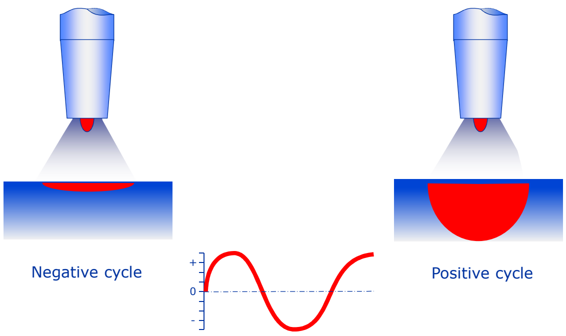

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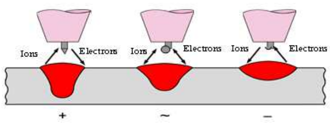
Polarity



Current type/polarity	DCEN	AC	DCEP
Heat balance	70% at work 30% at electrode	50% at work 50% at electrode	30% at work 70% at electrode
Weld profile	Deep, narrow	Medium	Shallow, wide
Cleaning action	No	Yes – every half cycle	Yes
Electrode capacity	Excellent (3.2mm/400A)	Good (3.2mm/225A)	Poor (6.4mm/120A)

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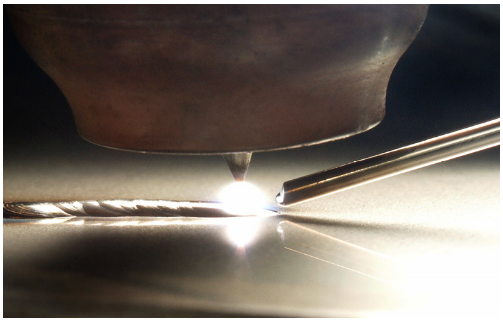
Manual TIG



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Ideal for Root Runs

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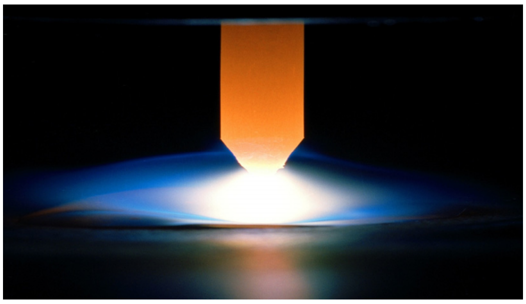
DC Arc



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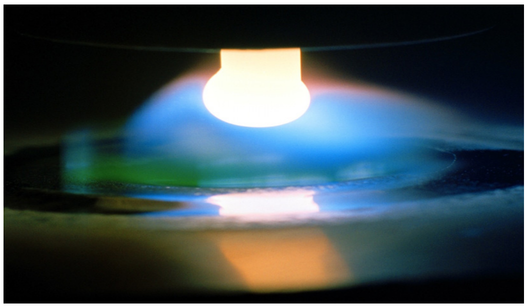
AC Arc



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GTAW Torch

Torch types:

- **Gas cooled:** Cheap, simple, large size, short life for component parts.
- **Water cooled:** Recommended over 150A, expensive, complex, longer life of parts.

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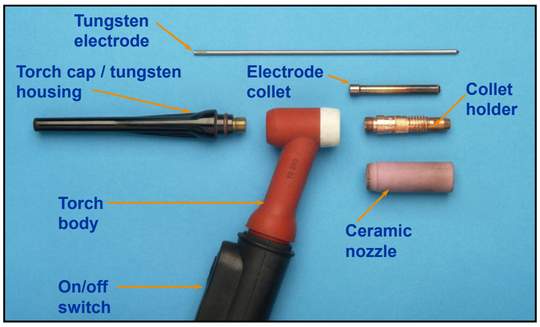
GTAW Torch



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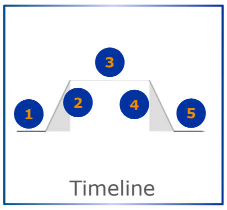
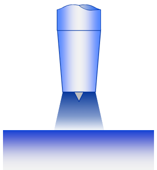
TIG Welding Sequence





5. Post gas supply to protect molten pool upon cooling

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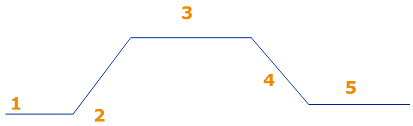
Purpose of These Functions



1. Purges the line, protect weld area, improve ionization.
2. Prevent thermal shock to tungsten electrode.
3. Main welding current.
4. Prevents thermal shock and crater cracking.
5. Protects weld and tungsten electrode from contamination.

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Shielding Gas Selection

Argon (Ar)

- Suitable for welding C-steel, stainless steel, Al and Mg.
- Lower cost, lower flow rates.
- More suitable for thinner materials and positional welding.

He/Ar mixes

- Suitable for welding C-steel, stainless steel, Cu, Al and Mg.
- High cost, high flow rates.
- More suitable for thicker materials and materials of high thermal conductivity.

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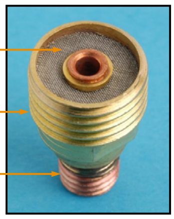
Gas Lens

Stainless steel wire sieve

Thread for gas ceramic

Thread for torch body



- Reduces eddies in gas flow.
- Extends length of laminar flow prevents contamination.
- Highly recommended for reactive metals (eg Ti, Al).

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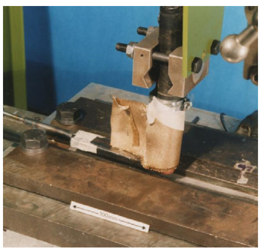
Special Shielding Methods



Torch trailing shield

Welding in protective tent

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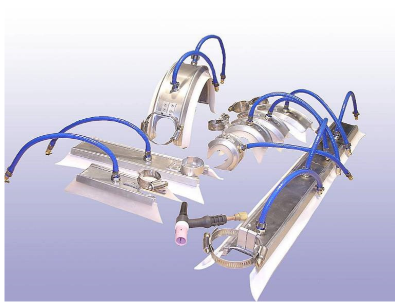
Commercially Available Trailing Shields



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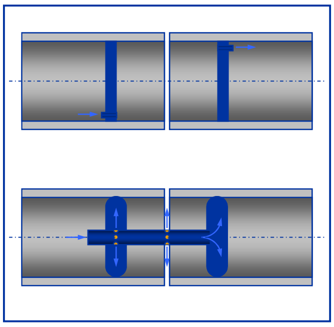
Pipe Backing Gas Dams



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Purging Methods

- There are many ways to purge a pipe or void, the easiest being to displace all the air with inert gas by pumping it in and capping the end of the pipe allowing the heavier inert gas to push the oxygen up through the top of the butt.
- Soluble dams and tapes can also be used as well as the chain and bung method.
- Calibrated purge monitors should record the oxygen content in the pipe and confirm that welding can commence.

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Tungsten Types

- Pure W – green band
  - Cheap, but short life. Poor arc start.
- W +ThO_2 – yellow (1%), red (2%)
  - High current carrying but slightly radioactive.
- W + CeO_2 – grey (Europe), orange (USA)
  - Good for low current DC work.
- W + La_2O_3 – black
  - Increasing use to replace thoriated.
- W + ZrO_2 – white (Europe), brown (USA)
  - Used for AC.

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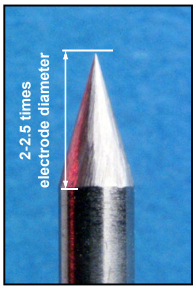
Electrode Tip for DCEN



Electrode tip for low current welding

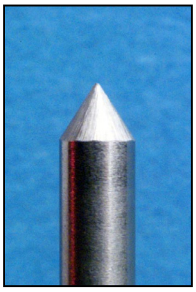
Penetration increase

Increase

Vertex angle

Decrease

Bead width increase



Electrode tip for high current welding

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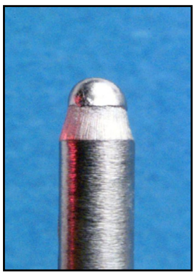
Electrode Tip for AC

Electrode tip ground



Electrode tip ground and then conditioned

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Autogenous Welding and Fillers

- TIG can be used autogenously.
- Can mechanise and use more than one head.
- Can add filler from reel for mechanised.
- Manual filler – 1m rods in 5kg pack.
- Stamped for identity:

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Orbital TIG

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Orbital TIG

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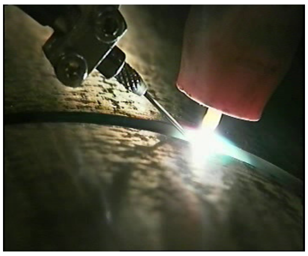

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Potential Defects

Tungsten inclusions

- Thermal shock splinters W.
- Touch start fuses spots to workpiece.
- Spitting and melting can throw pieces into pool.
- Very visible on radiograph but not critical defect.

Solidification cracking

- Some compositions inherently crack sensitive.
- Impurities often make eutectics.
- Fillers designed with elements to react with impurities, eg Mn used to give high MPt MnS.

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Potential Defects

Oxide inclusions

- Oxides contribute to lack of fusion.
- No fluxing to absorb oxides.
- Need to keep good gas cover to avoid oxidation of reactive metals.

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Advantages of TIG

- No spatter, high cleanliness.
- Good welder easily produces quality welds.
- Good for penetration beads in all positions.
- Wide range metals, including dissimilar.
- Good protection for reactive.
- Very good for joining thin materials.
- Very low levels of diffusible hydrogen.

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Disadvantages of TIG

- Low deposition rates.
- Higher dexterity and co-ordination.
- Less economical for thicker sections.
- Not good in draughty conditions.
- Low tolerance of contaminants.
- Tungsten inclusions can occur.

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Any Questions

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MIG/MAG Welding

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MIG/MAG Welding

- Also known as Gas Metal Arc Welding.
- Uses continuous wire electrode.
- Weld pool protected by shielding gas.
- Classified as semi-automatic – may be fully automated.
- Wire can be bare or coated solid wire, flux or metal cored hollow wire.

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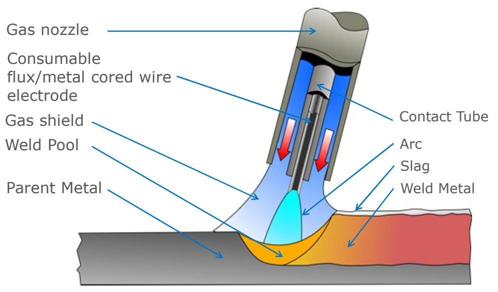
MIG/MAG - Principle of Operation



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Process Characteristics

- DCEP from CV power source.
- Wire 0.6 to 1.6mm diameter. Gas shielded.
- Wire fed through conduit. Melt rate maintains constant arc length/arc voltage.
- WFS directly related to burn-off rate.
- Burn-off rate directly related to current.
- Semi-automatic – set controls arc length.
- Can be mechanised and automated.

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MIG/MAG Equipment

External wire feed unit

Internal wire feed system

Power control panel

15kg wire spool

Power return cable

Transformer / Rectifier

Power cable & hose assembly

Liner for wire

Welding gun assembly

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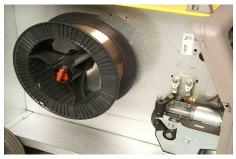
Wire Feeding

Separate wire feeder



Wire feeder in set

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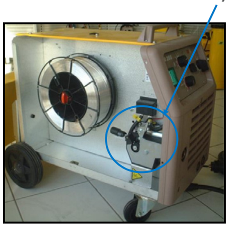
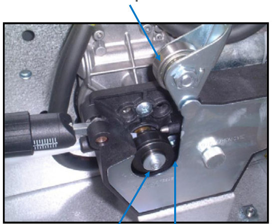
Feeder Drive Rolls

Internal wire drive system



Plain top roller



Half grooved bottom roller

Wire guide

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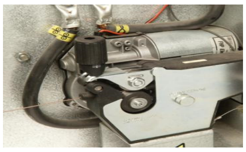
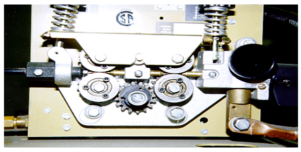
Types of Wire Drive System



Two roll



Four roll

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Roll Grooves

- Often have plain top roll.
- Bottom, and sometimes top, roll grooved.
- V shape for steel.
- U shape for softer wire, eg Al.
- Knurled for positive feed.
- Care needed on tightness of rolls.
  - Too light – rolls skid, wire stalls.
  - Too tight – rolls deform wire, wire can jam.
- If wire stops arc burns back to contact tube.

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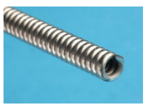
Liners for MIG/MAG

Close wound stainless steel wire



Teflon liner

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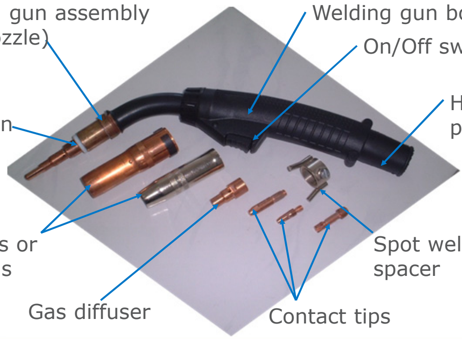
Torch Components



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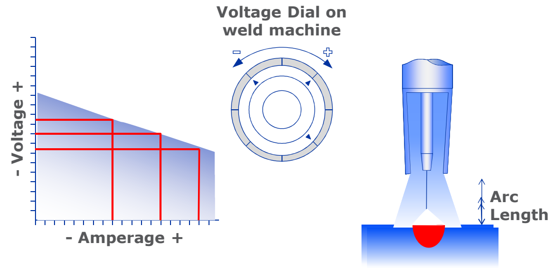
The Relationship Between Amps and Volts



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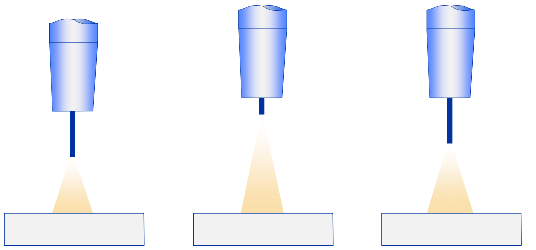
Self-Adjusting Arc



Arc and wire feed rate in equilibrium.

Arc length increased momentarily, burn off reduces.

Wire feed rate is constant so original arc length is re established.

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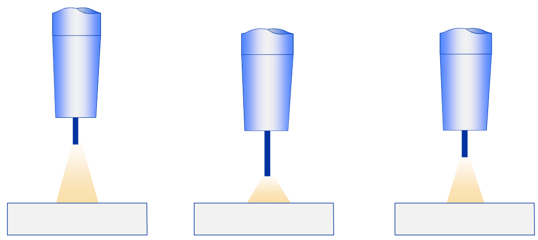
Self-Adjusting Arc



Arc and wire feed rate in equilibrium.

Arc length is decreased momentarily, burn off increases.

Arc length returns to original condition.

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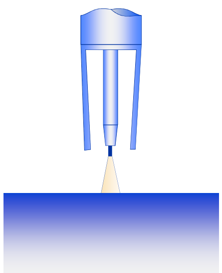
Example: Self-Adjusting Arc

Wire feed at constant speed

As wire feed is constant, the original arc length is re established.



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Welding Parameters

Wire feed speed:
- Increasing wfs automatically gives more current.

Voltage:
- Controls arc length and bead width.

Current:
- Wire feed sets, Mainly affects penetration.

Inductance:
- In dip, controls rise in current. Lowers spatter. Gives hotter or colder welding.

More info on several websites, eg:
www.millerwelds.com/resources/articles/MIG-GMAW-welding-basics

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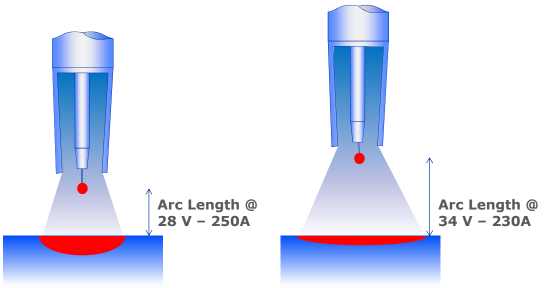
The Effect of Increasing Arc Voltage



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Shielding Gas

Argon:
- OK for all metals weldable by MIG.
- Supports spray transfer, not good for dip.
- Low penetration.

Carbon dioxide:
- Use on ferritic steel.
- Supports dip and globular, not spray.

Ar based mixtures:
- Add He, O_2, CO_2 to increase penetration.
- >20Ar + He, >80Ar + O_2, CO_2 can spray and dip.

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MIG and MAG Shielding Gases

Metal Inert Gas (MIG)
- Usually Ar shielding.
- Can be Ar + He mixture – gives hotter action.
- Used for non-ferrous alloys, eg Al, Ni.

Metal Active Gas (MAG)
- Has oxidising gas shield.
- Can be 100% CO_2 for ferritic steels.
- Often Ar + 12 to 20% CO_2 for both dip and spray.
- Ar + O_2 for stainless steel.

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Metal Transfer Modes

Depending on shielding gas and voltage, metal crosses from wire to work in:
- Spray mode – wire tapers to a point and very fine droplets stream across from the tip.
- Globular mode – large droplets form and drop under action of gravity and arc force.
- Short-circuiting (dip) mode – wire touches pool surface before arc re-ignition.
- Pulsed mode – current and voltage cycled between no transfer and spray mode.

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Use of Transfer Modes

Spray Transfer: V > 26; i > 220
- Thicker material, flat welding, high deposition.

Globular Transfer: between dip and spray
- Mechanised MAG process using CO_2.

Dip Transfer: V < 24; i < 200
- Thin material positional welding.

Pulse Transfer: spray + no transfer cycle
- Frequency range 50-300 pulses/second.
- Positional welding and root runs.

These values will depend on gas mixture.

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Droplet Growth and Detachment

- Current heating wire causes melting and droplet formation.
- Droplet held by surface tension and viscosity.
- Droplet detachment by electromagnetic forces (Lorentz and arc forces), gravity.
- Electromagnetic forces proportional to current – hence dip at low current.

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Dip Transfer

- Droplet stays attached and touches pool causing short-circuit.
- Current rises very quickly giving energy to pinch-off droplet violently.
- Akin to blowing a fuse – causes spatter.
- Droplet detaches, arc re-establishes and current falls.
- Cycle occurs up to 200 times per second.

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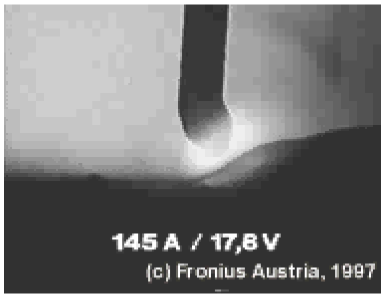
Dip Transfer



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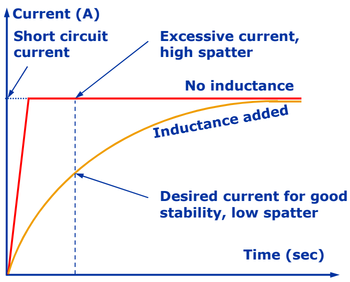
The Effect of Inductance

Controls the rate of current rise



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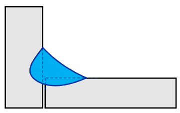
Practical Effect of Inductance

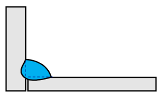
Maximum inductance

- Reduced spatter.
- Hotter arc more penetration.
- Fluid weld pool flatter, smoother weld.
- Good for thicker materials and stainless steels.

Minimum inductance

- Colder arc used for wide gaps.
- Convex weld, more spatter.
- Good pool control.
- Recommended on thin materials.





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Dip Transfer Attributes

Advantages

- Low energy allows welding in all positions.
- Good for root runs in single-sided welds.
- Good for welding thin material.

Disadvantages

- Prone to lack of fusion.
- May not be allowed for high-integrity applications.
- Tends to give spatter.

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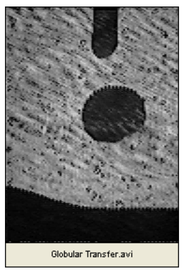
Globular Transfer



- Transfer by gravity or short circuit.
- Requires CO_2 shielding.
- Drops larger than electrode hence severe spatter.
- Can use low voltage and bury arc to reduce spatter.
- High current and voltage, so high distortion.

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Gas Metal Arc Welding

Spray transfer

When current and voltage are raised together higher energy is available for fusion (typically > ~ 25 volts & ~ 250 amps).

This causes a fine droplets of weld metal to be sprayed from the tip of the wire into the weld pool.

Transfer-mode advantages

- High energy gives good fusion.
- High rates of weld metal deposition are given.
- These characteristics make it suitable for welding thicker joints.
- Transfer-mode disadvantages.
- It cannot be used for positional welding.

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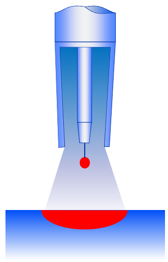
Spray Transfer



- Continuous transfer of metal.
- High voltage long arc.
- High heat input.
- Fluid weld pool.
- High deposition.
- No spatter.

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Dip, Globular and Spray Transfer

Dip, Globular and Spray Film

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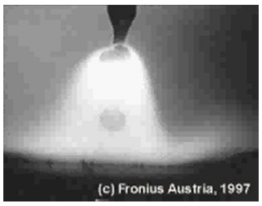
Spray Transfer

- Tapered tip as anode climbs wire.
- Small droplets with free flight from pinch effect.
- Requires Ar-rich gas.
- High current and voltage, high distortion.
- Large pool, not positional.
- Used for thick material and flat/horizontal weld.



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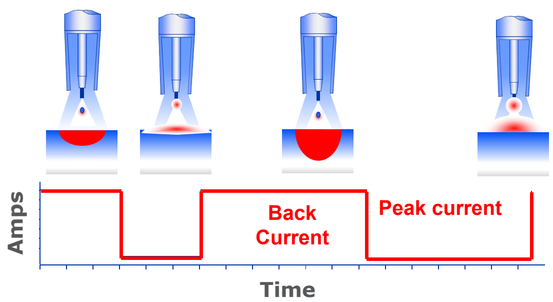
Pulsed Transfer



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Pulsed Transfer Attributes

Advantages

- Good fusion.
- Small weld pool allows all-position welding.

Disadvantages

- More complex and expensive power source.
- Difficult to set parameters.
- But synergic easy to set, manufacturer provides programmes to suit wire type, dia. and type of gas.

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Pulse Transfer

Pulse Transfer Film

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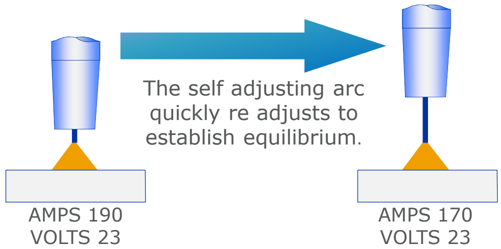
The Effect of Increasing CTWD



Although the arc length remains the same, the current will decrease due to the increased resistance of lengthening the CTWD.

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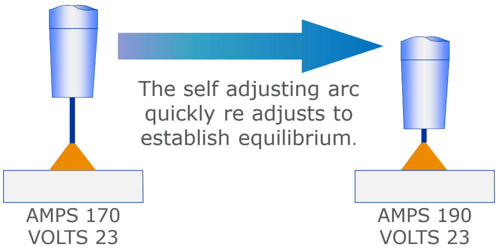
The Effect of Decreasing CTWD



Although the arc length remains the same, the current will increase due to the decreased resistance of shortening the CTWD.

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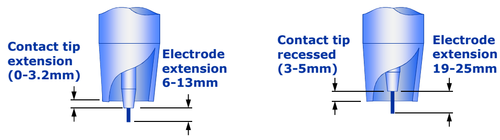
Contact Tip to Nozzle Distance

Metal transfer mode	Contact tip to nozzle
Dip	+/- 2mm
Spray	4-8mm inside
Spray (Al)	6-10mm inside



Set up for Dip transfer   Set up for Spray transfer

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Filler Wire

- Similar composition to base material.
- Solid, flux cored or metal cored.
- FCW run in spray, gives good fusion. FCW allows all-positional welding, slag formation.
- Metal cored wires similar to solid wires, but better deposition rate.
- Some FCW are self-shielded.

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Potential Defects

- Most defects caused by lack of welder skill, or incorrect settings of equipment.
- Worn contact tip causes poor power pick up and this causes wire to stub into work.
- Silica inclusions build in steels if poor inter-run cleaning.
- Lack of fusion (primarily with dip transfer).
- Porosity (from loss of gas shield on site etc).
- Cracking, centerline pipes, crater pipes on deep narrow welds.

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MIG/MAG Attributes

Advantages

- High productivity.
- Easily automated.
- All positional (dip and pulse).
- Material thickness range.
- Continuous electrode.

Disadvantages

- Lack of fusion (dip).
- Small range of consumables.
- Protection on site.
- Complex equipment.
- Not so portable.

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Any Questions

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Flux Core Welding

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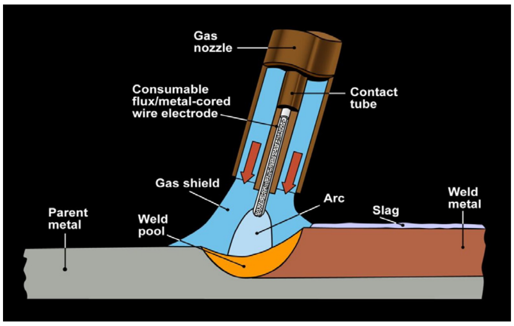
Gas Shielded Principle of Operation



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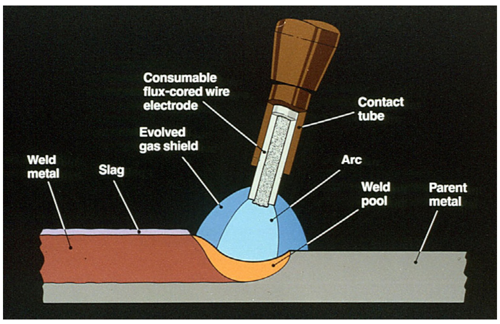
Self-Shielded Principle of Operation



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Benefit of Flux

- Flux assists in producing gas cover, more tolerant to draughts than solid wire.
- Flux creates slag that protects hot metal.
- Slag holds bead when positional welding.
- Flux alloying can improve weld metal properties.
- Reduced cross-section carrying current gives increased burn-off at any current, higher resistance.

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FCAW - Differences from MIG/MAG

- Usually operate DCEP but some self-shielded wires run DCEN.
- Some hardfacing wires are larger diameter – need big power source.
- Don't work in dip.
- Need knurled feed rolls.
- Self-shielded wires use a different torch.

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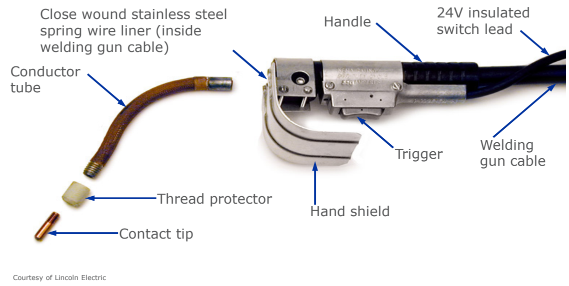
Self-Shielded Welding Gun



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Backhand (Drag) Technique

Advantages

- Preferred for flat or horizontal with FCAW.
- Slower travel.
- Deeper penetration.
- Weld hot longer so gasses removed.

Disadvantages

- Produces higher weld profile.
- Difficult to follow weld joint.
- Can lead to burn-through on thin sheet.

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Forehand (Push) Technique

Advantages

- Preferred method for vertical up or overhead with FCAW.
- Arc gives preheat effect.
- Easy to follow weld joint and control penetration.

Disadvantages

- Produces low weld profile, with coarser ripples.
- Fast travel gives low penetration.
- Amount of spatter can increase.

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FCAW Advantages

- Less sensitive to lack of fusion.
- Smaller included angle compared to MMA.
- High productivity, up to 10kg per hour.
- All positional.
- Smooth bead surface, less danger of undercut.
- Basic types produce excellent toughness.
- Good control of weld pool in positional welding especially with rutile wires.
- Ease of varying alloying constituents gives wide range of consumables.
- Some can run without shielding gas.

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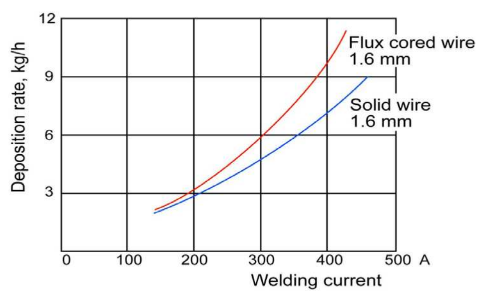
Deposition Rate for C-Steel



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FCAW Disadvantages

- Limited to steels and Ni-base alloys.
- Slag covering must be removed.
- FCAW wire is more expensive per kg than solid wires (except some high alloy steels) but note may be more cost effective.
- Gas shielded wires may be affected by winds and draughts like MIG.
- More fume than MIG/MAG.

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Submerged Arc Welding

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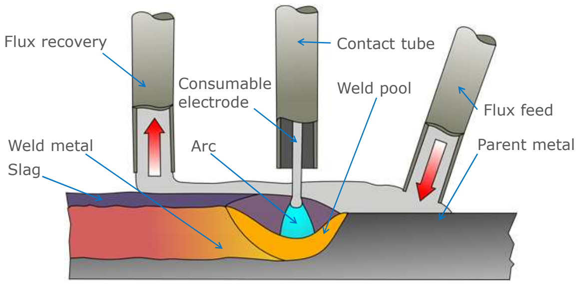
SAW Principle of Operation



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SAW FILM

SAW Film

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Process Characteristics

- Arc between bare wire and parent plate.
- Arc, electrode end and the molten pool submerged in powdered flux.
- Flux makes gas and slag in lower layers under heat of arc giving protection.
- Wire fed by voltage-controlled motor driven rollers to ensure constant arc length.

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Process Characteristics

- Flux fed from hopper in continuous mound along line of intended weld.
- Mound is deep to submerge arc. No spatter, weld shielded from atmosphere, no UV light.
- Un melted flux reclaimed for further use.
- Only for flat and horizontal-vertical positions in most cases.

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SAW Basic Equipment

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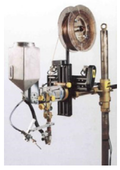
Types of Equipment

Hand-held gun

Tractor



Column and boom

Gantry

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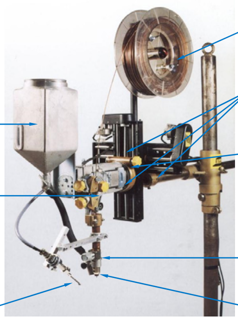
SAW Equipment



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Tractor Units

- For straight or gently curved joints.
- Ride tracks alongside joint or directly on workpiece.
- Can have guide wheels to track.
- Good portability, used where piece cannot be moved.

Courtesy of ESAB AB

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Column and Boom

- Linear travel only.
- Can move in 3 axes.
- Workpiece must be brought to weld station.
- Mostly used in workshop.

Courtesy of ESAB AB

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Gantry

- 2D linear movement only.
- For large production.
- May have more than one head.

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Power Sources

Power sources can be:

- Transformers for AC.
- Transformer-rectifiers for DC.

Static characteristic can be:

- Constant Voltage (flat) – most popular.
- Constant Current (drooping) – used for high current.

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Constant Voltage Power Supply

- Most commonly used.
- Can be mechanised or automatic welding.
- Self-regulating arc so simple WFS control.
- WFS controls current, power supply controls voltage.
- DC limited to 1000A by severe arc blow.

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Constant Current Power

- Preferred >1000A.
- Can be mechanised or automatic welding.
- Not self-regulating arc so must have voltage-sensing WFS control.
- More expensive.
- Voltage from WFS control, power source controls current.
- Not for high-speed welding of thin steel.

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Wire

- Usually 2 to 6mm diameter.
- Copper coated to avoid rusting.
- 25 or 30kg coils.
- Can be supplied in bulk 300 to 2000kg.



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Fused Fluxes

- Original Unionmelt design – manganese, aluminium and calcium silicates.
- Non-hygroscopic, no need to bake.
- Good for recycling, composition doesn't vary.
- Some can accept up to 2000A.
- Very limited alloying and property control.
- Cannot make basic fused flux.

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Bonded or Agglomerated Flux

- Powdered minerals pelletised with silicate.
- Baked to high temperature but hygroscopic.
- Flexible composition, can alloy, make basic.
- Can add de oxidants for good properties.
- Composition can vary as particle breakdown.
- Needs to be filtered when recycling.
- Can add Mn and Si flux.

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SAW Operating Variables

- Welding current.
- Current type and polarity.
- Welding voltage.
- Travel speed.
- Electrode size.
- Electrode extension **why?**
- Width and depth of the layer of flux.

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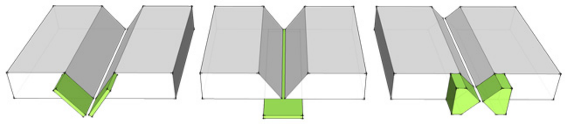
Starting/Finishing the Weld



Extension bars

Run off plate

Extension bars simulating identical joint preparation

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Any Questions

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Section 12

TIG Welding

12 TIG Welding

12.1 Process characteristics

In the US the TIG process is also called gas tungsten arc welding (GTAW). Melting is produced by heating with an arc struck between a non-consumable tungsten electrode and the workpiece. An inert gas shields the electrode and weld zone to prevent oxidation of the tungsten electrode and atmospheric contamination of the weld and hot filler wire (as shown below).

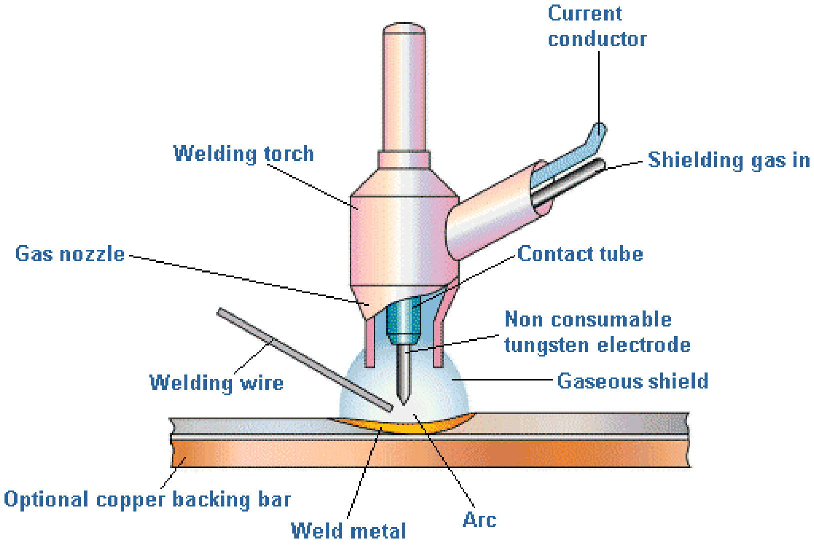

Figure 12.1 Manual TIG welding.

Tungsten is used because it has a melting point of 3370°C, well above any other common metal.

12.2 Process variables

The main variables in TIG welding are:

- Welding current.
- Current type and polarity.
- Travel speed.
- Shape of tungsten electrode tip and vertex angle.
- Shielding gas flow rate.
- Electrode extension.

Each of these is considered in more detail in the following sub-sections.

12.2.1 Welding current

- Weld penetration is directly related to welding current.
- If the welding current is too low, the electrode tip will not be properly heated and an unstable arc may result.
- If the welding current is too high, the electrode tip might overheat and melt, leading to tungsten inclusions.

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12.2.2 Current type and polarity

- Best welding results are usually obtained with DC-ve.
- Refractory oxides such as those of aluminium or magnesium can hinder fusion but can be removed by using AC or DC electrode positive.
- With a DC positively connected electrode, heat is concentrated at the electrode tip so the electrode needs to be of greater diameter than when using DC-ve if overheating of the tungsten is to be avoided. A water cooled torch is recommended if DC positive is used.
- The current carrying capacity of a DC positive electrode is about one tenth that of a negative one so it is limited to welding sections.

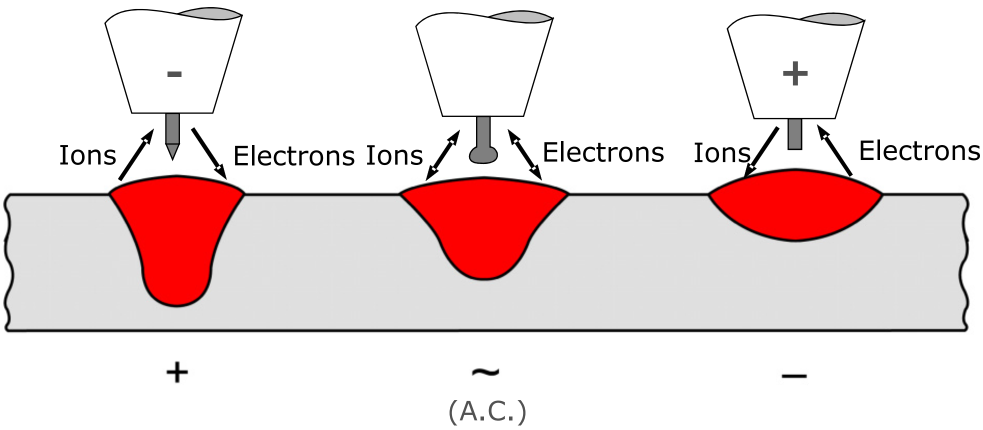

Figure 12.2 Effect of current type and polarity.

Table 12.1 Current type and polarity.

Current type/polarity	DC-ve	AC	DC+ve
Heat balance	70% at work 30% at electrode	50% at work 50% at electrode	30% at work 70% at electrode
Weld profile	Deep, narrow	Medium	Shallow, wide
Cleaning action	No	Yes – every half cycle	Yes
Electrode capacity	Excellent (3.2mm/400A)	Good (3.2mm/225A)	Poor (6.4mm/120A)

12.2.3 Travel speed

- Affects both weld width and penetration but the effect on width is more pronounced.
- Increasing the travel speed reduces the penetration and width.
- Reducing the travel speed increases the penetration and width.

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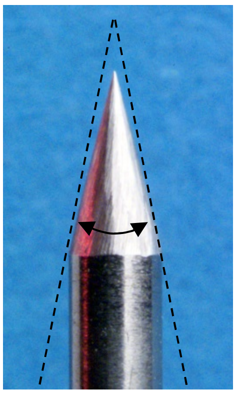
12.2.4 Tungsten electrode types

Different types of tungsten electrodes suit different applications:

- Pure tungsten electrodes are used when welding light metals with AC because they maintain a clean balled end, but possess poor arc initiation and stability in AC mode compared with other types.
- Thoriated electrodes are alloyed with thorium oxide (thoria) to improve arc initiation and have higher current carrying capacity than pure tungsten electrodes and maintain a sharp tip for longer. Unfortunately, thoria is slightly radioactive (emitting α radiation) and the dust generated during tip grinding should not be inhaled. Electrode grinding machines used for thoriated tungsten grinding should be fitted with a dust extraction system.
- Ceriated and lanthaniated electrodes are alloyed with cerium and lanthanum oxides, for the same reason as thoriated electrodes and operate successfully with DC or AC and as cerium and lanthanum are not radioactive, they have been used as replacements for thoriated electrodes.
- Zirconiated electrodes are alloyed with zirconium oxide with operating characteristics between the thoriated types and pure tungsten. They are able to retain a balled end during welding, so are recommended for AC welding. They have a high resistance to contamination so are used for high integrity welds where tungsten inclusions must be avoided.

12.2.5 Shape of tungsten electrode tip

- With DC-ve, thoriated, ceriated or lanthanated tungsten electrodes are used with the end ground to a specific angle (the electrode tip or vertex angle, shown below).
- As a general rule the length of the ground portion of the electrode tip should have a length equal to approximately 2-2.5 times the electrode diameter.
- When using AC the electrode tip is ground flat to minimise the risk of it breaking off when the arc is initiated or during welding (shown on the next page).
- If the vertex angle is increased, the penetration increases.
- If the vertex angle is decreased, bead width increases.
- Pure or zirconiated tungsten electrodes are used for AC welding with a hemispherical (balled) end (as shown below). To produce a balled end the electrode is ground, an arc initiated and the current increased until it melts the tip of the electrode.


Electrode tip (or vertex angle)


Electrode tip with flat end


Electrode tip with a balled end

Figure 12.3 Examples of tungsten electrode tip shapes.

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12.2.6 Shielding gases

The following inert gases can be used as shielding gases for TIG welding:

- Argon.
- Helium.
- Mixtures of argon and helium.

Note: For austenitic stainless steels and some cupro-nickel alloys, argon with up to ~5% hydrogen improves penetration and reduces porosity.

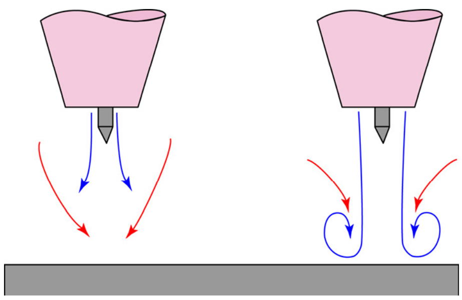
Table 12.2 Characteristics of argon and helium shielding gases for TIG welding.

Argon	Performance item	Helium
Lower than with helium which can be helpful when welding thin sections. Less change in arc voltage with variations in arc length.	Arc voltage	Higher than with argon. Arc is hotter which is helpful in welding thick sections and viscous metals, (eg nickel.
Lower than with helium which gives reduced penetration.	Heating power of the arc	High, advantageous when welding metals with high thermal conductivity and thick materials.
Argon is heavier than air so requires less gas to shield in the flat and horizontal positions. Better draught resistance.	Protection of weld	Helium is lighter than air and requires more gas to properly shield the weld. Exception: Overhead welding.
Obtained from the atmosphere by the separation of liquefied air – lower cost and greater availability.	Availability and cost	Obtained by separation from natural gas – lower availability and higher cost.

Shielding gas flow rate

- Too low and the shielding gas cannot remove the air from the weld area resulting in porosity and contamination.
- Too high and turbulence occurs at the base of the shielding gas column, air tends to be sucked in from the surrounding atmosphere and this may also lead to porosity and contamination.
- Typically in the range ~10-~12 l/min.

Flow rate too low



Flow rate too high

Figure 12.4 Shielding gas flow rate.

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Back purging

It is necessary to protect the back of the weld from excessive oxidation during TIG welding, achieved by using a purge gas, usually pure argon.

For pipe welding spools it is relatively easy to purge the pipe bore, but for plate/sheet welding it is necessary to use a purge channel or sometimes another operator positions and moves a back purge nozzle as the weld progresses. For purging large systems soluble dams or bungs are required and can it can be a complex operation.

The initial stage of back purging is to exclude all the air at the back of the weld and having allowed sufficient time for this the flow rate should be reduced prior to starting to weld so there is positive flow (typically ~4 l/min).

Back purging should continue until two or more layers of weld have been deposited.

For C and C-Mn steels it is possible to make satisfactory welds without a back purge.

12.2.7 Electrode extension

- The distance from the contact tube to the tungsten tip.
- Because the contact tube is recessed inside the gas nozzle this parameter can be checked indirectly by measuring the stickout length, as shown below.

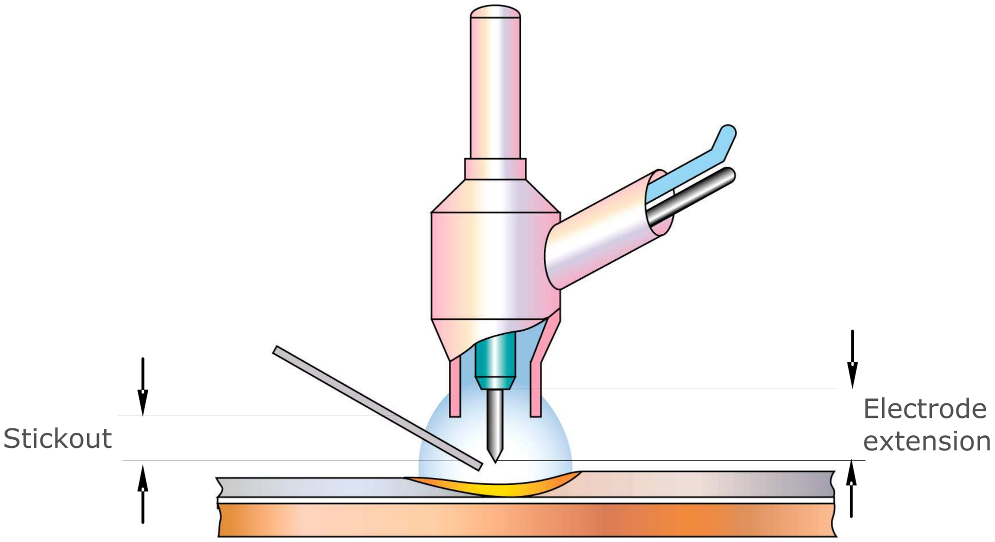

Figure 12.5 Electrode extension.

- If the electrode extension is too short, the electrode tip will not be adequately heated leading to an unstable arc.
- If the electrode extension is too long, the electrode tip might overheat, causing melting and lead to tungsten inclusions.
- As a general rule stickout length should be 2-3 times the electrode diameter.

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12.3 Filler wires

Filler wires usually have a similar composition to the parent metal but contain small additions of elements that will combine with any oxygen and nitrogen present.

12.4 Tungsten inclusions

Small fragments of tungsten that enter a weld will always show up on radiographs because of the relatively high density of this metal and for most applications will not be acceptable.

Thermal shock to the tungsten causing small fragments to enter the weld pool is a common cause of tungsten inclusions and is why modern power sources have a current slope-up device to minimise this risk.

This device allows the current to rise to the set value over a short period so the tungsten is heated more slowly and gently.

12.5 Crater cracking

One form of solidification cracking which some filler metals are sensitive to. Modern power sources have a current slope-out device so that at the end of a weld when the welder switches off the current it reduces gradually and the weld pool gets smaller and shallower. The weld pool will have a more favourable shape when it finally solidifies and crater cracking can be avoided.

12.6 Common applications

Include autogenous welding of longitudinal seams in thin walled pipes and tubes in stainless steel and other alloys on continuous forming mills.

Using filler wires, TIG is used for making high quality joints in heavier gauge pipe and tubing for the chemical, petroleum and power generating industries.

It is also used in the aerospace industry for items such as airframes and rocket motor cases.

12.7 Advantages

- Produces superior quality welds with very low levels of diffusible hydrogen so there is less danger of cold cracking.
- No weld spatter or slag inclusions which makes it particularly suitable for applications that require a high degree of cleanliness, eg pipework for the food and drinks industry, manufacturing semiconductors, etc.
- Can be used with filler metal and on thin sections without filler and can produces welds at relatively high speed.
- Enables welding variables to be accurately controlled and is particularly good for controlling weld root penetration in all welding.
- Can weld almost all weldable metals including dissimilar joints but welding in position is not generally used for those with low melting points such as lead and tin. Especially useful in welding reactive metals with very stable oxides such as aluminium, magnesium, titanium and zirconium.
- The heat source and filler metal additions are controlled independently so it is very good for joining thin base metals.

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12.8 Disadvantages

- Gives low deposition rates compared with other arc welding processes.
- Need higher dexterity and welder co-ordination than with MIG/MAG or MMA welding.
- Less economical than MMA or MIG/MAG for sections thicker than ~10mm.
- Difficult to fully shield the weld zone in draughty conditions so may not be suitable for site/field welding.
- Tungsten inclusions can occur if the electrode contacts the weld pool.
- No cleaning action so low tolerance for contaminants on filler or base metals.

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Section 13

MIG/MAG Welding

13 MIG/MAG Welding

13.1 Process

Known in the US as gas metal arc welding (GMAW), the MIG/MAG welding process (Figure 13.1) is a versatile technique suitable for both thin sheet and thick section components in most metallic materials. An arc is struck between the end of a wire electrode and the workpiece, melting both to form a weld pool. The wire serves as the source of heat (via the arc at the wire tip) and filler metal for the joint and is fed through a copper contact tube (also called a contact tip) which conducts welding current into the wire. The weld pool is protected from the surrounding atmosphere by a shielding gas fed through a nozzle surrounding the wire. Shielding gas selection depends on the material being welded and the application. The wire is fed from a reel by a motor drive and the welder or machine moves the welding gun or torch along the joint line. The process offers high productivity and is economical because the consumable wire is continuously fed.

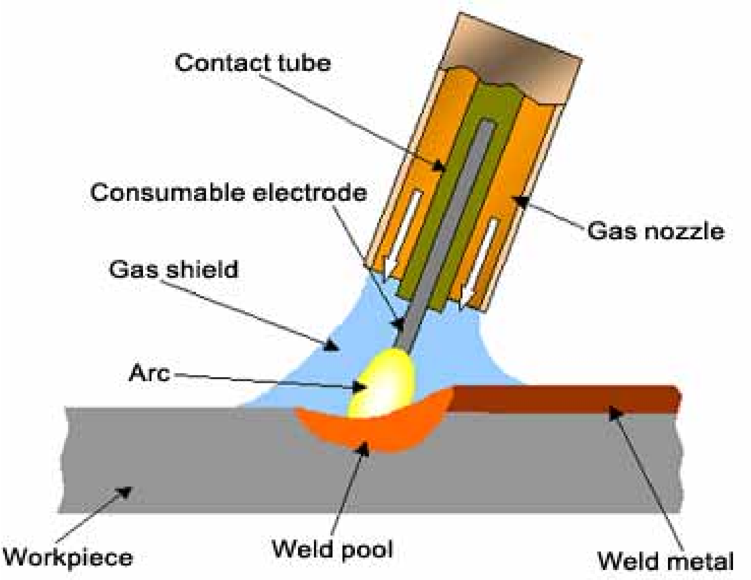

Figure 13.1 MIG/MAG welding.

The MIG/MAG process uses semi-automatic, mechanised or automatic equipment. In semi-automatic welding, the wire feed rate and arc length are controlled automatically, but the travel speed and wire position are under manual control. In mechanised welding, all parameters are under automatic control but can be varied manually during welding, eg steering of the welding head and adjustment of wire feed speed and arc voltage. With automatic equipment there is no manual intervention during welding. Figure 13.2 shows equipment required for the MIG/MAG process.

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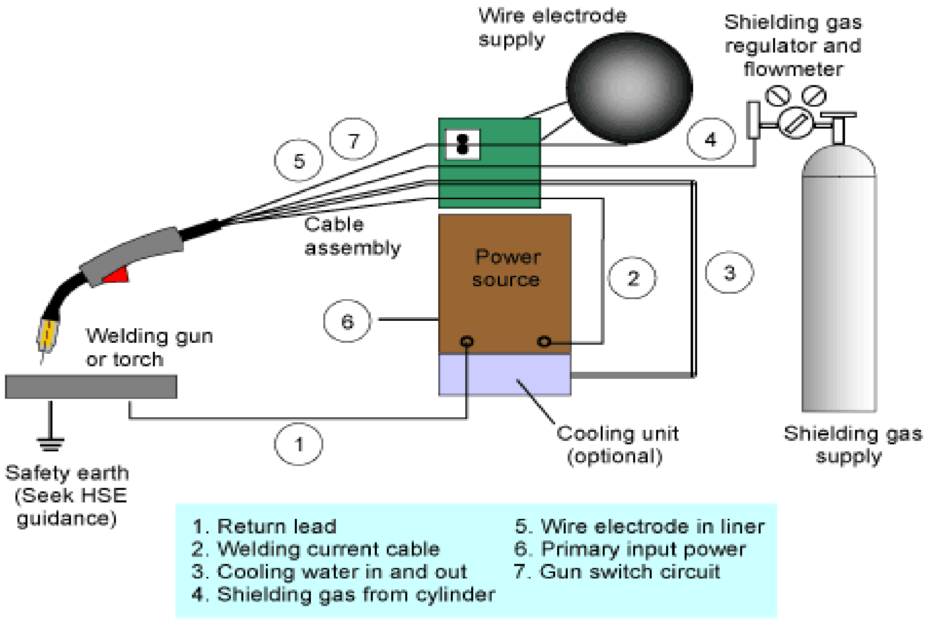

Figure 13.2 MIG/MAG welding equipment.

Advantages

- Continuous wire feed.
- Automatic self-regulation of the arc length.
- High deposition rate and minimal number of stop/start locations.
- High consumable efficiency.
- Heat inputs in the range 0.1-2kJ/mm.
- Low hydrogen potential process.
- Welder has good visibility of weld pool and joint line.
- Little or no post-weld cleaning.
- Can be used in all positions (dip transfer).
- Good process control possibilities.
- Wide range of applications.

Disadvantages

- No independent control of filler addition.
- Difficult to set up optimum parameters to minimise spatter levels.
- Risk of lack of fusion when using dip transfer on thicker weldments.
- High level of equipment maintenance.
- Lower heat input can lead to high hardness values.
- Higher equipment cost than MMA welding.
- Site welding requires special precautions to exclude draughts which may disturb the gas shield.
- Joint and part access is not as good as MMA or TIG welding.
- Cleanliness of base metal, slag processes tolerate greater contamination.

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13.2 Primary variables

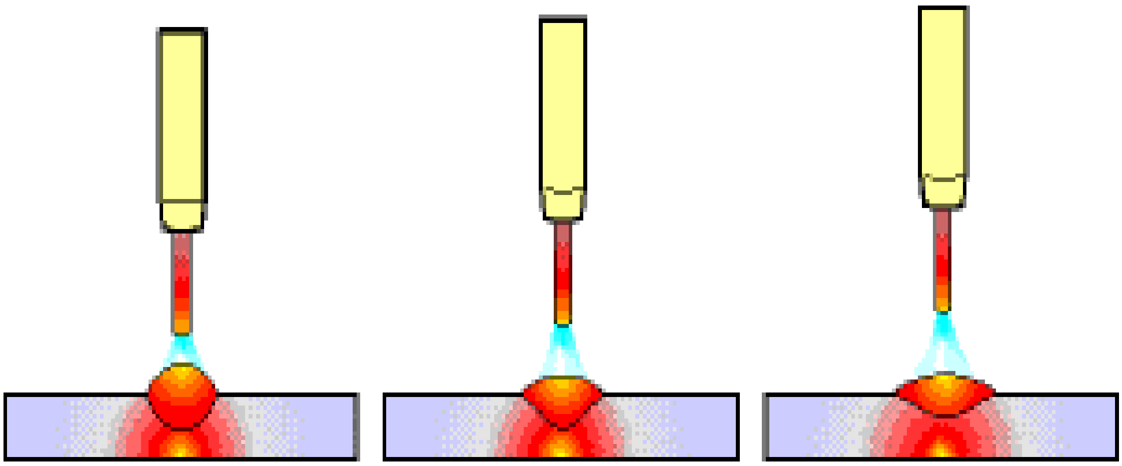
- Welding current/wire feed speed.
- Voltage.
- Gases.
- Travel speed and electrode orientation.
- Inductance.
- Contact tip to work distance (CTWD).
- Nozzle to work distance.
- Shielding gas nozzle.
- Type of metal transfer.

13.2.1 Wire feed speed

Increasing wire feed speed automatically increases the current in the wire. Wires are generally produced in 0.6, 0.8, 1, 1.2, 1.4 and 1.6mm diameter.

13.2.2 Voltage

The most important setting in spray transfer as it controls the arc length. In dip transfer it also affects the rise of current and the overall heat input into the weld. Increase both wire feed speed/current and voltage will increase heat input. Welding connections need to be checked for soundness as any loose ones will result in resistance and cause a voltage drop in the circuit and will affect the characteristic of the welding arc. The voltage will affect the type of transfer achievable but this is also highly dependent on the type of gas being used.



a 22V b 23V c 24

Figure 13.3 The effect of arc voltage:

a Increasing arc voltage;

b Reduced penetration, increased width;

C Excessive voltage can cause porosity, spatter and undercut.

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13.2.3 Gases

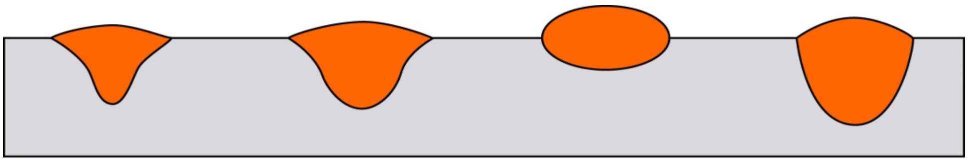

Figure 13.4 Gas composition effect on weld bead profile.

For non-ferrous metals and their alloys (such as Al, Ni and Cu) an inert shielding gas must be used, usually pure argon or an argon rich gas with a helium addition. The use of a fully inert gas is why the process is also called metal inert gas (MIG) welding and for precise use of terminology this should only be used when referring to the welding of non-ferrous metals.

The addition of some helium to argon gives a more uniform heat concentration within the arc plasma which affects the shape of the weld bead profile. Argon-helium mixtures give a hotter arc so are beneficial for welding thicker base materials, those with higher, thermal conductivity, eg copper or aluminium.

For welding all grades of steels, including stainless steels, a controlled addition of oxygen or carbon dioxide (CO_2) to generate a stable arc and give good droplet wetting. Because these additions react with the molten metal they are referred to as active gases, hence metal active gas (MAG) welding is the technical term when referring to welding steels.

100%CO_2

CO_2 gas cannot sustain spray transfer as the ionisation potential of the gas is too high it gives very good penetration but promotes globular droplet transfer also a very unstable arc and lots of spatter.

Argon +15-20%CO_2

The percentage of CO_2 or oxygen depends on the type of steel being welded and the mode of metal transfer used. Argon has a much lower ionisation potential and can sustain spray transfer above 24 welding volts. Argon gives a very stable arc, little spatter but lower penetration than CO_2. Argon and 5-20%CO_2 gas mixtures give the benefit of both gases ie good penetration with a stable arc and very little spatter. CO_2 gas is much cheaper than argon or its mixtures and is widely used for carbon and some low alloy steels.

Argon +1-5%CO_2

Widely used for stainless steels and some low alloy steels.

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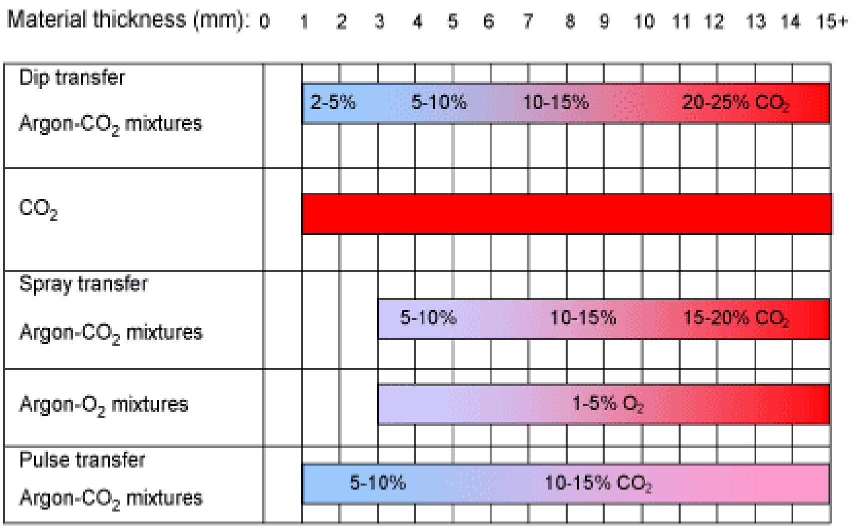

Figure 13.5 Active shielding gas mixtures for MAG welding of carbon, C-Mn and low alloy steels. Blue is a cooler and red a hotter mixture gas.

Gas mixtures with helium instead of argon give a hotter arc, more fluid weld pool and better weld profile. These quaternary mixtures permit higher welding speeds but may not be suitable for thin sections.

Stainless steels

Austenitic stainless steels are typically welded with argon-CO_2/O_2 mixtures for spray transfer or argon-helium-CO_2 mixtures for all modes of transfer. The oxidising potential of the mixtures is kept to a minimum (2-2.5% maximum CO_2 content) to stabilise the arc but with minimum effect on corrosion performance. Because austenitic steels have a low thermal conductivity, the addition of helium helps to avoid lack of fusion defects and overcome the high heat dissipation into the material. Helium additions are up to 85%, compared with ~25% for mixtures used for carbon and low alloy steels. CO_2-containing mixtures are sometimes avoided to eliminate potential carbon pick-up.

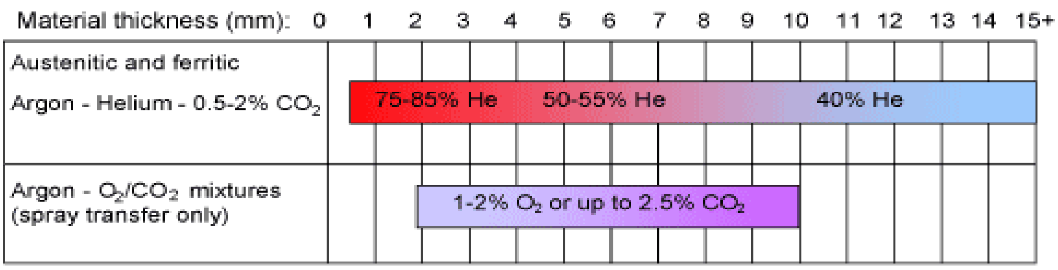

Figure 13.6 Active shielding gas mixtures for MAG welding of stainless steels. Blue is a cooler and red a hotter gas mixture.

For martensitic and duplex stainless steels, specialist advice should be sought. Some Ar-He mixtures containing up to 2.5%N_2 are available for welding duplex stainless steels.

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Light alloys (aluminium magnesium, titanium, copper and nickel and their alloys)

Inert gases are used for light alloys and those sensitive to oxidation. Welding grade inert gases should be purchased rather than commercial purity to ensure good weld quality.

Argon

Can be used for aluminium because there is sufficient surface oxide available to stabilise the arc. For materials sensitive to oxygen, such as titanium and nickel alloys, arc stability may be difficult to achieve with inert gases in some applications. The density of argon is approximately 1.4 times that of air so in the downhand position, the relatively heavy argon is very effective at displacing air. A disadvantage is when working in confined spaces there is a risk of argon building up to dangerous levels and asphyxiating the welder.

Argon-helium mixtures

Argon is most commonly used for MIG welding of light alloys but an advantage can be gained by use of helium and argon/helium mixtures. Helium possesses a higher thermal conductivity than argon and the hotter weld pool produces improved penetration and/or an increase in welding speed. High helium contents give a deep broad penetration profile but produce high spatter levels. With less than 80% argon a true spray transfer is not possible. With globular-type transfer the welder should use a buried arc to minimise spatter. Arc stability can be problematic in helium and argon-helium mixtures, since helium raises the arc voltage so there is a larger change in arc voltage with respect to arc length. Helium mixtures require higher flow rates than argon shielding to provide the same gas protection.

There is a reduced risk of lack of fusion defects when using argon-helium mixtures particularly on thick section aluminium. Ar-He gas mixtures will offset the high heat dissipation in material over about 3mm thickness.

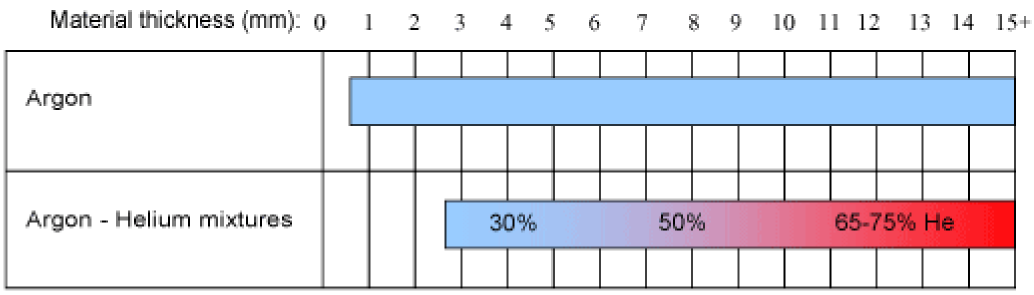

Figure 13.7 Inert shielding gas mixtures for MIG welding of aluminium, magnesium, titanium, nickel and copper alloys. Blue is a cooler and red a hotter gas mixture.

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Table 13.1 Summary of shielding gases and mixtures used for different base materials for MIG/MAG welding.

Metal	Shielding gas	Reaction behaviour	Characteristics
Carbon steel	Argon-CO_2	Slightly oxidising	Increasing CO_2 content gives hotter arc, improved arc stability, deeper penetration, transition from finger-type to bowl-shaped penetration profile, more fluid weld pool giving flatter weld bead with good wetting, increased spatter levels, better toughness than CO_2. Minimum 80% argon for axial spray transfer. General purpose mixture: Argon-10-15%CO_2.
	Argon-O_2	Slightly oxidising	Stiffer arc than Ar-CO_2 mixtures minimises undercutting, suited to spray transfer mode, lower penetration than Ar-CO_2 mixtures, finger-type weld bead penetration at high current levels. General purpose mixture: Argon-3% CO_2.
	Ar-He-CO_2	Slightly oxidising	Substituting of helium for argon gives hotter arc, higher arc voltage, more fluid weld pool, flatter bead profile, more bowl-shaped and deeper penetration profile and higher welding speeds, compared with Ar-CO_2 mixtures. High cost.
	CO_2	Oxidising	Arc voltages 2-3V higher than Ar-CO_2 mixtures, best penetration, higher welding speeds, dip transfer or buried arc technique only, narrow working range, high spatter levels, low cost.
Stainless steels	He-Ar-CO_2	Slightly oxidising	Good arc stability with minimum effect on corrosion resistance (carbon pick-up), higher helium contents designed for dip transfer, lower helium contents designed for pulse and spray transfer. General purpose gas: He-Ar-2%CO_2.
	Argon-O_2	Slightly oxidising	Spray transfer only, minimises undercutting on heavier sections, good bead profile.
Aluminium, copper, nickel, titanium alloys	Argon	Inert	Good arc stability, low spatter and general-purpose gas. Titanium alloys require inert gas backing and trailing shields to prevent air contamination.
	Ar-He	Inert	Higher heat input offsets high heat dissipation on thick sections, lower risk of lack of fusion defects, higher spatter and higher cost than argon.

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13.2.4 Travel speed and electrode orientation

The faster the travel speed the less penetration, narrower bead width and the higher risk of undercut.

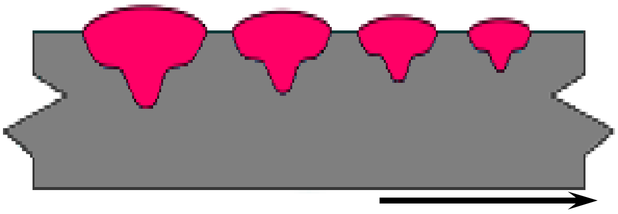
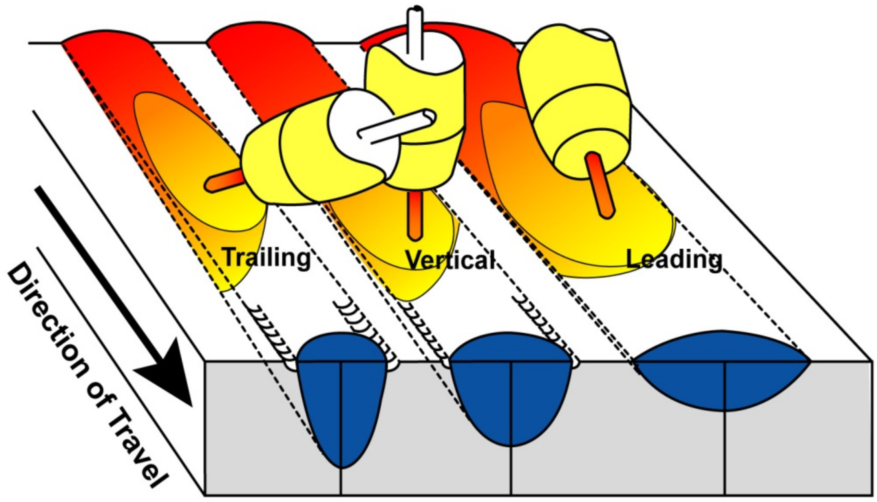


Figure 13.8 The effect of travel speed. As travel speed increases, reducing penetration and width, undercut.



Penetration	Deep	Moderate	Shallow
Excess weld metal	Maximum	Moderate	Minimum
Undercut	Severe	Moderate	Minimum

Figure 13.9 Effect of torch angle.

13.2.5 Effect of contact tip to workpiece distance

CTWD has an influence over the welding current because of resistive heating in the electrode extension (Figure 13.10). The welding current required to melt the electrode at the required rate to match the wire feed speed reduces as the CTWD is increased. Long electrode extensions can cause lack of penetration, for example, in narrow gap joints or with poor manipulation of the welding gun. Conversely, the welding current increases when the CTWD is reduced. This provides the experienced welder with a means of controlling the current during welding but can result in variable penetration in manual welding with a constant voltage power source.

As the electrode extension is increased the burn-off rate increases for a given welding current due to increased resistive heating. Increasing the electrode extension, eg in mechanised applications, is therefore one way of increasing deposition rates, as the wire feed speed is increased to maintain the required welding current.

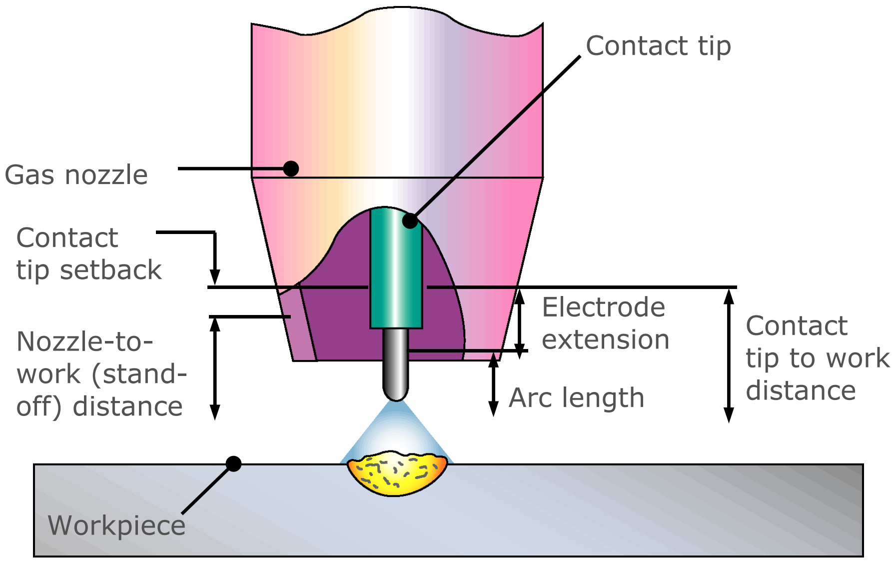


Figure 13.10 Contact tip to workpiece distance; electrode extension and nozzle to workpiece distance.

Resistive heating depends on the resistivity of the electrode, the electrode extension length and wire diameter so is more pronounced for welding materials which have high resistivity, such as steels. The electrode extension should be kept small when small diameter wires are being used to prevent excessive heating in the wire and avoid the resulting poor bead shape.

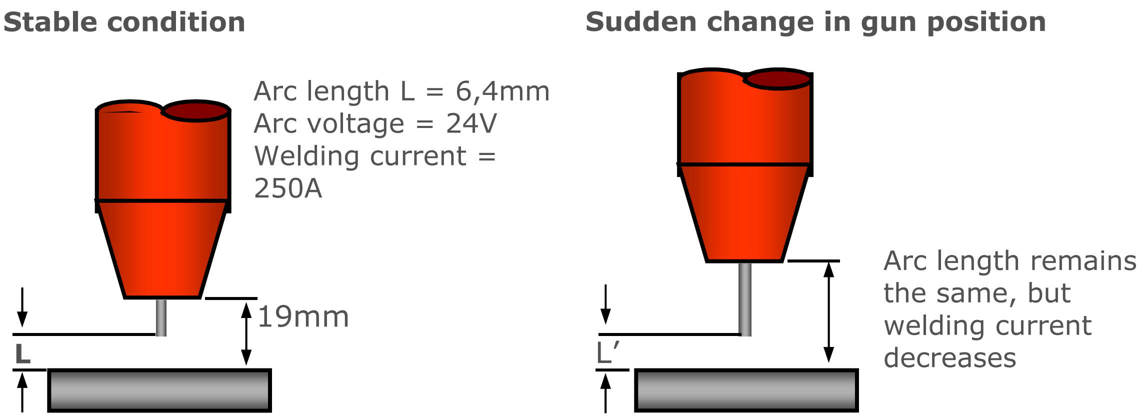


Figure 13.11 Effect of increasing the contact tip to workpiece distance. Arc length remains same length.

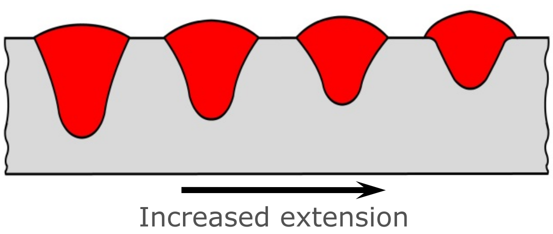


Figure 13.12 Effect of increasing electrode extension.

At short CTWDs, radiated heat from the weld pool can cause overheating of the contact tube and welding torch which can lead to spatter adherence and increased wear of the contact tube.

The electrode extension should be checked when setting-up welding conditions or fitting a new contact tube. Normally measured from the contact tube to the workpiece (Figure 13.13) suggested CTWDs for the principal metal transfer modes are:

Metal transfer mode	CTWD, mm
Dip	10-15
Spray	20-25
Pulse	15-20

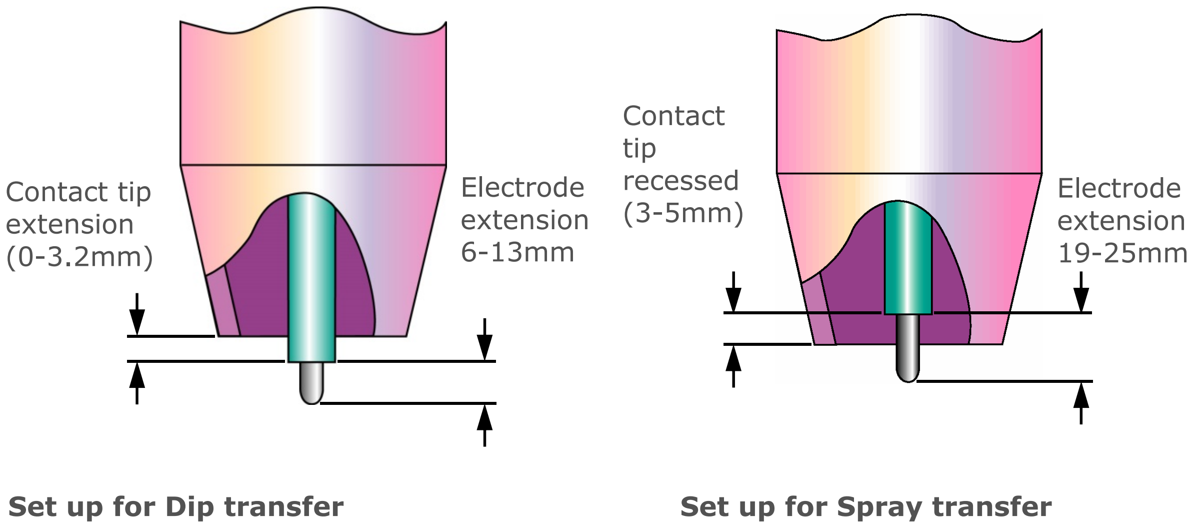


Figure 13.13 Suggested contact tip to work distance.

13.2.6 Effect of nozzle to work distance

Nozzle to work distance (Figure 13.13) has a considerable effect on gas shielding efficiency with a decrease stiffening the column. The nozzle to work distance is typically 12-15mm. If the CTWD is simultaneously reduced, however, the deposition rate at a given current is decreased and visibility and accessibility are affected; so in practice a compromise is necessary. The following gives suggested settings for the mode of metal transfer being used.

Metal transfer mode	Contact tip position relative to nozzle
Dip	2mm inside to 2mm protruding
Spray	4-8mm inside
Spray (aluminium)	6-10mm inside

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13.2.7 Shielding gas nozzle

The purpose of the shielding gas nozzle is to produce a laminar gas flow to protect the weld pool from atmospheric contamination. Nozzle diameters range from 13-22mm and should be increased in relation to the size of the weld pool. Therefore, larger diameter nozzles are used for high current, spray transfer application and smaller diameter for dip transfer. The flow rate must also be tuned to the nozzle diameter and shielding gas type to give sufficient weld pool coverage. Gas nozzles for dip transfer welding tend to be tapered at the outlet of the nozzle.

Joint access and type should also be considered when selecting the required gas nozzle and flow rate. Too small a nozzle may cause it to become obstructed by spatter more quickly and if the wire bends on leaving the contact tube, the shielding envelope and arc location may not coincide.

13.2.8 Types of metal transfer

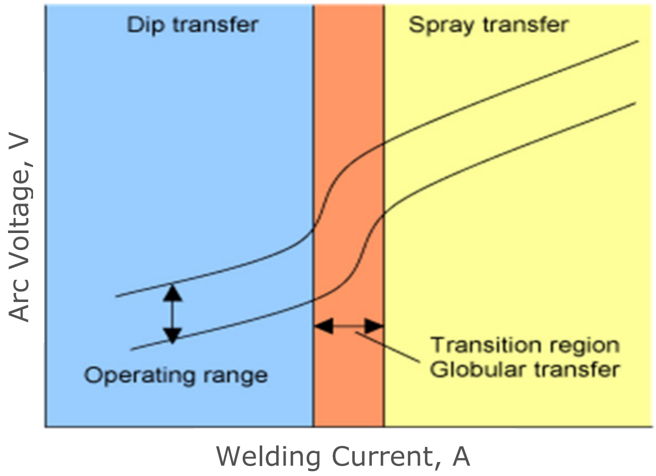

Figure 13.14 Arc characteristic curve.

Key characteristics of dip transfer

- Metal transfer by wire dipping or short-circuiting into the weld pool.
- Relatively low heat input process.
- Low weld pool fluidity.
- Used for thin sheet metal above 0.8mm and typically less than 3.2mm, positional welding of thicker section and root runs in open butt joints.
- Process stability and spatter can be a problem if poorly tuned.
- Lack of fusion of poorly set-up and applied.
- Not used for non-ferrous metals and alloys.

Figure 13.15 Dip transfer.

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In dip transfer the wire short-circuits the arc 50-200 times/second and this type of transfer is normally achieved with CO_2 or mixtures of CO_2 and argon gas + low amps and welding volts <24V.

Key characteristics of spray transfer

- Free-flight metal transfer.
- High heat input.
- High deposition rate.
- Smooth stable arc.
- Used on steels above 6mm and aluminium alloys above 3mm thickness.

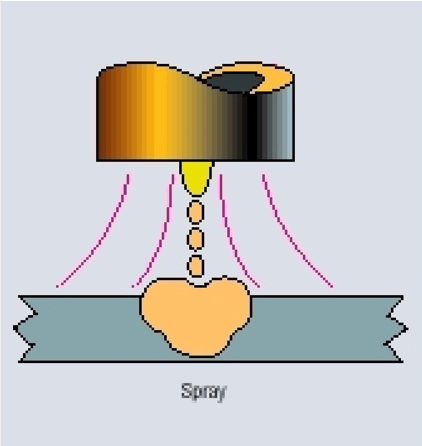

Figure 13.16 Spray transfer.

Spray transfer occurs at high currents and voltages. Above the transition current, metal transfer is a fine spray of small droplets projected across the arc with low spatter levels. The high welding current produces strong electromagnetic forces (pinch effect) that cause the molten filament supporting the droplet to neck down. Droplets detach from the tip of the wire and accelerate across the arc gap. The frequency with which the droplets detach increases with the current. The droplet size equates to the wire diameter at the threshold level but decreases significantly as the welding current increases. At very high currents (wire feed speeds), the molten droplets can start to rotate (rotating transfer). The arc current is flowing during the drop detachment resulting in maximum penetration and a high heat input. When the correct arc voltage to give spray transfer is used, the arc is short with the wire tip 1-3mm from the surface of the plate.

With steels it can be used only in downhand butts and H/V fillet welds but gives higher deposition rate, penetration and fusion than dip transfer because of the continuous arc heating. It is mainly used for steel plate thicknesses >3mm but has limited use for positional welding due to the potential large weld pool involved.

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Key characteristics pulsed transfer

- Free-flight droplet transfer without short-circuiting over the entire working range.
- Very low spatter.
- Lower heat input than spray transfer.
- Reduced risk of lack of fusion compared with dip transfer.
- Control of weld bead profile for dynamically loaded parts.
- Process control/flexibility.
- Enables use of larger diameter, less expensive wires with thinner plates – more easily fed (particular advantage for aluminium welding).

Pulsing the welding current extends the range of spray transfer operation well below the natural transition from dip to spray transfer. This allows smooth, spatter-free spray transfer at mean currents below the transition level, eg 50-150A and at lower heat inputs. Pulsing was introduced originally to control metal transfer by imposing artificial cyclic operation on the arc system by applying alternately high and low currents.

A typical pulsed waveform and the main pulse welding variables are shown in Figure 13.17. A low background current (typically 20-80A) is supplied to maintain the arc, keep the wire tip molten, give stable anode and cathode roots and maintain average current during the cycle. Droplet detachment occurs during a high current pulse at current levels above the transition current level. The pulse of current generates very high electromagnetic forces which cause a strong pinch effect on the metal filament supporting the droplet the droplet is detached and projected across the arc gap. Pulse current and current density must be sufficiently high to ensure that spray transfer (not globular) always occurs so that positional welding can be used.

Pulse transfer uses pulses of current to fire a single globule of metal across the arc gap at a frequency of 50-300 pulses/second. It is a development of spray transfer that gives positional welding capability for steels, combined with controlled heat input, good fusion and high productivity and may be used for all sheet steel thickness >1mm, but is mainly used for positional welding of steels >6mm.

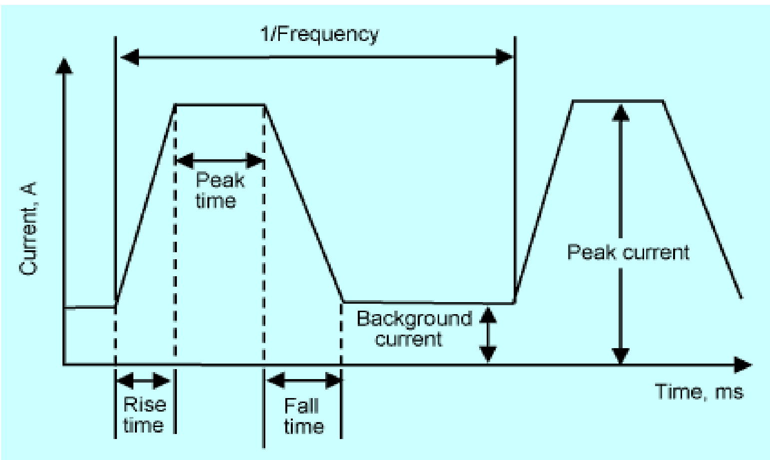

Figure 13.17 Pulsed welding waveform and parameters.

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Key characteristics of globular transfer

- Irregular metal transfer.
- Medium heat input.
- Medium deposition rate.
- Risk of spatter.
- Not widely used in the UK can be used for mechanised welding of medium thickness (typically 3-6mm) steel in the flat (PA) position.

Synergic

Is a term meaning working together and was originally designed to establish correct pulse parameters in MIG/MAG welding over a range of wire diameters and gas mixtures. Manually adjusting pulse parameters was problematic with many variables to adjust; pulse peak, pulse time, background current and background time. Consequently, to arrive at the correct arc condition was time consuming and fraught with errors.

With the advancement in electronically controlled power sources and subsequent CPU inverter controlled systems, it has allowed manufacturers to produce a one knob control system. Therefore, all parameters previously mentioned can be controlled via a one knob control operation to establish the correct arc condition as determined by the manufacturers of the power source. In essence, as the knob is turned the wire feed increases, possibly voltage (and all pulse parameters) change to keep a balanced arc condition.

The manufacturers, have predetermined synergic curves based on material type, wire diameter and gas mixture. To facilitate set up, this information is programmed in by the user and a unique curve is produced based on the inputs. The user can then adjust, via one knob control, up and down the synergic curve. Most machines however have an option to adjust the voltage of the synergic curve if required. In addition, once an acceptable welding condition is found, most manufacturers have the ability to save to memory for later re-call.

The globular transfer range occupies the transitional range of arc voltage between free-flight and fully short-circuiting transfer. Irregular droplet transfer and arc instability are inherent, particularly when operating near the transition threshold. In globular transfer a molten droplet several times the electrode diameter forms on the wire tip, gravity eventually detaches it when its weight overcomes surface tension forces and transfer takes place often with excessive spatter. Before transfer the arc wanders and its cone covers a large area, dissipating energy.

There is a short duration short-circuit when the droplet contacts with the molten pool but rather than causing droplet transfer it occurs as a result of it. Although the short-circuit is of very short duration, some inductance is necessary to reduce spatter, although to the operator the short-circuits are not discernible and the arc has the appearance of a free-flight type.

To further minimise spatter levels, it is common to operate with a very short arc length and in some cases a buried arc technique is adopted. Globular transfer can only be used in the flat position and is often associated with lack of penetration, fusion defects and uneven weld beads because of the irregular transfer and tendency for arc wander.

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13.2.9 Inductance

When MIG/MAG welding in the dip transfer mode, the welding electrode touches the weld pool causing a short-circuit during which the arc voltage is nearly zero. If the constant voltage power supply responded instantly, very high current would immediately begin to flow through the welding circuit and the rapid rise in current to a high value would melt the short-circuited electrode free with explosive force, dispelling the weld metal and causing considerable spatter.

Inductance is the property in an electrical circuit that slows down the rate of current rise (Figure 13.18). The current travelling through an inductance coil creates a magnetic field which creates a current in the welding circuit in opposition to the welding current. Increasing inductance will also increase the arc time and decrease the frequency of short-circuiting.

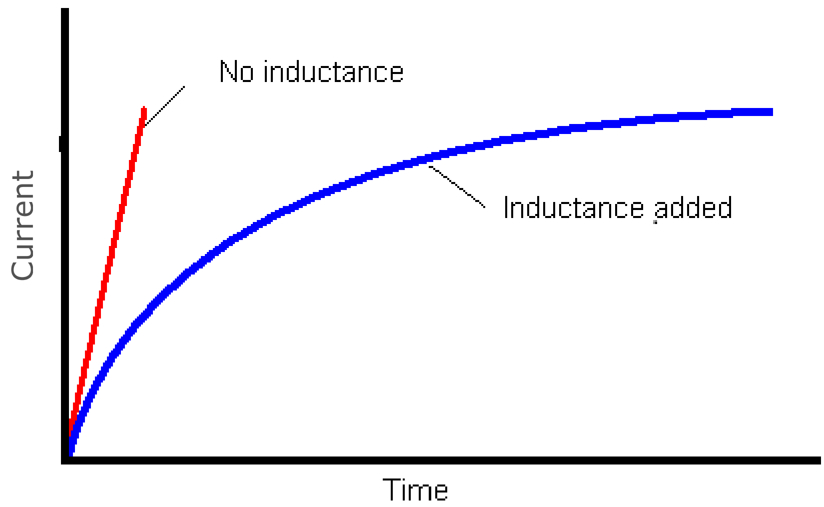

Figure 13.18 Relationship between inductance and current rise.

There is an optimum value of inductance for each electrode feed rate,. Too little results in excessive spatter, too much and current will not rise fast enough and the molten tip of the electrode is not heated sufficiently causing the electrode to stub into the base metal. Modern electronic power sources automatically set inductance to give a smooth arc and metal transfer.

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13.3 MIG basic equipment requirements

1 Power source-transformer/rectifier (constant voltage type).
2 Inverter power source.
3 Power hose assembly (liner, power cable, water hose, gas hose).
4 Liner.
5 Spare contact tips.
6 Torch head assembly.
7 Power-return cable and clamp.
8 15kg wire spool (copper coated and uncoated wires).
9 Power control panel.
10 External wire feed unit.

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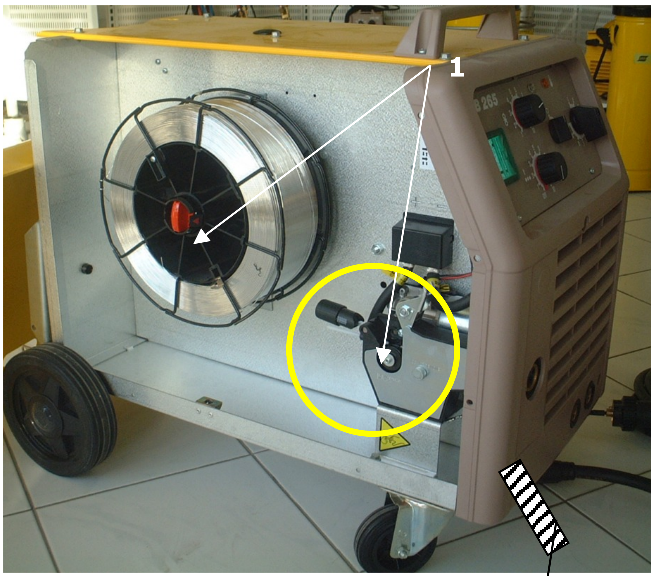
The MIG/MAG wire drive assembly

Internal wire drive system.



Flat plain top drive roller.

Groove half bottom drive roller.

Wire guide.

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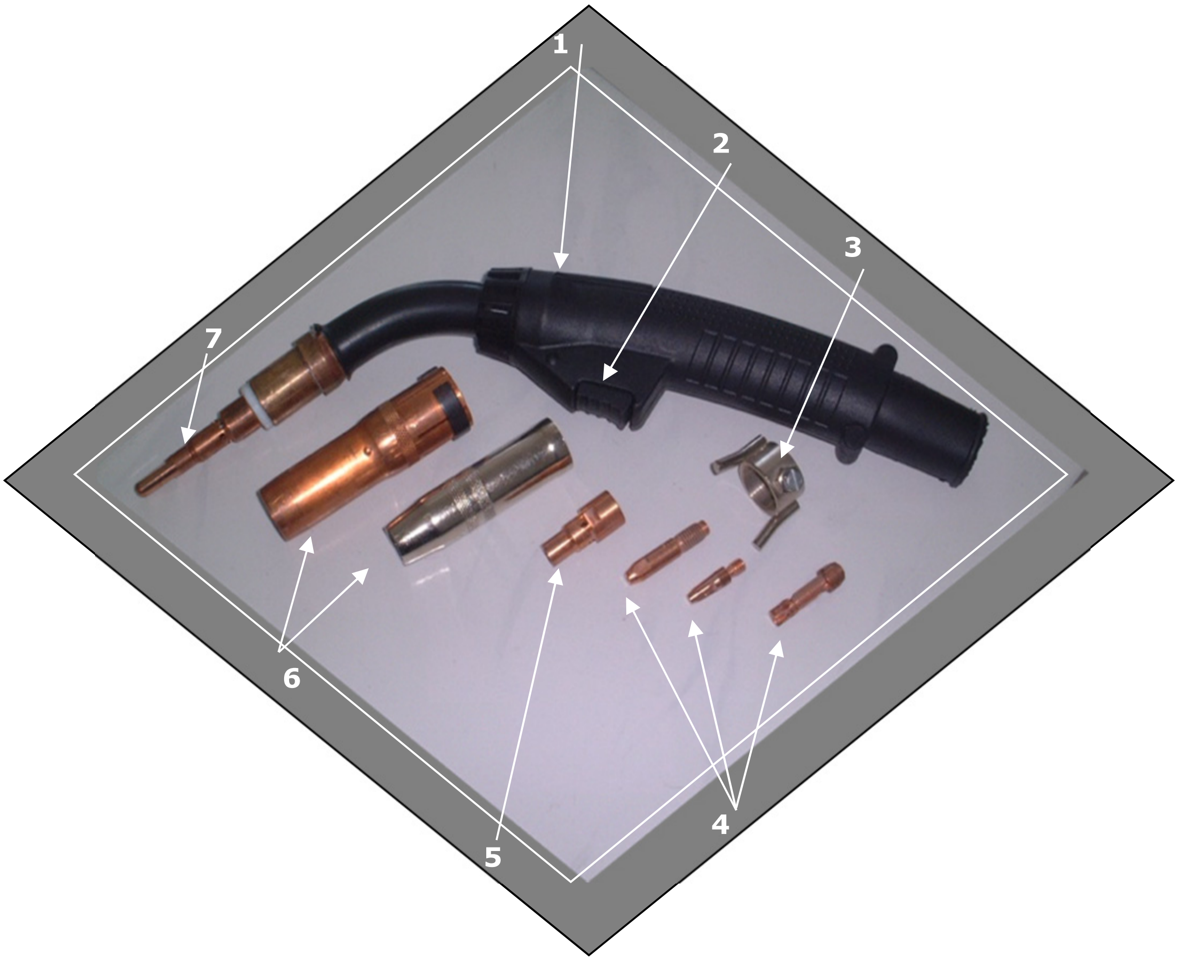
The MIG torch head assembly



1 Torch body.
2 On/off or latching switch.
3 Spot welding spacer attachment.
4 Contact tips.
5 Gas diffuser.
6 Gas shrouds.
7 Torch head assembly (minus the shroud).

13.4 Inspection when MIG/MAG welding

13.4.1 Welding equipment

Visual check to ensure the welding equipment is in good condition.

13.4.2 Electrode wire

The diameter, specification and quality of wire are the main inspection headings. The level of de-oxidation of the wire is an important factor with single, double and triple de-oxidised wires being available.

The higher the level of de-oxidants in the wire, the lower the chance of porosity in the weld. The quality of the wire winding, copper coating and temper are also important factors in minimising wire feed problems.

Quality of wire windings and increasing costs

a) Random wound. b) Layer wound. c) Precision layer wound.

13.4.3 Drive rolls and liner

Check the drive rolls are the correct size for the wire and that the pressure is hand tight or just sufficient to drive the wire. Excess pressure will deform the wire to an ovular shape making it very difficult to drive through the liner, resulting in arcing in the contact tip and excessive wear of the contact tip and liner.

Check that the liner is the correct type and size for the wire. One size of liner generally fits two sizes of wire, ie 0.6 and 0.8, 1 and 1.2, 1.4 and 1.6mm diameter. Steel liners are used for steel wires and Teflon for aluminium wires.

13.4.4 Contact tip

Check the contact tip is the right size for the wire being driven and the amount of wear frequently. Any loss of contact between the wire and contact tip will reduce the efficiency of current pick. Most steel wires are copper coated to maximise the transfer of current by contact between two copper surfaces at the contact tip but this also inhibits corrosion. The contact tip should be replaced regularly.

13.4.5 Connections

The electric arc length in MIG/MAG welding is controlled by the voltage settings, achieved by using a constant voltage volt/amp characteristic inside the equipment. Any poor connection in the welding circuit will affect the nature and stability of the electric arc so is a major inspection point.

13.4.6 Gas and gas flow rate

The type of gas used is extremely important to MIG/MAG welding, as is the flow rate from the cylinder which must be adequate to give good coverage over the solidifying and molten metal to avoid oxidation and porosity.

13.4.7 Other variable welding parameters

Checks should be made for correct wire feed speed, voltage, speed of travel and all other essential variables of the process given on the approved welding procedure.

13.4.8 Safety checks

Checks should be made on the current carrying capacity or duty cycle of equipment and electrical insulation. Correct extraction systems should be used to avoid exposure to ozone and fumes.

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A check should always be made to ensure that the welder is qualified to weld the procedure being used.

Typical welding imperfections

- Silica inclusions on ferritic steels only caused by poor inter-run cleaning.
- Lack of sidewall fusion during dip transfer welding of thick section vertically down.
- Porosity caused by loss of gas shield and low tolerance to contaminants.
- Burn-through from using the incorrect metal transfer mode on sheet metal.

13.5 Flux-cored arc welding (FCAW)

In the mid-1980s the development of self-and gas-shielded FCAW was a major step in the successful application of on-site semi-automatic welding and has enabled a much wider range of materials to be welded.

The cored wire consists of a metal sheath containing a granular flux which can contain elements normally used in MMA electrodes so the process has a very wide range of applications.

In addition, gas producing elements and compounds can be added to the flux so the process can be independent of a separate gas shield, which restricts the use of conventional MIG/MAG welding in many field applications.

Most wires are sealed mechanically and hermetically with various forms of joint. The effectiveness of the were joint is an inspection point of cored wire welding as moisture can easily be absorbed into a damaged or poor seam.

Wire types commonly used are:

- Rutile which give good positional capabilities.
- Basic also positional but good on dirty material.
- Metal-cored higher productivity, some having excellent root run capabilities.
- Self-shielded no external gas needed.

Baking of cored wires is ineffective and will not restore the condition of a contaminated flux within a wire.

Note: Unlike MMA electrodes the potential hydrogen levels and mechanical properties of welds with rutile wires can equal those of the basic types.

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13.6 Summary of solid wire MIG/MAG

Equipment requirements

- Transformer/rectifier (constant voltage type).
- Power and power return cable.
- Inert, active or mixed shielding gas (argon or CO_2).
- Gas hose, flow meter and gas regulator.
- MIG torch with hose, liner, diffuser, contact tip and nozzle.
- Wire feed unit with correct drive rolls.
- Electrode wire to correct specification and diameter.
- Correct visor/glass, safety clothing and good extraction.

Parameters and inspection points

- Wire feed speed/amperage.
- Open circuit and welding voltage.
- Wire type and diameter.
- Gas type and flow rate.
- Contact tip size and condition.
- Roller type, size and pressure.
- Liner size.
- Inductance settings.
- Insulation/extraction.
- Connections (voltage drops).
- Travel speed, direction and angles.

Typical welding imperfections

- Silica inclusions.
- Lack of fusion (dip transfer).
- Surface porosity.

Advantages	Disadvantages
High productivity	Lack of fusion (dip transfer)
Easily automated	Small range of consumables
All positional (dip, pulse and FCAW)	Protection for site working
Material thickness range	Complex equipment
Continuous electrode	High ozone levels

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Section 14

Submerged Arc Welding

14 Submerged Arc Welding

14.1 Process

In submerged arc welding (SAW) an arc is struck between a continuous bare wire and the parent plate. The arc, electrode end molten pool are submerged in an agglomerated or fused powdered flux, which turns into a gas and slag in its lower layers when subjected to the heat of the arc thus protecting the weld from contamination. The wire electrode is fed continuously by a feed unit of motor driven rollers which are usually voltage-controlled to ensure an arc of constant length. A hopper fixed to the welding head has a tube which spreads the flux in a continuous elongated mound in front of the arc along the line of the intended weld and of sufficient depth to submerge the arc completely so there is no spatter. The weld is shielded from the atmosphere and there are no ultraviolet or infrared radiation effects (see below). Unmelted flux is reclaimed for use. The use of powdered flux restricts the process to the flat and horizontal-vertical welding positions.

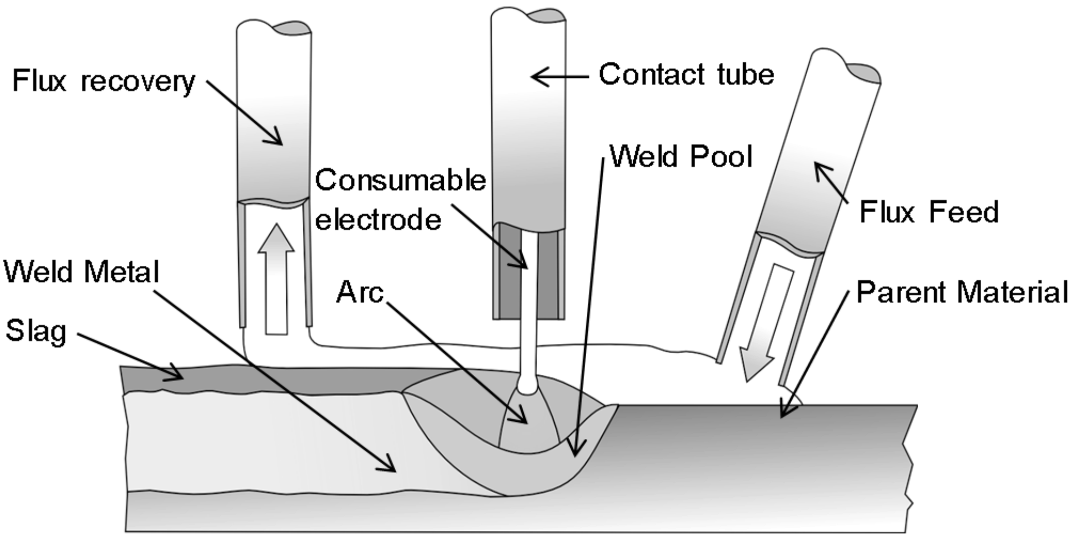

Figure 14.1 SAW.

Submerged arc welding is able to use where high weld currents (owing to the properties and functions of the flux) which give deep penetration and high deposition rates. Generally DC+ve is used up to about 1000A because it produces deep penetration. On some applications (ie cladding operations) DC-ve is needed to reduce penetration and dilution. At higher currents or with multiple electrode systems, AC is often preferred to avoid arc blow (when used with multiple electrode systems, DC+ve is used for the lead arc and AC for the trail arc).

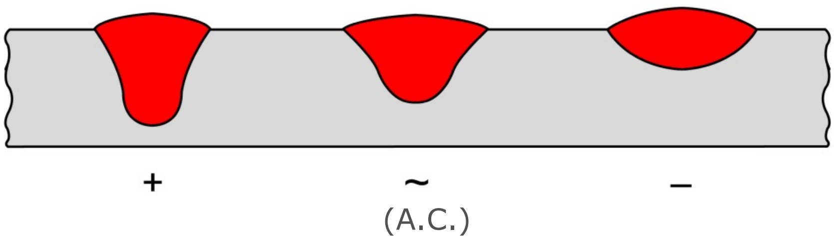

Figure 14.2 Effect of electrode polarity on penetration.

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Difficulties sometimes arise in ensuring conformity of the weld with a pre-determined line owing to the obscuring effect of the flux. Where possible, a guide wheel to run in the joint preparation is positioned in front of the welding head and flux hoppers.

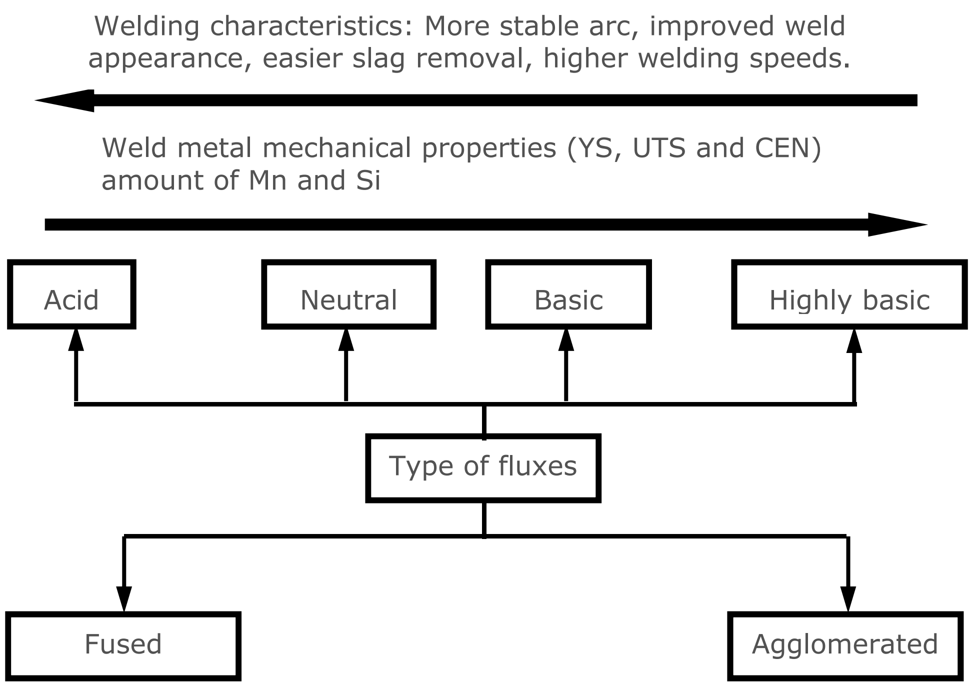
Submerged arc welding is widely used in the fabrication of ships, pressure vessels, linepipe, railway carriages and where long welds are required. It can be used to weld thicknesses from 5mm upwards.

Materials joined

- Welding of carbon steels.
- Welding low alloy steels (eg fine grained and creep resisting).
- Welding stainless steels.
- Welding nickel alloys.
- Cladding to base metals to improve wear and corrosion resistance.

14.2 Fluxes

Flux is granular mineral compounds mixed to various formulations.



Fused fluxes are produced by the constituents being dry mixed, melted in an electric furnace then granulated by pouring the molten mixture into water or on to an ice block. Subsequently these particles are crushed and screened to yield a uniform glass-like product.

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Advantages of fused fluxes

- Good chemical homogeneity.
- Less hygroscopic so handling and storage are easier.
- Fines (fine powders) can be removed without changes in composition.
- Easily recycled through the system without significant change in particle size or composition.

Disadvantages of fused fluxes

- Limitations in composition as some components, such as basic carbonates unable to withstand the melting process.
- Difficult to add deoxidisers and ferro-alloys (due to segregation or extremely high loss).

In agglomerated fluxes constituents may be bonded by mixing the dry constituents with potassium or sodium silicate and the wet mixture is then pelletised, dried, crushed and screened to size.

Advantages of agglomerated fluxes

- Deoxidisers and alloying elements can easily be added to the flux to adjust the weld metal composition.
- Allow a thicker flux layer when welding.
- Can be identified by colour and shape.

Disadvantages of agglomerated fluxes

- Generally more hygroscopic (baking hardly practical).
- Gas may evolve from the slag as it is melted, leading to porosity.
- May be changes in weld metal chemical composition from the segregation of fine particles produced by the mechanical handling of the granulated flux.

14.3 Process variables

Several variables when changed can have an effect on the weld appearance and mechanical properties:

- Welding current.
- Type of flux and particle distribution.
- Arc voltage.
- Travel speed.
- Electrode size.
- Electrode extension.
- Type of electrode.
- Width and depth of the layer of flux.
- Electrode angle (leading, trailing).
- Polarity.
- Single, double or multi-wire system.

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14.3.1 Welding current

Increasing current increases penetration and wire melt-off rate.

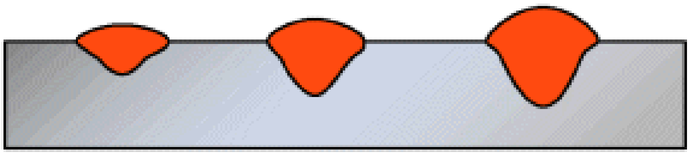

Figure 14.3 Effect of increasing welding current ampage on weld shape and penetration.

Welding current effect on weld profile (2.4mm electrode diameter, 35V arc voltage and 61cm/min travel speed).

- Excessively high current produces a deep penetrating arc with a tendency to burn-through, undercut or a high, narrow bead prone to solidification cracking.
- Excessively low current produces an unstable arc, lack of penetration and possibly a lack of fusion.

14.3.2 Arc voltage

Arc voltage adjustment varies the length of the arc between the electrode and the molten weld metal. As it increases, the arc length increases and vice versa. Voltage principally determines the shape of the weld bead cross- section and its external appearance.

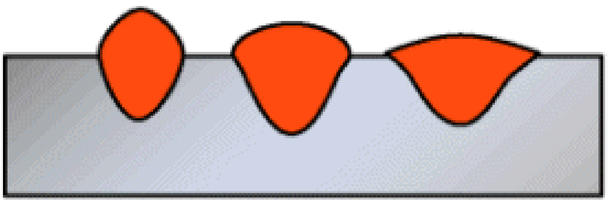

Figure 14.4 Effect of increasing arc voltage on weld shape and penetration.

Arc voltage effect on weld profile 2.4mm electrode diameter, 500A welding current and 61cm/min travel speed.

Increasing the arc voltage with constant current and travel speed will:

- Produce a flatter, wider bead.
- Increase flux consumption.
- Tend to reduce porosity caused by rust or scale on steel.
- Help to bridge excessive root opening when fit-up is poor.
- Increase pick-up of alloying elements from the flux if present.

Excessively high arc voltage will:

- Produce a wide bead shape subject to solidification cracking.
- Make slag removal difficult in groove welds.
- Produce a concave-shaped fillet weld that may be subject to cracking.
- Increase undercut along the edge(s) of fillet welds.
- Over-alloy the weld metal via the flux.

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Reducing the arc voltage with constant current and travel speed will produce a stiffer arc which improves penetration in a deep weld groove and resists arc blow.

Excessively low arc voltage will:

- Produce a high, narrow bead.
- Cause difficult slag removal along the weld toes.

14.3.3 Travel speed

If travel speed is increased:

- Heat input per unit length of weld decreases.
- Less filler metal is applied per unit length of weld therefore less excess weld metal.
- Penetration decreases so the weld bead becomes smaller.

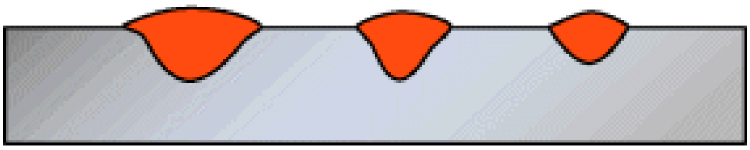

Figure 14.5 Effect of increasing travel speed on weld shape and penetration.

Travel speed effect on weld profile (2.4mm electrode diameter, 500A welding current and 35V arc voltage).

14.3.4 Electrode size affects

- **Weld bead shape and depth of penetration at a given current**
  A high current density results in a stiff arc that penetrates into the base metal. Conversely, a lower current density in the same size electrode results in a soft arc that is less penetrating.

- **Deposition rate**
  At any given amperage setting, a small diameter electrode will have a higher current density and deposition rate of molten metal than a larger diameter electrode. However, a larger diameter electrode can carry more current than a smaller one, so can ultimately produce a higher deposition rate at higher amperage.

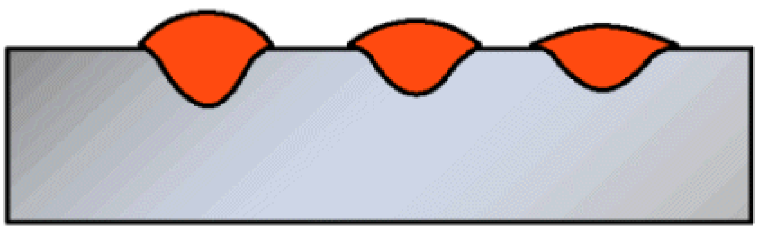

Figure 14.6 Effect of increasing electrod size on weld shape and penetration.

Electrode size effect on weld profile (600A welding current, 30V arc voltage and 76cm/min travel speed).

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14.3.5 Electrode extension

The electrode extension is the distance the continuous electrode protrudes beyond the contact tip. At high current densities resistance heating of the electrode between the contact tip and the arc can be to increase the electrode melting rate (as much as 25-50%). The longer the extension, the greater the amount of heating and the higher the melting rate but drecreases penetration and weld bead width (see below).

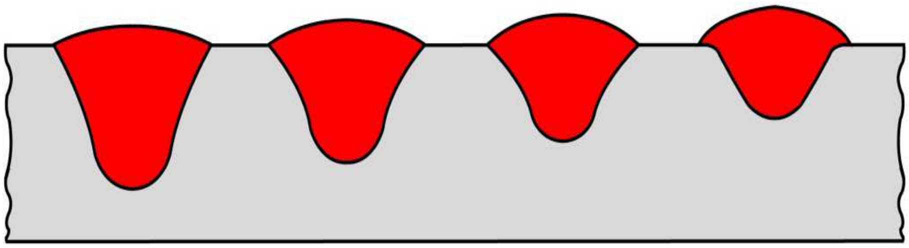

Figure 14.7 Effect of increasing electrode extension on weld shape and penetration.

14.3.6 Type of electrode

An electrode with low electrical conductivity, such as stainless steel, can with a normal electrode extension, experience greater resistance heating. Thus for the same size electrode and current, the melting rate of a stainless steel electrode will be higher than that of a carbon steel electrode.

14.3.7 Width and depth of flux

The width and depth of the layer of granular flux influence the appearance and soundness of the finished weld as well as the welding action. If the granular layer is too deep, the arc is too confined and a rough weld with a rope-like appearance is likely to result and it may produce local flat areas on the surface often referred to as gas flats. The gases generated during welding cannot readily escape and the surface of the molten weld metal is irregularly distorted. If the granular layer is too shallow the arc will not be entirely submerged in flux, flashing and spattering will occur and the weld will have a poor appearance and may show porosity.

14.4 Storage and care of consumables

Care must be taken with fluxes supplied for SAW which, although they may be dry when packaged, may be exposed to high humidity during storage. In such cases they should be dried as per the manufacturer's recommendations before use or porosity or cracking may result.

Ferrous wire coils supplied as continuous feeding electrodes are usually copper-coated which provides some corrosion resistance, ensures good electrical contacts and helps in smooth feeding. Rust and mechanical damage should be avoided in such products as they interrupt smooth feeding of the electrode. Rust is detrimental to weld quality generally since it is hygroscopic (may contain or absorb moisture) so can lead to hydrogen induced cracking.

Contamination by carbon-containing materials such as oil, grease, paint and drawing lubricants, is especially harmful with ferrous metals. Carbon pick-up in the weld metal can cause a marked and usually undesirable change in properties. Such contaminants may also result in hydrogen being absorbed in the weld pool.

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Welders should always follow the manufacturer's recommendations for consumables storage and handling.

14.5 Power sources

In arc welding it is principally the current which determines the amount of heat generated and this controls the melting of the electrode and parent metal and also such factors as penetration and bead shape and size. Voltage and arc length are also important factors with increasing voltage leading to increasing arc length and vice/versa. Usually in SAW a constant voltage or flat characteristic power source is used.

Power can be supplied from a welding generator with a flat characteristic or a transformer/rectifier arranged to give output voltages of approximately 14-50V and current according to the output of the unit, can be in excess of 1000A.

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Section 15

Thermal Cutting Processes

15 Thermal Cutting Processes

15.1 Oxy-fuel cutting

Oxy-fuel cutting cuts or removes metal by the chemical reaction of oxygen with the metal at elevated temperatures. Temperature is provided by a gas flame which preheats and brings the material up to the burning temperature (approximately 850°C). Once this is achieved, a stream of oxygen is released which rapidly oxidises most of the metal and performs the actual cutting operation. Metal oxides, together with molten metal, are expelled from the cut by the kinetic energy of the oxygen stream. Moving the torch across the workpiece produces a continuous cutting action.

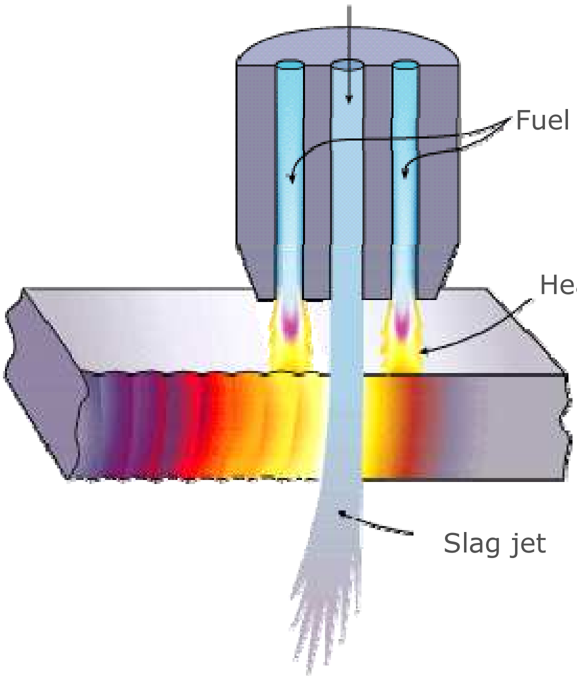

Figure 15.1 Oxy-fuel cutting.

A material must simultaneously fulfil two conditions to be cut by the oxy-fuel cutting process:

- Burning temperature must be below the parent material melting point.
- Melting temperature of the oxides formed during the cutting process must be below the parent material melting point.

These conditions are fulfilled by carbon steels and some low alloy steels. However, the oxides of many of the alloying elements in steels, such as aluminium and chromium have melting points higher than those of iron oxides. These high melting point oxides (which are refractory in nature!) may shield the material in the kerf so that fresh iron is not continuously exposed to the cutting oxygen stream, leading to a decrease of the cutting speed and ultimately an unstable process. In practice the process is effectively limited to low alloy steels containing <0.25%C, <5%Cr, <5%Mo, <5%Mn and <9%Ni.

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Advantages

- Steels can generally be cut faster than by most machining methods.
- Section shapes and thicknesses difficult to produce by mechanical means can be cut economically.
- Basic equipment costs are low compared with machine tools.
- Manual equipment is very portable so can be used on site.
- Cutting direction can be changed rapidly on a small radius.
- Large plates can be cut rapidly in place by moving the torch rather than the plate.
- Economical method of plate edge preparation.

Disadvantages

- Dimensional tolerances significantly poorer than machine tool capabilities.
- Process essentially limited to cutting carbon and low alloy steels.
- Preheat flame and expelled red hot slag present fire and burn hazards to plant and personnel.
- Fuel combustion and oxidation of the metal require proper fume control and adequate ventilation.
- Hardenable steels may require pre and/or post-heat adjacent to the cut edges to control their metallurgical structures and mechanical properties.
- Special process modifications are needed for cutting high alloy steels and cast irons (ie iron powder or flux addition).
- Being a thermal process, expansion and shrinkage of the components during and after cutting must be taken into account.

15.1.1 Requirements for gases

Oxygen for cutting operations should be 99.5% or higher purity: Lower will result in a decrease in cutting speed and an increase in consumption of cutting oxygen thus reducing the efficiency of the operation. With purity below 95% cutting becomes a melt-and-wash action that is usually unacceptable.

The preheating flame has the following functions in the cutting operation:

- Raises the temperature of the steel to the ignition point.
- Adds heat energy to the work to maintain the cutting reaction.
- Provides a protective shield between the cutting oxygen stream and the atmosphere.
- Dislodges from the upper surface of the steel any rust, scale, paint or other foreign substance that would stop or retard the normal forward progress of the cutting action.

Factors to be considered when selecting a fuel gas include:

- Preheating time.
- Effect on cutting speed and productivity.
- Cost and availability.
- Volume of oxygen required per volume of fuel gas to obtain a neutral flame.
- Safety in transporting and handling.

Some of the more common fuel gases used are acetylene, natural gas (methane), propane, propylene and methylacetylene propadiene (MAPP) gas.

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Table 15.1 Fuel gas characteristics and applications.

Fuel gas	Main characteristics	Applications
Acetylene	Highly focused, high temperature flame Rapid preheating and piercing Low oxygen requirement	Cutting of thin plates Bevel cuts Short, multi-pierce cuts
Propane	Low temperature flame, high heat content Slow preheating and piercing High oxygen requirement	Cutting of thicker sections (100-300mm), long cuts
MAPP	Medium temperature flame	Cutting underwater
Propylene	Medium temperature flame	Cutting of thicker sections
Methane	Low temperature flame	Cutting of thicker sections

15.1.2 Oxy-fuel gas cutting quality

Generally, oxy-fuel cuts are characterised by:

- Large kerf (>2mm).
- Low roughness values (Ra <50µm).
- Poor edge squareness (>0.7mm).
- Wide HAZ (>1mm).

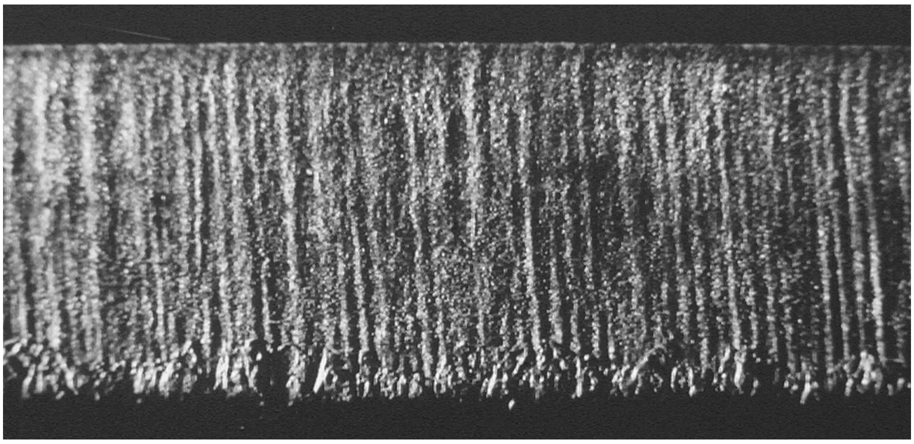

Figure 15.2 Cutting quality.

The face of a satisfactory cut has a sharp top edge, drag lines, which are fine and even, little oxide and a sharp bottom edge. Underside is free of slag.

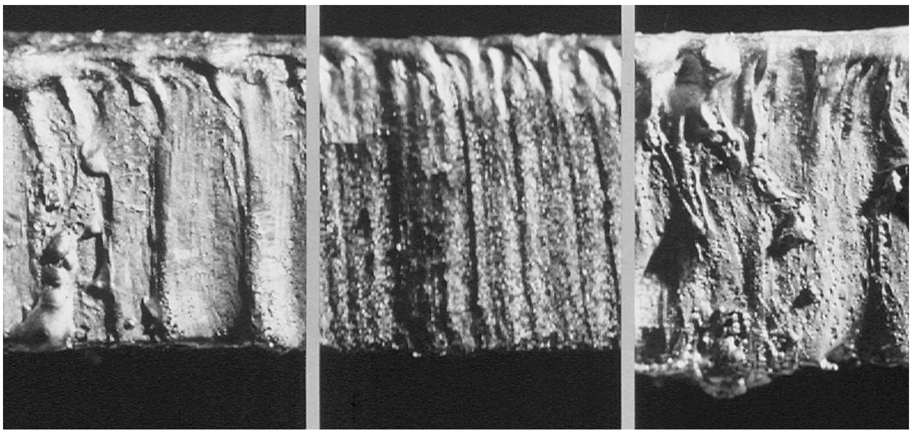

Figure 15.3 Effects of cutting speed on cut surface (face) quality.

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A satisfactory cut is shown in the centre. If the cut is too slow (left) the top edge is melted, there are deep grooves in the lower portion of the face, scaling is heavy and the bottom edge may be rough, with adherent dross. If the cut is too fast (right) the appearance is similar, with an irregular cut edge. Plate thickness 12mm.

Figure 15.4 Effect of excessive travel speed.

With a very fast travel speed the drag lines are coarse and at an angle to the surface with an excessive amount of slag sticking to the bottom edge of the plate, due to the oxygen jet trailing with insufficient oxygen reaching the bottom of the cut.

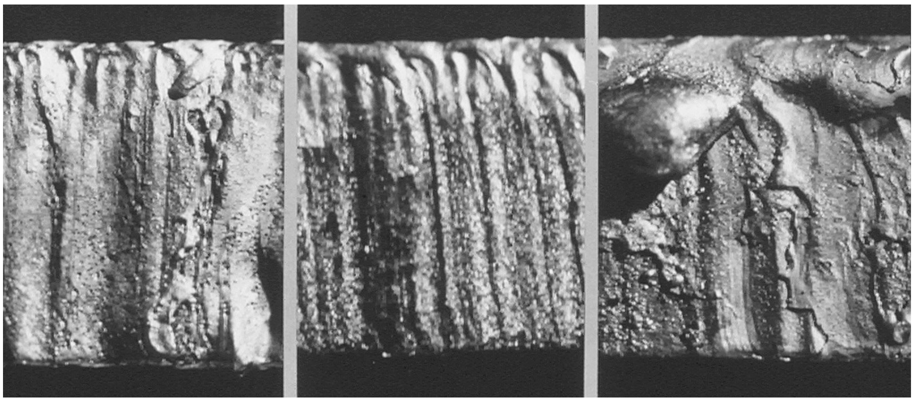

Figure 15.5 Effect of changing preheat flame intensity.

A satisfactory cut is shown in the centre. If the preheating flame is too low (left) the most noticeable effect on the cut edge is deep gouges in the lower part of the cut face. If the preheating flame is too high (right) the top edge is melted, the cut irregular and there is an excess of adherent dross. Plate thickness 12mm.

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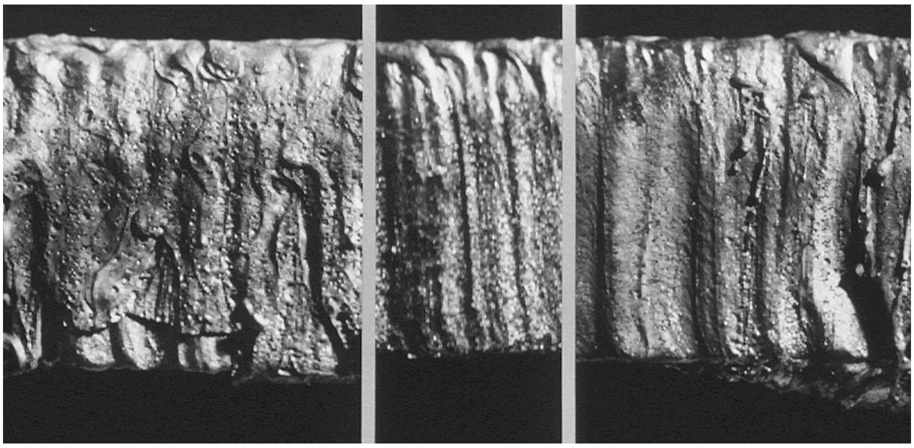

Figure 15.6 Effect of blowpipe nozzle height increase and irregular travel speed.

A satisfactory cut is shown in the centre. If the blowpipe nozzle is too high above the work (left) excessive melting of the top edge occurs with much oxide. If the torch travel speed is irregular (right) uneven spacing of the drag lines can be observed together with an irregular bottom surface and adherent oxide. Plate thickness 12mm.

15.2 Plasma arc cutting

Plasma arc cutting uses a constricted arc which removes the molten metal with a high velocity jet of ionised gas issuing from the constricting orifice. A pilot arc is struck between a tungsten electrode and a water-cooled nozzle, the arc is then transferred to the workpiece, thus being constricted by the orifice downstream of the electrode. As plasma gas passes through this arc, it is heated rapidly to a high temperature, expands and is accelerated as it passes through the constricting orifice towards the workpiece. The orifice directs the super heated plasma stream from the electrode toward the workpiece. When the arc melts the workpiece, the high velocity jet blows away the molten metal. The cutting arc attaches or transfers to the workpiece, known as the transferred arc method. Where materials are non-electrical conductors there is a method known as non-transferred arc where the positive and negative poles are inside the torch body creating the arc and the plasma jet stream travels toward the workpiece.

Advantages

- Not limited to materials which are electrical conductors so is widely used for cutting all types of stainless steels, non-ferrous materials and non-electrical conductive materials.
- Operates at a much higher energy level compared with oxy-fuel cutting resulting in faster cutting speeds.
- Instant start-up is particularly advantageous for interrupted cutting as it allows cutting without preheat.

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Disadvantages

- Dimensional tolerances significantly poorer than machine tool capabilities.
- Introduces hazards such as fire, electric shock (due to the high OCV), intense light, fumes, gases and noise levels that may not be present with other processes. However, in underwater cutting the level of fumes, UV radiation and noise are reduced to a low level.
- Compared with oxy-fuel cutting, plasma arc cutting equipment tends to be more expensive and requires a fairly large amount of electric power.
- Being a thermal process, expansion and shrinkage of the components during and after cutting must be taken into consideration.
- Cut edges slightly tapered.

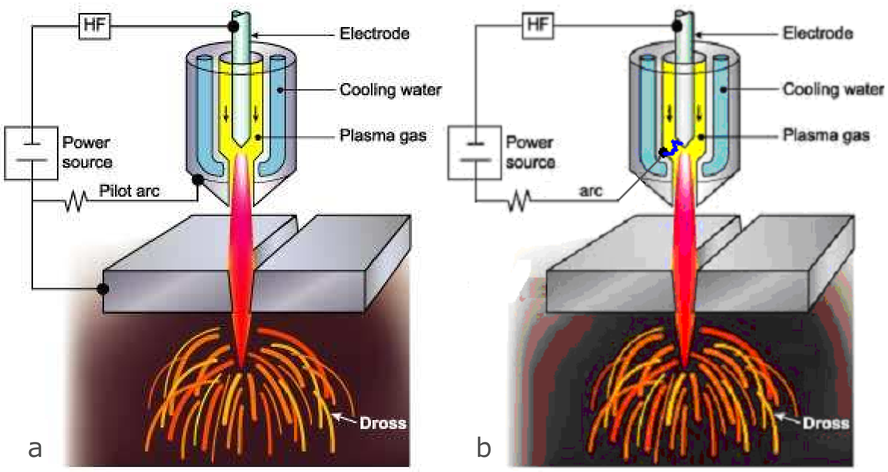

Figure 15.7 Plasma arc cutting:
a Transferred arc;
b Non-transferred.

15.3 Arc air gouging

During arc air gouging the metal to be gouged or cut is melted with an electric arc and blown away by a high velocity jet of compressed air. A special torch directs the compressed air stream along the electrode and underneath it. The torch is connected to an arc welding machine and compressed air line, which delivers approximately 690MPa (100psi) of compressed air and since pressure is not critical, a regulator is not necessary. The electrode is made of graphite and copper-coated to increase the current pick-up and operating life. This process is usually used for gouging and bevelling, being able to produce U and J preparations and can be applied to both ferrous and non-ferrous materials.

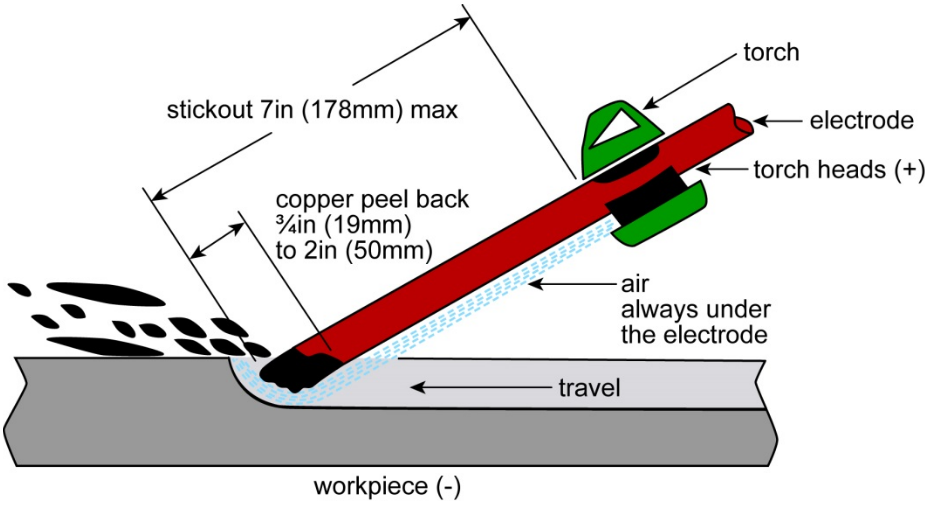

Figure 15.8 Arc air gouging.

Advantages

- Approximately five times faster than chipping.
- Easily controllable, removes defects with precision as they are clearly visible and may be followed with ease. The depth of cut is easily regulated and slag does not deflect or hamper the cutting action.
- Low equipment cost no gas cylinders or regulators necessary except on-site.
- Economical to operate as no oxygen or fuel gas required. The welder may also do the gouging (no qualification requirements for this operation).
- Easy to operate as the equipment is similar to MMA except the torch and air supply hose.
- Compact with the torch not much larger than an MMA electrode holder, allowing work in confined areas.
- Versatile.
- Can be automated.

Disadvantages

- Other cutting processes usually produce a better and quicker cut.
- Requires a large volume of compressed air.
- Increases the carbon content leading to an increase in hardness in of cast iron and hardenable metals. In stainless steels it can lead to carbide precipitation and sensitisation so grinding the carbide layer usually follows arc air gouging.
- Introduces hazards such as fire (due to discharge of sparks and molten metal), fumes, noise and intense light.

15.4 Manual metal arc gouging

The arc is formed between the tip of the electrode and are required workpiece and special purpose electrodes with thick flux coatings to generate a strong arc force and gas stream. Unlike MMA welding where a stable weld pool must be maintained, this process forces the molten metal away from the arc zone to leave a clean cut surface.

The gouging process is characterised by the large amount of gas generated to eject the molten metal. However, because the arc/gas stream is not as powerful as a gas or a separate air jet, the surface of the gouge is not as smooth as an oxy-fuel or air carbon arc gouge.

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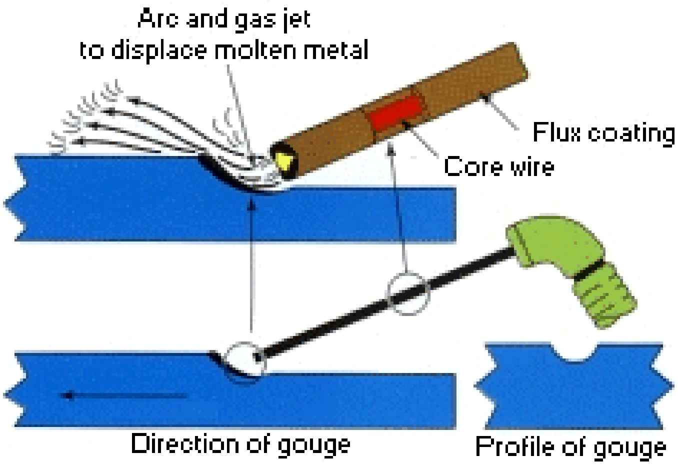

Figure 15.9 Manual metal arc gouging.

Although DC-ve is preferred, an AC constant current power source can also be used.

MMA gouging is used for localised gouging operations, removal of defects for example and where it is more convenient to switch from a welding to a gouging electrode rather than use specialised equipment. Compared with alternative gouging processes, metal removal rates are low and the quality of the gouged surface is inferior.

When correctly applied, MMA gouging can produce relatively clean gouged surfaces. For general applications, welding can be carried out without the need to dress by grinding, however when gouging stainless steel, a thin layer of higher carbon content material will be produced which should be removed by grinding.

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Thermal Cutting Processes

Section 15

Materials Joining and Engineering Technologies
Training and Examination Services

Thermal Cutting Objective

When this presentation has been completed you will be able to recognise different cutting methods and their advantages and limitations over each other in respect to materials and applicability.

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Oxyfuel Gas Cutting Process

A jet of pure oxygen reacts with iron, that has been preheated to its ignition point, to produce the oxide Fe_3O_4 by exothermic reaction. This oxide is then blown through the material by the velocity of the oxygen stream.

Different types of fuel gases may be used for the pre-heating flame in oxy fuel gas cutting: ie acetylene, hydrogen, propane etc.

By adding iron powder to the flame we are able to cut most metals - Iron Powder Injection.

The high intensity of heat and rapid cooling will cause hardening in low alloy and medium/high C steels - they are thus pre-heated to avoid the hardening effect.

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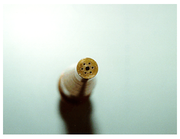
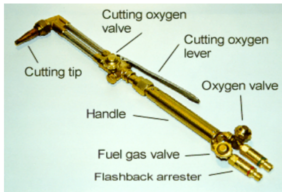
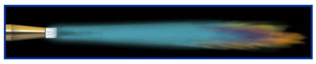
Oxyfuel Gas Cutting Process

The cutting torch

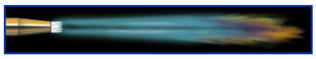




Neutral cutting flame.



Neutral cutting flame with oxygen cutting stream.



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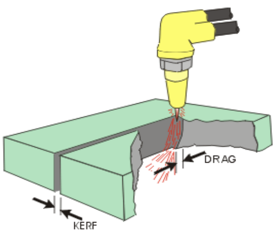
Oxyfuel Gas Cutting Related Terms



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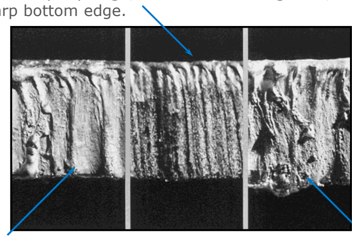
Oxyfuel Gas Cutting Quality

Good cut - sharp top edge, fine and even drag lines, little oxide and a sharp bottom edge.



Cut too slow - top edge is melted, deep groves in the lower portion, heavy scaling, rough bottom edge.

Cut too fast - pronounced break in the drag line, irregular cut edge.

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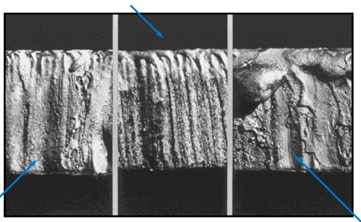
Oxyfuel Gas Cutting Quality

Good cut - sharp top edge, fine and even drag lines, little oxide and a sharp bottom edge.



Preheat flame too low - deep groves in the lower part of the cut face.

Preheat flame too high - top edge is melted, irregular cut, excess of adherent dross.

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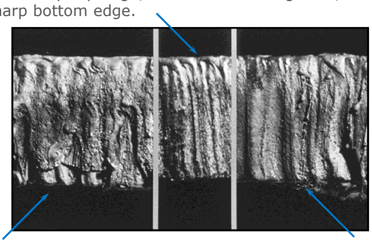
Oxyfuel Gas Cutting Quality

Good cut - sharp top edge, fine and even drag lines, little oxide and a sharp bottom edge.



Nozzle is too high above the works - excessive melting of the top edge, much oxide.

Irregular travel speed - uneven space between drag lines, irregular bottom with adherent oxide.

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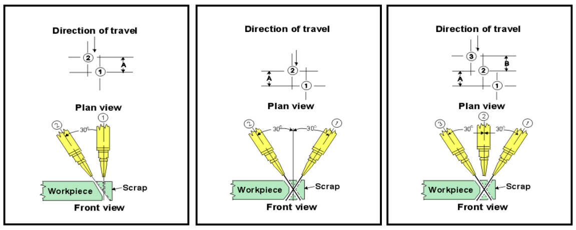
Mechanised Oxyfuel Cutting

- Can use portable carriages or gantry type machines high productivity.
- Accurate cutting for complicate shapes.



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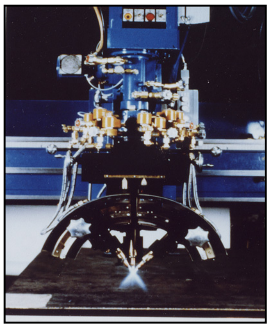
Mechanised Oxyfuel Cutting

- Cutting and bevelling head.



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OFW/C Advantages/Disadvantages

Advantages:

- No need for power supply portable.
- Versatile: preheat, brazing, surfacing, repair, straightening
- Low equipment cost.
- Can cut carbon and low alloy steels.
- Good on thin materials.

Disadvantages:

- High skill factor.
- Wide HAZ.
- Safety issues.
- Slow process.
- Limited range of consumables.
- Not suitable for reactive and refractory metals.

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Oxy Fuel Film

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Plasma Cutting

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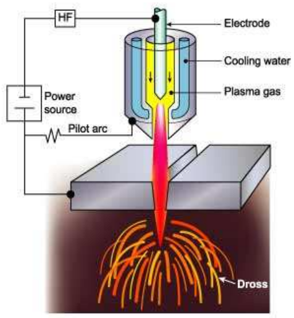
Plasma Cutting



- No need to promote oxidation and no preheat.
- Works by melting and blowing and/or vaporisation.
- Gases: air, Ar, N_2, O_2, mix of Ar + H_2, N_2 + H_2.
- Air plasma promotes oxidation and increased speed but special electrodes need.
- Shielding gas – optional.
- Applications: stainless steels, aluminium and thin sheet carbon steel.

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Plasma Cutting

Click for Plasma Cutting Video….

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Arc Air Gouging

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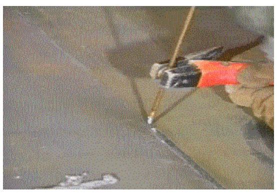
Arc Air Gouging Features

- Operate ONLY on DCEP.
- Special gouging copper coated carbon electrode.
- Can be used on carbon and low alloy steels, austenitic stainless steels and non-ferrous materials.
- Requires CLEAN/DRY compressed air supply.



- Provides fast rate of metal removal.
- Can remove complex shape defects.
- After gouging, grinding of carbured layer is mandatory.
- Gouging doesn't require a qualified welder!

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Arc Air Gouging

Click for Arc Air Gouges Video….

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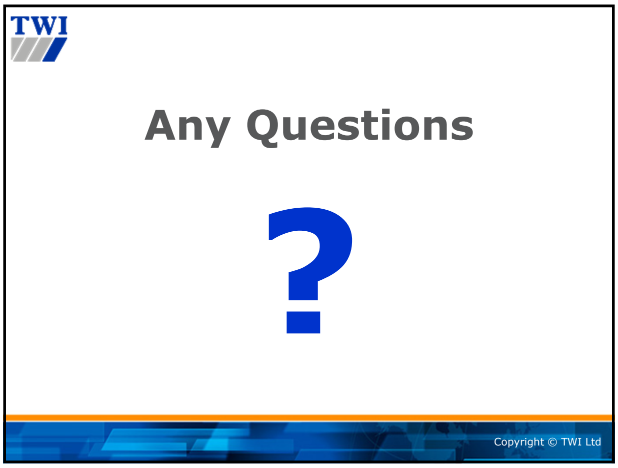
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Any Questions
?
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Section 16

Welding Consumables

16 Welding Consumables

Welding consumables are defined as all that is used up during the production of a weld.

This list could include all things used up in the production of a weld; however, we normally refer to welding consumables as those items used up by a particular welding process.

These are:

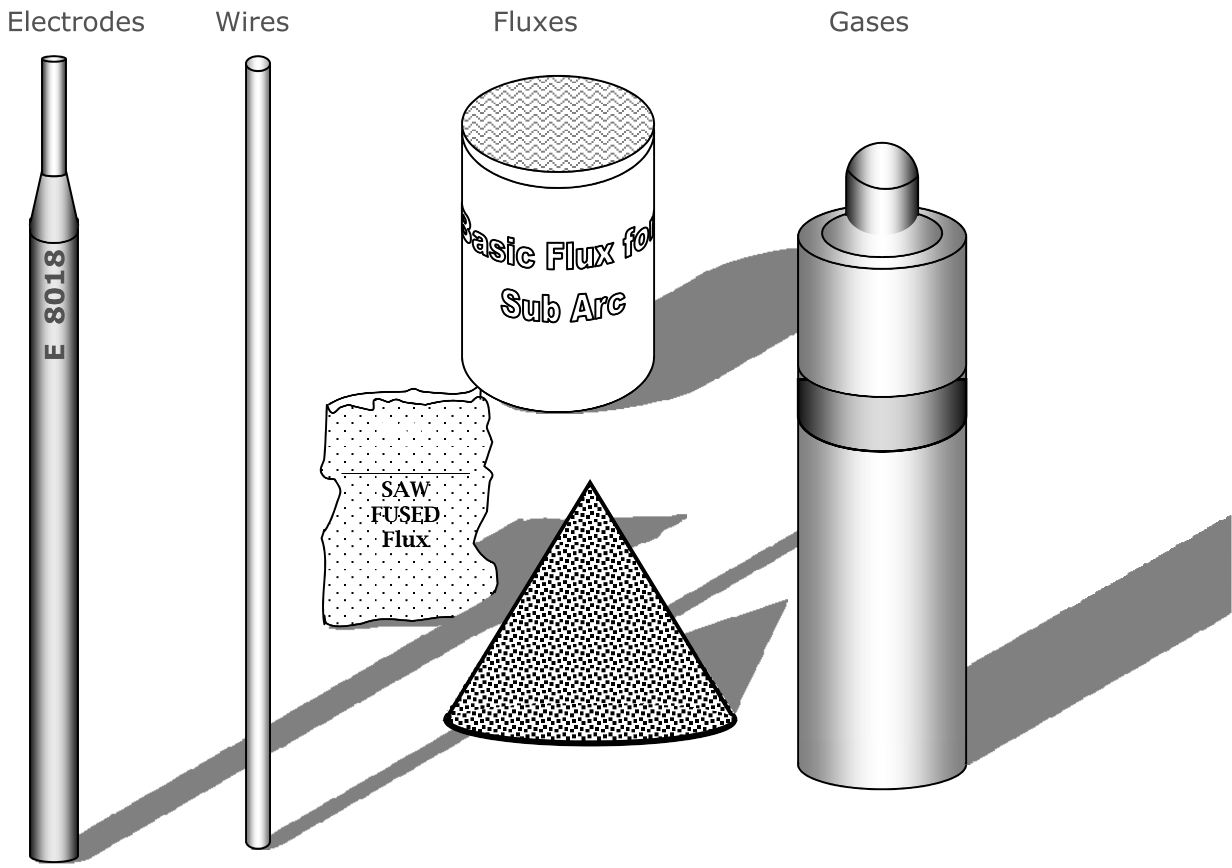

Figure 16.1 Welding consumables.

When inspecting welding consumables arriving at site it is important to check for the following:

- Size.
- Type or specification.
- Condition.
- Storage.

The checking of **suitable storage conditions** for all consumables is a **critical** part of the welding inspector's duties.

16.1 Consumables for MMA welding

Welding consumables for MMA consist of a core wire typically 350-450mm length and 2.5-6mm diameter but other lengths and diameters are available. The core wire is generally of low quality rimming steel as the weld can be considered a casting so can be refined by the addition of cleaning or refining agents in the extruded flux coating. This coating contains many elements and compounds which have a variety of jobs during welding. Silicon is mainly added as a de-oxidising agent (in the form of ferro-silicon), which removes oxygen from the weld metal by forming the oxide silica. Manganese additions of up to 1.6% will improve the strength and toughness of steel. Other metallic and non-metallic compounds are added that have many functions, including:

- Aid arc ignition.
- Improve arc stabilisation.
- Produce a shielding gas to protect the arc column.
- Refine and clean the solidifying weld metal.
- Form a slag which protects the solidifying weld metal.
- Add alloying elements.
- Control hydrogen content of the weld metal.
- Form a cone at the end of the electrode which directs the arc.

Electrodes for MMA/SMAW are grouped by the main constituent in their flux coating, which in turn has a major effect on the weld properties and ease of use.

Table 16.1 Common groups of electrodes.

Group	Constituent	Shield gas	Uses	AWS A 5.1
Rutile	Titania	Mainly CO_2	General purpose	E 6013
Basic	Calcium compounds	Mainly CO_2	High quality	E 7018
Cellulosic	Cellulose	Hydrogen + CO_2	Pipe root runs	E 6010

Some basic electrodes may be tipped with a carbon compound which eases arc ignition.

Figure 16.2 Electrodes tipped with a carbon compound.

Symbol	Tensile Strength N/mm²	Yield Strength min. N/mm²	Elongation min. %
35	440-570	355	22
38	470-600	380	20
42	500-640	420	20
46	530-680	460	20
50	560-720	500	18

Symbol	Welding position
1	All positions
2	All positions, except vertical down
3	Flat butt weld, flat fillet weld, horizontal-vertical fillet weld
4	Flat butt weld, flat fillet weld
5	Vertical down and positions according to symbol 3

Symbol	Metal recovery, %	Type of current
1	< 105	AC + DC
2	< 105	DC
3	> 105 ≤ 125	AC + DC
4	> 105 ≤ 125	DC
5	> 125 ≤ 160	AC + DC
6	> 125 ≤ 160	DC
7	> 160	AC + DC
8	> 160	DC

E 46 3 1Ni B 5 4 H5

Covered electrode for manual metal arc welding.

Symbol	Coating type
A	Acid
B	Basic
C	Cellulosic
R	Rutile
RR	Rutile (thick coated)
RC	Rutile-Cellulosic
RA	Rutile-Acid
RB	Rutile-Basic

Symbol	Hydrogen content, ml/100 g deposited weld metal, max.
H5	5
H10	10
H15	15

Symbol	Impact Energy Charpy-V Temp °C for 47J min.
Z	No requirements
A	+20
0	0
2	–20
3	–30
4	–40
5	–50
6	–60

Symbol	Chemical composition of all-weld metal, % *		
	Mn	Mo	Ni
No symbol	2.0	–	–
Mo	1.4	0.3 - 0.6	–
MnMo	> 1.4 - 2.0	0.3 - 0.6	–
1Ni	1.4	–	0.6 - 1.2
2Ni	1.4	–	1.8 - 2.6
3Ni	1.4	–	> 2.6 - 3.8
Mn1Ni	> 1.4 - 2.0	–	0.6 - 1.2
1NiMo	1.4	0.3 - 0.6	0.6 - 1.2
Z	Any other agreed composition		

* If not specified Mo < 0.2, Ni < 0.3, Cr < 0.2, V < 0.05, Nb < 0.05, Cu < 0.3
Single values shown in the table mean maximum values.

Figure 16.3 The electrode classification system of EN ISO 2560.

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EN ISO 2560 (supersedes BS EN 499 1994)

Classification of Welding Consumables for Covered Electrodes for Manual Metal Arc (111) Welding of Non-alloy and Fine Grain Steels.

This standard applies a dual approach to classification of electrodes using methods A and B as indicated below:

Classification of electrode mechanical properties of an all weld metal specimen:

Method A: Yield strength and average impact energy at 47J

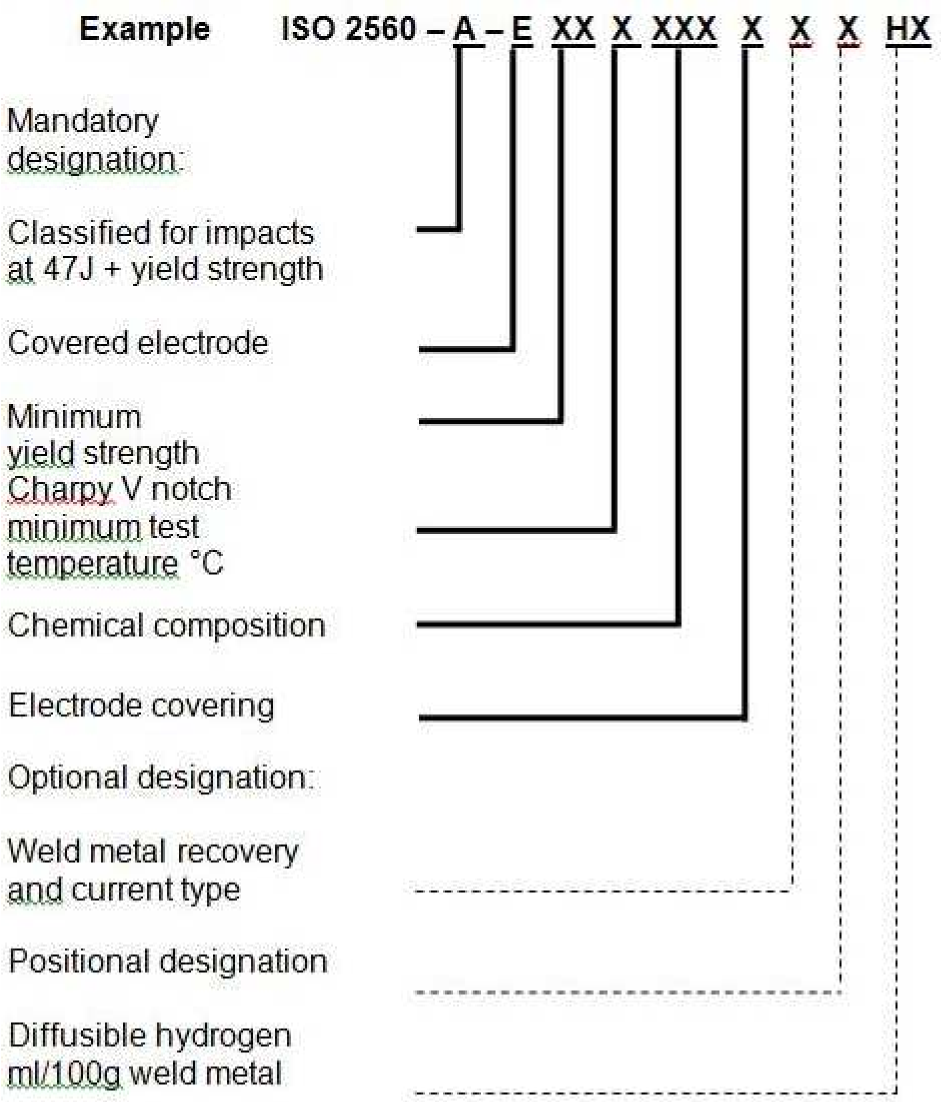

Figure 16.4 Typical example: ISO 2560 – A- E 43 2 1 Ni RR 6 3 H15.

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Method B: Tensile strength and average impact energy at 27J

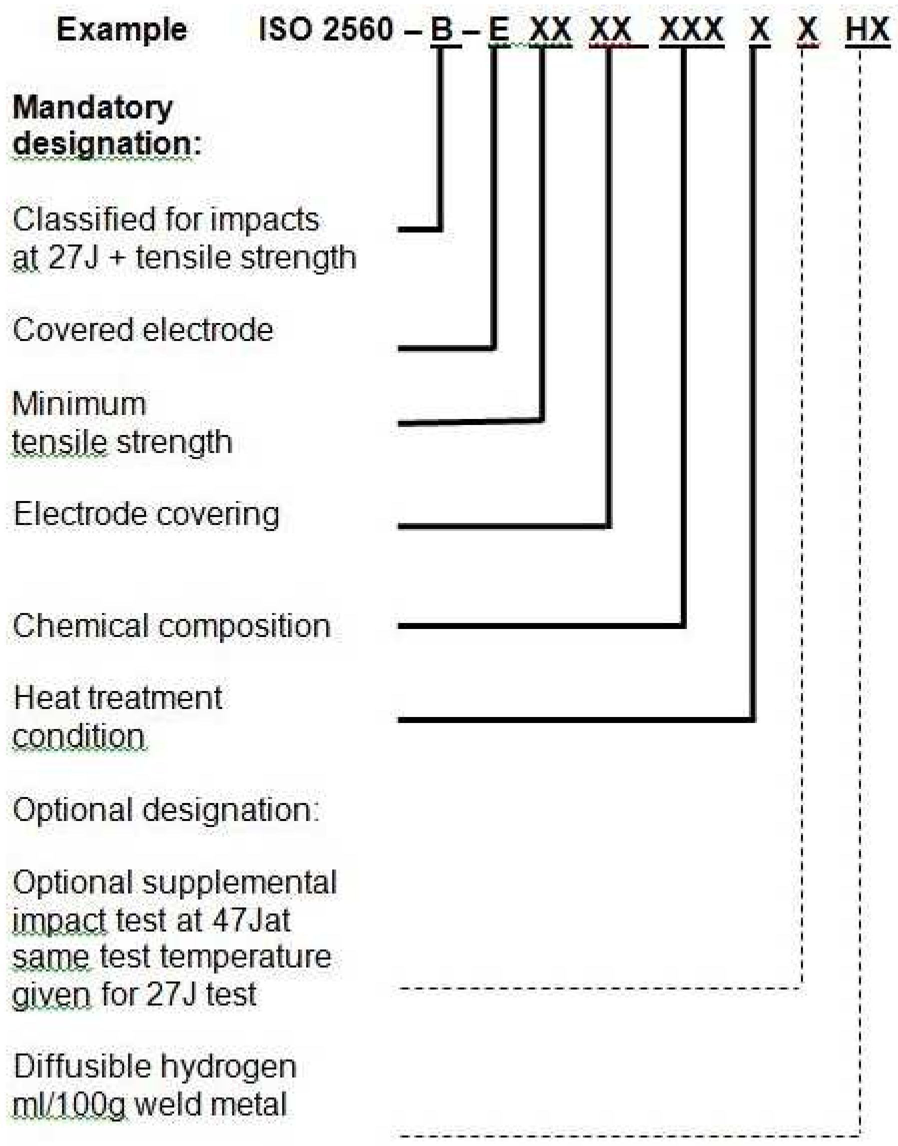

Figure 16.5 Typical example: ISO 2560-B-E55 16-N7 A U H5.

Classification of tensile characteristics

Table 16.2 Classification of tensile characteristics - Method A.

Symbol	Minimum yield N/mm^2	Tensile strength, N/mm^2	Minimum E% b, N/mm^2
35	355	440-570	22
38	380	470-600	20
42	420	500-640	20
46	460	530-680	20
50	500	560-720	18
Lower yield Rel shall be used. b Gauge length = 5 x ∅			

Table 16.3 Classification of tensile characteristics - Method B.

Symbol	Minimum tensile strength, N/mm^2
43	430
49	490
55	550
57	570

Other tensile characteristics ie **yield strength** and **elongation %** are contained within a tabular form in this standard (**Table 8B**) and are determined by classification of tensile strength, electrode covering and alloying elements, ie **E 55 16-N7**.

Classification of impact properties

Table 16.4 Classification of impact properties – Method A.

Symbol	Temperature for the minimum average impact energy of 47J
Z	No requirement
A	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

Method B

Impact or **Charpy V** notch testing temperature at **27J** temperature in method B is determined through the classification of tensile strength, electrode covering and alloying elements (**Table 8B**) ie **E 55 16-N7** which must reach **27J** at **–75°C**.

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Classification of electrode characteristics and electrical requirements varies between classification methods A and B as follows:

Method A

Uses an alpha/numerical designation from the tables as listed below:

Symbol	Electrode covering type	Symbol	Efficiency, %	Type of current
A	Acid	1	< 105	AC or DC
C	Cellulosic	2	<105	DC
R	Rutile	3	>105-<125	AC or DC
RR	Rutile thick covering	4	>105-<125	DC
RC	Rutile/cellulosic	5	>125-<160	AC or DC
RA	Rutile/acid	6	>125-<160	DC
RB	Rutile/basic	7	>160	AC or DC
B	Basic	8	>160	DC

Method B

This method uses a numerical designation from the table as listed below

Symbol	Covering type	Positions	Type of current
03	Rutile/basic	All	AC and DC +/-
10	Cellulosic	All	DC +
11	Cellulosic	All	AC and DC +
12	Rutile	All	AC and DC -
13	Rutile	All	AC and DC +/-
14	Rutile + Fe powder	All	AC and DC +/-
15	Basic	All	DC +
16	Basic	All	AC and DC +
18	Basic + Fe powder	All	AC and DC +
19	Rutile + Fe oxide (Ilmenite)	All	AC and DC +/-
20	Fe oxide	PA/PB	AC and DC -
24	Rutile + Fe powder	PA/PB	AC and DC +/-
27	Fe oxide + Fe powder	PA/PB only	AC and DC -
28	Basic + Fe powder	PA/PB/PC	AC and DC +
40	Not specified	As per manufacturer's recommendations	
48	Basic	All	AC and DC +
All positions may or may not include vertical-down welding			

Further guidance on flux type and applications is given in the standard in Annex B and C.

Hydrogen scales

Diffusible hydrogen is indicated in the same way in both methods, where after baking the amount of hydrogen is given as **ml/100g weld metal** ie **H 5 = 5ml/100g weld metal**.

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16.2 AWS A 5.1- and AWS 5.5-

A typical AWS A5.1 and A5.5 Specification Reference given in box letter:

E 80	1	8	G
A	B	C	D (A.5 only)

A Tensile + yield strength and E%					
Code	Min yield PSI x 1000	Min tensile PSI x 1000	Min E % In 2" min		
General					
E 60xx	48,000	60,000	17-22		
E 70xx	57,000	70,000	17-22		
E 80xx	68-80,000	80,000	19-22		
E 100xx	87,000	100,000	13-16		
Specific electrode information for E 60xx and 70xx				**V notch impact Izod test (ft.lbs)**	**Radiographic standard**
E 6010	48,000	60,000	22	20 ft.lbs at-20°F	Grade 2
E 6011	48,000	60,000	22	20 ft.lbs at-20°F	Grade 2
E 6012	48,000	60,000	17	Not required	Not required
E 6013	48,000	60,000	17	Not required	Grade 2
E 6020	48,000	60,000	22	Not required	Grade 1
E 6022	Not required	60,000	Not required	Not required	Not required
E 6027	48,000	60,000	22	20 ft.lbs at-20°F	Grade 2
E 7014	58,000	70,000	17	Not required	Grade 2
E 7015	58,000	70,000	22	20 ft.lbs at-20°F	Grade 1
E 7016	58,000	70,000	22	20 ft.lbs at-20°F	Grade 1
E 7018	58,000	70,000	22	20 ft.lbs at-20°F	Grade 1
E 7024	58,000	70,000	17	Not required	Grade 2
E 7028	58,000	70,000	20	20 ft.lbs at 0°F	Grade 2

B Welding position	
1	All positional
2	Flat butt and H/V fillet welds
3	Flat only

Note: Not all Category 1 electrodes can weld in the vertical-down position.

C Electrode coating and electrical characteristic		
Code	**Coating**	**Current type**
Exx10	Cellulosic/organic	DC + only
Exx11	Cellulosic/organic	AC or DC+
Exx12	Rutile	AC or DC-
Exx13	Rutile + 30% Fe powder	AC or DC+/-
Exx14	Rutile + Fe powder	AC or DC+/-
Exx15	Basic	DC + only
Exx16	Basic	AC or DC+
Exx18	Basic + 25% Fe powder	AC or DC+
Exx20	High Fe oxide content	AC or DC+/-
Exx24	Rutile + 50% Fe powder	AC or DC+/-
Exx27	Mineral + 50% Fe powder	AC or DC+/-
Exx28	Basic + 50% Fe powder	AC or DC+

D AWS A5.5 low alloy steels	
Symbol	**Approximate alloy deposit**
A1	0.5%Mo
B1	0.5%Cr + 0.5%Mo
B2	1.25%Cr + 0.5%Mo
B3	2.25%Cr + 1.0%Mo
B4	2.0%Cr+ 0.5%Mo
B5	0.5%Cr + 1.0%Mo
C1	2.5%Ni
C2	3.25%Ni
C3	1%Ni + 0.35%Mo + 0.15%Cr
D1/2	0.25-0.45%Mo + 0.15%Cr
G	0.5%Ni or/and 0.3%Cr or/and 0.2%Mo or/and 0.1%V
For G only 1 element is required	

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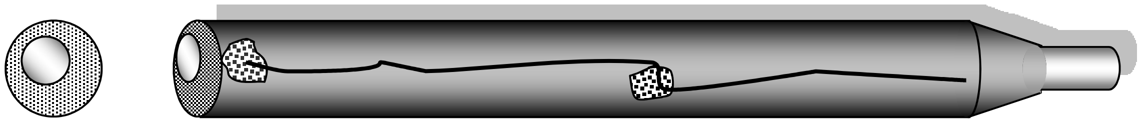
16.3 Inspection points for MMA consumables

Size Wire diameter and length

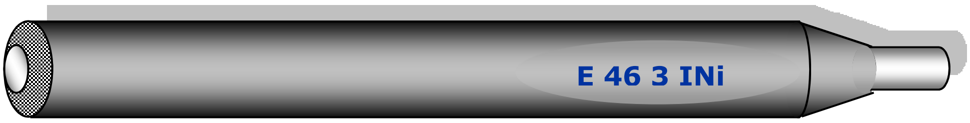
Condition Cracks, chips and concentricity



All electrodes showing signs of the effects of **corrosion** should be **discarded**.

Type (specification)

Correct specification/code



Storage Suitably dry and warm (preferably 0% humidity)

Figure 16.6 Inspection points for MMA consumables.

Checks should also be made to ensure that **basic electrodes** have been through the correct **pre-use procedure**. Having been baked to the correct temperature (typically 300-350°C) for **1 hour** then held in a holding oven (**150°C max**) basic electrodes are issued to welders in **heated quivers**. Most electrode flux coatings deteriorate rapidly when damp so care must be taken to inspect storage facilities to ensure they are adequately dry and that all electrodes are stored in controlled humidity.

Vacuum packed electrodes may be used directly from the carton only if the vacuum has been maintained. Directions for hydrogen control are always given on the carton and should be strictly adhered to. The cost of each electrode is insignificant compared with the cost of any repair, so basic electrodes left in the heated quiver after the day's shift may be rebaked but would normally be discarded to avoid the risk of H_2 induced problems.

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16.4 Consumables for TIG/GTAW

Consumables for TIG/GTAW welding consist of a wire and gas, though tungsten electrodes may also be grouped in this. Though it is considered a non-consumable electrode process, the electrode is consumed by erosion in the arc and by grinding and incorrect welding technique. The wire needs to be of a very high quality as normally no extra cleaning elements can be added to the weld. The wire is refined at the original casting stage to a very high quality where it is then rolled and finally drawn down to the correct size. It is then copper-coated and cut into 1m lengths and a code stamped on the wire with a manufacturer's or nationally recognised number for the correct identification of chemical composition. A grade of wire is selected from a table of compositions and wires are mostly copper-coated which inhibits the effects of corrosion. Gases for TIG/GTA are generally inert and pure argon or helium gases are generally used for TIG welding. The gases are extracted from the air by liquefaction and as argon is more common in air is generally cheaper than helium.

In the US helium occurs naturally so it is the gas more often used. It produces a deeper penetrating arc than argon but is less dense (lighter) than air and needs 2-3 times the flow rate of argon to produce sufficient cover to the weld area when welding downhand. Argon is denser (heavier) than air so less gas needs to be used in the downhand position. Mixtures of argon and helium are often used to balance the properties of the arc and the shielding cover ability of the gas. Gases for TIG/GTAW need to be of the highest purity (99.99%) so careful attention and inspection must be given to the purging and condition of gas hoses as contamination of the shielding gas can occur due to a worn or withered hose.

Tungsten electrodes for TIG welding are generally produced by powder forging technology and contain other oxides to increase their conductivity and electron emission and also affect the characteristics of the arc. They are available off-the-shelf 1.6-10mm diameter. Ceramic shields may also be considered a consumable item as they are easily broken, the size and shape depending mainly on the type of joint design and the diameter of the tungsten.

A particular consumable item that may be used during **TIG welding of pipes** is a **fusible insert** often referred to as an **EB insert** after the **Electric Boat Co of USA** who developed it. The insert is normally made of material matching the pipe base metal composition and is fused into the root during welding as shown below.

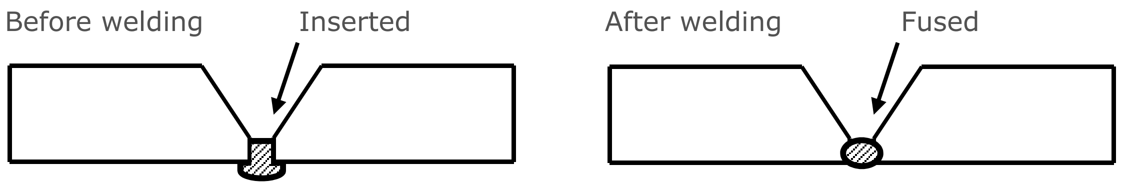

Figure 16.7 TIG fusible insert before welding and after welding.

16.5 Consumables for MIG/MAG

Consumables for MIG/MAG consist of a wire and gas. The wire specifications used for TIG are also used for MIG/MAG as a similar level of quality is required in the wire.

The main purpose of the copper coating of steel MIG/MAG welding wire is to maximise current pick-up at the contact tip and reduce the level of coefficient of friction in the liner with protection against the effects of corrosion being secondary.

Wires are available that have not been copper coated as copper flaking in the liner can cause many wire feed problems. These wires may be coated in a graphite compound, which again increases current pick-up and reduces friction in the liner. Some wires, including many cored wires, are nickel coated.

Wires are available from 0.6-1.6mm diameter with finer wires available on a 1kg reel, though most are supplied on a 15kg drum.

Table 16.5 Common gases and mixtures used for MIG/MAG welding.

Gas type	Process	Used for	Characteristics
Pure argon	MIG	Spray or pulse welding aluminium alloys	Very stable arc with poor penetration and low spatter levels.
Pure CO_2	MAG	Dip transfer welding of steels	Good penetration, unstable arc and high levels of spatter.
Argon + 5-20% CO_2	MAG	Dip spray or pulse welding of steels	Good penetration with a stable arc and low levels of spatter.
Argon + 1-2% O_2 or CO_2	MAG	Spray or pulse welding of austenitic or ferritic stainless steels only	Active additive gives good fluidity to the molten stainless and improves toe blend.

16.6 Consumables for SAW

Consumables for SAW consist of an electrode wire and flux. Electrode wires are normally high quality and for welding C-Mn steels are generally graded on their increasing carbon and manganese content level of de-oxidation.

Electrode wires for welding other alloy steels are generally graded by chemical composition in a table in a similar way to MIG and TIG electrode wires. Fluxes for SAW are graded by their manufacture and composition of which there are two normal methods, **fused** and **agglomerated**.

Fused fluxes

Mixed together and baked at a very high temperature (>1,000ºC) so all the components fuse. When cooled the resultant mass resembles a sheet of coloured glass, which is then pulverised into small particles.

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These particles are hard, reflective, irregularly shaped and cannot be crushed in the hand. It is impossible to incorporate certain alloying compounds, such as ferro-manganese, as these would be destroyed in the high temperatures of manufacturing. Fused fluxes tend to be of the **acidic type** and are fairly tolerant of poor surface conditions, but produce comparatively low quality weld metal in terms of tensile strength and toughness. They are easy to use and produce a good weld contour with an easily detachable slag.

Figure 16.8 Fused flux.

Agglomerated fluxes

A mixture of compounds baked at a much lower temperature and bonded together by bonding agents into small particles. They are dull, generally round granules that are friable (easily crushed) and can also be coloured. Many agents and compounds may be added during manufacture unlike the fused fluxes. Agglomerated fluxes tend to be of the basic type and produce weld metal of an improved quality in terms of strength and toughness, at the expense of usability they are much less tolerant of poor surface conditions and generally produce a slag much more difficult to detach and remove.

Figure 16.9 Agglomerated flux.

The weld metal properties result from using a particular wire with a particular flux in a particular weld sequence so the grading of SAW consumables is given as a function of a **wire/flux combination and welding sequence.**

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A typical grade will give values for:

- Tensile strength.
- Elongation, %.
- Toughness, Joules.
- Toughness testing temperature.

All consumables for SAW (wires and fluxes) should be stored in a dry, humid-free atmosphere. The flux manufacturer's handling/storage instruction and conditions must be very strictly followed to minimise any moisture pick-up. Any re-use of fluxes is totally dependent on applicable clauses within the application standard.

On no account should different types of fluxes be mixed.

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Welding Consumables

Section 16

Materials Joining and Engineering Technologies
Training and Examination Services

Welding Consumables

Welding consumables are any products that are used up in the production of a weld.

Welding consumables may be:

- Covered electrodes, filler wires and electrode wires.
- Shielding or oxy-fuel gases.
- Separately supplied fluxes.
- Fusible inserts.

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Welding Consumable Standards

MMA (SMAW)

- BS EN 2560: Steel electrodes.
- AWS A5.1 Non-alloyed steel electrodes.
- AWS A5.4 Chromium electrodes.
- AWS A5.5 Alloyed steel electrodes.

MIG/MAG (GMAW) TIG (GTAW)

- BS EN ISO 1668: Filler wires .
- BS EN ISO 14341: Wire electrodes.
- AWS A5.9: Filler wires.
- BS EN ISO 14175: Shielding gases.

SAW

- BS EN ISO 14171: Welding consumables; solid wire electrodes, tubular cored electrodes and electrode/flux combinations.
- BS EN ISO 14174: Fluxes.
- AWS A5.17: Wires and fluxes.

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Welding Consumables

Courtesy of ESAB AB

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Welding Consumable Gases

Welding Gases

- GMAW, FCAW, TIG, Oxy-Fuel.
- Supplied in cylinders or storage tanks for large quantities.
- Colour coded cylinders to minimise wrong use.
- Subject to regulations concerned handling, quantities and positioning of storage areas.
- Moisture content is limited to avoid cold cracking.
- Dew point (the temperature at which the vapour begins to condense) must be checked.

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Welding Consumables

Each consumable is critical in respect to:

- Size.
- Classification/supplier.
- Condition.
- Treatments eg baking/drying.
- Handling and storage is critical for consumable control.
- Handling and storage of gases is critical for safety.

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Quality Assurance

Welding Consumables:

- Filler material must be stored in an area with controlled temperature and humidity.
- Poor handling and incorrect stacking may damage coatings, rendering the electrodes unusable.
- There should be an issue and return policy for welding consumables (system procedure).
- Control systems for electrode treatment must be checked and calibrated; those operations must be recorded.
- Filler material suppliers must be approved before purchasing any material.

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Welding Consumables

MMA Covered Electrodes

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MMA Welding Consumables

Welding consumables for MMA:

- Consist of a core wire typically between 350-450mm in length and from 2.5-6mm in diameter.
- The wire is covered with an extruded flux coating.
- The core wire is generally of a low quality rimming steel.
- The weld quality is refined by the addition of alloying and refining agents in the flux coating.
- The flux coating contains many elements and compounds that all have a variety of functions during welding.

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MMA Welding Consumables

Function of the Electrode Covering:

- To facilitate arc ignition and give arc stability.
- To generate gas for shielding the arc and molten metal from air contamination.
- To de-oxidise the weld metal and flux impurities into the slag.
- To form a protective slag blanket over the solidifying and cooling weld metal.
- To provide alloying elements to give the required weld metal properties.
- To aid positional welding (slag design to have suitable freezing temperature to support the molten weld metal).
- To control hydrogen contents in the weld (basic type).

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MMA Welding Consumables

The three main electrode covering types used in MMA welding:

1. Cellulosic - deep penetration/fusion.
2. Rutile - general purpose.
3. Basic - low hydrogen.

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MMA Welding Consumables

Courtesy of Lincoln Electric

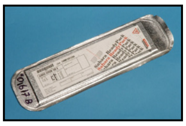
Plastic foil sealed cardboard box

- Rutile electrodes.
- General purpose basic electrodes.

Tin can

- Cellulosic electrodes.

Courtesy of Lincoln Electric



Vacuum sealed pack

- Extra low hydrogen electrodes.

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MMA Welding Consumables

Cellulosic electrodes:
- Covering contains cellulose (organic material).
- Produce a gas shield high in hydrogen raising the arc voltage.
- Deep penetration/fusion characteristics enables welding at high speed without risk of lack of fusion.
- Generates high level of fumes and H2 cold cracking.
- Forms a thin slag layer with coarse weld profile.
- Not require baking or drying (excessive heat will damage electrode covering).
- Mainly used for stove pipe welding.
- Hydrogen content is 80-90 ml/100g of weld metal.

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MMA Welding Consumables

Cellulosic electrodes

Disadvantages:
- Weld beads have high hydrogen.
- Risk of cracking (need to keep joint hot during welding to allow H to escape).
- Not suitable for higher strength steels - cracking risk too high (may not be allowed for Grades stronger than X70).
- Not suitable for very thick sections (may not be used on thicknesses > ~ 35mm).
- Not suitable when low temperature toughness is required (impact toughness satisfactory down to ~ -20°C).

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MMA Welding Consumables

Cellulosic electrodes

Advantages:
- Deep penetration/fusion.
- Suitable for welding in all positions.
- Fast travel speeds.
- Large volumes of shielding gas.
- Low control.

Disadvantages:
- High in hydrogen.
- High crack tendency.
- Rough weld appearance.
- High spatter contents.
- Low deposition rates.

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MMA Welding Consumables

Rutile electrodes:
- Covering contains TiO_2 slag former and arc stabiliser.
- Easy to strike arc, less spatter, excellent for positional welding.
- Stable, easy-to-use arc can operate in both DC and AC.
- Slag easy to detach, smooth profile.
- Reasonably good strength weld metal.
- Used mainly on general purpose work.
- Low pressure pipework, support brackets.
- Electrodes can be dried to lower H2 content but cannot be baked as it will destroy the coating.
- Hydrogen content is 25-30 ml/100g of weld metal.

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MMA Welding Consumables

Rutile electrodes

Disadvantages:
- They cannot be made with a low hydrogen content.
- Cannot be used on high strength steels or thick joints - cracking risk too high.
- They do not give good toughness at low temperatures.
- These limitations mean that they are only suitable for general engineering - low strength, thin steel.

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MMA Welding Consumables

Rutile electrodes

Advantages:
- Easy to use.
- Low cost/control.
- Smooth weld profiles.
- Slag easily detachable.
- High deposition possible with the addition of iron powder.

Disadvantages:
- High in hydrogen.
- High crack tendency.
- Low strength.
- Low toughness values.

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MMA Welding Consumables

High recovery rutile electrodes

Characteristics:
- Coating is bulked out with iron powder.
- Iron powder gives the electrode high recovery.
- Extra weld metal from the iron powder can mean that weld deposit from a single electrode can be as high as 180% of the core wire weight.
- Give good productivity.
- Large weld beads with smooth profile can look very similar to SAW welds.

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MMA Welding Consumables

High recovery rutile electrodes

Disadvantages:
- Same as standard rutile electrodes with respect to hydrogen control.
- Large weld beads produced cannot be used for all-positional welding.
- The very high recovery types usually limited to PA and PB positions.
- More moderate recovery may allow PC use.

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MMA Welding Consumables

Basic covering:
- Produce convex weld profile and difficult to detach slag.
- Very suitable for for high pressure work, thick section steel and for high strength steels.
- Prior to use electrodes should be baked, typically 350°C for 2 hour plus to reduce moisture to very low levels and achieve low hydrogen potential status.
- Contain calcium fluoride and calcium carbonate compounds.
- Cannot be rebaked indefinitely!
- Low hydrogen potential gives weld metal very good toughness and YS.
- Have the lowest level of hydrogen (less than 5ml/100g of weld metal).

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MMA Welding Consumables

Basic electrodes

Disadvantages:
- Careful control of baking and/or issuing of electrodes is essential to maintain low hydrogen status and avoid risk of cracking.
- Typical baking temperature 350°C for 1 to 2hours.
- Holding temperature 120-150°C.
- Issue in heated quivers typically 70°C.
- Welders need to take more care/require greater skill.
- Weld profile usually more convex.
- Deslagging requires more effort than for other types.

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Basic Electrodes

Advantages:
- High toughness values.
- Low hydrogen contents.
- Low crack tendency.

Disadvantages:
- High cost.
- High control.
- High welder skill required.
- Convex weld profiles.
- Poor stop/start properties.

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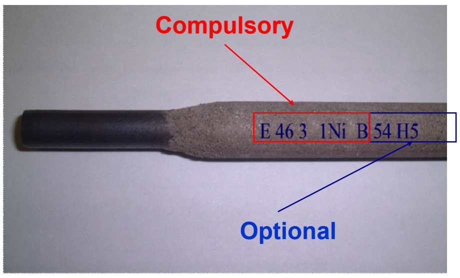
BS EN 2560 MMA Covered Electrodes



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BS EN 2560 MMA Covered Electrodes

E 50 3 2Ni B 7 2 H10

- E – Covered electrode
- 50 – Yield strength N/mm²
- 3 – Toughness
- 2Ni – Chemical composition
- B – Flux covering
- 7 – Weld metal recovery and current type
- 2 – Welding position
- H10 – Hydrogen content

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BS EN 2560 MMA Covered Electrodes

Electrodes classified as follows:

- **E 35 - Minimum yield strength 350 N/mm²**
  Tensile strength 440 - 570 N/mm²
- **E 38 - Minimum yield strength 380 N/mm²**
  Tensile strength 470 - 600 N/mm²
- **E 42 - Minimum yield strength 420 N/mm²**
  Tensile strength 500 - 640 N/mm²
- **E 46 - Minimum yield strength 460 N/mm²**
  Tensile strength 530 - 680 N/mm²
- **E 50 - Minimum yield strength 500 N/mm²**
  Tensile strength 560 - 720 N/mm²

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BS EN 2560 Electrode Designation

Recovery and type of current designation

Symbol	Weld metal recovery (%)	Type of current
1	≤105	AC/DC
2	≤105	DC
3	>105 ≤125	AC/DC
4	>105 ≤125	DC
5	>125 ≤160	AC/DC
6	>125 ≤160	DC
7	>160	AC/DC
8	>160	DC

Welding position designation

Symbol	Welding position
1	All positions
2	All positions except vertical down
3	Flat butt/fillet, horizontal fillet
4	Flat butt/fillet
5	Flat butt/fillet, horizontal fillet, vertical down

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AWS A5.1 Alloyed Electrodes

E 60 1 3

- E – Covered electrode
- 60 – Tensile strength (p.s.i)
- 1 – Welding position
- 3 – Flux covering

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AWS A5.5 Alloyed Electrodes

E 70 1 8 M G

- E – Covered Electrode
- 70 – Tensile Strength (p.s.i)
- 1 – Welding Position
- 8 – Flux Covering
- M – Moisture Control
- G – Alloy Content

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MMA Welding Consumables

Types of electrodes (for C, C-Mn Steels)

	BS EN 2560	AWS A5.1
Cellulosic	E XX X C	EXX10 EXX11
Rutile	E XX X R	EXX12 EXX13
Rutile Heavy Coated	E XX X RR	EXX24
Basic	E XX X B	EXX15 EXX16 EXX18

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AWS A5.1 and A5.5 Alloyed Electrodes

Example AWS electrode flux types:

- **Cellulosic:** Flux-ends in 0 - 1
  Examples: E601**0**, E601**1**, E701**0**, E801**1**
- **Rutile:** Flux-ends in 2 - 3 - 4
  Examples: E501**2**, E601**2**, E601**3**, E601**4**
- **Basic:** Flux-ends in 5 - 6 - 7 - 8
  Examples: E601**6**, E701**7**, E801**8**, E901**8**

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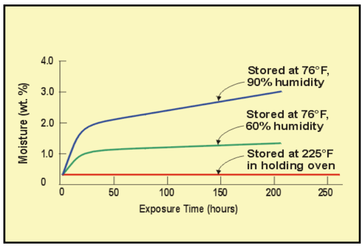
Moisture Pick-Up



Moisture pick-up as a function of:

- Temperature.
- Humidity.

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Electrode Efficiency

up to 180% for iron powder electrodes

$$\text{Electrode Efficiency} = \frac{\text{Mass of weld metal deposited}}{\text{Mass of core wire melted}}$$

75-90% for usual electrodes

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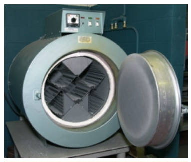
Covered Electrode Treatment

Baking oven:

- Need temperature control.
- Requires calibration.



Heated quivers:

- For maintaining moisture out of electrodes when removed from the holding oven ie on site.

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Covered Electrode Treatment

Cellulosic electrodes → Use straight from the box - No baking/drying!

Rutile electrodes → If necessary, dry up to 120°C- No baking!

Vacuum packed basic electrodes → Use straight from the pack within 4 hours - No rebaking!

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Covered Electrode Treatment

Basic electrodes → Baking in oven 2 hours at 350°C!

After baking, maintain in oven at 150°C

Use from quivers at 75°C → Weld

If not used within 4 hours, return to oven and rebake!

Limited number of rebakes!

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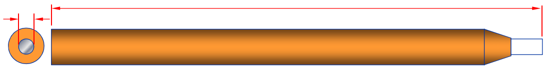
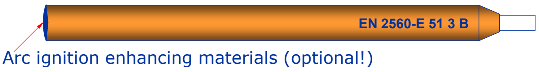
Covered Electrode Treatment

1. **Electrode size (diameter and length).**



2. **Covering condition: adherence, cracks, chips and concentricity.**

3. **Electrode designation.**



Arc ignition enhancing materials (optional!)

See BS EN ISO 544 for further information

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Any Questions

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Welding Consumables

TIG Consumables

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TIG Welding Consumables

Welding consumables for TIG:

- Filler wires, Shielding gases, tungsten electrodes (non-consumable).
- Filler wires of different materials composition and variable diameters available in standard lengths, with applicable code stamped for identification.
- Steel Filler wires of very high quality, with copper coating to resist corrosion.
- Shielding gases mainly Argon and Helium, usually of highest purity (99.9%).

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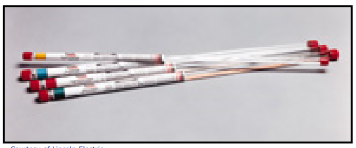
TIG Welding Consumables

Welding rods:

- Supplied in cardboard/plastic tubes.



Courtesy of Lincoln Electric

- Must be kept clean and free from oil and dust.
- Might require degreasing.

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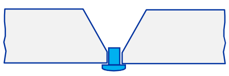
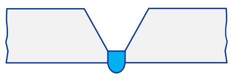
Fusible Inserts

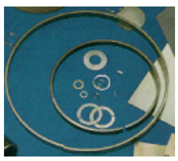
Pre-placed filler material



Before Welding



After Welding



Other terms used include:

- EB inserts (Electric Boat Company).
- Consumable socket rings (CSR).

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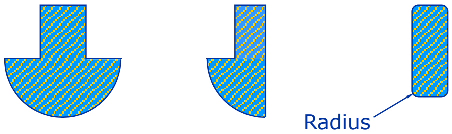
Fusible Inserts

Consumable inserts:

- Used for root runs on pipes.
- Used in conjunction with TIG welding.
- Available for carbon steel, Cr-Mo steel, austenitic stainless steel, nickel and copper-nickel alloys.
- Different shapes to suit application.



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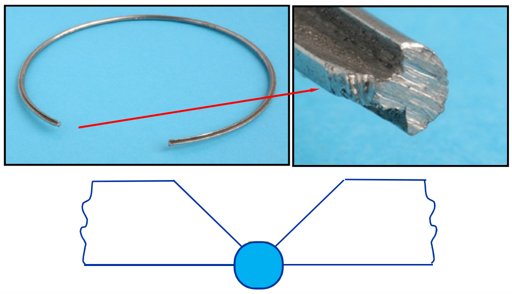
Fusible Inserts

Application of consumable inserts



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Shielding Gases for TIG Welding

Argon

- Low cost and greater availability.
- Heavier than air - lower flow rates than Helium.
- Low thermal conductivity - wide top bead profile.
- Low ionisation potential - easier arc starting, better arc stability with AC, cleaning effect.
- For the same arc current produce less heat than helium - reduced penetration, wider HAZ.
- To obtain the same arc power, argon requires a higher current - increased undercut.

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Shielding Gases for TIG Welding

Helium

- Costly and lower availability than Argon.
- Lighter than air - requires a higher flow rate compared with argon (2-3 times).
- Higher ionisation potential - poor arc stability with AC, less forgiving for manual welding.
- For the same arc current produce more heat than argon - increased penetration, welding of metals with high melting point or thermal conductivity.
- To obtain the same arc power, helium requires a lower current - no undercut.

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Shielding Gases for TIG Welding

Hydrogen

- Not an inert gas - not used as a primary shielding gas.
- Increase the heat input - faster travel speed and increased penetration.
- Better wetting action - improved bead profile.
- Produce a cleaner weld bead surface.
- Added to argon (up to 5%) - only for austenitic stainless steels and nickel alloys.
- Flammable and explosive.

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Shielding Gases for TIG Welding

Nitrogen

- Not an inert gas.
- High availability – cheap.
- Added to argon (up to 5%) - only for back purge for duplex stainless, austenitic stainless steels and copper alloys.
- Not used for mild steels (age embrittlement).
- Strictly prohibited in case of Ni and Ni alloys (porosity).

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Any Questions

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Welding Consumables

MIG/MAG Consumables

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MIG/MAG Welding Consumables

Welding consumables for MIG/MAG

- Spools of Continuous electrode wires and shielding gases.
- variable spool size (1-15Kg) and Wire diameter (0.6-1.6mm) supplied in random or orderly layers.
- Basic Selection of different materials and their alloys as electrode wires.
- Some Steel Electrode wires copper coating purpose is corrosion resistance and electrical pick-up.
- Gases can be pure CO_2, CO_2+Argon mixes and Argon+2%O_2 mixes (stainless steels).

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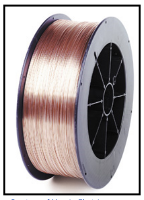
MIG/MAG Welding Consumables

Welding wires:

- Supplied on wire/plastic spools or coils.
- Random or line winding.



Courtesy of Lincoln Electric

Plastic spool

Courtesy of Lincoln Electric

Wire spool

Courtesy of Lincoln Electric

Coil

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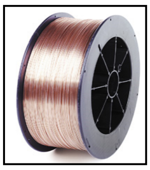
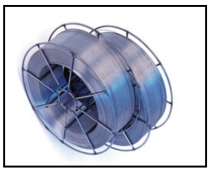
MIG/MAG Welding Consumables

Welding wires:

- Carbon and low alloy wires may be copper coated.
- Stainless steel wires are not coated.



Courtesy of Lincoln Electric



Courtesy of ESAB AB

- Wires must be kept clean and free from oil and dust.
- Flux cored wires does not require baking or drying.

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MIG/MAG Welding Consumables

Wire designation acc BS EN 14341:

Type of shielding gas

Tensile properties

Standard number

BS EN 14341 - G 46 3 M G3Si1

Weld deposit produced by gas shielded metal arc welding

Impact properties

Type of wire electrode

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MIG/MAG Welding Consumables

Wire designation acc AWS A-5.18:

Chemical composition of the solid wire or of the weld metal in case of composite electrodes

Minimum UTS of weld metal (ksi)

Standard number

AWS A-5.18 ER 70 S-6

Designate an electrode/rod (ER) or only an electrode (E)

Solid (S) or composite (C) wire

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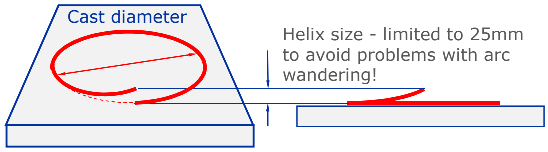
MIG/MAG Welding Consumables

How to check the quality of welding wires:



Cast diameter improves the contact force and defines the contact point; usually 400-1200mm.

Contact point close to contact tip end - GOOD!

Contact point remote from contact tip end - POOR!

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MIG/MAG Shielding Gases

Gas shielded metal arc welding

- MIG process (131)
- MAG process (135)

BS EN 14175

- Group I - Ar, He and Ar-He mixtures
- Group R - Ar + H_2 (<35%)
- Group M - Ar + CO_2/O_2 (<50/15%)
- Group C - CO_2, CO_2 + O_2 (<30%)

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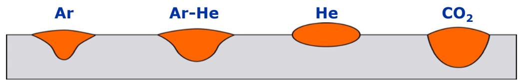
MIG/MAG Shielding Gases



Argon (Ar):
Higher density than air; low thermal conductivity - the arc has a high energy inner cone; good wetting at the toes; low ionisation potential.
Helium (He):
Lower density than air; high thermal conductivity - uniformly distributed arc energy; parabolic profile; high ionisation potential.
Carbon Dioxide (CO_2):
Cheap; deep penetration profile; cannot support spray transfer; poor wetting; high spatter.

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MIG/MAG Shielding Gases

Gases for dip transfer:

- CO_2: Carbon steels only; deep penetration; fast welding speed; high spatter levels.
- Ar + up to 25% CO_2: Carbon and low alloy steels; minimum spatter; good wetting and bead contour.
- 90% He + 7,5% Ar + 2,5% CO_2: Stainless steels; minimises undercut; small HAZ.
- Ar: Al, Mg, Cu, Ni and their alloys on thin sections.
- Ar + He mixtures: Al, Mg, Cu, Ni and their alloys on thicker sections (over 3mm).

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MIG/MAG Shielding Gases

Gases for spray transfer

- Ar + (5-18)% CO_2: Carbon steels; minimum spatter; good wetting and bead contour.
- Ar + 2% O_2: Low alloy steels; minimise undercut; provides good toughness.
- Ar + 2% O2 or CO_2: Stainless steels; improved arc stability; provides good fusion.
- Ar: Al, Mg, Cu, Ni, Ti and their alloys.
- Ar + He mixtures: Al, Cu, Ni and their alloys; hotter arc than pure Ar to offset heat dissipation.
- Ar + (25-30)% N_2: Cu alloys; greater heat input.

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Welding Consumables

Flux Core Wire Consumables

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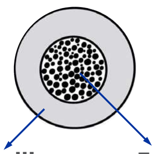
Flux Core Wire Consumables



Functions of metallic sheath:

- Provide form stability to the wire.
- Serves as current transfer during welding.

Function of the filling powder:

- Stabilise the arc.
- Add alloy elements.
- Produce gaseous shield.
- Produce slag.
- Add iron powder.

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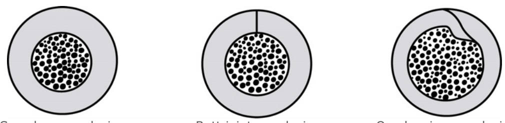
Types of Cored Wire



Seamless cored wire

- Not sensitive to moisture pick-up.
- Can be copper coated - better current transfer.
- Thick sheath → good form stability - 2 roll drive feeding possible.
- Difficult to manufacture.

Butt joint cored wire

- Good resistance to moisture pick-up.
- Can be copper coated.
- Thick sheath.
- Difficult to seal the sheath.

Overlapping cored wire

- Sensitive to moisture pick-up.
- Cannot be copper coated.
- Thin sheath.
- Easy to manufacture.

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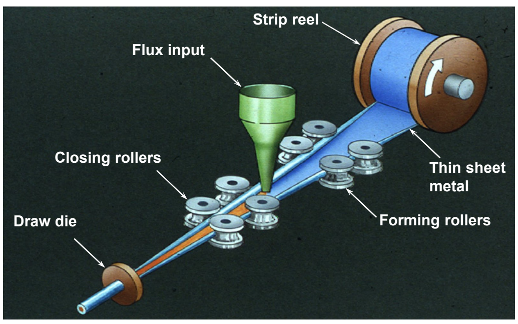
Cored Wire Manufacturing Process



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Core Elements and Their Function

- **Aluminium** - deoxidize and denitrify.
- **Calcium** - provide shielding and form slag.
- **Carbon** - increase hardness and strength.
- **Manganese** - deoxidize and increase strength and toughness.
- **Molybdenum** - increase hardness and strength.
- **Nickel** - improve hardness, strength, toughness and corrosion resistance.
- **Potassium** - stabilize the arc and form slag.
- **Silicon** - deoxidize and form slag.
- **Sodium** - stabilize arc and form slag.
- **Titanium** - deoxidize, denitrify and form slag.

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FCAW Wire Designation

Wire designation acc. BS EN 17632:

BS EN 17632 - T 46 3 1Ni B M 4 H5

- Diffusible hydrogen content (optional)
- Shielding gas
- Light alloy additions
- Tensile properties
- Standard number
- Tubular cored electrode
- Impact properties
- Type of electrode core
- Welding position (optional)

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FCAW Wire Designation

Wire designation acc AWS A-5.20:

E 71 T-6 M J H8

- 27J at -40°C requirement (optional)
- Electrode usability (polarity, shielding and KV); can range from 1 to 14
- Welding position (0 - F/H only; 1- all positions)
- Designates an electrode
- Minimum UTS of weld metal (ksi x 10)
- Flux cored electrode
- Shielding gas for classification
- Diffusible hydrogen content (optional); can be 4, 8 or 16

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Any Questions

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Welding Consumables

SAW Consumables

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SAW Filler Material

Wire/flux combination designation acc. BS EN 14171:

BS EN 14171 S46 3 AB S2

- Type of welding flux
- Tensile properties
- Standard number
- Wire electrode and/or wire/flux combination
- Impact properties
- Chemical composition of wire electrode

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SAW Filler Material

Wire/flux combination designation acc. AWS A-5.17:

AWS A-5.17 F 6 A 2-EM12K

- Temperature for impact test
- Minimum UTS of weld metal (10 ksi)
- Standard number
- SAW welding flux
- Heat treatment conditions
- Chemical composition of wire electrode

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SAW Filler Material

Welding wires

- Supplied on coils, reels or drums.
- Random or line winding.

Courtesy of Lincoln Electric

Coil (approx. 25 kg)

Courtesy of Lincoln Electric

Reel (approx. 300 kg)

Courtesy of ESAB AB

Drum (approx. 450 kg)

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SAW Filler Material

Welding wires can be used to weld:

- Carbon steels.
- Low alloy steels.
- Creep resisting steels.
- Stainless steels.
- Nickel-base alloys.
- Special alloys for surfacing applications.

Welding wires can be:

- Solid wires.
- Metal-cored wires.

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SAW Filler Material

Welding wires:

- Carbon and low alloy wires are copper coated.
- Stainless steel wires are not coated.

Courtesy of Lincoln Electric

Courtesy of Lincoln Electric

- Wires must be kept clean and free from oil and dust.

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SAW Filler Material

Copper coating functions:

- To assure a good electric contact between wire and contact tip.
- To assure a smooth feed of the wire through the guide tube, feed rolls and contact tip (decrease contact tube wear).
- To provide protection against corrosion.

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SAW Consumables

Welding fluxes:

- Are granular mineral compounds mixed according to various formulations.
- Shield the molten weld pool from the atmosphere.
- Clean the molten weld pool.
- Can modify the chemical composition of the weld metal.
- Prevents rapid escape of heat from welding zone.
- Influence the shape of the weld bead (wetting action).
- Can be fused, agglomerated or mixed.
- Must be kept warm and dry to avoid porosity.

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SAW Consumables

Welding flux:

- Supplied in bags/pails (approx. 25kg) or bulk bags (approx. 1200kg).
- Might be fused, agglomerated or mixed.

Courtesy of Lincoln Electric

Courtesy of Lincoln Electric

Courtesy of Lincoln Electric

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SAW Consumables

Welding flux:

- Might be fused or agglomerated.
- Supplied in bags.
- Must be kept warm and dry.
- Handling and stacking requires care.

Courtesy of Lincoln Electric

- Fused fluxes are normally not hygroscopic but particles can hold surface moisture so only drying.
- Agglomerated fluxes contain chemically bonded water. Similar treatment as basic electrodes.
- If flux is too fine it will pack and not feed properly. It cannot be recycled indefinitely.

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SAW Consumables

SA Welding flux:

- Must be kept warm and dry.
- Handling and stacking requires care.

Fused fluxes are normally not hygroscopic but particles can hold surface moisture.

- Only drying.

Agglomerated fluxes contain chemically bonded water.

- Similar treatment as basic electrodes.
- For high quality, agglomerated fluxes can be recycled with new flux added.
- If flux is too fine it will pack and not feed properly.
- Cannot be recycled indefinitely.

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SAW Consumables

Fused flux

- Flaky appearance.
- Lower weld quality.
- Low moisture intake.
- Low dust tendency.
- Good re-cycling.
- Very smooth weld profile.

Fused flux:

Baked at high temperature, glossy, hard and black in colour, cannot add ferro-manganese, non moisture absorbent and tends to be of the acidic type.

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SAW Consumables

Fused welding fluxes

Components are dry mixed. → Components are melted in an electric furnace. → Charge is cooled by:

- Shooting the melt through a stream of water.
- Pouring melt onto large chill blocks.

→ Product is crushed and screened for size.

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SAW Consumables

Fused fluxes advantages:

- Good chemical homogeneity.
- Easy removal of fines without affecting flux composition.
- Normally not hygroscopic → easy storage and handling.
- Readily recycled without significant change in particle size or composition.

Fused fluxes disadvantages:

- Difficult to add deoxidizers and ferro-alloys (due to segregation or extremely high loss).
- High temperatures needed to melt ingredients limit the range of flux compositions.

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SAW Consumables

Agglomerated flux

- Granulated appearance.
- High weld quality.
- Addition of alloys.
- Lower consumption.
- Easy slag removal.
- Smooth weld profile

Agglomerated flux:

Baked at a lower temperature, dull, irregularly shaped, friable, (easily crushed) can easily add alloying elements, moisture absorbent and tend to be of the basic type.

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SAW Consumables

Agglomerated welding fluxes

Components are powdered and dry mixed. → Components are bonded. → The wet mix is pelletized. → Pellets are baked. → Pellets are broken up and screened for size.

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SAW Consumables

Agglomerated fluxes advantages:

- Easy addition of deoxidizers and alloying elements.
- Usable with thicker layer of flux when welding.
- Colour identification.

Agglomerated fluxes disadvantages:

- Tendency to absorb moisture.
- Possible gas evolution from the molten slag leading to porosity.
- Possible change in flux composition due to segregation or removal of fine mesh particles.

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SAW Consumables

Mixed fluxes

Two or more fused or bonded fluxes are mixed in any ratio necessary to yield the desired results.

Mixed fluxes advantages:

Several commercial fluxes may be mixed for highly critical or proprietary welding operations.

Mixed fluxes disadvantages:

- Segregation of the combined fluxes during shipment, storage and handling.
- Segregation occurring in the feeding and recovery systems during welding.
- Inconsistency in the combined flux from mix to mix.

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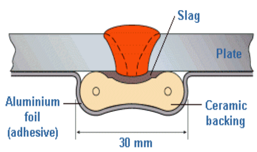
Ceramic Backing

Ceramic backing:

- Used to support the weld pool on root runs.
- Usually fitted on an aluminium self adhesive tape.



- Allow increased welding current without danger of burn-through → increased productivity, consistent quality.
- Different profiles to suit different applications.
- No backing/drying required.

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Questions

Welding consumables:

- QU 1: Why are basic electrodes used mainly on high strength materials and what controls are required when using basic electrodes?
- QU 2: What standard is the following electrode classification taken from and briefly discuss each separate part of the coding? E 80 18 M
- QU 3: Why are cellulose electrodes commonly used for the welding of pressure pipe lines?
- QU 4: Give a brief description of fusible insert and state two alterative names given for the insert?
- QU 5: What standard is the following electrode classification taken from, and briefly discuss each separate part of the coding?
  E 42 3 1Ni B 4 2 H10

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CSWIP 3.1 Welding Inspector

Inspection and Validation

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Inspection of Consumables

Why? To assess whether the products are in compliance with the requirements of the order or not - see BS EN 10204.

How?

Non-specific inspection

- Carried out by the manufacturer in accordance with its own procedures.
- The products inspected are NOT necessarily the products supplied!

Specific inspection

- Carried out before delivery in accordance to product specification.
- Inspection is performed on the products to be supplied or on test units of which the products supplied are part.

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BS EN 10204 - Type of Documents

Non-specific inspection documents

Type 2.1

- **Name:** Declaration of compliance with the order.
- **Content:** statement of compliance with the order (doesn't include test results!)
- **Who validate it** - the manufacturer.

Type 2.2

- **Name:** Test report.
- **Content:** statement of compliance with the order (include test results!)
- **Who validate it** - the manufacturer.

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BS EN 10204 - Type of Documents

Specific inspection documents

Type 3.1

- **Name:** Inspection certificate 3.1.
- **Content:** statement of compliance with the order (include specific test results!)
- **Who validate it** - the manufacturer inspection (independent of manufacturing department!)

Type 3.2

- **Name:** Inspection certificate 3.2
- **Content:** statement of compliance with the order (include specific test results!)
- **Who validate it** - the manufacturer inspection (independent of manufacturing department!) + purchaser's/official designated authorised inspector.

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Any Questions

?

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Section 17

Weldability of Steels

17 Weldability of Steels

17.1 Introduction

Weldability simply means the ability to be welded and many types of weldable steel have been developed for a wide range of applications.

The ease or difficulty of making a weld with suitable properties and free from defects determines whether steels are considered as having good or poor weldability. A steel is usually said to have poor weldability if it is necessary to take special precautions to avoid a particular type of imperfection. Another reason for poor weldability may be the need to weld within a very narrow range of parameters to achieve properties required for the joint.

17.2 Factors that affect weldability

A number of inter-related factors determine whether a steel has good or poor weldability:

- Actual chemical composition.
- Weld joint configuration.
- Welding process to be used.
- Properties required from the weldment.

For steels with poor weldability it is particularly necessary to ensure that:

- WPSs give welding conditions that do not cause cracking but achieve the specified properties.
- Welders work strictly in accordance with the specified welding conditions.
- Welding inspectors regularly monitor welders to ensure they are working strictly in accordance with the WPSs.

Having a good understanding of the characteristics, causes and ways of avoiding imperfections in steel weldments should enable welding inspectors to focus attention on the most influential welding parameters when steels with poor weldability are used.

17.3 Hydrogen cracking

During fabrication by welding, cracks can occur in some types of steel due to the presence of hydrogen, the technical name is hydrogen induced cold cracking (HICC) but is often referred to by names that describe various characteristics of hydrogen cracks:

Cold cracking	Cracks occur when the weld has cooled down.
HAZ cracking	Cracks occur mainly in the HAZ.
Delayed cracking	Cracks may occur some time after welding has finished (possibly up to ~72h).
Underbead cracking	Cracks occur in the HAZ beneath a weld bead.

Although most hydrogen cracks occur in the HAZ, there are circumstances when they may form in weld metal.

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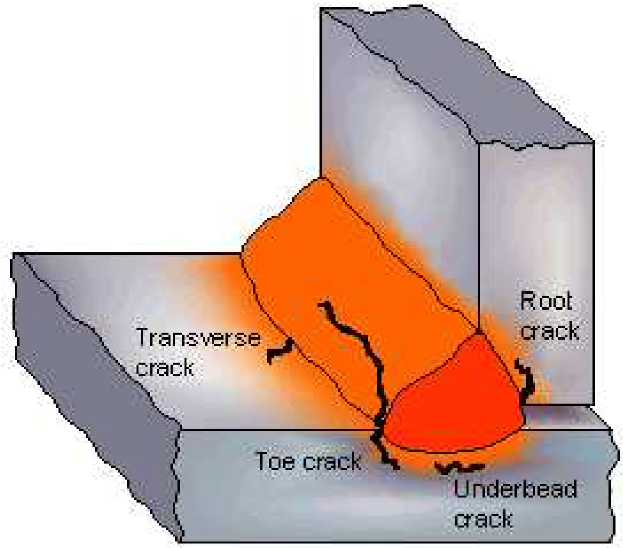

Figure 17.1 Typical locations of hydrogen induced cold cracks.

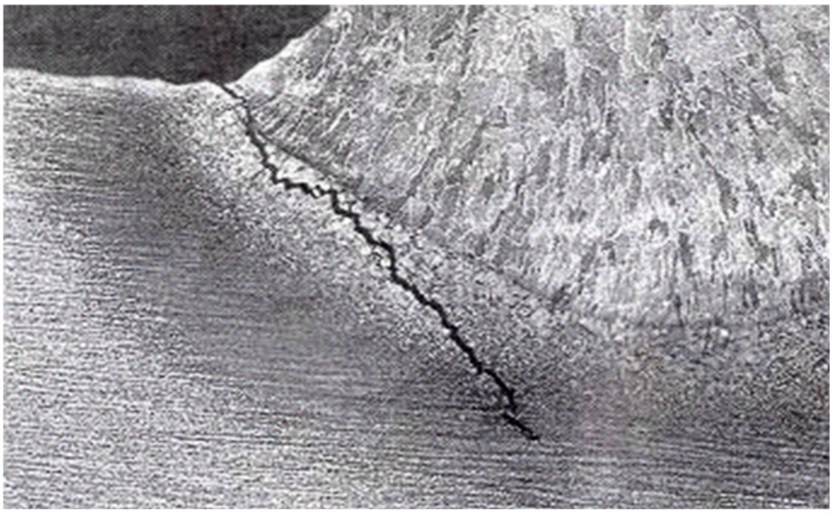

Figure 17.2 Hydrogen induced cold crack that initiated at the HAZ at the toe of a fillet weld.

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17.3.1 Factors influencing susceptibility to hydrogen cracking

Hydrogen cracking in the HAZ of a steel occurs when four conditions exist at the same time:

Hydrogen level	>15ml/100g of weld metal deposited
Stress	>0.5 of the yield stress
Temperature	<300°C
Susceptible microstructure	>400HV hardness

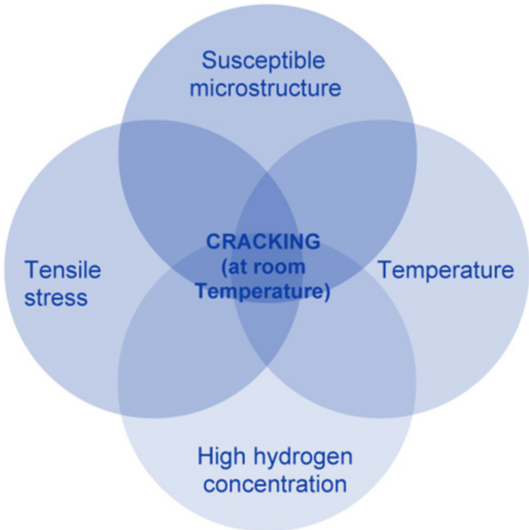

Figure 17.3 Factors susceptibility to hydrogen cracking.

These four factors are mutually interdependent so the influence of one condition (its active level) depends on how active the other three are.

17.3.2 Cracking mechanism

Hydrogen (H) can enter the molten weld metal when hydrogen-containing molecules are broken down into H atoms in the welding arc.

Because H atoms are very small they can move about (diffuse) in solid steel and while weld metal is hot can diffuse to the weld surface and escape into the atmosphere.

However, at lower temperatures H cannot diffuse as quickly and if the weldment cools down quickly to ambient temperature H will become trapped, usually in the HAZ.

If the HAZ has a susceptible microstructure, indicated by being relatively hard and brittle and there are also relatively high tensile stresses in the weldments, then H cracking can occur.

The precise mechanism that causes cracks to form is complex but H is believed to cause embrittlement of regions of the HAZ so that high localised stresses cause cracking rather than plastic straining.

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17.3.3 Avoiding HAZ hydrogen cracking

Because the factors that cause cracking are interdependent and each must be at an active level at the same time, cracking can be avoided by ensuring that at least one of the factors is not active during welding.

Methods to minimise the influence of each of the four factors are considered in the following sub-sections.

Hydrogen

The main source of hydrogen is moisture (H_2O) and the principal source is being welding flux. Some fluxes contain cellulose and this can be a very active source of hydrogen.

Welding processes that do not require flux can be regarded as low hydrogen processes.

Other sources of hydrogen are moisture present in rust or scale and oils and greases (hydrocarbons).

Reducing the influence of hydrogen is possible by:

- Ensuring that fluxes (coated electrodes, flux-cored wires and SAW fluxes) are low in H when welding commences.
- Either baking then storing low H electrodes in a hot holding oven or supplying them in vacuum-sealed packages.
- Basic agglomerated SAW fluxes in a heated silo until issue to maintain their as-supplied, low moisture, condition.
- Checking the diffusible hydrogen content of the weld metal (sometimes specified on the test certificate).
- Ensuring that a low H condition is maintained throughout welding by not allowing fluxes to pick up moisture from the atmosphere.
- Issuing low hydrogen electrodes in small quantities and limiting exposure time; heated quivers do this.
- Covering or returning flux covered wire spools that are not seamless to suitable storage condition when not in use.
- Returning basic agglomerated SAW fluxes to the heated silo when welding is not continuous.
- Checking the amount of moisture present in the shielding gas by checking the dew point (must be below -60°C).
- Ensuring the weld zone is dry and free from rust/scale and oil/grease.

Tensile stress

There are always tensile stresses acting on a weld because there are always residual stresses from welding.

The magnitude of the tensile stresses is mainly dependent on the thickness of the steel at the joint, heat input, joint type and the size and weight of the components being welded.

Tensile stresses in highly restrained joints can be as high as the yield strength of the steel and this is usually the case in large components with thick joints and is not a factor that can easily be controlled.

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The only practical ways of reducing the influence of residual stresses may be by:

- Avoiding stress concentrations due to poor fit-up.
- Avoiding poor weld profile (sharp weld toes).
- Applying a stress relief heat treatment after welding.
- Increasing the travel speed as practicable to reduce the heat input.
- Keeping weld metal volume as low as possible.

These measures are particularly important when welding some low alloy steels that are particularly sensitive to hydrogen cracking.

Susceptible HAZ microstructure

A susceptible HAZ microstructure is one that contains a relatively high proportion of hard brittle phases of steel, particularly martensite.

The HAZ hardness is a good indicator of susceptibility and when it exceeds a certain value that steel is considered susceptible. For C and C-Mn steels this value is ~350HV and susceptibility to H_2 cracking increases as hardness increases above this value.

The maximum hardness of an HAZ is influenced by:

- Chemical composition of the steel.
- Cooling rate of the HAZ after each weld run.

For C and C-Mn steels a formula has been developed to assess how the chemical composition will influence the tendency for significant HAZ hardening – the carbon equivalent value (CEV) formula.

The CEV formula most widely used (and adopted by IIW) is:

$$CEV_{IIW} = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

The CEV of a steel is calculated by inserting the material test certificate values shown for chemical composition into the formula. The higher the CEV the greater its susceptibility to HAZ hardening therefore the greater the susceptibility to H_2 cracking.

The element with most influence on HAZ hardness is carbon. The faster the rate of HAZ cooling after each weld run, the greater the tendency for hardening.

Cooling rate tends to increase as:

- Heat input decreases (lower energy input).
- Joint thickness increases (bigger heat sink).

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Avoiding a susceptible HAZ microstructure (for C and C-Mn steels) requires:

- Procuring steel with a CEV at the low end of the range for the steel grade (limited scope of effectiveness).
- Using moderate welding heat input so that the weld does not cool quickly and give HAZ hardening.
- Applying preheat so that the HAZ cools more slowly and does not show significant HAZ hardening; in multi-run welds maintain a specific interpass temperature.

The CEV formula is not applicable to low alloy steels, with additions of elements such as Cr, Mo and V. The HAZ of these steels will always tend to be relatively hard regardless of heat input and preheat and so this is a factor that cannot be effectively controlled to reduce the risk of H cracking. This is why some of the low alloy steels have a greater tendency to show hydrogen cracking than in weldable C and C-Mn steels which enable HAZ hardness to be controlled.

Weldment at low temperature

Weldment temperature has a major influence on susceptibility to cracking mainly by influencing the rate at which H can move (diffuse) through the weld and HAZ. While a weld is relatively warm (>~300°C) H will diffuse quite rapidly and escape into the atmosphere rather than be trapped and cause embrittlement.

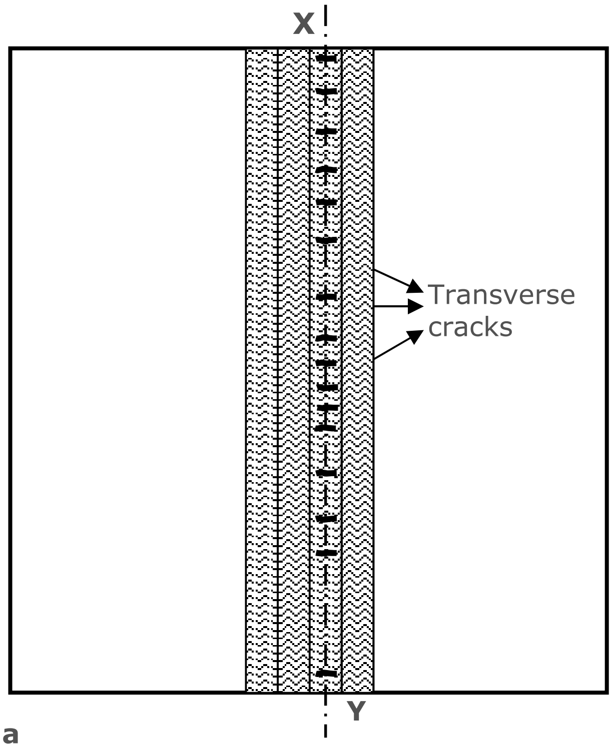
The influence of low weldment temperature and risk of trapping H in the weldment can be reduced by:

- Applying a suitable preheat temperature (typically 50 to ~250°C).
- Preventing the weld from cooling down quickly after each pass by maintaining the preheat and specific interpass temperatures during welding.
- Maintaining the preheat temperature (or raising it to ~250°C) when welding has finished and holding the joint at this temperature for a minimum of two hours to facilitate the escape of H (post-heat).
- Post-heat in accordance with specification, (not to be confused with PWHT) at a temperature ≥~600°C.

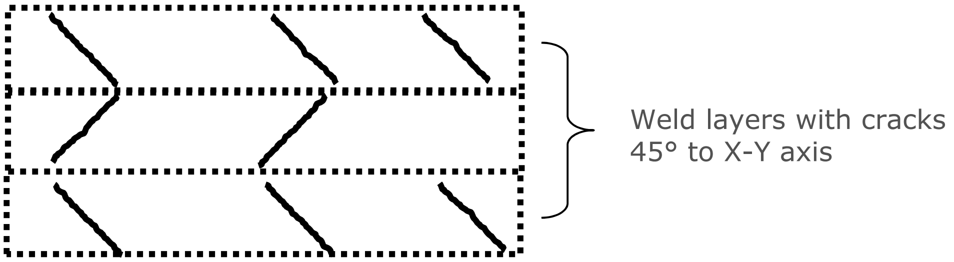
17.3.4 Hydrogen cracking in weld metal

Hydrogen cracks can form in steel weld metal under certain circumstances. The mechanism of cracking and identification of all the influencing factors is less clearly understood than for HAZ cracking but can occur when welding conditions cause H to become trapped in weld metal rather than in HAZ. It is recognised that welds in higher strength materials, thicker sections and using large beads are the most common problem areas.

Hydrogen cracks in weld metal usually lie at 45° to the direction of principal tensile stress in the weld metal, usually the longitudinal axis of the weld (Figure 17.4).



a



b

Figure 17. 4:

a Plan view of a plate butt weld showing subsurface transverse cracks;

b Longitudinal section X-Y of the above weld showing how the transverse cracks lie at 45° to the surface. They tend to remain within an individual weld run and may be in weld several layers.

Their appearance in this orientation gives the name chevron cracks (arrow-shaped cracks). There are no well defined rules for avoiding weld metal hydrogen cracks apart from:

- Use a low hydrogen welding process.
- Apply preheat and maintain a specific interpass temperature.

BS EN 1011-2 Welding - Recommendations for welding of metallic materials - Part 2: Arc welding of ferritic steels gives in Annex C practical guidelines about how to avoid H cracking. These are based principally on the application of preheat and control of potential H associated with the welding process.

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17.4 Solidification cracking

The technical name for cracks that form during weld metal solidification is solidification cracks but other names are sometimes used:

- Hot cracking: Occur at high temperatures while the weld is hot.
- Centreline cracking: Down the centreline of the weld bead.
- Crater cracking: Small cracks in weld craters are solidification cracks.

A weld metal particularly susceptible to solidification cracking may be said to show hot shortness because it is short of ductility when hot so tends to crack.

Figure 17.5 shows a transverse section of a weld with a typical centreline solidification crack.

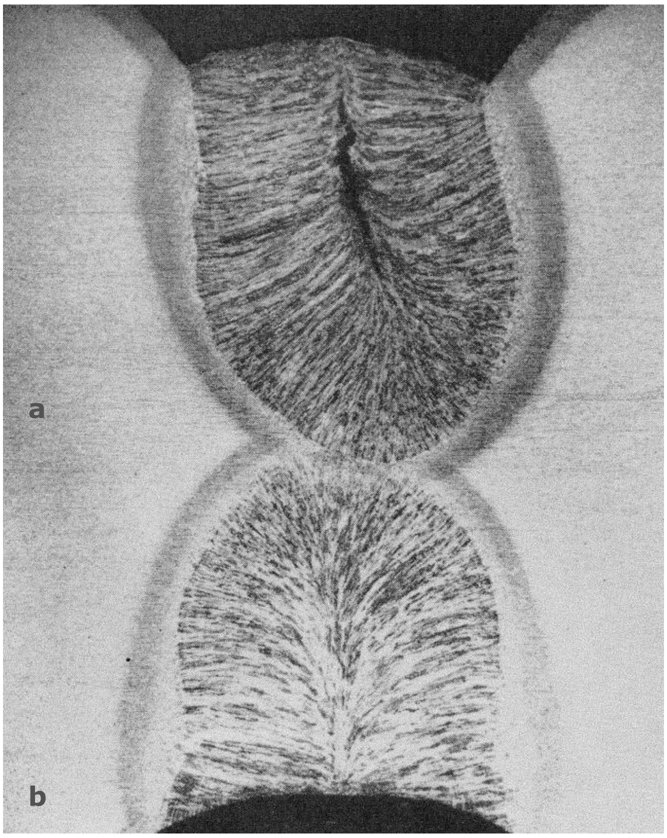

Figure 17.5:

a Solidification crack at the weld centre where columnar dendrites have trapped some lower melting point liquid;

b The weld bead does not have an ideal shape but has solidified without the dendrites meeting end-on and trapping lower melting point liquid thereby resisting solidification cracking.

17.4.1 Factors influencing susceptibility to solidification cracking

Solidification cracking occurs when three conditions exist at the same time:

- Weld metal has a susceptible chemical composition.
- Welding conditions used give an unfavourable bead shape.
- High level of restraint or tensile stresses present in the weld area.

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17.4.2 Cracking mechanism

All weld metals solidify over a temperature range and since solidification starts at the fusion line towards the centreline of the weld pool, during the last stages of weld bead solidification there may be enough liquid to form a weak zone in the centre of the bead. This liquid film is the result of low melting point constituents being pushed ahead of the solidification front.

During solidification, tensile stresses start to build up due to contraction of the solid parts of the weld bead and these stresses can cause the weld bead to rupture. These circumstances result in a weld bead showing a centreline crack as soon as the bead has been deposited.

Centreline solidification cracks tend to be surface-breaking at some point in their length and can be easily seen during visual inspection because they tend to be relatively wide.

17.4.3 Avoiding solidification cracking

Avoiding solidification cracking requires the influence of one of the factors to be reduced to an inactive level.

Weld metal composition

Most C and C-Mn steel weld metals made by modern steelmaking methods do not have chemical compositions particularly sensitive to solidification cracking. However, they can become sensitive to this type of cracking if they are contaminated with elements or compounds that produce relatively low melting point films in weld metal.

Sulphur and copper can make steel weld metal sensitive to solidification cracking if present in the weld at relatively high levels. Sulphur contamination may lead to the formation of iron sulphides that remain liquid when the bead has cooled down as low as ~980°C, whereas bead solidification started above 1400°C.

The source of sulphur may be contamination by oil or grease or it could be picked up from the less refined parent steel being welded by dilution into the weld.

Copper contamination in weld metal can be similarly harmful because it has low solubility in steel and can form films that are still molten at ~1100°C.

Avoiding solidification cracking (of an otherwise non-sensitive weld metal) requires the avoidance of contamination with potentially harmful materials by ensuring:

- Weld joints are thoroughly cleaned immediately before welding.
- Any copper containing welding accessories are suitable/in suitable condition, such as backing-bars and contact tips used for GMA, FCA and SAW.

Unfavourable welding conditions

Encourage weld beads to solidify so that low melting point films become trapped at the centre of a solidifying weld bead and become the weak zones for easy crack formation.

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Figure 17.6 shows a weld bead that has solidified under unfavourable welding conditions associated with centreline solidification cracking.

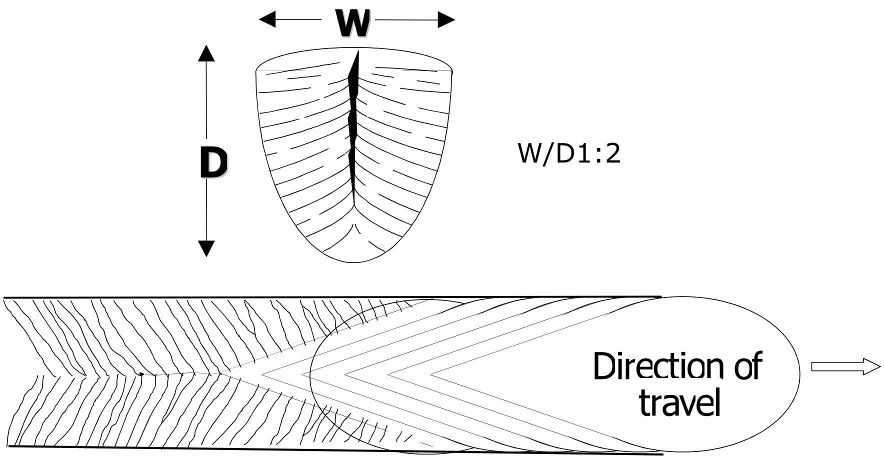

Figure 17.6 Weld bead with an unfavourable width-to-depth ratio. This is responsible for liquid metal being pushed into the centre of the bead by the advancing columnar dendrites and becoming the weak zone that ruptures.

The weld bead has a cross-section that is quite deep and narrow – a width-to-depth ratio greater than 1:2 and the solidifying dendrites have pushed the lower melting point liquid to the centre of the bead where it has become trapped. Since the surrounding material is shrinking as a result of cooling, this film would be subjected to tensile stress, which leads to cracking.

In contrast, Figure 17.7 shows a bead with a width-to-depth ratio less than 1:2. This bead shape shows lower melting point liquid pushed ahead of the solidifying dendrites but it does not become trapped at the bead centre, thus, even under tensile stresses resulting from cooling, this film is self-healing and cracking avoided.

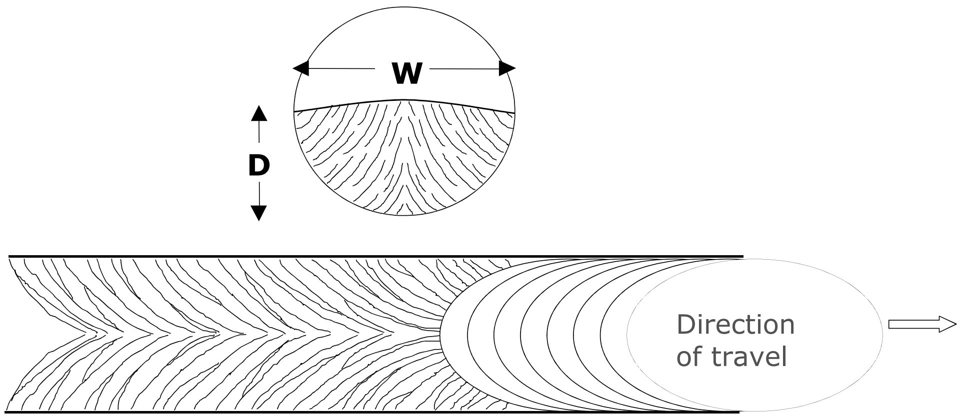

Figure 17.7 Weld bead with favourable width-to-depth ratio. The dendrites push the lowest melting point metal towards the surface at the centre of the bead centre so it does not form a weak central zone.

SAW and spray-transfer GMA are the arc welding processes most likely to give weld beads with an unfavourable width-to-depth ratio. Also, electron beam and laser welding processes are extremely sensitive to this kind of cracking as a result of the deep, narrow beads produced.

Avoiding unfavourable welding conditions that lead to centreline solidification cracking (of weld metals with sensitive compositions) may require significant changes to welding parameters, such as reducing:

- Welding current (give a shallower bead).
- Welding speed (give a wider weld bead).

Avoiding unfavourable welding conditions that lead to crater cracking of a sensitive weld metal requires changes to the technique used at the end of a weld when the arc is extinguished, such as:

- TIG welding when using a current slope-out device so that the current and weld pool depth gradually reduce before the arc is extinguished (gives more favourable weld bead width-to-depth ratio). It is also a common practice to backtrack the bead slightly before breaking the arc or lengthen the arc gradually to avoid the crater cracks.

- Modify weld pool solidification mode by feeding the filler wire into the pool until solidification is almost complete and avoiding a concave crater.

- When MMA welding modify the weld pool solidification mode by reversing the direction of travel at the end of the weld run so that the crater is filled.

17.5 Lamellar tearing

A type of cracking that occurs only in steel plate or other rolled products underneath a weld.

Characteristics of lamellar tearing are:

- Cracks only occur in the rolled products eg plate and sections.
- Most common in C-Mn steels.
- Cracks usually form close to but just outside, the HAZ.
- Cracks tend to lie parallel to the surface of the material and the fusion boundary of the weld having a stepped aspect.

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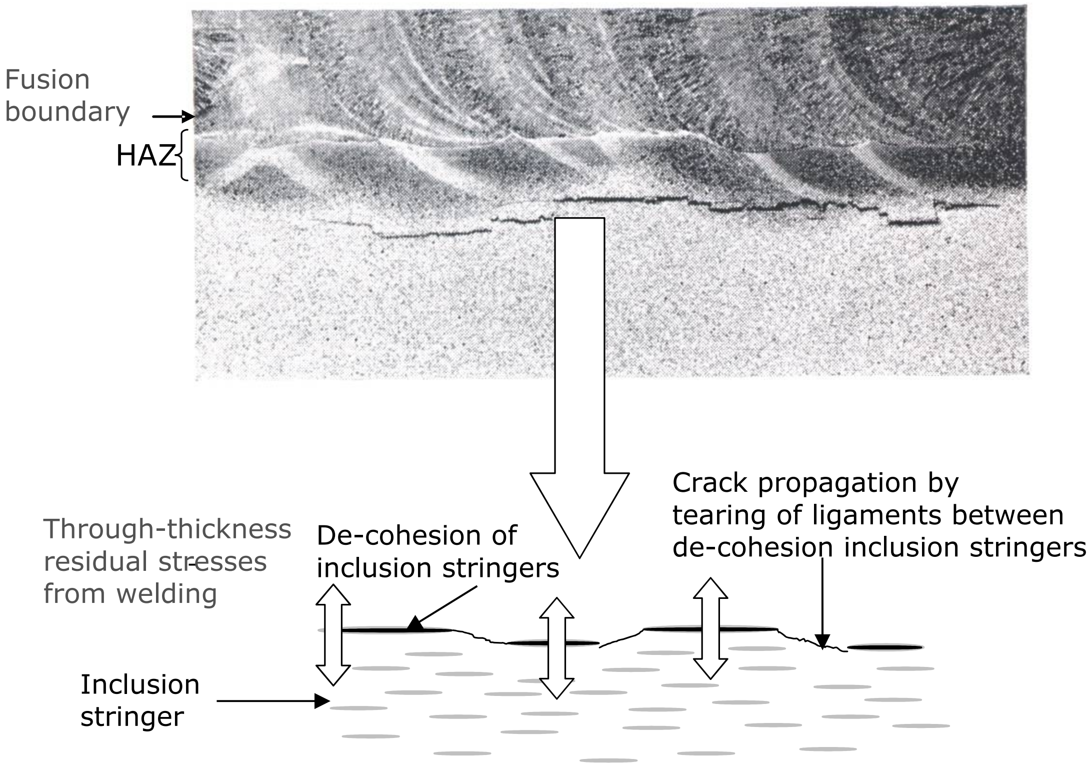

Figure 17.8 Typical lamellar tear located just outside the visible HAZ leading to step-like crack a characteristic of a lamellar tear.

17.5.1 Factors influencing susceptibility to lamellar tearing

Lamellar tearing occurs when two conditions exist at the same time:

- Susceptible rolled plate is used to make a weld joint.
- High stresses act in the through-thickness direction of the susceptible material (known as the short-transverse direction).

Susceptible rolled plate

A material susceptible to lamellar tearing has very low ductility in the through-thickness (short transverse) direction and is only able to accommodate the residual stresses from welding by tearing rather than by plastic straining.

Low through-thickness ductility in rolled products is caused by the presence of numerous non-metallic inclusions in the form of elongated stringers. The inclusions form in the ingot but are flattened and elongated during hot rolling of the material.

Non-metallic inclusions associated with lamellar tearing are principally manganese sulphides and silicates.

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High through-thickness stress

Weld joints that are T, K and Y configurations end up with a tensile residual stress component in the through-thickness direction.

The magnitude of the through-thickness stress increases as the restraint (rigidity) of the joint increases. Section thickness and size of weld are the main influencing factors and lamellar tearing is more likely to occur in thick section, full penetration T, K and Y joints.

17.5.2 Cracking mechanism

High stresses in the through-thickness direction present as welding residual stresses cause the inclusion stringers to open-up (de-cohese) and the thin ligaments between individual de-cohesed inclusions then tear and produce a stepped crack.

17.5.3 Avoiding lamellar tearing

Lamellar tearing can be avoided by reducing the influence of one or both of the factors.

Susceptible rolled plate

EN 10164 (Steel products with improved deformation properties perpendicular to the surface of the product, Technical delivery conditions) gives guidance on the procurement of plate to resist lamellar tearing.

Resistance to lamellar tearing can be evaluated by tensile test pieces taken with their axes perpendicular to the plate surface (through-thickness direction). Through-thickness ductility is measured as the % reduction of area (%R of A) at the point of fracture of the tensile test piece (Figure 17.9).

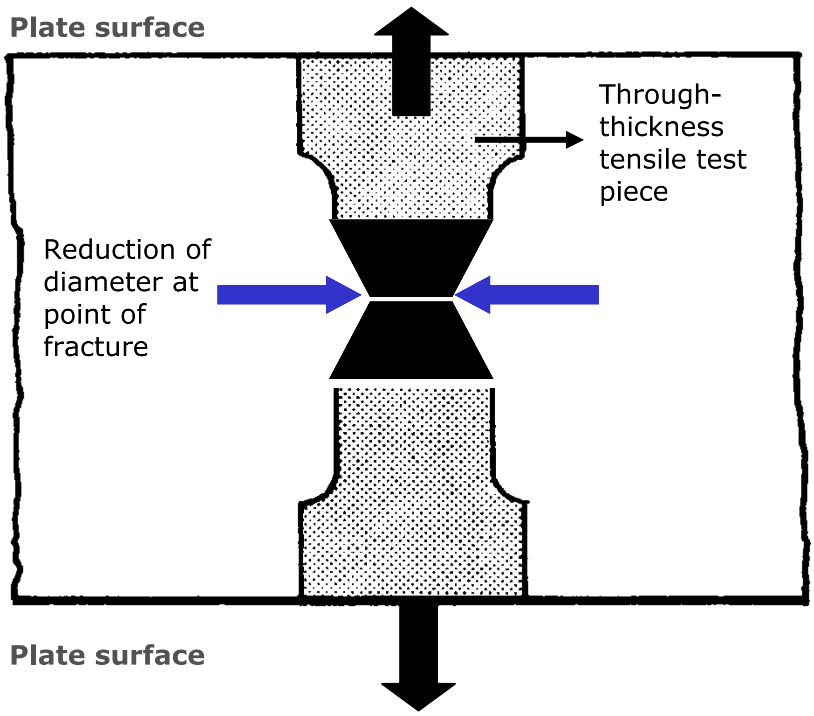

Figure 17.9 Round tensile test piece taken with its axis in the short-transverse direction (through-thickness of plate) to measure the %R of A and assess resistance to lamellar tearing.

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The greater the measured %R of A, the greater the resistance to lamellar tearing. Values in excess of ~20% indicate good resistance even in very highly constrained joints.

Reducing the susceptibility of rolled plate to lamellar tearing can be achieved by ensuring that it has good through-thickness ductility by:

- Using clean steel that has low sulphur content (<~0.015%) and consequently relatively few inclusions.
- Procuring steel plate that has been subjected to through-thickness tensile testing to demonstrate good through-thickness ductility (as EN 10164).

Through-thickness stress

Through-thickness stress in T, K and Y joints is principally the residual stress from welding, although the additional service stress may have some influence.

Reducing the magnitude of through-thickness stresses for a particular weld joint would require modification to the joint so may not be practical because of the need to satisfy design requirements. However, methods that could be considered are:

Reducing the size of the weld by:

- Using a partial butt weld instead of full penetration.
- Using fillet welds instead of a full or partial penetration butt weld (Figure 17.11).
- Applying a buttering layer of weld metal to the surface of a susceptible plate so that the highest through-thickness strain is located in the weld metal and not the susceptible plate (Figure 17.10).
- Changing the joint design, such as using a forged or extruded intermediate piece so that the susceptible plate does not experience through-thickness stress (Figure 17.12).

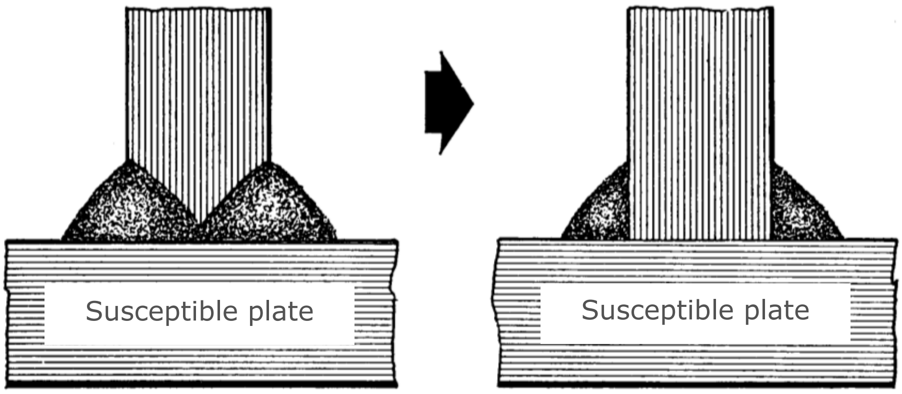

Figure 17.10 Reducing the effective size of a weld will reduce the through-thickness stress on the susceptible plate and may be sufficient to reduce the risk of lamellar tearing.

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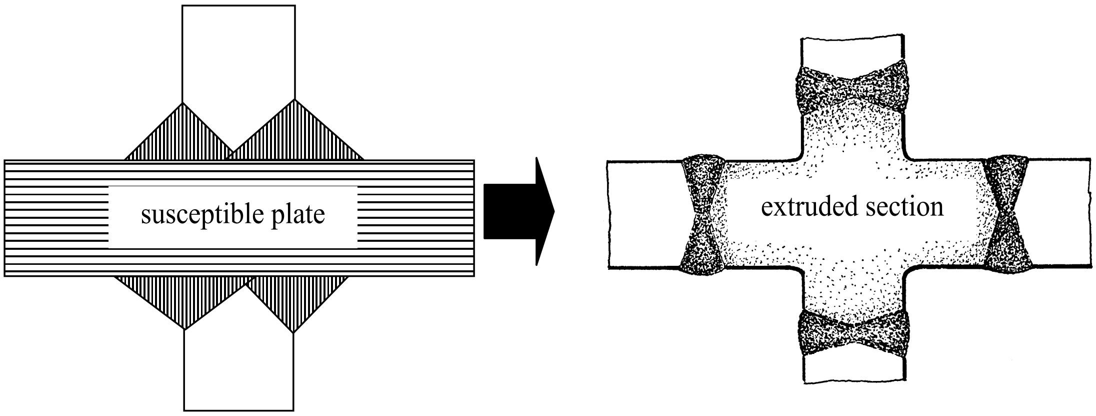

Figure 17.11 Lamellar tearing can be avoided by changing the joint design.

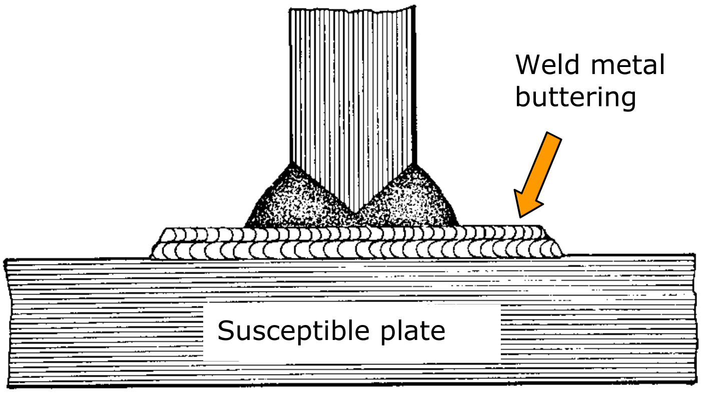

Figure 17.12 Two layers of weld metal applied usually by MMA to susceptible plate before the T butt is made.

17.6 Weld decay

Occurance

Service failure problem, caused by corrosion, may be long time in service (associated with welding but is not a fabrication defect, like H cracking, etc).

Appearance

Called weld decay because a narrow zone in the HAZ can be severely corroded but surrounding areas (weld and parent metal) may not be affected.

Only affects certain types of austenitic stainless steels.

Requires two factors at the same time:

- Sensitive HAZ.
- Corrosive liquid in contact with the sensitive HAZ, in service.

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17.6.1 Avoiding weld decay

Characteristics of sensitive HAZ and failure mechanism

- Occurs in stainless steels which are not low carbon grades (L grades) eg 304 and 316.
- HAZ becomes sensitive to preferential corrosion because chromium carbides form at grain boundaries in HAZ thereby locally reducing the corrosion resistance of the HAZ.
- More prone to HAZ degradation the more weld runs put in the joint, thicker sections (more thermal cycles and HAZ spends more time in temperature range where carbides form).

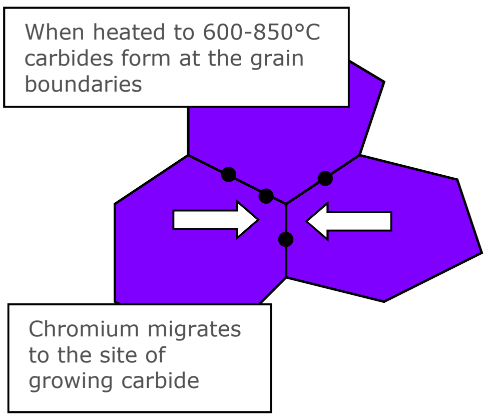
To reduce sensitivity of HAZ

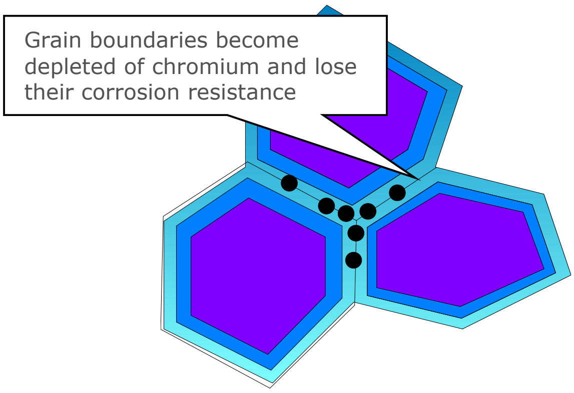
- Use low C grades of austenitic stainless steel (304 and 316L) not enough carbon to form a large number of Cr carbides during welding, corrosion resistance thus not degraded.
- Use stabilised grades of stainless steel (321 and 347) which contain titanium 321 and niobium 347 which combine with carbon rather than Cr so no local reduction in corrosion resistance).
- If welding higher carbon grades use low heat input welding and fewest weld runs possible (less time available in temperature range when Cr carbides form).
- It is possible to remove HAZ sensitivity by solution heat treatment of the welded item. As this requires temperature of 1050-1100°C (this has practical difficulties).

Service environment

- Corrosion of HAZ determined by service conditions, type of chemicals and temperature.
- Problem not solved by trying to address service conditions but by selection of material, taking account of effects of welding/welding parameters.

Weld decay, also called sensitisation or intercrystalline corrosion, occurs within the susceptible temperature range of approximately 600-850°C, ie in the HAZ or during high temperature service. At this temperature, carbon diffuses to the grain boundaries and combines with chromium to form carbides, leaving a Cr-depleted layer susceptible to corrosion along the grain boundaries, therefore corrosion cracking occurs along grain boundaries in the HAZ. Weld decay can be avoided by keeping the carbon low, eg using low carbon grades like 304L and the heat input low by avoiding preheat or PWHT. It is also possible to use grades with added elements which combine with the carbon eg 321 (which contains Ti) or 347 (which contains Nb).





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Weldability of Steels

Section 17

Materials Joining and Engineering Technologies
Training and Examination Services

Weldability Objective

When this presentation has been completed you will have a greater understanding of what this term means and have a better understanding of cracking mechanisms and how steels and alloys are defined.

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Weldability of Steels

Definition
It relates to the ability of the metal (or alloy) to be welded with mechanical soundness by most of the common welding processes. The resulting welded joint retain the properties for which it has been designed is a function of many inter-related factors but these may be summarised as:

- Composition of parent material.
- Joint design and size.
- Process and technique.
- Access.

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Weldability of Steels

- The weldability of steel is mainly dependant on carbon and other alloying elements content.
- If a material has limited weldability, we need to take special measures to ensure the maintenance of the properties required.
- Poor weldability normally results in the occurrence of cracking.
- A steel is considered to have poor weldability when:
  - An acceptable joint can only be made by using very narrow range of welding conditions.
  - Great precautions to avoid cracking are essential (eg high pre-heat etc).

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The Effect of Alloying on Steels

- Elements may be added to steels to produce the properties required to make it useful for an application.
- Most elements can have many effects on the properties of steels.
- Other factors which affect material properties are:
  - The temperature reached before and during welding.
  - Heat input.
  - The cooling rate after welding and or PWHT.

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Steel Alloying Elements

Iron (Fe):
Main steel constituent. On its own, is relatively soft, ductile, with low strength.
Carbon (C):
Major alloying element in steels, a strengthening element with major influence on HAZ hardness. Decreases weldability typically < ~ 0.25%.
Manganese (Mn):
Secondary only to carbon for strength, toughness and ductility, secondary de-oxidiser and also reacts with sulphur to form manganese sulphides typically < ~0.8% is residual from steel de-oxidation. Up to ~1.6% (in C-Mn steels) improves strength and toughness.
Silicon (Si):
Residual element from steel de-oxidation typically to ~0.35%.

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Steel Alloying Elements

Phosphorus (P):
- Residual element from steel-making minerals.
- Difficult to reduce below < ~ 0.015% brittleness.

Sulphur (S):
- Residual element from steel-making minerals.
- Typically < ~ 0.015% in modern steels < ~ 0.003% in very clean steels.

Aluminium (Al):
- De-oxidant and grain size control.
- Typically ~ 0.02 to ~ 0.05%.

Chromium (Cr):
- For creep resistance and oxidation (scaling) resistance for elevated temperature service. Widely used in stainless steels for corrosion resistance, increases hardness and strength but reduces ductility.
  - Typically ~ 1 to 9% in low alloy steels.

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Steel Alloying Elements

Nickel (Ni):
Used in stainless steels, high resistance to corrosion from acids, increases strength and toughness.

Molybdenum (Mo):
Affects hardenability. Steels containing molybdenum are less susceptible to temper brittleness than other alloy steels. Increases the high temperature tensile and creep strengths of steel. typically ~ 0.5 to 1.0%.

- **Niobium (Nb):**
- **Vanadium (V):**
- **Titanium (Ti) :**

a grain refiner, typically ~ 0.05%

- **Copper (Cu):**

Present as a residual, (typically < ~ 0.30%) added to weathering steels (~ 0.6%) to give better resistance to atmospheric corrosion.

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Materials

Iron	Fe	
Carbon	C	is for Strength
Manganese	Mn	is for Toughness
Silicon	Si	< 0.3% Deoxidiser
Aluminium	Al	Grain refiner, <0.008% Deoxidiser + Toughness
Chromium	Cr	Corrosion resistance
Molybdenum	Mo	1% is for Creep resistance
Vanadium	V	Strength
Nickel	Ni	Low temperature applications
Copper	Cu	Used for weathering steels (Corten)
Sulphur	**S**	**Residual element (can cause hot shortness)**
Phosphorous	**P**	**Residual element**
Titanium	Ti	Grain refiner, Used a micro alloying element (S&T)
Niobium	Nb	Grain refiner, Used a micro alloying element (S&T)

(S&T) = Strength & Toughness

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Classification of Steels

Steels are classified into groups as follows:
- Plain carbon steels.
- Alloy steels.

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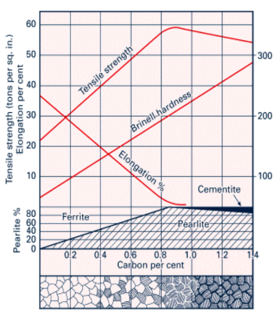
Carbon – The Key Element in Steel

It affects:

1. Strength.
2. Hardness.
3. Ductility.



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Classification of Steels

Plain carbon steels:
- Low Carbon Steel 0.01 – 0.3% Carbon.
- Medium Carbon Steel 0.3 – 0.6% Carbon.
- High Carbon Steel 0.6 – 1.4% Carbon.
- Plain carbon steels contain only iron and carbon as main alloying elements, but traces of Mn, Si, Al, S and P may also be present.

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Classification of Steels

Alloy steels:

- Low Alloy Steels <7% alloying elements.
- High Alloy Steels >7% alloying elements.

Alloy steels are considered the type of steels that predominantly contain extra alloying elements other than iron and carbon.

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Classification of Steels

Types of weldable C, C-Mn and low alloy steels

Carbon steels

- Carbon contents up to about ~ 0.25%.
- Manganese up to ~ 0.8%.
- Low strength and moderate toughness.

Carbon-manganese steels

- Manganese up to ~ 1.6%.
- Carbon steels with improved toughness due to additions of manganese.

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Classification of Steels

Types of weldable C, C-Mn and low alloy steels low alloy steels

Strength and toughness raised even higher by very small additions of grain refining elements like aluminium, niobium, vanadium.

Higher strength grades may be referred to as HSLA steels (high strength low alloy steels, eg API 5L X65 and higher).

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Classification of Steels

Types of weldable low alloy steels

Steels for Elevated Temperature Service

- Chromium (Cr) and Molybdenum (Mo) additions give improved strength at high temperature and good creep resistance.
- Typical steels are:
  - 2.25% Cr +1% Mo.
  - 9%Cr + 1%Mo.

Steels for Low Temperature Service

- Ni additions give good toughness at low temperatures.
- Steels may be referred to as cryogenic steels.

Typical examples are:

- 3.5%Ni steel.
- 9%Ni steels.

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Classification of Steels

Types of Stainless Steels

Austenitic Grades

- Alloyed with Chromium & Nickel.
- Examples - 304 & 316 (18%Cr + 8%Ni).
- Main phase is austenite.
- Very wide range of applications:
  - Very low temperature service (cryogenic).
  - High temperature service.
- Moderate corrosion resistance.
- Non-magnetic.
- Low thermal conductivity (hold the heat during welding).
- High coefficient of expansion - more distortion during welding.

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Classification of Steels

Types of stainless steels

Ferritic and Martensitic Grades

- Alloyed with chromium (but have no or low nickel content).
- Examples - 13% Cr (ferritic) 13%Cr +4%Ni.
- Ferritic grades have ferrite as main phase and so can be magnetised.
- Martensitic grades have martensitic as main phase
- Similar characteristics to C and Mn steels but with improved corrosion resistance.
- Not suitable for very low temperatures but some ferritic grades used for good resistance to scaling at high temperatures.

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Classification of Steels

Types of stainless steels

Duplex grades

- Alloyed with Chromium & some Nickel.
- Examples - 22%Cr + 5%Ni & 25%Cr + 7%Ni.
- Called duplex because there are 2 phases - 50% ferrite + 50% austenite.
- The presence of ferrite means that the steels can be magnetised.
- Stronger than 304 and 316 and good resistance to certain types of corrosion.
- Not suitable for very low temperature service or very high temperature service.

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Carbon Equivalent Formula

- The weldability of the material will also be affected by the amount of alloying elements present.
- The carbon equivalent of a given material also depends on its alloying elements.
- The higher the CE, higher the susceptibility to brittleness, and lower the weldability.
  - The CE or CEV is calculated using the following formula:

$$CEV = \%C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

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Classification of Steels

Mild steel (CE < 0.4)

- Readily weldable, preheat generally not required if low hydrogen processes or electrodes are used.
- Preheat may be required when welding thick section material, high restraint and with higher levels of hydrogen being generated.

C-Mn, medium carbon, low alloy steels (CE 0.4 to 0.5)

- Thin sections can be welded without preheat but thicker sections will require low preheat levels and low hydrogen processes or electrodes should be used.

Higher carbon and alloyed steels (CE > 0.5)

- Preheat, low hydrogen processes or electrodes, post weld heating and slow cooling may be required.

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Process Cracks

- Hydrogen induced HAZ cracking (C/Mn steels).
- Hydrogen induced weld metal cracking (HSLA steels).
- Solidification or hot cracking (all steels).
- Lamellar tearing (all steels).
- Re-heat cracking (all steels, very susceptible Cr/Mo/V steels).
- Inter-crystalline corrosion or weld decay (stainless steels).

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Cracking

When considering any type of cracking mechanism, *four elements must always be present:

Stress

- Residual stress is always present in a weldment, through unbalanced local expansion and contraction.

Restraint

- Restraint may be a local restriction, or through plates being welded to each other.

Susceptible microstructure

- The microstructure may be made susceptible to cracking by the process of welding.

***Temperature (only applicable to certain types of cracking).**

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Cracks

Hydrogen Induced Cold Cracking

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Hydrogen Induced Cold Cracking

Also known as HCC, hydrogen, toe, underbead, delayed, chevron cracking.

Occurs in:

- Carbon steels.
- Carbon-manganese.
- Low, medium and high alloy steels:
  - Mainly in ferritic or martensitic steels.
  - **Very rarely in duplex stainless steels.**
  - **Never in nickel or copper alloys.**

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Hydrogen Induced Cold Cracking

Crack type:
Hydrogen HAZ and weld metal cracking.

Location:
HAZ (longitudinal) weld metal (transverse).

Steel types:
All hardenable steels.

Including:
HSLA (high strength low alloy) steels. Quench and tempered steels TMCP (thermal mechanically controlled processed) steels.

Susceptible microstructure: Martensite.

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Hydrogen Induced Cold Cracking

There is a risk of hydrogen cracking when all of the 4 factors occur together:

Hydrogen:
More than 15ml/100g of weld metal.
Stress:
More than ½ the yield stress.
Temperature:
Below 300°C.
Susceptible Microstructure:
Hardness Greater than 400HV Vickers (Martensite).

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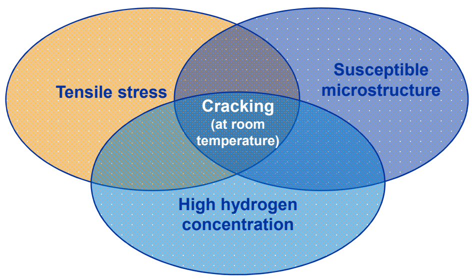
Hydrogen Induced Cold Cracking



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Hydrogen Induced Cold Cracking

May occur:

- Up to 72hrs after completion.
- In weld metal, HAZ, parent metal.
- At weld toes.
- Under weld beads.
- At stress raisers.

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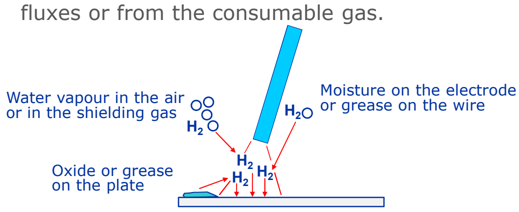
Hydrogen Induced Cold Cracking

- Hydrogen is the smallest atom known.
- Hydrogen enters the weld via the arc.
- Source of hydrogen mainly from moisture pick-up on the electrodes coating, welding fluxes or from the consumable gas.



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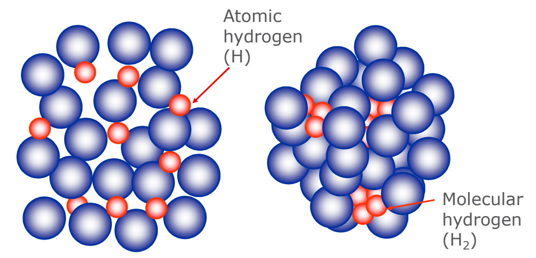
Hydrogen Induced Cold Cracking



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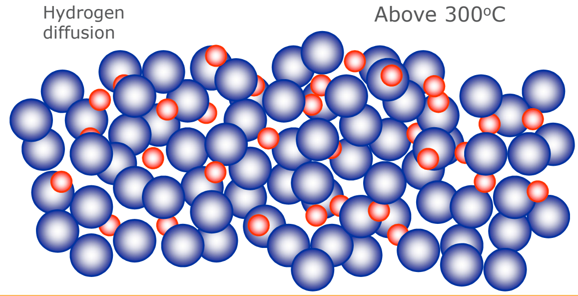

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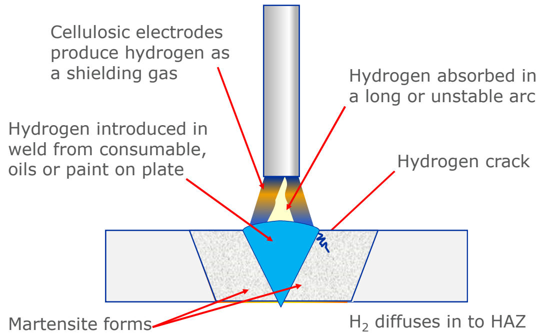

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Hydrogen Induced Cold Cracking

Susceptible microstructure:
Hard brittle structure – Martensite promoted by:

a High carbon content, carbon equivalent (CE)

$$CEV = \%C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15}$$

b High alloy content.

c Fast cooling rate:
- Inadequate pre-heating.
- Cold material.
- Thick material.
- Low heat input.

$$\text{Heat input (Kj/mm)} = \frac{\text{Amps x Volts x arc time}}{\text{Run out length x } 10^3 \text{ (1000)}}$$

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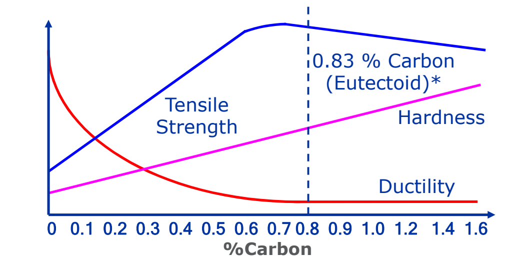
Effect of Carbon in the Properties of Iron

Increasing the carbon content will increase the strength, but will also increase greatly the risk of formation of martensite.



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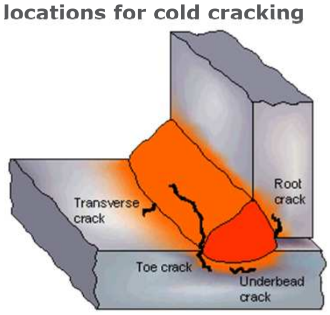
Hydrogen Induced Cold Cracking

Typical locations for cold cracking



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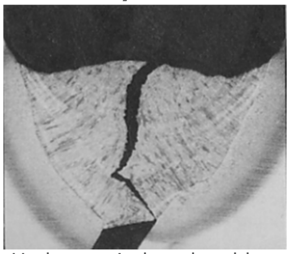
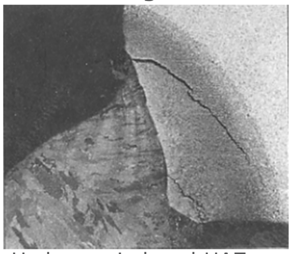
Hydrogen Induced Cold Cracking

Micro alloyed steel



Hydrogen induced weld metal cracking

Carbon manganese steel



Hydrogen induced HAZ cracking

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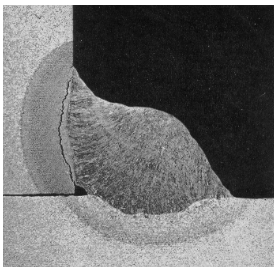
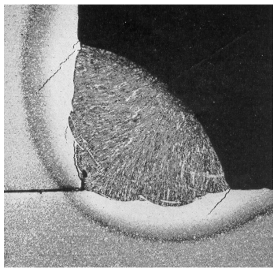
Hydrogen Induced Cold Cracking

Under bead cracking



Toe cracking



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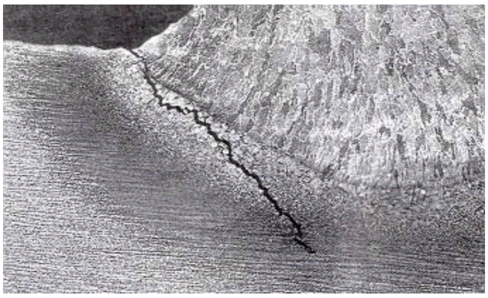
Hydrogen Induced Cold Cracking



Toe cracking in MMA fillet weld

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Hydrogen Induced Cold Cracking

Precautions for controlling hydrogen cracking

- Pre heat, removes moisture from the joint preparations, and slows down the cooling rate.
- Ensure joint preparations are clean and free from contamination.
- The use of a low hydrogen welding process and correct arc length.
- Ensure all welding is carried out is carried out under controlled environmental conditions.
- Ensure good fit-up as to reduced stress.
- The use of a PWHT.
- Avoid poor weld profiles.

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Hydrogen Scales

List of hydrogen scales from BS EN 1011: Part 2. Hydrogen content per 100 grams of weld metal deposited.

Scale A	High:	>15ml
Scale B	Medium:	10-15ml
Scale C	Low:	5-10ml
Scale D	Very low:	3-5ml
Scale E	Ultra-low:	<3ml

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Potential Hydrogen Level Processes

List of welding processes in order of potential lowest hydrogen content with regards to 100 grams of deposited weld metal.

TIG	< 3ml
MIG	< 5ml
ESW	< 5ml
MMA (Basic Electrodes)	< 5ml
SAW	< 10ml
FCAW	< 15ml

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Hydrogen Cold Cracking Avoidance

To eliminate the risk of hydrogen cracking how do you remove the following:

Hydrogen:	MMA (basic electrodes). MAG cleaning weld prep etc.
Stress:	Design, balanced welding.
Temperature:	Heat to 300°C (wrap and cool slowly).
Hardness:	Preheat-reduces cooling rate which reduces the risk of susceptible microstructure.

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Hydrogen Cold Cracking Avoidance

Reduce Hydrogen Level

- Select lower hydrogen potential process eg:
  - BASIC vs RUTILE.
  - MAG vs MMA.
- Increase hydrogen diffusion with increased preheat.
- Maintain preheat after welding allowing diffusion from weld.
- Bake basic MMA electrodes/SAW fluxes - manufacturers recommendations!
- Cleanliness/dryness of consumables and weld preparations eg rust scale grease cutting fluids.
- Use austenitic or nickel fillers (if acceptable).

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Hydrogen Cold Cracking Avoidance

Prevention

- Slow the cooling rate.
- Reduce hydrogen level.
- Reduce residual stress.

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Residual Stress

Residual stress will be increased by:

- Increasing plate thickness.
- Restraint - rigid fixtures
  - Weld volume.
  - Insert in plate.
- Multi-pass vs single pass.
- Small weld beads vs large weld beads.

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Hydrogen Cold Cracking Avoidance

How to reduce residual stress

- Ensure good fit-up: Minimum root gap and misalignment.
- Avoid restraints: Preset the join.
- Preheat may help: To slow down cooling rate.
- Large weld passes: Higher deposition rate.
- Minimise volume of weld metal: Less residual stress.
- PWHT from preheat temperature.
- Dress weld toes at preheat temperature.

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Pre-Heat Application

Application of preheat

- Heat either side of joint.
- Measure temp 2mins after heat removal.
- Always best to heat complete component rather than local if possible to avoid distortion.
- Preheat always higher for fillet than butt welds due to different combined thicknesses and chill effect factors.

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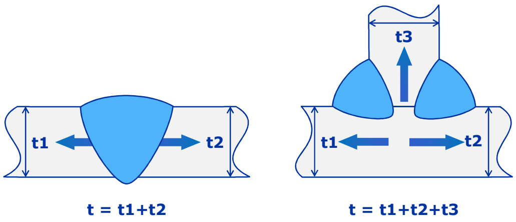
Combined Thickness

Combined chilling effect of joint type and thickness.



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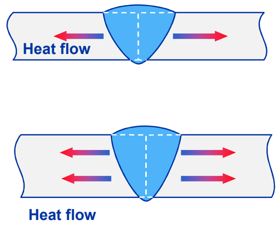
Combined Thickness

The chilling effect of the joint



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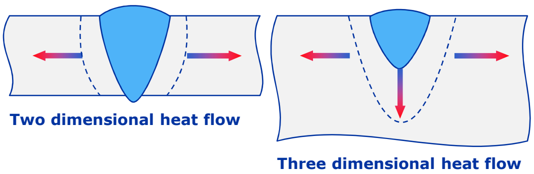
Combined Thickness

The chilling effect of the joint



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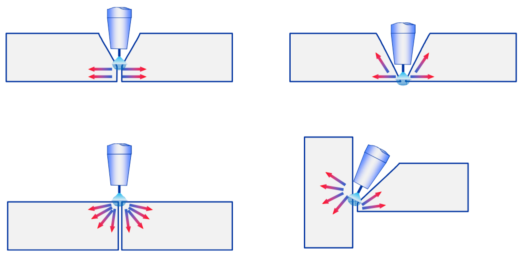
The Chill Effect of the Material



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Pre-Heat Application

Furnace:
- Heating entire component - best.

Electrical elements:
- Controllable; portable; site use; clean; component cannot be moved.

Gas burners:
- Direct flame impingement; possible local overheating; less controllable, portable, manual operation possible, component can be moved.

Radiant gas heaters:
- Capable of automatic control, no flame impingement, no contact with component, portable.

Induction heating:
- Controllable, rapid heating (mins not hours), large power supply, expensive equipment.

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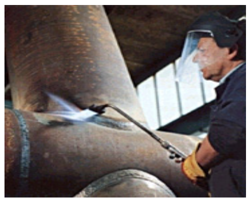
Pre-Heat Application

Electrical heated elements



Manual gas operation

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Heating Temperature Control

- Tempilsticks - crayons, melt at set temps. Will not measure max temp.
- Pyrometers - contact or remote, measure actual temp.
- Thermocouples - contact or attached, very accurate, measure actual temp.

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Hydrogen Cold Cracking Avoidance

Slow cooling rate

- Apply or increase preheat - BS EN 1011 Part 2 Gives recommendations on suitable preheat levels.
- Recommendations in specifications eg BS 2633, ASME VIII, ASME B31.3.
- Increase process heat input complying with toughness requirements.

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Hydrogen Cold Cracking Avoidance

- Maintain calculated preheats, and never allow the inter-pass temperature to go below the pre-heat value.
- Use Low Hydrogen processes with short arcs and ensure consumables are correctly baked and stored as required.
- If using a cellulosic E 6010 for the root run, hot pass as soon as possible. (Before HAZ < 300°C).
- Remove any paint, oil or moisture from the plate or pipe.
- Carry out any specified PWHT as soon as possible.
- Avoid any restraint, and use high ductility weld metal.

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Heat Input

High heat input - slow cooling.

- Low toughness (grain growth).
- Reduction in yield strength.

Low heat input - fast cooling.

- Increased hardness.
- Hydrogen entrapment.
- Lack of fusion.

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Cracks

Solidification Cracking

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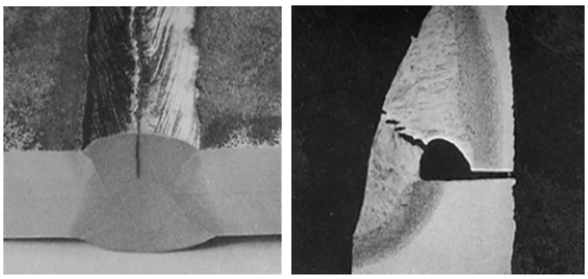
Solidification Cracking



Usually Occurs in Weld Centerline

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Solidification Cracking

Also referred as hot cracking

Crack type:
- Solidification cracking.

Location:
- Weld centreline (longitudinal).

Steel types:
- High sulphur and phosphor concentration in steels.

Susceptible microstructure:
- Columnar grains In direction of solidification.

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Solidification Cracking

- Sulphur in the parent material may dilute in the weld metal to form iron sulphides (low strength, low melting point compounds).
- During weld metal solidification, columnar crystals push still liquid iron sulphides in front to the last place of solidification, weld centerline.
- The bonding between the grains which are themselves under great stress. may now be very poor to maintain cohesion and a crack will result, weld centerline.

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Solidification Cracking

Factors for solidification cracking
- Columnar grain growth with impurities in weld metal (sulphur, phosphor and carbon).
- The amount of stress/restraint.
- Joint design high depth to width ratios.
- Liquid iron sulphides are formed around solidifying grains.
- High contractional strains are present.
- High dilution processes are being used.
- There is a high carbon content in the weld metal.
- Most commonly occurring in sub-arc welded joints.

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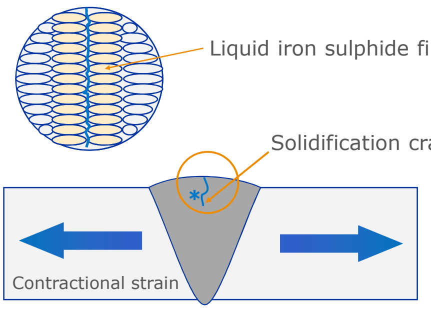
Solidification Cracking in Fe Steels



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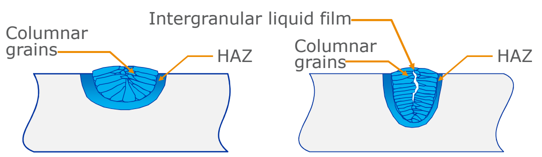
Solidification Cracking



Shallow, wider weld bead

On solidification the bonding between the grains may be adequate to maintain cohesion and a crack is unlikely to occur.

Deep, narrower weld bead

On solidification the bonding between the grains may now be very poor to maintain cohesion and a crack may result.

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Solidification Cracking

Precautions for controlling solidification cracking

The first steps in eliminating this problem would be to choose a low dilution process, and change the joint design.

Grind and seal in any lamination and avoid further dilution?
- Add Manganese to the electrode to form spherical Mn/S which form between the grain and maintain grain cohesion.
- As carbon increases the Mn/S ratio required increases exponentially and is a major factor. Carbon content % should be a minimised by careful control in electrode and dilution.
- Limit the heat input, hence low contraction and minimise restraint.

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Solidification Cracking

Precautions for controlling solidification cracking

- The use of high manganese and low carbon content fillers.
- Minimise the amount of stress/restraint acting on the joint during welding.
- The use of high quality parent materials, low levels of impurities (phosphor and sulphur).
- Clean joint preparations contaminants (oil, grease, paints and any other sulphur containing product).
- Joint design selection depth to width ratios.

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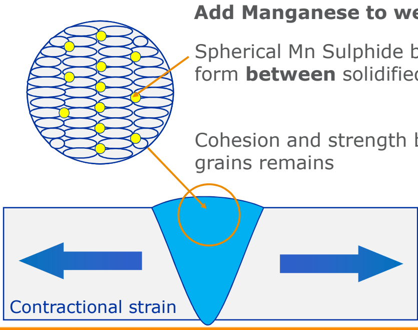
Solidification Cracking

Add Manganese to weld metal

Spherical Mn Sulphide balls form **between** solidified grains

Cohesion and strength between grains remains



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Solidification Cracking

Solidification cracking in austenitic stainless steel

- Particularly prone to solidification cracking.
- Large grain size gives rise to a reduction in grain boundary area with high concentration of impurities.
- Austenitic structure very intolerant to contaminants (sulphur, phosphorous and other impurities).
- High coefficient of thermal expansion/low coefficient of thermal conductivity, with high resultant residual stress.
- Same precautions against cracking as for plain carbon steels with extra emphasis on thorough cleaning and high dilution controls.

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Cracks

Lamellar Tearing

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Lamellar Tearing

- **Location:** Parent metal just below the HAZ.
- **Steel Type:** Any steel type possible.
- **Susceptible Microstructure:** Poor through thickness ductility.

- Lamellar tearing has a step like appearance due to the solid inclusions in the parent material (eg sulphides and silicates) linking up under the influence of welding stresses.
- Low ductile materials (often related to thickness) in the short transverse direction containing high levels of impurities are very susceptible to lamellar tearing.
- It forms when the welding stresses act in the short transverse direction of the material (through thickness direction).

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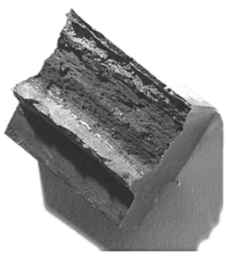
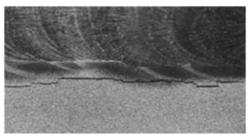
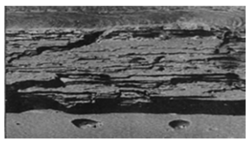
Lamellar Tearing





Step like appearance



Cross section

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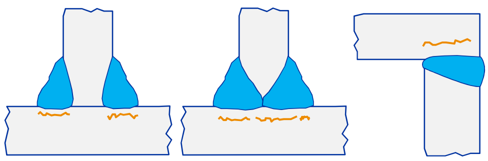
Lamellar Tearing

Susceptible joint types



T fillet weld

T butt weld (double-bevel)

Corner butt weld (single-bevel)

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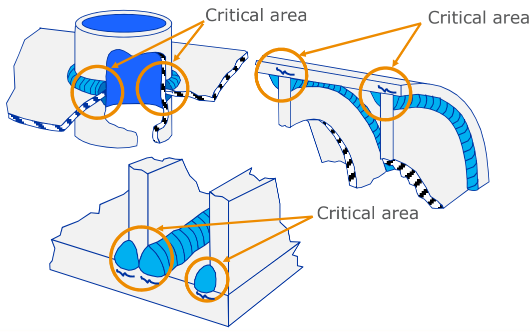
Lamellar Tearing



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Lamellar Tearing

Factors for lamellar tearing to occur

- Low quality parent materials, high levels of impurities there is a high sulfur content in the base metal.
- Joint design, direction of stress 90° to the rolling direction, the level of stress acting across the joint during welding.
- **Note:** Very susceptible joints may form lamellar tearing under very low levels of stress.
- High contractional strains are through the short transverse direction.
- There is low through thickness ductility in the base metal.
- There is high restraint on the work.

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Lamellar Tearing

Assessment of susceptibility to lamellar tearing:

- Carry out through thickness tensile test.
- Carry out cruciform welded tensile test.

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Lamellar Tearing

Precautions for controlling lamellar tearing

- The use of high quality parent materials, low levels of impurities.
- The use of buttering runs.
- A gap can be left between the horizontal and vertical members enabling the contraction movement to take place.
- Joint design selection.
- Minimise the amount of stress/restraint acting on the joint during welding.
- Hydrogen precautions.

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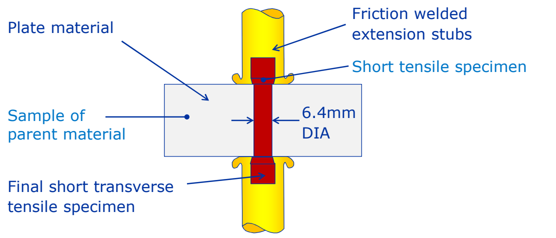
Short Tensile (Through Thickness) Test

The short tensile test or through thickness test is a test to determine a materials susceptibility to lamellar tearing



The results are given as a STRA value Short Transverse Reduction in Area

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Lamellar Tearing

Methods of avoiding lamellar tearing:*

1. Avoid restraint*.
2. Use controlled low sulfur plate*.
3. Grind out surface and butter*.
4. Change joint design*.
5. Use a forged T piece (critical applications)*.

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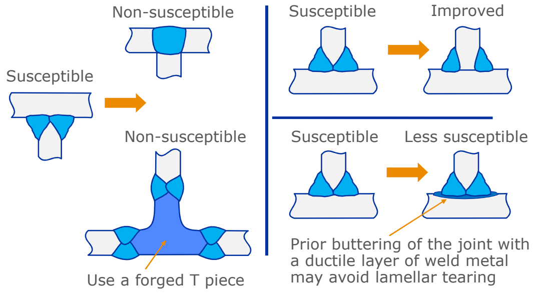
Lamellar Tearing

Modifying a T joint to avoid lamellar tearing



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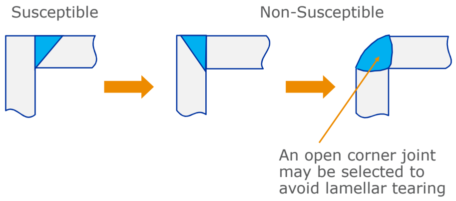
Lamellar Tearing

Modifying a corner joint to avoid lamellar tearing



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Cracks

Weld Decay

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Inter-Granular Corrosion

Crack type:	Inter-granular corrosion
Location:	Weld HAZ. (longitudinal)
Steel types:	Stainless steels
Microstructure:	Sensitised grain boundaries*

Occurs when:

An area in the HAZ has been sensitised by the formation of chromium carbides. This area is in the form of a line running parallel to and on both sides of the weld. This depletion of chromium will leave the effected grains low in chromium oxide which is what produces the corrosion resisting effect of stainless steels. If left untreated corrosion and failure will be rapid*

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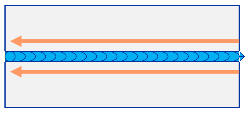
Inter-Granular Corrosion



- During the welding of stainless steels, a small grain area in the HAZ, parallel to the weld will form chromium carbide at the grain boundaries. This depletes this grain of the corrosion resisting chrome oxide
- We say that the steel has become sensitised or has become sensitive to corrosion*

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Inter-Granular Corrosion

1. Use stabilized stainless steels*.
2. Use low carbon stainless steels (Below 04%)*.
3. A sensitized stainless steel may be de-sensitized by heating it to above 1100°C where the chrome carbide will be dissolved. The steel is normally quenched from this temperature to stop re-association*.

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Inter-Granular Corrosion

Also known as weld decay

- **Location:** Weld HAZ. (longitudinal).
- **Steel type:** Austenitic stainless steels.
- **Susceptible microstructure:** Sensitised HAZ grain boundaries.

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Inter-Granular Corrosion

- Weld decay, intergranular corrosion or knife line attack, may occur in austenitic stainless steels.
- At the critical range of 600-850°C chromium carbide precipitation at the grain boundaries takes place.
- At this temperature range chromium is absorbed by the carbon at the grain boundaries, which causes a local depletion of chromium content in the adjacent areas.
- The depletion of chromium content in the affected areas results in lowering the materials resistance to corrosion attack, allowing rusting to occur.

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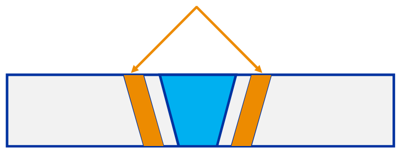
Inter-Granular Corrosion

Sensitisation range where peak temperatures in the HAZ reaches about 600°C to 850°C.



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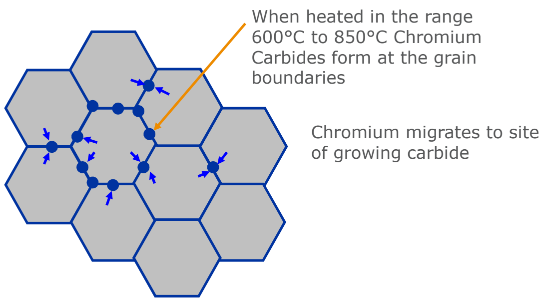
Inter-Granular Corrosion



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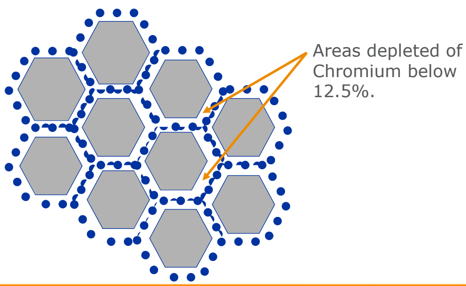
Inter-Granular Corrosion

Grain boundary adjacent areas become depleted of chromium and lose their corrosion resistance.



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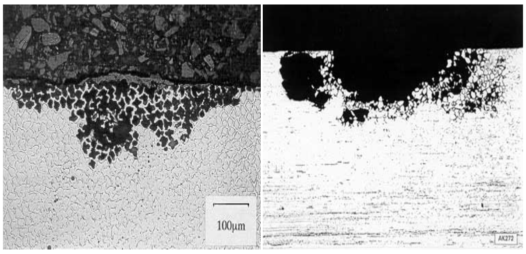
Inter-Granular Corrosion



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Weld Decay

Precautions against weld decay

- Using low carbon grade stainless steel eg 304L, 316L, as the amount of free carbon in solution is sufficiently low to ensure that Cr carbide formation is minimal and therefore that sensitisation is not usually of practical significance during welding.
- Stabilized grade stainless steel eg 321, 347, 348 recommended for severe corrosive conditions and high temperature operating conditions containing Ti or Nb, to form carbides preferentially to Cr.

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Weld Decay

Precautions against weld decay

- Standard austenitic grades may require PWHT, this involves heating the material to a temperature over 1100°C and quench the material, this restores the chromium content at the grain boundary, a major disadvantage of this heat treatment is the high amount of distortion.

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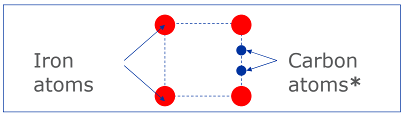
Basic Atomic Structure of Steels

A most important function in the metallurgy of steels, is the ability of iron to dissolve carbon in solution*.

The carbon atom is very much smaller than the iron atom and does not replace it in the atomic structure but fits between it*.



Iron is an element that can exist in 2 types of cubic structures, depending on the temperature. This is an important feature*.

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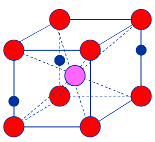
Basic Atomic Structure of Steels

At temperatures below Ac/r 1, (LCT) iron exists like this*

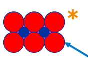


α Alpha iron

This structure occurs below 723°C and is body centred or BCC in structure

It can only dissolve up to **0.02% Carbon**

Also known as Ferrite or BCC iron*



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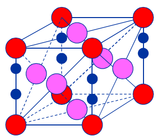
Basic Atomic Structure of Steels

At temperatures above the Ac/r 3, (UCT) iron exists like this*

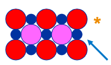


γ Gamma iron

This structure occurs above the UCT in Plain Carbon Steels and is FCC in structure.

It can dissolve up **2.06% Carbon**

Also called Austenite or FCC iron*



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Basic Atomic Structure of Steels

- If steel is heated and then cooled slowly in equilibrium, then exact reverse atomic changes take place*.
- If a steel that contains more than 0.3% carbon is cooled quickly, then the carbon does not have time to **precipitate** out of solution, hence trapping the carbon in the BCC form of iron.
- This now distorts the cube to an irregular cube, or tetragon*.
- This supersaturated solution is called **martensite** and is the hardest structure that can be produced in steels*.

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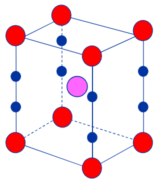
Basic Atomic Structure of Steels

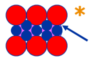
Some steels if cooled quickly their structure looks like this*



Martensite can be defined as:

A supersaturated solution of carbon in BCT iron (Body Centred Tetragonal)

It is the hardest structure we can produce in steels*



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The Important Points of Steel Microstructures

Solubility of Carbon in BCC & FCC phases of steels*

Ferrite:	a **Low carbon solubility**. Maximum 0.02%*
Austenite:	g **High carbon solubility**. Maximum 2.06%*
Martensite:	The hardest phase in steels, which is produced by rapid cooling from the Austenite phase:
	It mainly occurs below 300°C*

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Summary of Steel Microstructures

- To summarize the effect of increasing the hardness of steels by thermal treatment, it can be said that the formation of Martensite is caused by the **entrapment of carbon in solution**, produced by rapid cooling from temperatures above the Upper Critical*
- In plain carbon steels there must be sufficient carbon to trap. In low alloy steels however, the alloying elements play a significant part in the thermal hardening of steels*

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Any Questions

?

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Section 18

Weld Repairs

18 Weld Repairs

18.1 Two specific areas

- Production.
- In-service.

The reasons for making a repair are many and varied, from the removal of weld defects induced during manufacture to a quick and temporary running-repair to an item of production plant. The subject of welding repairs is also wide and varied and often confused with maintenance and refurbishment where the work can be scheduled.

With planned maintenance and refurbishment, sufficient time enables the tasks to be completed without production pressures being applied. In contrast, repairs are usually unplanned and may result in shortcuts being taken to allow production to continue so it is advisable for a fabricator to have an established policy on repairs and to have repair methods and procedures in place.

The manually controlled welding processes are the easiest to use, particularly if it is a local repair or carried out onsite. Probably the most frequently used is MMA as it is versatile, portable and readily applicable to many alloys because of the wide range of off-the-shelf consumables. Repairs almost always result in higher residual stresses and increased distortion compared with first time welds. With C-Mn and low/medium alloy steels, pre- and postweld heat treatments may be required.

A number of key factors need to be considered before any repair, the most important being it is financially worthwhile. Before this judgement can be made, the fabricator needs to answer the following questions:

- Can structural integrity be achieved if the item is repaired?
- Are there any alternatives to welding?
- What caused the defect and is it likely to happen again?
- How is the defect to be removed and which welding process is to be used?
- Which NDT method is required to ensure complete removal of the defect?
- Will the welding procedures require approval/re-approval?
- What will be the effect of welding distortion and residual stress?
- Will heat treatment be required?
- What NDT is required and how can acceptability of the repair be demonstrated?
- Will approval of the repair be required, if yes, how and by whom?

Weld repairs may be relatively straightforward or quite complex and various engineering disciplines may need to be involved to ensure a successful outcome.

It is recommended that ongoing analysis of the types of defect is carried out by the QC department to discover the likely reason for their occurrence (material/process or skill related).

In general terms, a welding repair involves:

- Detailed assessment to find out the extremity of the defect possibly using a surface or sub-surface NDT method.
- Cleaning the repair area (removal of paint grease, etc).
- Once established the excavation site must be clearly identified and marked out.
- An excavation procedure may be required (method used ie grinding, arc/air gouging, preheat requirements, etc).
- NDT to locate the defect and confirm its removal.
- A welding repair procedure/method statement with the appropriate (suitable for the alloys being repaired and may not apply in specific situations.) welding process, consumable, technique, controlled heat input and interpass temperatures, etc will need to be approved.
- Use of approved welders.
- Dressing the weld and final visual.
- NDT procedure/technique prepared and carried out to ensure that the defect has been successfully removed and repaired.
- Any post repair heat treatment requirements.
- Final NDT procedure/technique prepared and carried out after heat treatment requirements.
- Applying protective treatments (painting, etc as required).

Production repairs

Repairs are usually identified during production inspection. Evaluation of the reports is by the Welding Inspector or NDT operator. Discontinuities in the welds are only classed as defects when they are outside the range permitted by the applied code or standard.

Before any repair a number of elements need to be fulfilled.

Analysis

As this defect is surface-breaking and at the fusion face the problem could be cracking or lack of sidewall fusion. The former may be to do with the material or welding procedure, if it is done the latter can be apportioned to the welder's lack of skill.

Assessment

As the defect is open to the surface, magnetic particle inspection (MPI) or dye penetrant inspection (DPI) may be used to gauge the length of the defect and ultrasonic testing (UT) to gauge the depth.

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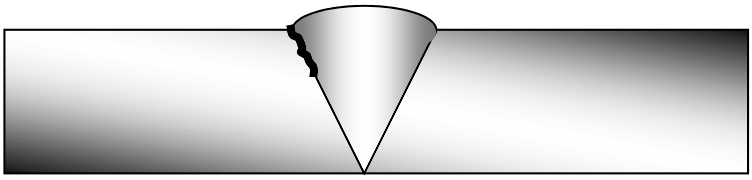

Figure 18.1 A typical defect.

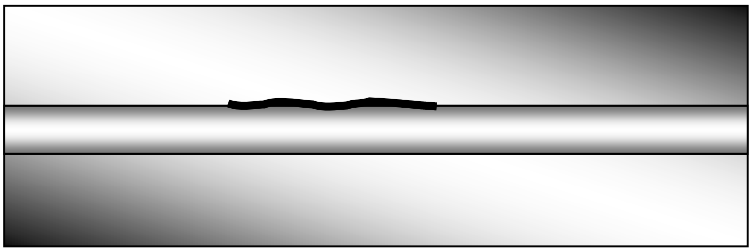

Figure 18.2 Plan view of defect.

Excavation

If a thermal method of excavation is to be used, ie arc/air gouging it may be a requirement to qualify a procedure as the heat generated may affect the metallurgical structure, resulting in the risk of cracking in the weld or parent material.

Figure 18.3 Thermal excavation using arc/air gouging.

To prevent cracking it may be necessary to apply a preheat. Depth to width ratio shall not be less than 1 (depth) to 1 (width), ideally depth 1 to width 1.5.

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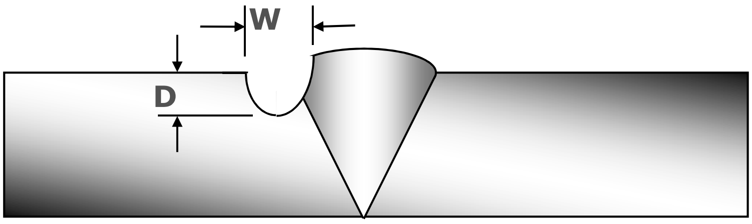

Figure 18.4 Side view of excavation for slight sub-surface defect

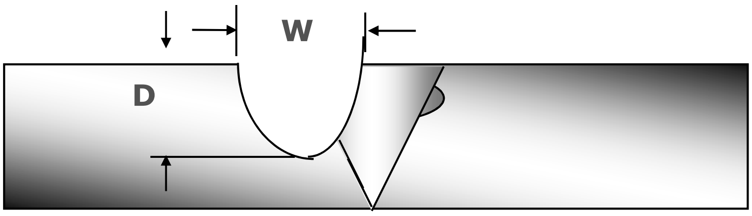

Figure 18.5 Side view of excavation for deep defect.

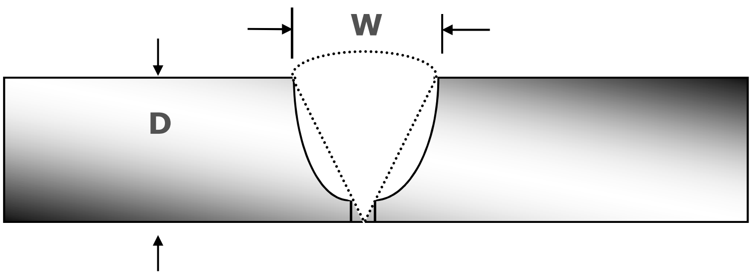

Figure 18.6 Side view of excavation for full root repair.

Cleaning the excavation

At this stage grinding the repair area is important due to the risk of carbon becoming impregnated into the weld metal/parent material and it should be ground back typically 3-4mm to bright metal.

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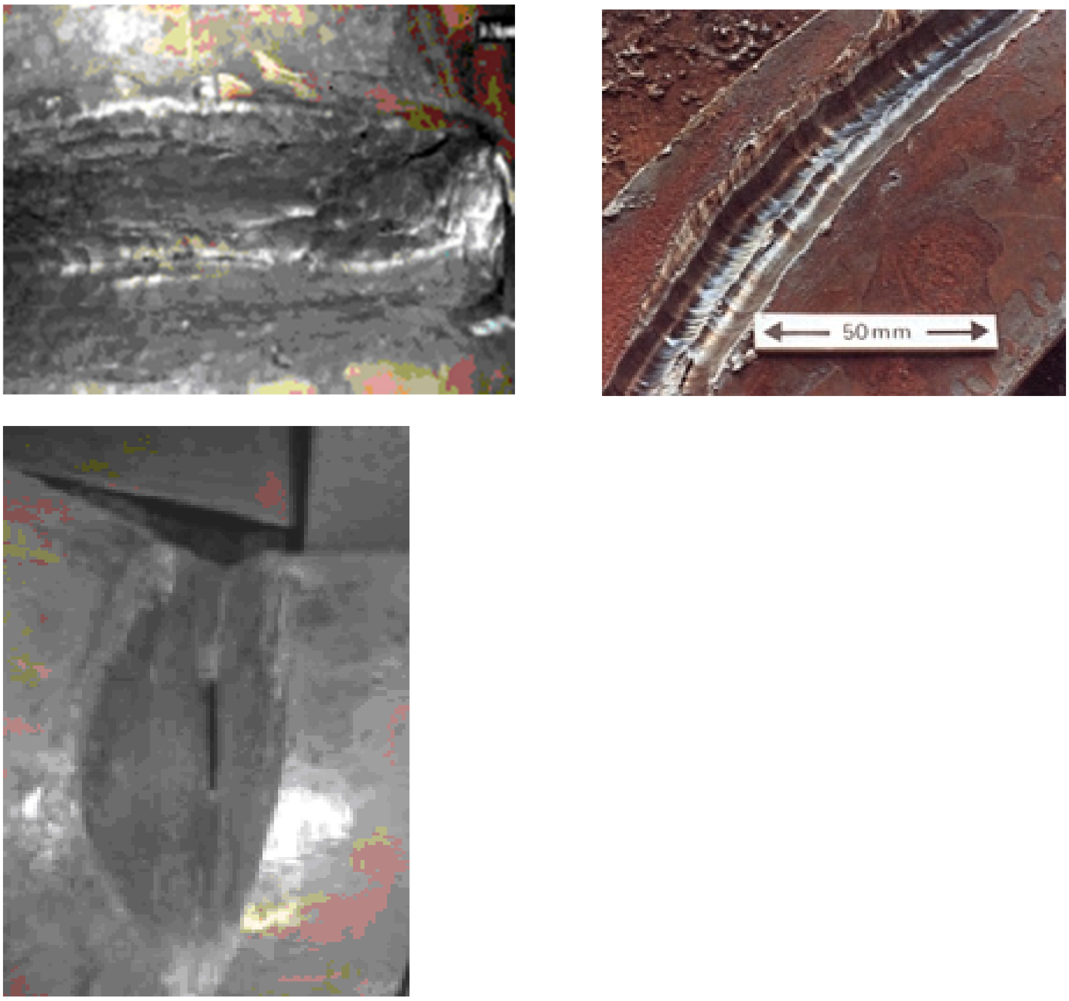

Figure 18.7 Cleaned excavations.

Confirmation of excavation

NDT must confirm that the defect has been completely excavated from the area.

Rewelding of the excavation

Prior to rewelding a detailed repair welding procedure/method statement shall be approved.

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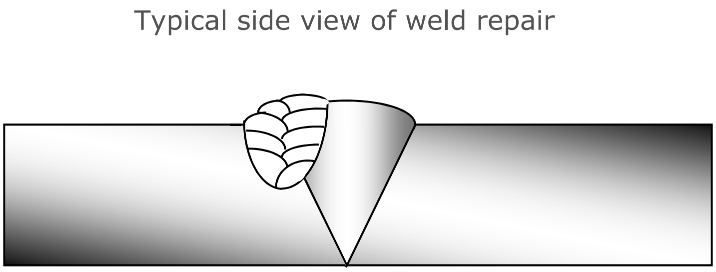

Figure 18.8 Weld repair and typical side view.

NDT confirmation of successful repair

After the excavation has been filled the weldment should undergo a complete retest using the NDT techniques previously used to establish the original repair to ensure no further defects have been introduced by the repair welding process. NDT may need to be further applied after any additional PWHT.

In-service repairs

Most in-service repairs are very complex as the component is likely to be in a different welding position and condition than during production. It may have been in contact with toxic or combustible fluids so a permit to work will be needed prior to any work. The repair welding procedure may look very different to the original production procedure due to changes.

Other factors may be taken into consideration such as the effect of heat on surrounding areas of the component, ie electrical components, or materials that may be damaged by the repair procedure. This may also include difficulty in carrying out any required pre- or post-welding heat treatments and a possible restriction of access to the area to be repaired. For large fabrications it is likely that the repair must also take place on-site without a shutdown of operations which may bring other considerations.

Repair of in-service defects may require consideration of these and many other factors so are generally considered more complicated than production repairs.

Joining technologies often play a vital role in the repair and maintenance of structures. Parts can be replaced, worn or corroded parts can be built up and cracks repaired.

When a repair is required it is important to determine two things: The reason for failure and, can the component be repaired? The latter infers that the material type is known. For metals, particularly those to be welded, chemical composition is vitally important. Failure modes often indicate the approach required to make a sound repair. When the cause-effect analysis, is not followed through the repair is often unsafe, sometimes disastrously so.

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In many instances, the Standard or Code used to design the structure will define the type of repair that can be carried out and give guidance on the methods to be followed. Standards imply that when designing or manufacturing a new product it is important to consider a maintenance regime and repair procedures. Repairs may be required during manufacture and this situation should also be considered.

Normally there is more than one way of making a repair, for example, cracks in cast iron might be held together or repaired by pinning, bolting, riveting, welding or brazing. The choice will depend on factors such as the reason for failure, material composition and cleanliness, environment and the size and shape of the component.

It is **very important** that repair and maintenance welding are not regarded as activities which are simple or straightforward. A repair may seem undemanding but getting it wrong can result catastrophic failure with disastrous consequences.

Is welding the best method of repair?

If repair is needed because a component has a local irregularity or a shallow defect, grinding out any defects and blending to a smooth contour might be acceptable. It is if the steel has poor weldability or fatigue loading is severe. It is often better to reduce the so-called factor of safety slightly than risk putting defects, stress concentrations and residual stresses into a brittle material.

Brittle materials, including some steels (particularly in thick sections) as well as cast irons, may not withstand the residual stresses imposed by heavy weld repairs, particularly if defects are not totallyl removed, leaving stress concentrations to initiate cracking.

Is the repair like earlier repairs?

Repairs of one sort may have been routine for years but it is important to check that the next one is not subtly different, the section thickness may be greater; the steel to be repaired may be different and less weldable or the restraint higher. If there is any doubt, answer the remaining questions.

What is the composition and weldability of the base metal?

The original drawings usually give some idea of the steel involved although the specification limits may then have been less stringent and the specification may not give enough detail to be helpful. If sulphur-bearing free-machining steel is involved, it could give hot cracking problems during welding.

If there is any doubt about the composition, a chemical analysis should be carried out, to analyse for all elements which may affect weldability (Ni, Cr, Mo, Cu, V, Nb and B) as well as those usually, specified (C, S, P, Si and Mn).

The small cost of analysis could prevent a valuable component being ruined by ill-prepared repairs or save money by reducing or avoiding the need for preheat if the composition is leaner than expected. Once the composition is known, a welding procedure can be devised.

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What strength is required from the repair?

The higher the yield strength of the repair weld metal the greater the residual stress level on completion of welding, risk of cracking, clamping needed to avoid distortion and more difficulty in formulating the welding procedure. The practical limit for the yield strength of conventional steel weld metals is about $1000N/mm^2$.

Can preheat be tolerated?

A high level of preheat makes conditions more difficult for the welder and the parent steel can be damaged if it has been tempered at a low temperature. The steel being repaired may contain items damaged by excessive heating. Preheat levels can be reduced by using consumables of ultra-low hydrogen content or non-ferritic weld metals. Of these, austenitic electrodes may need some preheat, but the more expensive nickel alloys usually do not but may be sensitive to high sulphur and phosphorus contents in the parent steel if diluted into the weld metal.

Can softening or hardening of the HAZ be tolerated?

Softening of the HAZ is likely in very high strength steels, particularly if they have been tempered at low temperatures. It cannot be avoided but its extent can be minimised. Hard HAZs are particularly vulnerable where service conditions can lead to stress corrosion. Solutions containing H_2S (hydrogen sulphide) may demand hardness below 248HV (22HRC) although fresh aerated seawater appears to tolerate up to about 450HV. Excessively hard HAZs may, require PWHT to soften them provided cracking has been avoided.

Is PWHT practicable?

Although desirable, PWHT may not be possible for the same reasons preheating is not. For large structures local PWHT may be possible but care should be taken to abide by the relevant codes because it is easy to introduce new residual stresses by improperly executed PWHT.

Is PWHT necessary?

PWHT may be needed for several reasons and the reason must be known before considering whether it can be avoided.

Will the fatigue resistance of the repair be adequate?

If the repair is in an area highly stressed by fatigue and particularly if it is of a fatigue crack, inferior fatigue life can be expected unless the weld surface is ground smooth and no surface defects left. Fillet welds in which the root cannot be ground smooth are not tolerable in areas of high fatigue stress.

Will the repair resist its environment?

Besides corrosion it is important to consider the possibility of stress corrosion, corrosion fatigue, thermal fatigue and oxidation in-service.

Corrosion and oxidation resistance usually requires filler metal to be at least as noble or oxidation resistant as the parent metal for corrosion fatigue the repair weld profile may need to be blended.

To resist stress corrosion, PWHT may be necessary to restore the correct microstructure, reduce hardness and the residual stress left by the repair.

Can the repair be inspected and tested?

For onerous service, radiography and/or ultrasonic examination are often desirable, but problems are likely if stainless steel or nickel alloy filler is used. Such repairs cannot be assessed by MPI as it is very important to carry out the procedural tests very critically, to ensure there is no risk of cracking nor likelihood of serious welder-induced defects.

For all repair welds it is vital to ensure that welders are properly motivated and carefully supervised.

As-welded repairs

Repair without PWHT is, normal where the original weld was not heat treated but some alloy steels and many thick-sectioned components require PWHT to maintain a reasonable level of toughness, corrosion resistance, etc. However, PWHT of components in-service is not always easy or even possible and local PWHT may cause more problems than it solves except in simple structures.

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Weld Repairs

Section 18

Materials Joining and Engineering Technologies
Training and Examination Services

Weld Repairs Objective

When this presentation has been completed you will be able to establish effective methods of repair when required and methods of excavation.

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Weld Repairs

A weld repair can be a relatively straight forward activity, but in many instances it is quite complex, and various engineering disciplines may need to be involved to ensure a successful outcome.

Analysis of the defect types may be carried out by the Q/C department to discover the likely reason for their occurrence, (material/process or skill related).

In general terms, a welding repair involves **what!**

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Weld Repairs

- Is welding the best method of repair?
- Is the repair really like earlier repairs?
- What is the composition and weldability of the base metal?
- What strength is required from the repair?
- Can preheat be tolerated?
- Can softening or hardening of the HAZ be tolerated?
- Is PWHT necessary and practicable?
- Will the fatigue resistance of the repair be adequate?
- Will the repair resist its environment?
- Can the repair be inspected and tested?

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Weld Repair Related Problems

- Heat from welding may affect dimensional stability and/or mechanical properties of repaired assembly.
- Due to heat from welding, YS goes down = danger of collapse.
- Filler materials used on dissimilar welds may lead to galvanic corrosion.
- Local preheat may induce residual stresses.
- Cost of weld metal deposited during a weld joint repair can reach up to 10 times the original weld metal cost!

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Weld Repairs

- Cleaning the repair area, (removal of paint, grease, etc).
- A detailed assessment to find out the extremity of the defect. This may involve the use of a surface or sub surface NDE method.
- Once established the excavation site must be clearly identified and marked out.
- An excavation procedure may be required (method used ie grinding, arc-air gouging, preheat requirements etc).
- NDE should be used to locate the defect and confirm its removal.
- A welding repair procedure/method statement with the appropriate* welding process, consumable, technique, controlled heat input and interpass temperatures etc will need to be approved.

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Weld Repairs

A weld repair may be used to improve weld profiles or extensive metal removal:

- Repairs to fabrication defects are generally easier than repairs to service failures because the repair procedure may be followed.
- The main problem with repairing a weld is the maintenance of mechanical properties.
- During the inspection of the removed area prior to welding the inspector must ensure that the defects have been totally removed and the original joint profile has been maintained as close as possible.

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Weld Repairs

In the event of repair, it is required:

- Authorisation and procedure for repair.
- Removal of material and preparation for repair.
- Monitoring of repair weld.
- Testing of repair - visual and NDT.

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Weld Repairs

The specification or procedure will govern how the defective areas are to be removed. The method of removal may be:

- Grinding.
- Chipping.
- Machining.
- Filing.
- Oxy-Gas gouging.
- Arc air gouging.

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Weld Repairs

Weld repairs can be divided into 2 specific areas:

1. Production repairs.
2. In service repairs.

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Production Weld Repairs

Production repairs

- Are usually identified during production inspection.
- Evaluation of the reports is usually carried out by the Welding Inspector or NDT operator.

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Production Weld Repairs

Before the repair can commence, a number of elements need to be fulfilled:

- If the defect is surface breaking and has occurred at the fusion face the problem could be cracking or lack of sidewall fusion.
- If the defect is found to be cracking the cause may be associated with the material or the welding procedure.
- If the defect is lack of sidewall fusion this can be apportioned to the lack of skill of the welder.
- In this particular case as the defect is open to the surface, MPI or DYE-PEN may be used to gauge the length of the defect and U/T inspection used to gauge the depth.

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In Service Weld Repairs

Service repairs

- Can be of a very complex nature, as the component is very likely to be in a different welding position and condition than it was during production.
- It may also have been in contact with toxic, or combustible fluids hence a permit to work will need to be sought prior to any work being carried out.
- The repair welding procedure may look very different to the original production procedure due to changes in these elements.

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In Service Weld Repairs

Other factors to be taken into consideration:

Effect of heat on any surrounding areas of the component ie electrical components, or materials that may become damaged by the repair procedure.

This may also include difficulty in carrying out any required pre or post welding heat treatments and a possible restriction of access to the area to be repaired.

For large fabrications it is likely that the repair must also take place on site and without a shut down of operations, which may bring other elements that need to be considered.

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Weld Repairs

There are a number of key factors that need to be considered before undertaking any repair:

- The most important - is it financially worthwhile?
- Can structural integrity be achieved if the item is repaired?
- Are there any alternatives to welding?
- What caused the defect and is it likely to happen again?
- How is the defect to be removed and what welding process is to be used?
- What NDE is required to ensure complete removal of the defect?
- Will the welding procedures require approval/re-approval?

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Weld Repairs

- What will be the effect of welding distortion and residual stress?
- Will heat treatment be required?
- What NDE is required and how can acceptability of the repair be demonstrated?
- Will approval of the repair be required – if yes, how and by whom?

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Weld Repairs

- Use of approved welders.
- Dressing the weld and final visual.
- A NDT procedure/technique prepared and carried out to ensure that the defect has been successfully removed and repaired.
- Any post repair heat treatment requirements.
- Final NDT procedure/technique prepared and carried out after heat treatment requirements.
- Applying protective treatments (painting etc as required).
- (*Appropriate' means suitable for the alloys being repaired and may not apply in specific situations)

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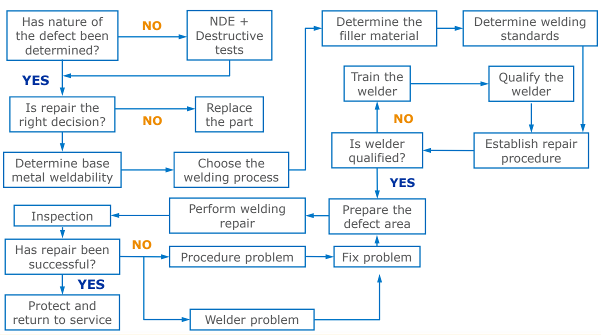
Weld Repair Decision Tree



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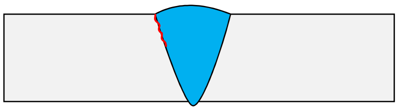
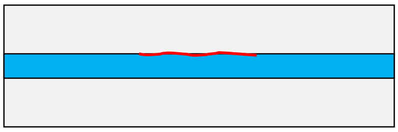
Weld Repairs



Plan View of defect



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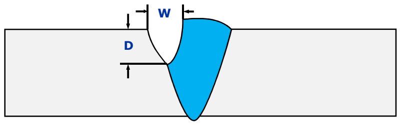
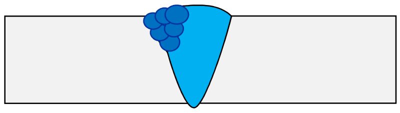
Production Weld Repairs

Side View of defect excavation



Side View of repair welding



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Costs of Weld Repairs

Original weld	Cost	Repair weld	Extra cost
Cut, prep, tack weld	£	Inspector Repair report (NCR etc)	££
Welder time	£	Inspector Identify repair area	££
Consumable & gas	£	Inspector Mark out repair area	££
Visual inspection	£	Welder Remove defect	££
NDT	££	Inspector Visual inspection of excavation	££
Documentation	£	Inspector NDT area of excavation	££
		Inspector Monitor repair welding	££
		Welder time	£
		Consumable & gas	£
		Inspector Visual inspection	££
		NDT	££
		Extra repair Documentation	£
		Penalty % NDT	££

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Any Questions

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Section 19

Residual Stresses and Distortions

19 Residual Stresses and Distortions

19.1 Development of residual stresses

Because welding involves highly localised heating of joint edges to fuse the material, non-uniform stresses are set up in the components being joined, generated because of expansion and contraction of the heated material. Initially, compressive stresses are created in the surrounding cold parent metal when the weld pool is formed due to the thermal expansion of the hot metal HAZ adjacent to the weld pool. Tensile stresses occur on cooling when contraction of the weld metal and the immediate HAZ is resisted by the bulk of the cold parent metal.

As long as these stresses are above the yield point of the metal at the prevailing temperature, they continue to produce permanent deformation, but in so doing are relieved and fall to yield-stress level so cease to cause further distortion. But, if at this point we could release the weld from the plate by cutting along the joint line, it would shrink further because, even when distortion has stopped, the weld contains an elastic strain equivalent to the yield stress. Visualise the completed joint as weld metal being stretched elastically between two plates.

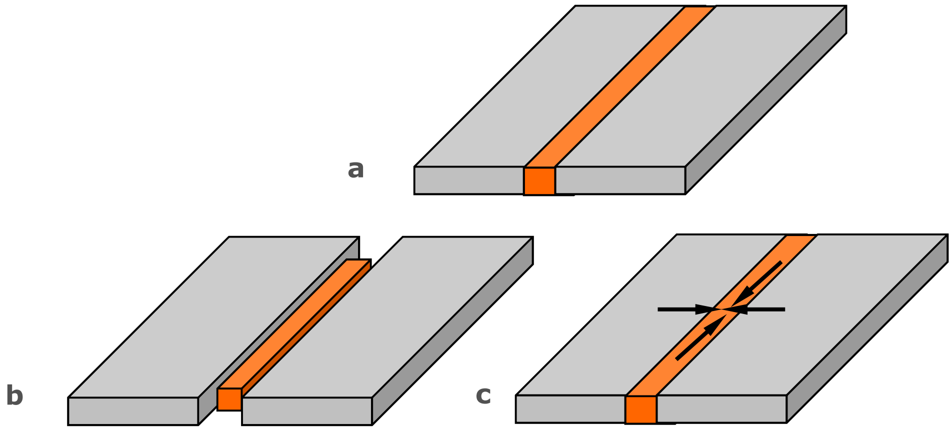

Figure 19.1 Shrinkage of a weld metal element during cooling:

a The entire length of weld is hot and starts to cool;
b If unfused to the parent metal, the weld will shrink, reducing its dimensions on all three directions;
c Since the weld is fused to the parent metal under combined cooling residual stresses will occur.

The stresses left in the joint after welding are referred to as residual stresses. From the above it can be seen there will be both longitudinal and transverse stresses (in the case of a very thick plate there is a through-thickness component of residual stress as well).

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19.1.1 Distribution of residual stresses

The magnitude of thermal stresses induced into the material can be seen by the volume change in the weld area on solidification and subsequent cooling to room temperature. For example, when welding C-Mn steel the molten weld metal volume will be reduced by approximately 3% on solidification and the volume of the solidified weld metal/ HAZ will be reduced by a further 7% as its temperature falls from the melting point of steel to room temperature.

Perpendicular to the weld, in the transverse direction, the stresses in the weld are more dependent on the clamping condition of the parts. Transverse residual stresses are often relatively small although transverse distortion is substantial. The distribution of transverse residual stresses in a butt joint is shown below. Tensile stress of a relatively low magnitude is produced in the middle section while compressive stress is generated at both ends of the joint. It must be noted that the longer the weld, the higher the tensile residual stress until yield stress is reached.

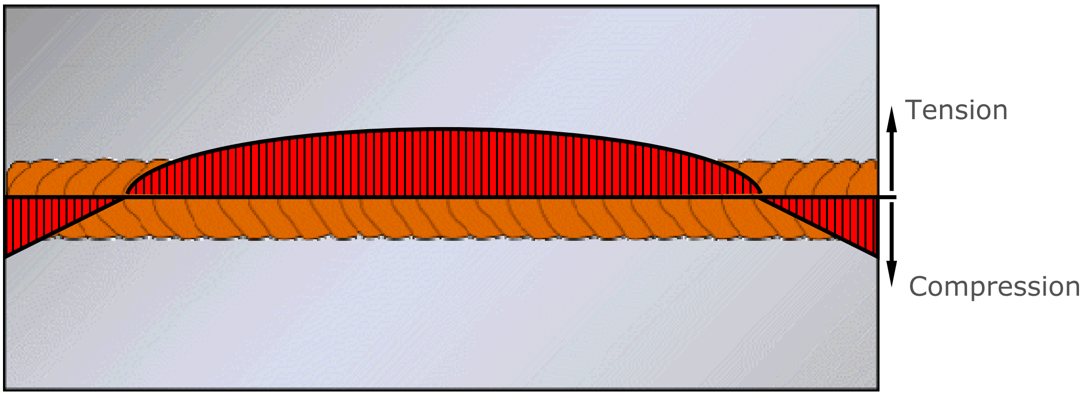

Figure 19.2 The pattern of residual stresses on transverse direction.

In longitudinal stresses the weld and some of the plate which has been heated are at or near yield-stress level. Moving out into the plate from the HAZ, the stresses first fall to zero (the tensile stress region extends beyond the weld and HAZ into the parent plate) and beyond this there is a region of compressive stress. The width of the band where tensile residual stresses are present depends on the heat input during welding, the higher the heat input the wider the band where these tensile residual stresses occur.

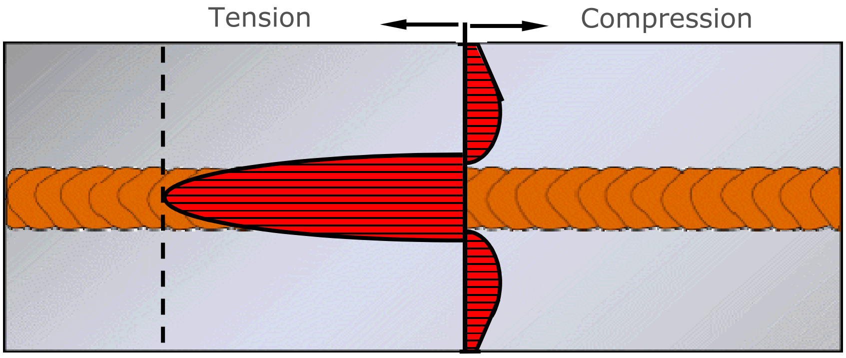

Figure 19.3 The pattern of residual stresses in the longitudinal direction in the as-welded conditions.

The maximum level of tensile residual stress is equal to the value of the yield strength of the weld metal at room temperature.

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All fusion welds which have not been subjected to postweld treatments, the vast majority of welded joints, contain residual stresses. Procedures developed to minimise distortion may alter the distribution of the residual stresses but do not eliminate them or even reduce their peak level.

One method of reducing the level of residual stress in a welded joint is to perform PWHT to relieve these stresses. So once the temperature is raised the yield stress starts to drop. As a result of this the peak residual stresses which were up to the value of yield stress at room temperature, cannot be carried over any more by the material and are relaxed by plastic deformation (usually, this plastic deformation is confined at the level of grains but in some situations can lead to significant deformation of the welded component). This process ends when the material has reached the soaking temperature. So the level of residual stresses will be reduced by the difference between the value of the yield stress at room temperature (at the beginning of PWHT) at the soaking temperature. As can be seen from the following figure, this can reduce the level of tensile residual stresses up to a quarter of its initial level but compressive residual stresses are left unchanged. It must be pointed out that PWHT does not completely eliminate these residual stresses.

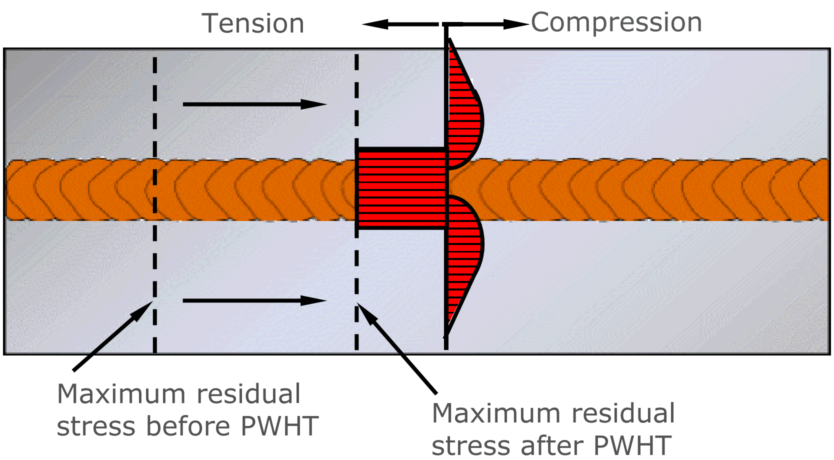

Figure 19.4 Pattern of residual stresses on longitudinal direction after PWHT.

19.1.2 Effect of residual stresses

Since formation of residual stresses cannot be avoided, it is appropriate to ask if their presence is a concern. As with many engineering situations the answer is not a simple yes or no. There are numerous applications where the existence of residual stresses would have little or no influence on the service behaviour of the joint, storage tanks, building frames, low pressure pipework and domestic equipment examples where the joints can be used in the as-welded condition without detriment.

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Residual stresses are considered detrimental because they:

- Lead to distortion and an out-of-shape welded structure is not fit-for-purpose.
- Affect dimensional stability of the welded assembly. When machining welded components, removing layers of metal near the joint may disturb the balance between the tensile and compressive residual stresses and further deformation or warping can occur. This can make it difficult to hold critical machining tolerances and it may be desirable to stress-relieve to achieve dimensional stability.
- Enhance the risk of brittle fracture. When residual stresses are present in a welded component, a small extra stress added may initiate a brittle fracture, providing other conditions are met (ie low temperature).
- Can facilitate certain types of corrosion. Some metals in certain environments corrode rapidly in the presence of tensile stress, ie stress corrosion cracking. In these cases, a joint in the as-welded condition containing residual stresses suffers excessive attack; retarded if the joint is stress-relieved.

If the service requirements indicate that residual stresses are undesirable, the designer must take them into account when selecting materials and deciding upon a safe working stress. This can be seen in the design of ships, where the combination of low temperatures and residual stress could lead to brittle fracture. The designer selects a material not susceptible to this mode of failure even at the low temperatures which may be experienced during the working life of the ship; the presence of residual stresses is then not important. Similarly, in many structures subjected to loads which fluctuate during service, for example, bridges, earthmoving equipment and cranes, the designer recognises the existence of residual stresses by choosing a working stress range which takes account of the role these stresses play in the formation and propagation of fatigue cracks. There are some specific applications where it is essential to reduce the level of residual stresses in the welded joint: With pressure vessels because of the risk of a catastrophic failure by brittle fracture, stress-relieving is often a statutory or insurance requirement.

19.1.3 Factors affecting residual stresses

Can be grouped into five categories:

1. Material properties.
2. Amount of restraint.
3. Joint design.
4. Fit-up.
5. Welding sequence.

19.2 Causes of distortion

Welding involves highly localised heating of joint edges to fuse the material and non-uniform stresses are set up in the component because of expansion and contraction of the heated material.

Initially, compressive stresses are created in the surrounding cold parent metal when the weld pool is formed due to the thermal expansion of the hot metal (HAZ) adjacent to the weld pool. Tensile stresses occur on cooling when the contraction of the weld metal and immediate HAZ is resisted by the bulk of the cold parent metal.

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The magnitude of thermal stresses induced into the material can be seen by the volume change in the weld area on solidification and subsequent cooling to room temperature. For example, when welding C-Mn steel, the molten weld metal volume will be reduced by approximately 3% on solidification and the volume of the solidified weld metal/HAZ will be reduced by a further 7% as its temperature falls from the melting point of steel to room temperature.

If the stresses generated from thermal expansion/contraction exceed the yield strength of the parent metal, localised plastic deformation of the metal occurs, causing a permanent reduction in the component dimensions and distorts the structure.

19.3 The main types of distortion

- Longitudinal shrinkage.
- Transverse shrinkage.
- Angular distortion.
- Bowing and dishing.
- Buckling.

Contraction of the weld area on cooling results in both **transverse** and **longitudinal** shrinkage.

Non-uniform contraction (through-thickness) produces **angular** distortion as well as longitudinal and transverse shrinking.

For example, in a single V butt weld, the first weld run produces longitudinal and transverse shrinkage and rotation. The second run causes the plates to rotate using the first weld deposit as a fulcrum so balanced welding in a double-sided V butt joint can produce uniform contraction and prevent angular distortion.

In a single-sided fillet weld, non-uniform contraction will produce angular distortion of the upstanding leg so double-sided fillet welds can be used to control distortion in the upstanding fillet but because the weld is only deposited on one side of the base plate, angular distortion will now be produced in the plate.

Longitudinal **bowing** in welded plates happens when the weld centre is not coincident with the neutral axis of the section so that longitudinal shrinkage in the welds bends the section into a curved shape. Clad plate tends to bow in two directions due to longitudinal and transverse shrinkage of the cladding, producing a dished shape.

Dishing is also produced in stiffened plating. Plates usually dish inwards between the stiffeners, because of angular distortion at the stiffener attachment welds.

In plating, long range compressive stresses can cause elastic buckling in thin plates, resulting in dishing, bowing or rippling, Figure 19.5.

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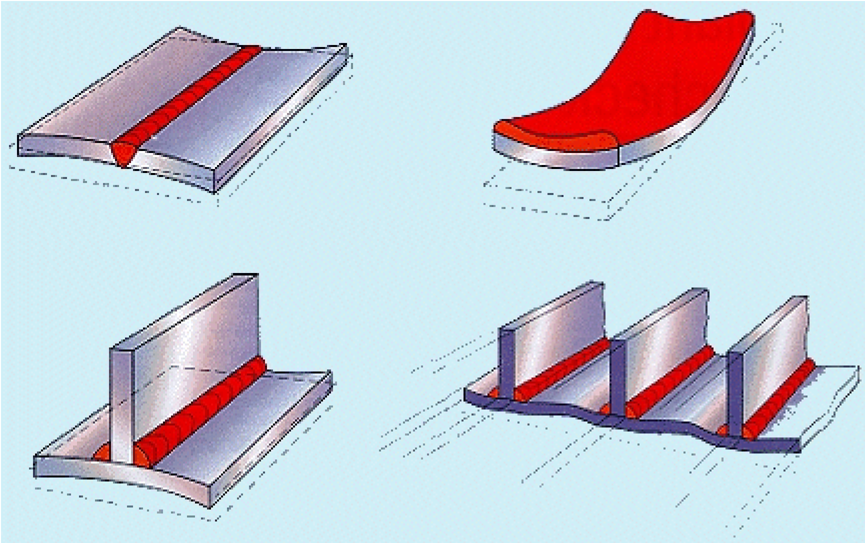

Figure 19.5 Examples of distortion.

Increasing the leg length of fillet welds, in particular, increases shrinkage.

19.4 Factors affecting distortion

If a metal is uniformly heated and cooled there would be almost no distortion but because the material is locally heated and restrained by the surrounding cold metal, stresses are generated higher than the material yield stress causing permanent distortion. The principal factors affecting the type and degree of distortion are:

- Parent material properties.
- Amount of restraint.
- Joint design.
- Part fit-up.
- Welding procedure.

19.4.1 Parent material properties

Parent material properties which influence distortion are coefficient of thermal expansion, thermal conductivity and to a lesser extent, yield stress and Young's modulus. As distortion is determined by expansion and contraction of the material so the coefficient of thermal expansion of the material plays a significant role in determining the stresses generated during welding and the degree of distortion. For example, as stainless steel has a higher coefficient of expansion and lesser thermal conductivity than plain carbon steel, it generally has significantly more distortion.

19.4.2 Restraint

If a component is welded without any external restraint, it distorts to relieve the welding stresses. Methods of restraint such as strongbacks in butt welds, can prevent movement and reduce distortion. Restraint produces higher levels of residual stress in the material, so there is a greater risk of cracking in weld metal and HAZ especially in crack-sensitive materials.

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19.4.3 Joint design

Both butt and fillet joints are prone to distortion. It can be minimised in butt joints by adopting a joint type which balances the thermal stresses through the plate thickness, eg double-sided in preference to a single-sided weld. Double-sided fillet welds should eliminate angular distortion of the upstanding member especially if the two welds are deposited at the same time.

19.4.4 Part fit-up

Fit-up should be uniform to produce predictable and consistent shrinkage. Excessive joint gap can increase the degree of distortion by increasing the amount of weld metal needed to fill the joint. The joints should be adequately tacked to prevent relative movement between the parts during welding.

19.4.5 Welding procedure

This influences the degree of distortion mainly through its effect on heat input. As welding procedures are usually selected for reasons of quality and productivity, the welder has limited scope for reducing distortion. As a general rule weld volume should be kept to a minimum. Also, the welding sequence and technique should balance the thermally induced stresses around the neutral axis of the component.

19.5 Prevention by pre-setting, pre-bending or use of restraint

Distortion can often be prevented at the design stage, eg by placing the welds about the neutral axis, reducing the amount of welding and depositing the weld metal using a balanced welding technique. Where this is not possible, distortion may be prevented by one of the following:

- Pre-setting of parts.
- Pre-bending of parts.
- Use of restraint.

The technique chosen will be influenced by the size and complexity of the component or assembly, the cost of any restraining equipment and the need to limit residual stresses.

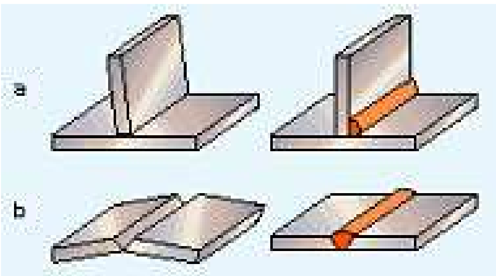

Figure 19.6 Pre-setting of parts to produce correct alignment after welding:
a Fillet joint to prevent angular distortion;
b Butt joint to prevent angular distortion.

19.5.1 Pre-setting

The parts are pre-set and left free to move during welding, see Figure 19.6. The parts are pre-set by a pre-determined amount so that distortion occurring during welding is used to achieve overall alignment and dimensional control.

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The main advantages compared with restraint are there is no expensive equipment needed and it gives lower residual stress in the structure.

As it is difficult to predict the amount of pre-setting needed to accommodate shrinkage, a number of trial welds will be required. For example when MMA or MIG/MAG welding butt joints the joint gap will normally close ahead of welding; whereas with SAW the joint may open up during welding. When carrying out trial welds it is essential that the test structure is reasonably representative of the full size structure to generate the level of distortion likely to occur. So pre-setting is more suitable for simple components or assemblies.

19.5.2 Pre-bending

Pre-bending or pre-springing parts before welding pre-stresses the assembly to counteract shrinkage during welding. As shown in Figure 19.7, pre-bending using strongbacks and wedges can pre-set a seam before welding to compensate for angular distortion. Releasing the wedges after welding will allows the parts to move back into alignment.

The figure below shows the diagonal bracings and centre jack used to pre-bend the fixture, not the component, counteracting the distortion introduced through out-of-balance welding.

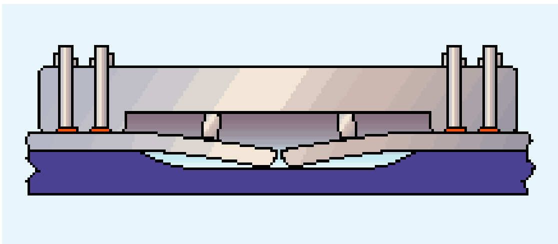

Figure 19.7 Pre-bending using strongbacks and wedges to accommodate angular distortion in thin plates.

19.5.3 Use of restraint

Because of the difficulty in applying pre-setting and pre-bending restraint is the more widely used technique. The basic principle is that the parts are placed in position and held under restraint to minimise any movement during welding. When removing the component from the restraining equipment a relatively small amount of movement will occur due to locked-in stresses which can be cured by applying a small amount of pre-set or stress-relieving before removing the restraint.

When welding assemblies all the component parts should be held in the correct position until completion of welding and a suitably balanced fabrication sequence used to minimise distortion.

Welding with restraint will generate additional residual stresses in the weld which may cause cracking. When welding susceptible materials a suitable welding sequence and the use of preheating will reduce this risk. Restraint is relatively simple to apply using clamps, jigs and fixtures.

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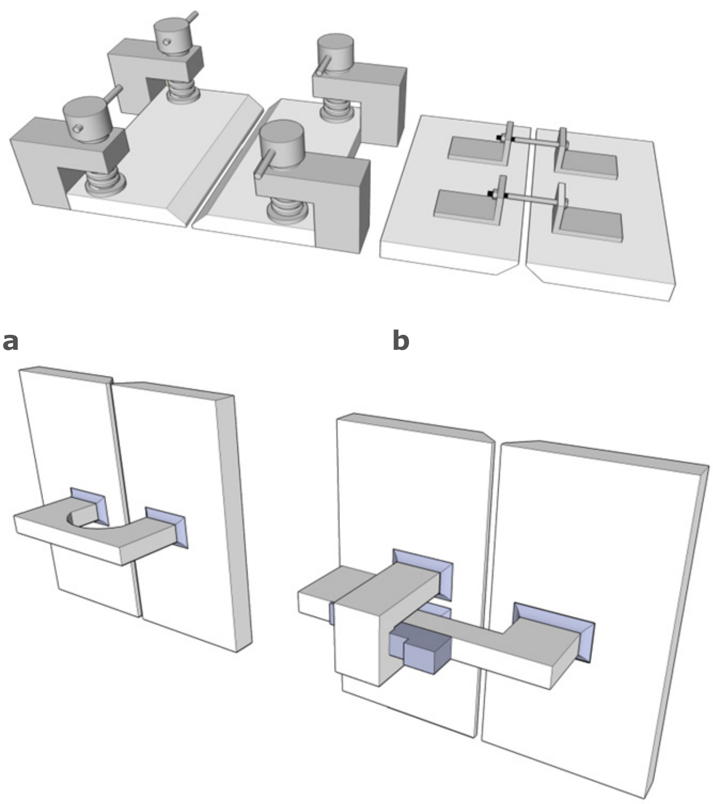
Welding jigs and fixtures

Used to locate the parts and ensure that dimensional accuracy is maintained whilst welding, can be of a relatively simple construction as shown in Figure 19.8a but the welding engineer will need to ensure that the finished fabrication can be removed easily after welding.

Flexible clamps

Can be effective in applying restraint but also in setting up and maintaining the joint gap (can also be used to close a gap that is too wide), Figure 19.8b.

A disadvantage is that as the restraining forces in the clamp will be transferred into the joint when the clamps are removed, the level of residual stress across the joint can be quite high.



a **b**

c **d**

Figure 19.8 Restraint techniques to prevent distortion:

a **Welding jig;**

b **Flexible clamp;**

c **Strongbacks with wedges;**

d **Fully wedged strongbacks.**

Strongbacks and wedges

A popular way of applying restraint especially for site work, wedged strongbacks (Figure 19.8c), will prevent angular distortion in plate and help prevent peaking in welding cylindrical shells. As they allow transverse shrinkage the cracking risk will be greatly reduced compared with fully welded strongbacks.

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Fully welded (welded on both sides of the joint) strongbacks (Figure 19.8d) will minimise both angular distortion and transverse shrinkage. As significant stresses can be generated across the weld which will increase any tendency for cracking, care should be taken in their use.

19.5.4 Best practice

Adopting the following assembly techniques will help control distortion:

- Pre-set parts so that welding distortion will achieve overall alignment and dimensional control with the minimum of residual stress.
- Pre-bend joint edges to counteract distortion and achieve alignment and dimensional control with minimal residual stress.
- Apply restraint during welding using jigs and fixtures, flexible clamps, strongbacks and tack welding but consider the cracking risk which can be quite significant, especially for fully welded strongbacks.
- Use an approved procedure for welding and removal of welds for restraint techniques which may need preheat to avoid inperfections forming in the component surface.

19.6 Prevention by design

Design principles

At the design stage welding distortion can often be prevented or restricted by considering:

- Elimination of welding.
- Weld placement.
- Reducing the volume of weld metal.
- Reducing the number of runs.
- Use of balanced welding.

19.6.1 Elimination of welding

As distortion and shrinkage are an inevitable result of welding, good design requires that welding is kept to a minimum and the smallest amount of weld metal is deposited. Welding can often be eliminated at the design stage by forming the plate or using a standard rolled section, as shown in Figure 19.9.

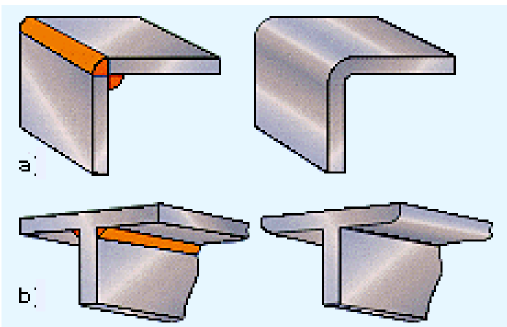

Figure 19.9 Elimination of welds by:

a Forming the plate;

b Use of rolled or extruded section.

If possible the design should use intermittent welds rather than a continuous run to reduce the amount of welding. For example in attaching stiffening plates, a substantial reduction in the amount of welding can often be achieved whilst maintaining adequate strength.

19.6.2 Weld placement

Placing and balancing of welds are important in designing for minimum distortion. The closer a weld is to the neutral axis of a fabrication, the lower the leverage effect of the shrinkage forces and the final distortion. Examples of poor and good designs are shown in Figure 19.10.

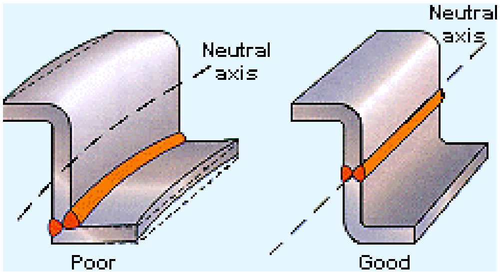

Figure 19.10 Distortion may be reduced by placing the welds around the neutral axis.

As most welds are deposited away from the neutral axis, distortion can be minimised by designing the fabrication so the shrinkage forces of an individual weld are balanced by placing another weld on the opposite side of the neutral axis. Where possible welding should be carried out alternately on opposite sides instead of completing one side first. In large structures if distortion is occurring preferentially on one side it may be possible to take corrective action, for example, by increasing welding on the other side to control the overall distortion.

19.6.3 Reducing the volume of weld metal

To minimise distortion as well as for economic reasons the volume of weld metal should be limited to the design requirements. For a single-sided joint, the cross-section of the weld should be kept as small as possible to reduce the level of angular distortion, as illustrated in Figure 19.11.

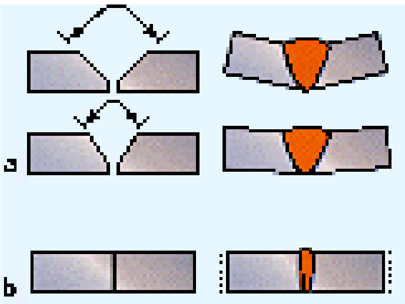

Figure 19.11 Reducing the amount of angular distortion and lateral shrinkage.

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Ways of reducing angular distortion and lateral shrinkage:

- Reducing the volume of weld metal.
- Using single pass welds.
- Ensure fillet welds are not oversize.

Joint preparation angle and root gap should be minimised providing the weld can be made satisfactorily. To facilitate access it may be possible to specify a larger root gap and smaller preparation angle. By reducing the difference in the amount of weld metal at the root and face of the weld the degree of angular distortion will be correspondingly reduced. Butt joints made in a single pass using deep penetration have little angular distortion, especially if a closed butt joint can be welded (Figure 19.11). For example thin section material can be welded using plasma and laser welding processes and thick section can be welded in the vertical position using electrogas and electroslag processes. Although angular distortion can be eliminated there will still be longitudinal and transverse shrinkage.

In thick section material, as the cross-sectional area of a double V joint preparation is often only half that of a single V, the volume of weld metal to be deposited can be substantially reduced. The double V joint preparation also permits balanced welding about the middle of the joint to eliminate angular distortion.

As weld shrinkage is proportional to the amount of weld metal both poor joint fit-up and over-welding will increase the amount of distortion. Angular distortion in fillet welds is particularly affected by over-welding. As design strength is based on throat thickness, over-welding to produce a convex weld bead does not increase the allowable design strength but will increase the shrinkage and distortion.

19.6.4 Reducing the number of runs

There are conflicting opinions on whether it is better to deposit a given volume of weld metal using a small number of large weld passes or a large number of small passes. Experience shows that for a single-sided butt joint, or fillet weld, a large single weld deposit gives less angular distortion than a weld made with a number of small runs. Generally in an unrestrained joint the degree of angular distortion is approximately proportional to the number of passes.

Completing the joint with a small number of large weld deposits results in more longitudinal and transverse shrinkage than using in a larger number of small passes. In a multi-pass weld, previously deposited weld metal provides restraint, so the angular distortion per pass decreases as the weld is built up. Large deposits also increase the risk of elastic buckling particularly in thin section plate.

19.6.5 Use of balanced welding

Balanced welding is an effective means of controlling angular distortion in a multi-pass butt weld by arranging the welding sequence to ensure that angular distortion is continually being corrected and not allowed to accumulate during welding. Comparative amounts of angular distortion from balanced welding and welding one side of the joint first are shown in Figure 19.12. Balanced welding can also be applied to fillet joints.

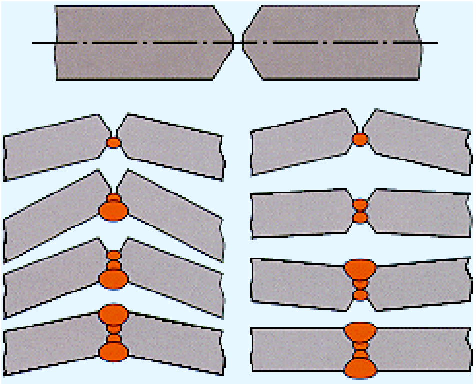

Figure 19.12 Balanced welding to reduce the amount of angular distortion.

If welding alternately on either side of the joint is not possible or if one side has to be completed first, an asymmetrical joint preparation may be used with more weld metal being deposited on the second side. The greater contraction resulting from depositing the weld metal on the second side will help counteract the distortion on the first side.

19.6.6 Best practice

The following design principles can control distortion:

- Eliminate welding by forming the plate and using rolled or extruded sections.
- Minimise the amount of weld metal.
- Do not over-weld.
- Use intermittent welding in preference to a continuous weld pass.
- Place welds about the neutral axis.
- Balance the welding about the middle of the joint by using a double rather than a single V joint.

Adopting best practice principles can have cost benefits. For example, for a design fillet leg length of 6mm, depositing an 8mm leg length will result in the deposition of 57% additional weld metal. Besides the extra cost of depositing weld metal and the increased risk of distortion, it is costly to remove this extra weld metal later. Designing for distortion control may incur additional fabrication costs, for example, the use of a double V joint preparation is an excellent way to reduce weld volume and control distortion but extra costs may be incurred in production through manipulation of the workpiece for the welder to access the reverse side.

19.7 Prevention by fabrication techniques

19.7.1 Assembly techniques

In general, the welder has little influence on the choice of welding procedure but assembly techniques can often be crucial in minimising distortion. The principal assembly techniques are:

- Tack welding.
- Back-to-back assembly.
- Stiffening.

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Tack welding

Ideal for setting and maintaining the joint gap but can also be used to resist transverse shrinkage. To be effective, thought should be given to the number of tack welds, their length and the distance between them. Too few risks the joint progressively closing up as welding proceeds. In a long seam using MMA or MIG/MAG the joint edges may even overlap. When using the submerged arc process the joint might open up if not adequately tacked.

The tack welding sequence is important to maintain a uniform root gap along the length of the joint. Three alternative tack welding sequences are shown:

- Straight through to the end of the joint (Figure 19.13a). It is necessary to clamp the plates or use wedges to maintain the joint gap during tacking.
- One end then use a back stepping technique for tacking the rest of the joint (Figure 19.13b).
- Centre and complete the tack welding by back stepping (Figure19.13c).

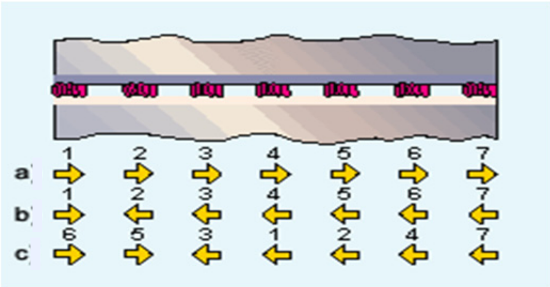

Figure 19.13 Alternative procedures used for tack welding to prevent transverse shrinkage.

Directional tacking is useful for controlling the joint gap, for example closing a joint gap which is or has become too wide.

When tack welding it is important that tacks to be fused into the main weld are produced to an approved procedure using appropriately qualified welders. The procedure may require preheat and an approved consumable as specified for the main weld. Removal of the tacks also needs careful control to avoid causing defects in the component surface.

Back-to-back assembly

By tack welding or clamping two identical components back-to-back, welding of both components can be balanced around the neutral axis of the combined assembly (see Figure 19.14a). It is recommended that the assembly is stress-relieved before separating the components or it may be necessary to insert wedges between the components (Figure 19.14b) so when the wedges are removed the parts will move back to the correct shape or alignment.

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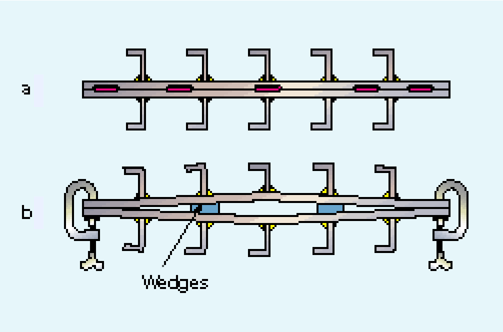

Figure 19.14 Back-to-back assembly to control distortion when welding two identical components:

a Assemblies tacked together before welding;

b Use of wedges for components that distort on separation after welding.

Stiffening

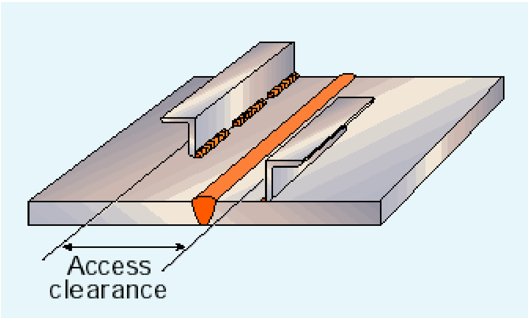

Figure 19.15 Longitudinal stiffeners prevent bowing in butt welded thin plate joints.

Longitudinal shrinkage in butt welded seams often results in bowing, especially when fabricating thin plate structures. Longitudinal stiffeners in the form of flats or angles, welded along each side of the seam (Figure 19.15) are effective in preventing longitudinal bowing. Stiffener location is important unless located on the reverse side of a joint welded from one side they must be placed at a sufficient distance from the joint so they do not interfere with welding.

19.7.2 Welding procedure

A suitable procedure is usually determined by productivity and quality requirements rather than the need to control distortion. The welding process, technique and sequence do influence the distortion level.

Welding process

General rules for selecting a welding process to prevent angular distortion:

- Deposit the weld metal as quickly as possible.
- Use the least number of runs possible to fill the joint.

Unfortunately, selecting a suitable welding process based on these rules may increase longitudinal shrinkage resulting in bowing and buckling.

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In manual welding, MIG/MAG, a high deposition rate process, is preferred to MMA. Weld metal should be deposited using the largest diameter electrode (MMA), or the highest current level (MIG/MAG) without causing lack-of-fusion imperfections. As heating is much slower and more diffuse, gas welding normally produces more angular distortion than the arc processes.

Mechanised techniques combining high deposition rates and welding speeds have the greatest potential for preventing distortion. As the distortion is more consistent, simple techniques such as pre-setting are more effective in controlling angular distortion.

Welding technique

General rules for preventing distortion are:

- Keep the weld (fillet) to the minimum specified size.
- Use balanced welding about the neutral axis.
- Keep the time between runs to a minimum.

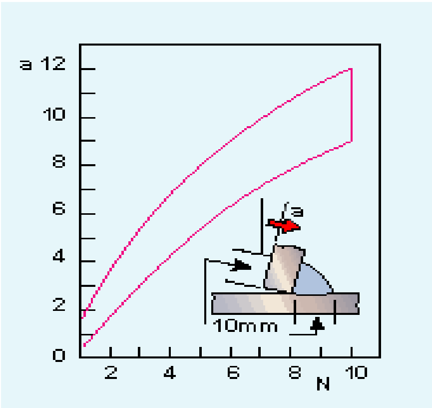

Figure 19.16 Angular distortion of the joint as determined by the number of runs in the fillet weld.

Without restraint angular distortion in both fillet and butt joints is due to joint geometry, weld size and the number of runs for a given cross-section. Angular distortion, measured in degrees as a function of the number of runs for a 10mm leg length fillet weld is shown.

If possible, balanced welding around the neutral axis should be done, for example on double-sided fillet joints, by two people welding simultaneously. In butt joints, the run order may be crucial as balanced welding can be used to correct angular distortion as it develops.

Welding sequence

The welding sequence or direction is important and should be towards the free end of the joint. For long welds the whole of the weld is not completed in one direction. Short runs, for example using the back-step or skip welding technique, are very effective in distortion control (Figure 19.16).

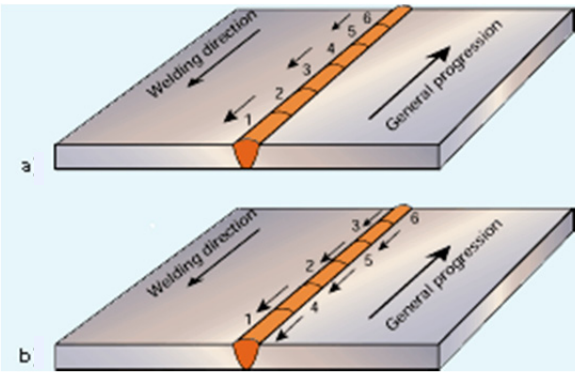

Figure 19.17 Use of welding direction to control distortion:

a Back-step welding;

b Skip welding.

Back-step welding involves depositing short adjacent weld lengths – the appropriate direction to the general progression, Figure19.17a.

Skip welding is laying short weld lengths in a predetermined, evenly spaced, sequence along the seam (Figure 19.17b). Weld lengths and the spaces between them are generally equal to the natural run-out length of one electrode. The direction of deposit for each electrode is the same, but it is not necessary for the welding direction to be opposite to the direction of general progression.

19.7.3 Best practice

The following fabrication techniques are used to control distortion:

- Tack welds to set-up and maintain the joint gap.
- Identical components welded back-to-back so welding can be balanced about the neutral axis.
- Attachment of longitudinal stiffeners to prevent longitudinal bowing in butt welds of thin plate structures.
- Where there is a choice of welding procedure, process and technique should aim to deposit the weld metal as quickly as possible; MIG/MAG in preference to MMA or gas welding and mechanised rather than manual welding.
- In long runs, the whole weld should not be completed in one direction; back-step or skip welding techniques should be used.

19.8 Corrective techniques

Distortion should be avoided at the design stage and by using suitable fabrication procedures. As it is not always possible to avoid distortion during fabrication, several well-established corrective techniques can be used. Reworking to correct distortion should not be undertaken lightly as it is costly and needs considerable skill to avoid damaging the component.

General guidelines are provided on best practice for correcting distortion using mechanical or thermal techniques.

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19.8.1 Mechanical techniques

The principal techniques are hammering which may cause surface damage and work hardening.

With bowing or angular distortion the complete component can often be straightened on a press without the disadvantages of hammering. Packing pieces are inserted between the component and the platens of the press. It is important to impose sufficient deformation to give over-correction so that the normal elastic spring-back will allow the component to assume its correct shape.

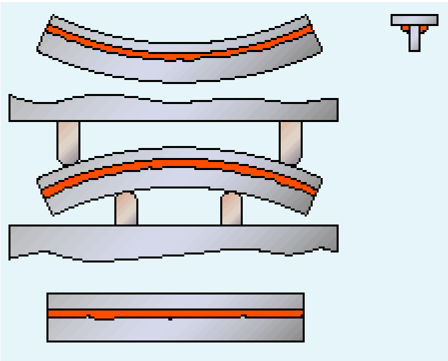

Figure 19.18 Use of press to correct bowing in a T butt joint.

Pressing to correct bowing in flanged plate in long components distortion is removed progressively in a series of incremental pressings; each one acting over a short length. With flanged plate, the load should act on the flange to prevent local damage to the web at the load points. As incremental point loading will only produce an approximately straight component, it is better to use a former to achieve a straight component or to produce a smooth curvature.

Best practice for mechanical straightening

The following should be adopted when using pressing techniques to remove distortion:

- Use packing pieces which will over-correct the distortion so that the spring-back will return the component to the correct shape.
- Check that the component is adequately supported during pressing to prevent buckling.
- Use a former or rolling to achieve a straight component or produce a curvature.
- As unsecured packing pieces may fly out from the press, the following safe practices must be adopted:
  - Bolt the packing pieces to the platen.

19.8.2 Thermal techniques

The basic principle is to create sufficiently high local stresses so that on cooling the component is pulled back into shape.

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Achieved by locally heating the material to a temperature where plastic deformation will occur as the hot, low yield strength material tries to expand against the surrounding cold, higher yield strength metal. On cooling to room temperature the heated area will attempt to shrink to a smaller size than before heating. The stresses generated pull the component into the required shape (Figure 19.19).

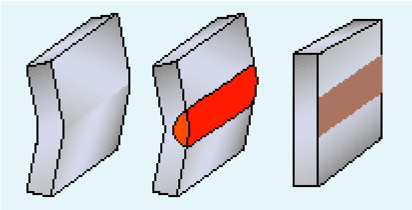

Figure 19.19 Localised heating to correct distortion.

Local heating is a relatively simple but an effective means of correcting welding distortion. Shrinkage level is determined by size, number, location and temperature of the heated zones. Thickness and plate size determine the area of the heated zone, number and placement of heating zones are largely a question of experience and for new jobs, tests will often be needed to quantify the level of shrinkage.

Spot, **line**, or **wedge-shaped** heating techniques can be used in thermal correction of distortion.

Spot heating

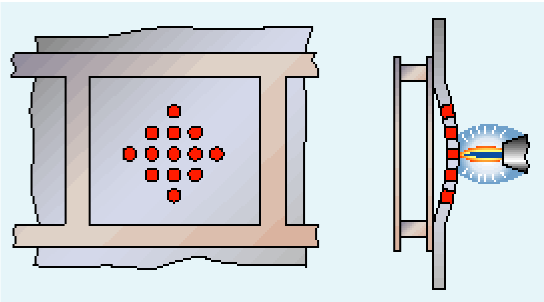

Figure 19.20 Spot heating for correcting buckling.

Spot heating is used to remove buckling, for example when a relatively thin sheet has been welded to a stiff frame. Distortion is corrected by spot heating on the convex side. If the buckling is regular, the spots can be arranged symmetrically, starting at the centre of the buckle and working outwards.

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Line heating

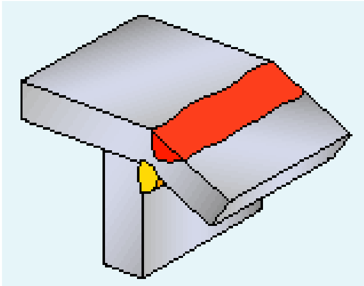

Figure 19.20 Line heating to correct angular distortion in a fillet weld.

Heating in straight lines is often used to correct angular distortion, for example, in fillet welds, Figure 19.20. The component is heated along the line of the welded joint but on the opposite side to the weld so the induced stresses will pull the flange flat.

Wedge-shaped heating

To correct distortion in larger complex fabrications it may be necessary to heat whole areas in addition to using line heating. The pattern aims at shrinking one part of the fabrication to pull the material back into shape.

Apart from spot heating of thin panels, a wedge-shaped heating zone should be used; Figure 19.21 from base to apex and the temperature profile should be uniform through the plate thickness. For thicker section material it may be necessary to use two torches, one on each side of the plate.

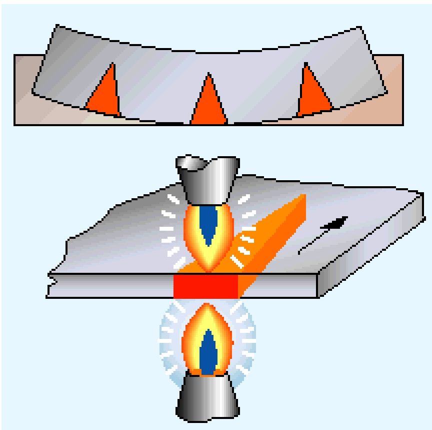

Figure 19.21 Use of wedge-shaped heating to straighten plate.

As a general guideline, to straighten a curved plate wedge dimensions should be:

- Length of wedge - two-thirds of the plate width.
- Width of wedge (base), one sixth of its length (base to apex).

The degree of straightening will typically be 5mm in a 3m length of plate. Wedge-shaped heating can be used to correct distortion in a variety of situations, Figure 19.22.

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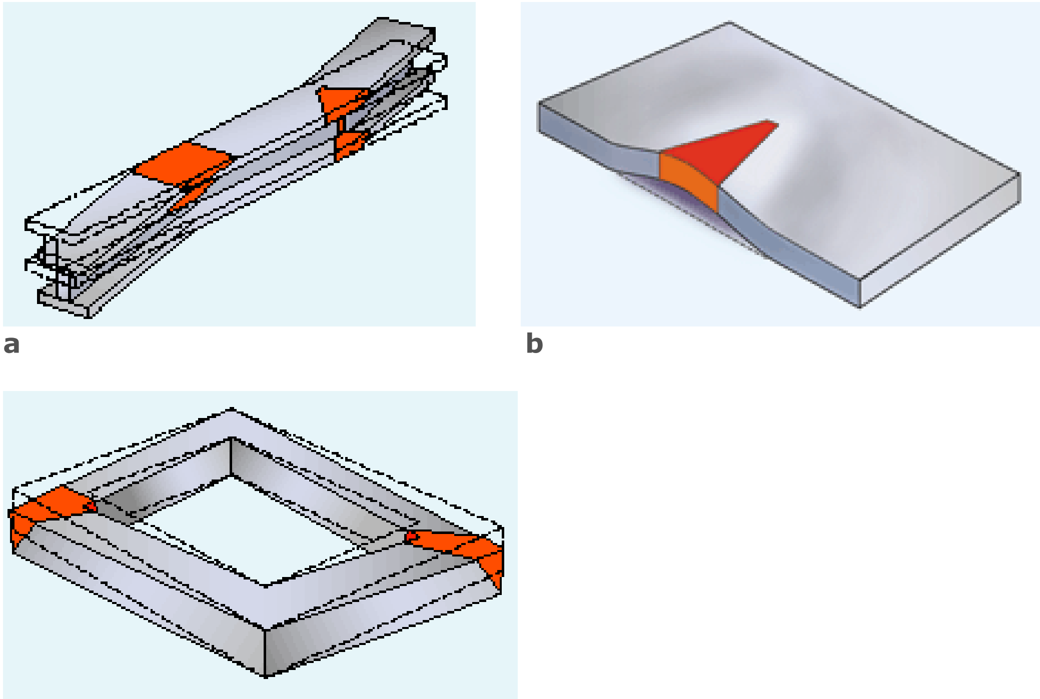

Figure 19.22 Wedge-shaped heating to correct distortion:

a Standard rolled section which needs correction in two planes;

b Buckle at edge of plate as an alternative to rolling;

c Box section fabrication distorted out of plane.

General precautions

The dangers of using thermal straightening techniques are over-shrinking too large an area or causing metallurgical changes by heating to too high a temperature. When correcting distortion in steels the temperature of the area should be restricted to approximately 600-650°C, dull red heat. If the heating is interrupted or the heat lost, the operator must allow the metal to cool then begin again.

Best practice for distortion correction by thermal heating

The following should be adopted when using thermal techniques to remove distortion:

- Use spot heating to remove buckling in thin sheet structures.
- Other than in spot heating of thin panels, use a wedge-shaped heating technique.
- Use line heating to correct angular distortion in plate.
- Restrict the area of heating to avoid over-shrinking the component.
- Limit the temperature to 600-650°C (dull red heat) in steels to prevent metallurgical damage.
- In wedge-shaped heating, heat from the base to the apex of the wedge, penetrate evenly through the plate thickness and maintain an even temperature.

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Residual Stress and Distortion

Section 19

Materials Joining and Engineering Technologies
Training and Examination Services

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Residual Stress and Distortion Objective

When this presentation has been completed you should be able to identify the reasons and preventions of residual stress and distortion.

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Residual Stress

In case of a heated bar, the resistance of the surrounding material to the expansion and contraction leads to formation of residual stress.

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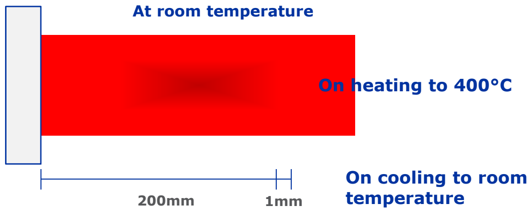
Residual Stress



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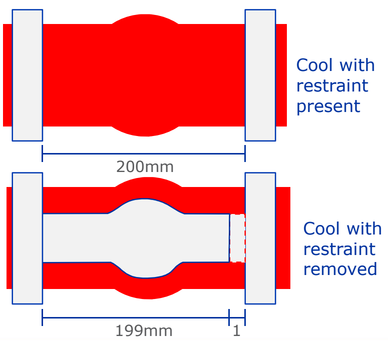
Residual Stress



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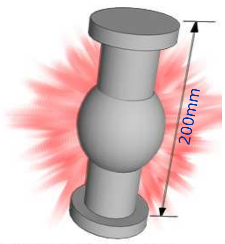
Residual Stress

Ambient temperature.

Heat to 400°C.

Cool with restraint present.



The resistance of the surrounding material to the expansion and contraction leads to formation of residual stress.

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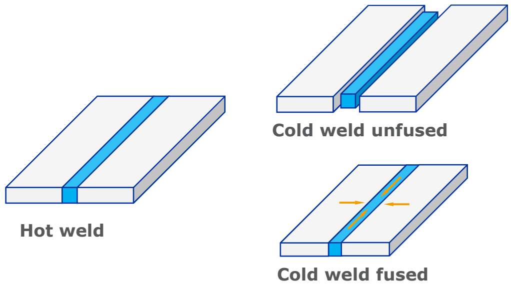
Residual Stress

Origins of residual stress in welded joints



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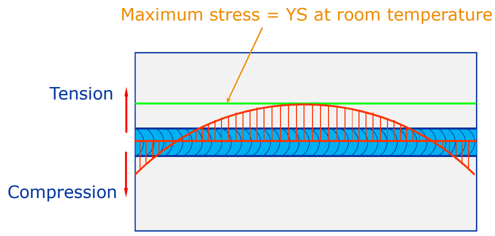
Types of Residual Stress

Transverse residual stress after welding



The longer the weld, the higher the tensile stress!

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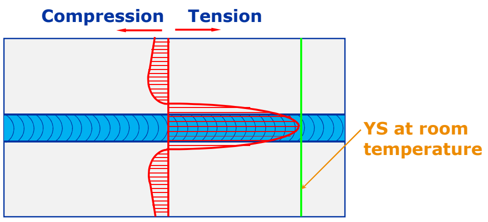
Types of Residual Stress

Longitudinal residual stress after welding



The higher the heat input the wider the tensile zone!

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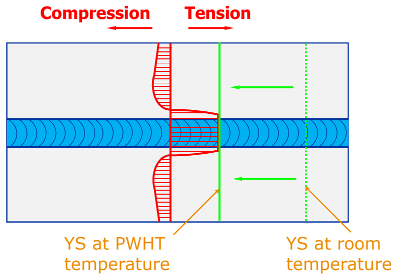
Types of Residual Stress

Residual stress after PWHT



After PWHT, peak residual stress is less than a quarter of its initial level!

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Residual Stress

Residual stresses are undesirable because:

- They lead to distortion.
- They affect dimensional stability of the welded assembly.
- They enhance the risk of brittle fracture.

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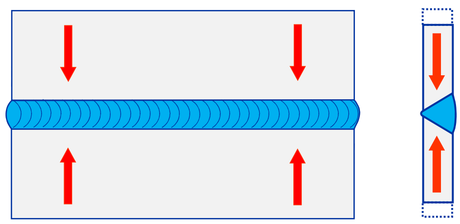
Types of Distortion

Transverse shrinkage



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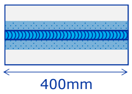
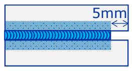
Distortion

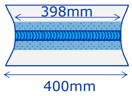
Origins of distortion in welded joints:



Hot weld and HAZ.



Separate cooling.



Combined cooling.

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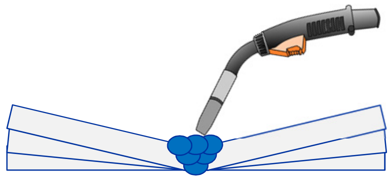
Distortion



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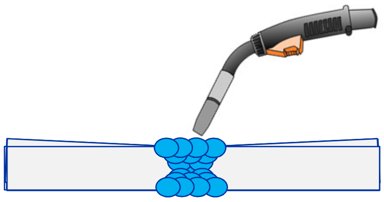

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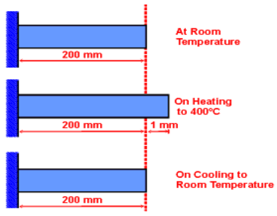
Residual Stress

Heating and cooling causes expansion and contraction.



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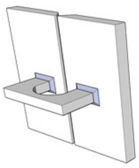
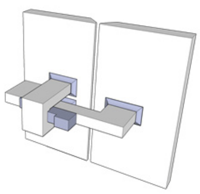
Distortion Prevention

Distortion prevention by restraint techniques.

Use of fully welded strongbacks.





Use of strongbacks with wedges.

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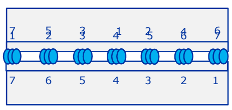
Distortion Prevention

Distortion prevention by fabrication techniques

Tack welding



a Tack weld straight through to end of joint.

b Tack weld one end, then use back-step technique for tacking the rest of the joint.

c Tack weld the centre, then complete the tack welding by the back-step technique.

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Distortion

Factors affecting distortion:

- Parent material properties.
- Amount of restrain.
- Joint design.
- Fit-up.
- Welding sequence.

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Factors Affecting Distortion

Parent material properties:

- Thermal expansion coefficient - the greater the value, the greater the residual stress.
- Yield strength - the greater the value, the greater the residual stress.
- Thermal conductivity - the higher the value, the lower the residual stress.

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Factors Affecting Distortion

Joint design:

- Weld metal volume.
- Type of joint - butt vs. fillet, single vs double side.

Amount of restrain:

- Thickness - as thickness increases, so do the stresses.
- High level of restrain lead to high stresses.
- Preheat may increase the level of stresses.

Fit-up:

- Root gap - increase in root gap increases shrinkage.

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Factors Affecting Distortion

Welding sequence:

- Number of passes - every pass adds to the total contraction.
- Travel speed - the faster the welding speed, the less the stress.
- Build-up sequence.

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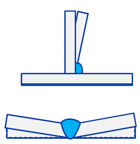
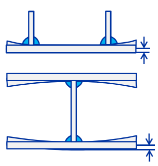
Types of Distortion

Angular distortion



Transverse shrinkage producing angular distortion.



Transverse shrinkage producing distortion.

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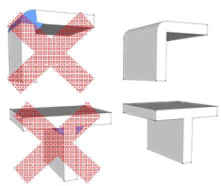
Distortion Prevention

Distortion prevention by design

Consider eliminating the welding!!



a. By forming the plate.
b. By use of rolled or extruded sections.

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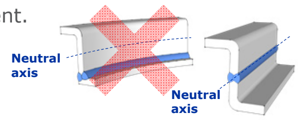
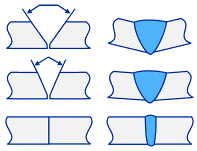
Distortion Prevention

Distortion prevention by design

Consider weld placement.



Reduce weld metal volume and/or number of runs.



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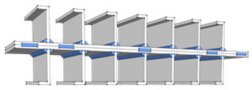
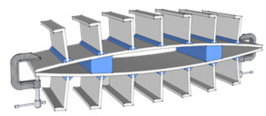
Distortion Prevention

Distortion prevention by fabrication techniques

Back to back assembly



a. Assemblies tacked together before welding.



b. Use of wedges for components that distort on separation after welding.

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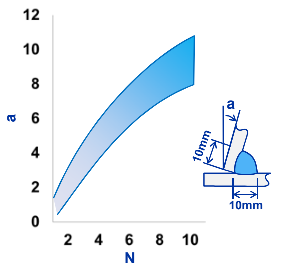
Distortion Prevention

Distortion prevention by fabrication techniques



Reduce the number of runs required to make a weld (eg angular distortion as a function of number of runs for a 10mm leg length weld).

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Distortion Prevention

Distortion prevention by fabrication techniques

- Control welding techniques by use balanced welding about the neutral axis.
- Control welding techniques by keeping the time between runs to a minimum.

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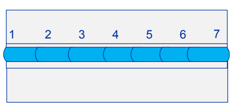
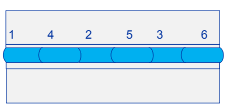
Distortion Prevention

Distortion prevention by fabrication techniques

Control welding techniques by:



a. Back-step welding.



b. Skip welding.

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Distortion Prevention

Distortion - Best practice for fabrication corrective techniques

- Using tack welds to set up and maintain the joint gap.
- Identical components welded back to back so welding can be balanced about the neutral axis.
- Attachment of longitudinal stiffeners to prevent longitudinal bowing in butt welds of thin plate structures.
- Where there is choice of welding procedure, process and technique should aim to deposit the weld metal as quickly as possible; MIG in preference to MMA or gas welding and mechanised rather than manual welding.
- In long runs, the whole weld should not be completed in one direction; back-step or skip welding techniques should be used.

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Section 20

Heat Treatment

20 Heat Treatment

20.1 Introduction

The heat treatment given to a particular grade of steel by the steelmaker/ supplier should be shown on the material test certificate and may be referred to as the supply condition.

Welding inspectors may need to refer to material test certificates so must be familiar with the terminology used and have some understanding of the principles of some of the most commonly applied heat treatments.

Welded joints may need to be subjected to heat treatment after welding (PWHT) and the tasks of monitoring the thermal cycle and checking the heat treatment records are often delegated to welding inspectors.

20.2 Heat treatment of steel

The main supply conditions for weldable steels are:

As-rolled, hot roller and hot finished

Plate is hot rolled to finished size and allowed to air cool; the temperature at which rolling finishes may differ from plate to plate and so strength and toughness properties vary and are not optimised.

Applied to

Relatively thin, lower strength C-steel.

Thermomechanical controlled processing (TMCP), control-rolled, thermomechanically rolled

Steel plate given precisely controlled thickness reductions during hot rolling within carefully controlled temperature ranges; final rolling temperature is also carefully controlled.

Applied to

Relatively thin, high strength low alloy (HSLA) steels and some steels with good toughness at low temperatures, eg cryogenic steels.

Normalised

After working (rolling or forging) the steel to size, it is heated to ~900°C then allowed to cool in air to ambient temperature; which optimises strength and toughness and gives uniform properties from item to item for a particular grade of steel (Figure 20.1).

Applied to

C-Mn steels and some low alloy steels.

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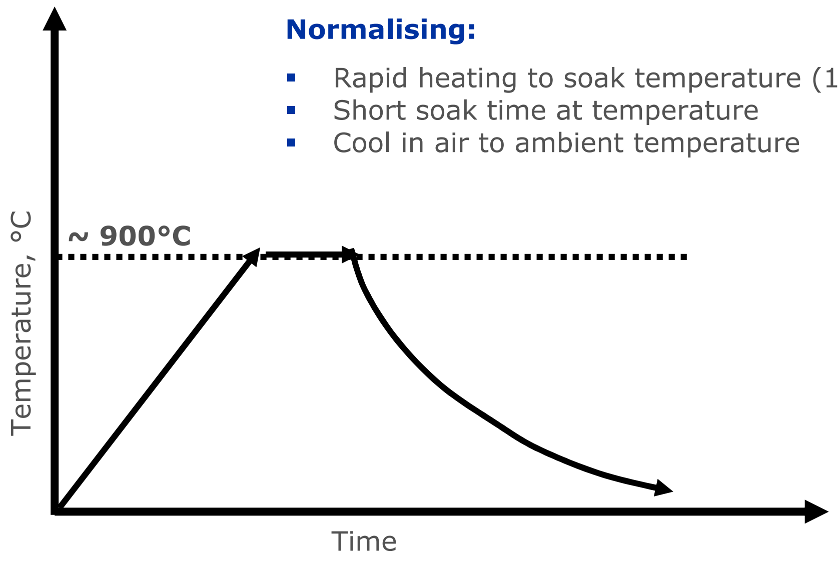

Figure 20.1 Typical normalising heat treatment applied to C-Mn and some low alloy steels.

Quenched and tempered

After working the steel (rolling or forging) to size it is heated to ~900°C then cooled as quickly as possible by quenching in water or oil. After quenching, the steel must be tempered (softened) to improve the ductility of the as-quenched steel (Figure 20.2).

Applied to

Some low alloy steels to give higher strength toughness or wear resistance.

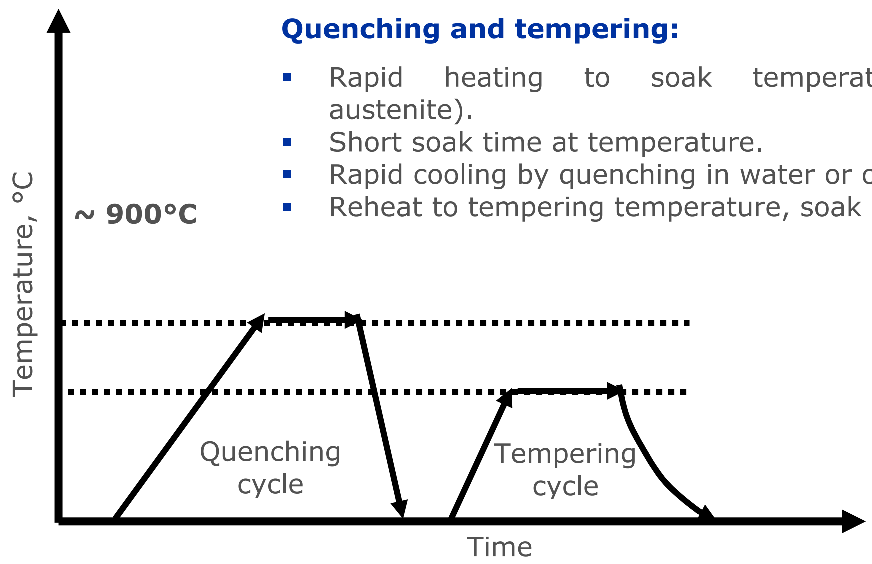

Figure 20.2 A typical quenching and tempering heat treatment applied to some low alloy steels.

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Solution annealed

Hot or cold working to size, steel heated to ~1100°C after.

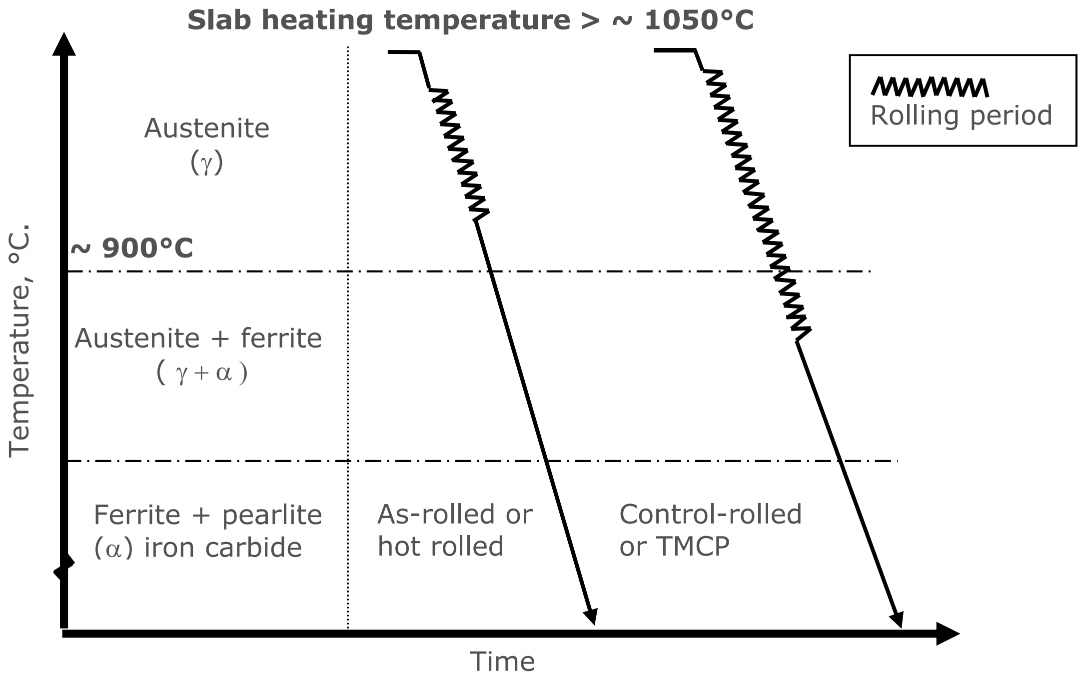

Figure 20.3 Comparison of the control-rolled (TMCP) and as-rolled (hot rolling) conditions.

Solution heat treated

Rapidly cooled by quenching in water to prevent any carbides or other phases forming (Figure 20.4).

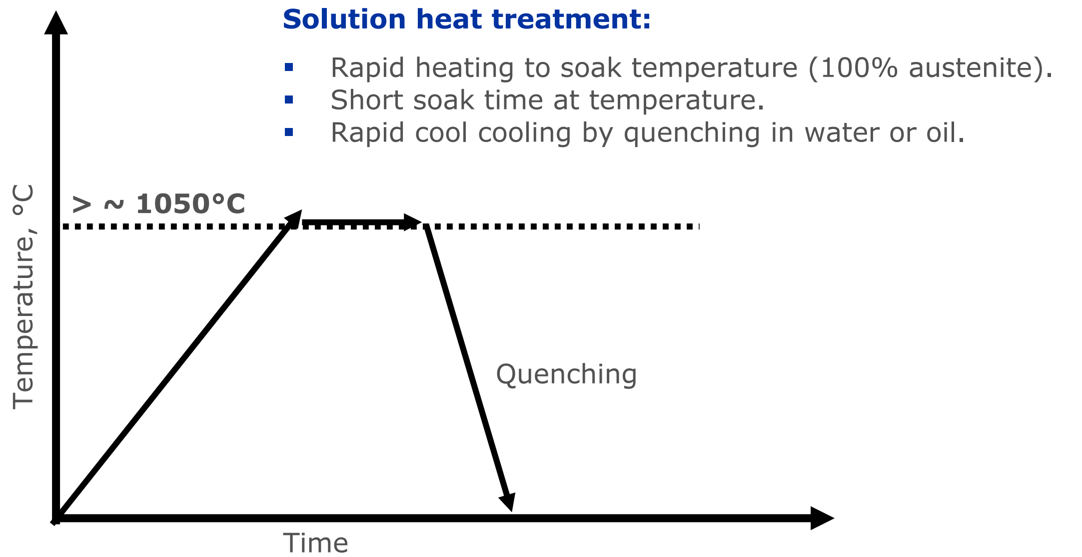

Figure 20.4 Typical solution heat treatment (solution annealing) applied to austenitic stainless steels.

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Applied to

Austenitic stainless steels such as 304 and 316 grades.

Annealed

After working the steel (pressing or forging, etc) to size, it is heated to ~900°C then allowed to cool in the furnace to ambient temperature; this reduces strength and toughness but improves ductility (Figure 20.5).

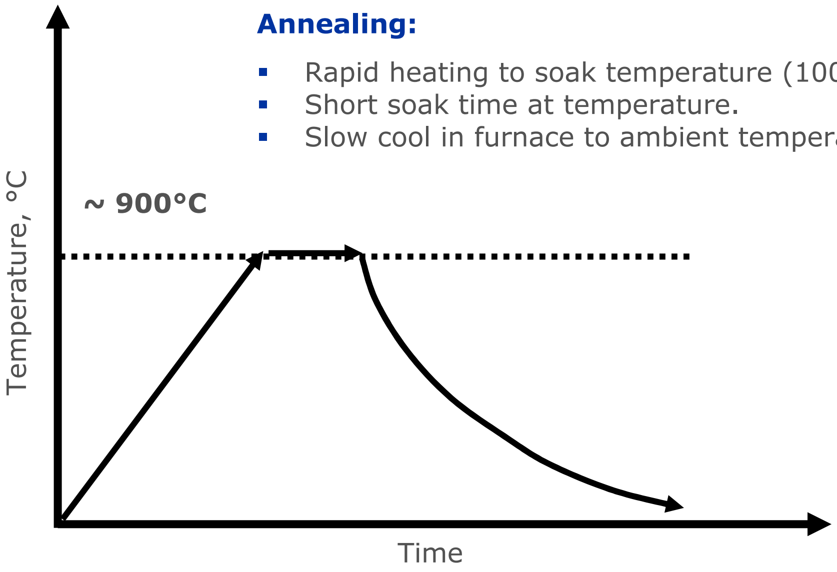

Figure 20.5 Typical annealing heat treatment applied to C-Mn and some low alloy steels.

Applied to

C-Mn steels and some low alloy steels.

Figures 20.1-20.5 show thermal cycles for the main supply conditions and subsequent heat treatment that can be applied to steels.

20.3 Postweld heat treatment (PWHT)

Postweld heat treatment has to be applied to some welded steels to ensure that the properties of the weldment is suitable for the intended applications.

The temperature at which PWHT is usually carried out well below the temperature where phase changes can occur (see Note), but high enough to allow residual stresses to be relieved quickly and to soften (temper) any hard regions in the HAZ.

Note There are circumstances when a welded joint may need to be normalised to restore HAZ toughness, these are relatively rare and it is necessary to ensure that welding consumables are carefully selected because normalising will significantly reduce weld metal strength.

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The major benefits of reducing residual stress and ensuring that the HAZ hardness is not too high for steels for particular service applications are:

- Improves the resistance of the joint to brittle fracture.
- Improves the resistance of the joint to stress corrosion cracking.
- Enables welded joints to be machined to accurate dimensional tolerances.

Because the main reason for and benefit of PWHT is to reduce residual stresses, PWHT is often called **stress-relief**.

20.4 PWHT thermal cycle

The Application Standard/Code will specify when PWHT is required to give the first two benefits above and also give guidance about the thermal cycle that must be used.

To ensure that a PWHT cycle is carried out in accordance with a particular Code, it is essential that a PWHT procedure is prepared and the following parameters are specified:

- Maximum heating rate.
- Soak temperature range.
- Minimum time at the soak temperature (soak time).
- Maximum cooling rate.

20.4.1 Heating rate

Must be controlled to avoid large temperature differences, (large thermal gradients) within the fabricated item. Which will produce large stresses and may be high enough to cause distortion or even cracking.

Application Standards usually require control of the maximum heating rate when the temperature of the item is above ~300°C because steels start to show significant loss of strength above this temperature and are more susceptible to distortion if there are large thermal gradients.

The temperature of the fabricated item must be monitored during the thermal cycle by thermocouples attached to the surface at locations representing the thickness range of the item.

By monitoring furnace and item temperatures the rate of heating can be controlled to ensure compliance with Code requirements **at all positions within the item**.

Maximum heating rates specified for C-Mn steel depend on the thickness of the item but tend to be in the range ~60 to ~200°C/h.

20.4.2 Soak temperature

The soak temperature specified by the Code depends on the type of steel and thus the temperature range required reducing residual stresses to a low level.

C and C-Mn steels require a soak temperature of ~600°C whereas some low alloy steels (such as Cr-Mo steels used for elevated temperature service) require higher temperatures, typically in the range ~700-~760°C.

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Soak temperature is an essential variable for a WPQR, so it is very important it is controlled within the specified limits otherwise it may be necessary to carry out a new WPQ test to validate the properties of the item and at worst it may not be fit-for-purpose.

20.4.3 Soak time

It is necessary to allow time for all the welded joints to experience the specified temperature throughout the full joint thickness.

The temperature is monitored by surface contact thermocouples and it is the thickest joint of the fabrication that governs the minimum time for temperature equalisation.

Typical specified soak times are 1h per 25mm thickness.

20.4.4 Cooling rate

It is necessary to control the rate of cooling from the PWHT temperature for the same reason that heating rate needs to be controlled, to avoid distortion or cracking due to high stresses from thermal gradients.

Codes usually specify controlled cooling to ~300°C. Below this temperature the item can be withdrawn from a furnace and allowed to cool in air because steel is relatively strong and unlikely to suffer plastic strain by any temperature gradients that may develop.

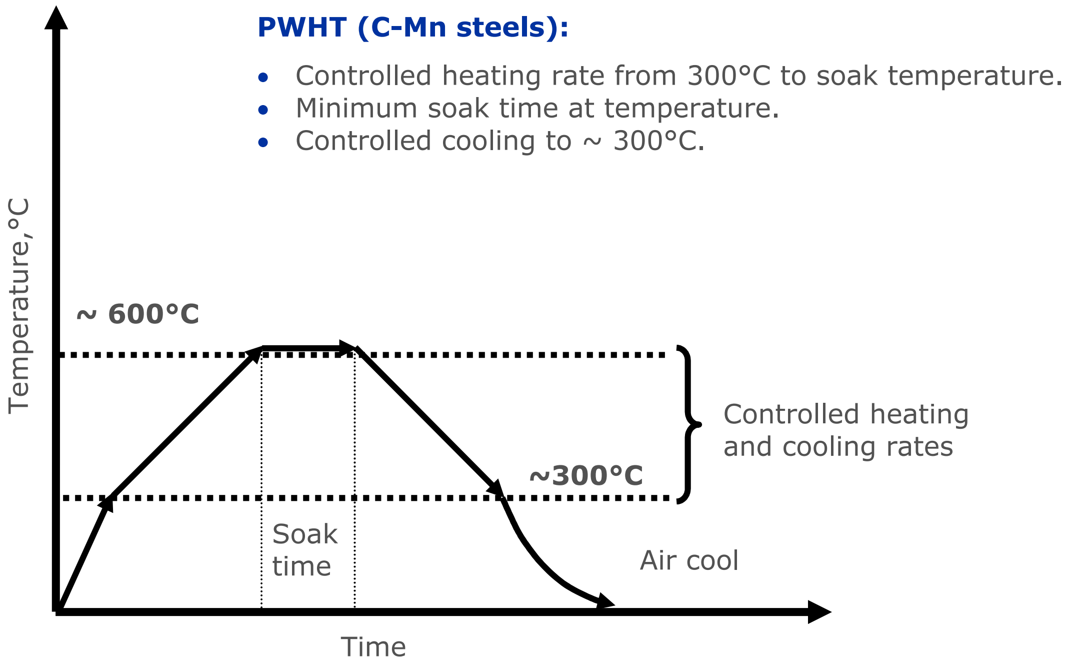

Figure 20.6 Typical PWHT applied to C-Mn steels.

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20.5 Heat treatment furnaces

Oil- and gas-fired furnaces used for PWHT must not allow flame contact with the fabrication as this may induce large thermal gradients.

It is also important to ensure that the fuel particularly for oil-fired furnaces does not contain high levels of potentially harmful impurities, such as sulphur.

20.5.1 Local PWHT

For a pipeline or pipe spool it is often necessary to apply PWHT to individual welds by local application of heat.

For this, a PWHT procedure must specify the previously described parameters for controlling the thermal cycle but it is also necessary to specify the following:

- Width of the heated band (must be within the soak temperature range).
- Width of the temperature decay band (soak temperature to ~300°C).

Other considerations are:

- Position of the thermocouples in the heated band width and the decay band.
- If the item needs support in a particular way to allow movement/ avoid distortion.

The commonest method of heating for local PWHT is by insulated electrical elements (electrical mats) attached to the weld.

Gas-fired, radiant heating elements can also be used.

Figure 20.7 shows typical control zones for localised PWHT of a pipe butt weld.

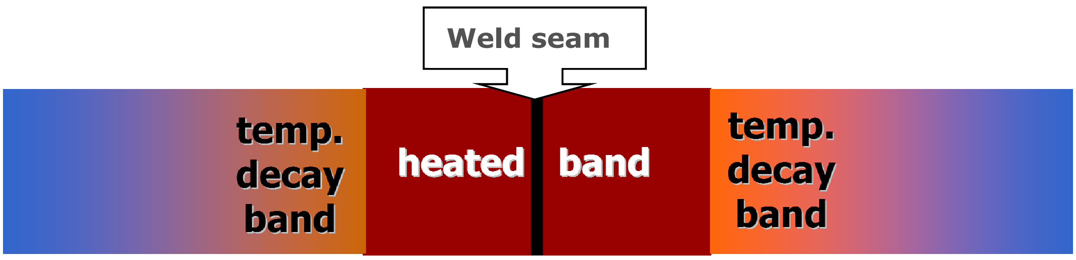

Figure 20.7 Local PWHT of a pipe girth seam.

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Heat Treatment of Welded Structures

Section 20

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Heat Treatment Objective

When this presentation has been completed you will have a greater understanding of the different types of heat treatment and their purposes in material manufacture and welding operations.

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Heat Treatment

Why?
- Improve mechanical properties.
- Change microstructure.
- Reduce residual stress level.
- Change chemical composition.

How?
- Flame oven.
- Electric oven/electric heating blankets.
- induction/HF heating elements.

Global ← Where? → Local

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Heat Treatment Methods

Gas furnace heat treatment

Advantages:
- Easy to set up.
- Good portability.
- Repeatability and temperature uniformity.

Disadvantages:
- Limited to size of parts.

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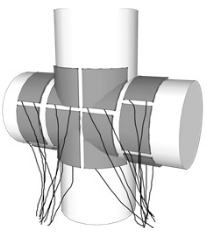
Heat Treatment Methods

Local heat treatment using electric heating blankets



Advantages:
- Ability to vary heat.
- Ability to continuously maintain heat.

Disadvantages:
- Elements may burn out or arcing during heating.

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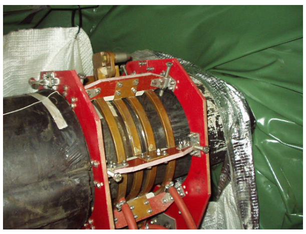
Heat Treatment Methods

HF local heat treatment



Advantages:
- High heating rates.
- Ability to heat a narrow band.

Disadvantages:
- High equipment cost.
- Large equipment, less portable.

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Heat Treatments

The inspector, in general, should ensure that:

- Equipment is as specified.
- Temperature control equipment is in good condition.
- Procedures as specified, is being used eg.
  - Method of application.
  - Rate of heating and cooling.
  - Maximum temperature.
  - Soak time.
  - Temperature measurement (and calibration).
- Documentation and records.

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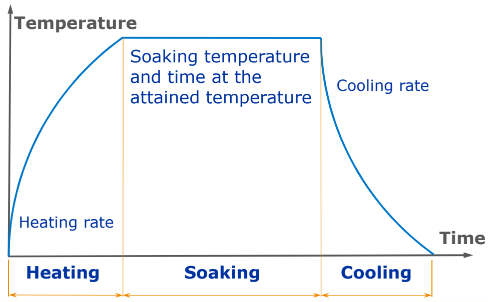
Heat Treatment Cycle

Variables for heat treatment process must be carefully controlled.



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Heat Treatment

Recommendations

- Provide adequate support (low YS at high temperature).
- Control heating rate to avoid uneven thermal expansions.
- Control soak time to equalise temperatures.
- Control temperature gradients - **No** direct flame impingement.
- Control furnace atmosphere to reduce scaling.
- Control cooling rate to avoid brittle structure formation.

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Heat Treatments

Many metals must be given heat treatment before and after welding.

The inspector's function is to ensure that the treatment is given correctly in accordance with the specification or as per the details supplied.

Types of heat treatment available:

- Preheat.
- Annealing.
- Normalising.
- Quench hardening.
- Temper.
- Stress relief.

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Heat Treatments

Pre-heat treatments

- Are used to increase weldability, by reducing sudden reduction of temperature, and control expansion and contraction forces during welding.

Post weld heat treatments

- Are used to change the properties of the weld metal, controlling the formation of crystalline structures.

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Heat Treatments

Preheat:

- We can preheat metals and alloys when welding for a number of reasons. Primarily we use most pre-heats to achieve one or more of the following:
- To control the structure of the weld metal and HAZ on cooling.
- To improve the diffusion of gas molecules through an atomic structure.
- To control the effects of expansion and contraction.
- Preheat controls the formation of un-desirable microstructures that are produced from rapid cooling of certain types of steels. Martensite is an undesirable grain structure very hard and brittle it is produced by rapid cooling form the austenite region.

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Heat Treatments

Preheat temperatures are arrived by taking into consideration the following:

- The heat input.
- The carbon equivalent (CE).
- The combined material thickness.
- The hydrogen scale required (A, B, C, D).

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Heat Treatments

Pre-heat requirements

- The welding heat input Increased – Reduced.
- Carbon Equivalent Increased – Increased.
- Hydrogen content Increased – Increased.
- Combined material thickness Increased - Increased.

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Heat Treatments

The temperatures mentioned are for steels:

- **Process:** Pre-heat for welding.
- **Temperature:** 50-2500C higher by exception.
- **Cooling:** Hold during welding.
- **Result:** Prevents cracking and hard zones.

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Heat Treatments

Advantages of preheat:

- Slows down the cooling rate, which reduces the risk of hardening.
- Allows absorbed hydrogen a better opportunity of diffusing out, thereby reducing the risk of cracking.
- Removes moisture from the material being welded.
- Improves overall fusion characteristics.
- Lowers stresses between the weld metal and parent material by ensuring a more uniform expansion and contraction.

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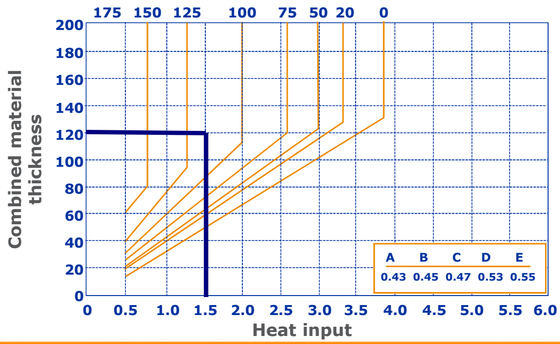
Preheat Comparison Chart



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Methods of Measuring Preheat

- Temperature indicating crayons (tempil sticks®).
- Thermocouples or touch pyrometers.
- At intervals along of around the joint to be welded.
- The number of measurements taken must allow the inspector to be confident that the required temperature has been reached.
- In certain cases the preheat must be maintained a certain distance back from the joint faces.
- If a gas flame is being used for preheat application the temperature should be taken form the opposite side to the heat source.
- If this is not possible time must be allowed before taking the preheat temperature eg 2 mins for 25mm thickness.

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Post Weld Heat Treatment

Question:
What is the main reason for carrying out PWHT (to steel joints)?

Answer:
- To reduce residual stresses.

Supplementary question:
- What is the **benefit** for reduce residual stresses?

Supplementary answer:
- To improve resistance to brittle fracture.

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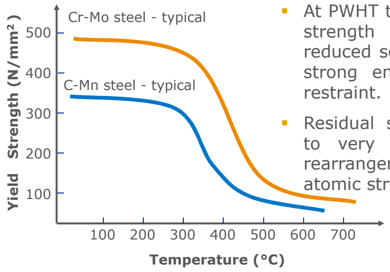
Post Weld Heat Treatment

Removal of residual stress



- At PWHT temp. the yield strength of steel is reduced so that it is not strong enough to give restraint.
- Residual stress reduced to very low level by rearrangement of the atomic structure.

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Post Weld Heat Treatment

PWHT Procedures - Basic Requirements

Maximum heating rate
Usually from 300 or 400°C - need to avoid large temperature gradients that may cause distortion/cracking.
Max rate depends on thickness but typically up to ~ 200°C/h.
Soak temperature depends on steel type - usually specified by code (~550 to ~710°C).
Minimum soak time
Need to make sure and whole item/full thickness reaches specified temp.
Codes typically specify 1h per 25mm related to maximum joint thickness.
Maximum cooling rate
Usually down to 400 or 300°C - for same reasons as controlled heating rate.

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Heat Treatments

Annealing (steels)

- **Temperature:** 920°C hold for sufficient time (full austenitization).
- **Cooling:** Hold, slow cooling in furnace.
- **Result:** Produces a very soft, low hardness material suitable for cold working or machining operations. Decreases toughness and l owers yield stress homogenising annealing.

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Heat Treatments

Stress relief (steels)

- **Temperature:** 550-650°C no phase transformation.
- **Cooling:** Hold, furnace or controlled cooling.
- **Result:** Relieves residual stresses, improves stability during machining, reduces hydrogen levels, prevents stress corrosion cracking.

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Heat Treatments

Post Hydrogen Release (according to BS EN1011-2)

- **Temperature:** Approximately 250°C hold up to 3 hours.
- **Cooling:** Slow cool in air.
- **Result:** Relieves residual hydrogen
- **Procedure:** Maintaining pre-heat/ interpass temperature after completion of welding for 2 to 3 hours.

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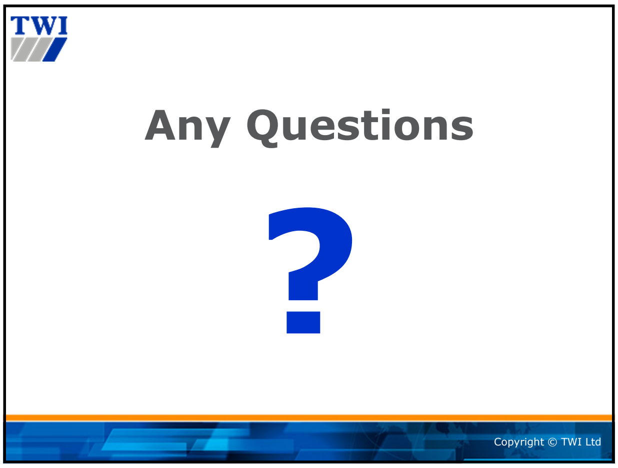
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Section 21

Arc Welding Safety

21 Arc Welding Safety

21.1 General

Working in a safe manner, whether in the workshop or on-site, is an important consideration in any welding operation. Responsibility for safety is on the individuals, not only for their own but also for other people's. The visual/welding inspector has an important function in ensuring that safe working legislation is in place and safe working practices implemented. The inspector may be required to carry out safety audits of welding equipment prior to welding, implement risk assessment/permit to work requirements or monitor the safe working operations for a particular task during welding.

The inspector may refer to a number of documents for guidance:

- Government legislation – The Health & Safety at Work Act.
- Health & Safety Executive – COSHH Regulations, Statutory instruments.
- Work or site instructions – permits to work, risk assessment documents, etc.
- Local Authority requirements.

There are four aspects of arc welding safety that the visual/welding inspector must consider:

1. Electric shock.
2. Heat and light.
3. Fumes and gases.
4. Noise.

21.2 Electric shock

One of the most serious and immediate risks facing personnel involved in the welding operation. Contact with metal parts, which are electrically hot can cause injury or death because of the effect of the shock on the body or a fall as a result of the reaction to electric shock.

The electric shock hazard associated with arc welding may be divided into two categories:

1. Primary voltage shock – 230 or 460V.
2. Secondary voltage shock – 60-90V.

Primary voltage shock is very hazardous because it is much greater than the secondary voltage of the welding equipment. Electric shock from the primary (input) voltage can occur by touching a lead inside the welding equipment with the power to the welder switched on while the body or hand touches the welding equipment case or other earthed metal. Residual circuit devices (RCDs) connected to circuit breakers of sufficient capacity will help protect the welder and other personnel from primary electric shock.

Secondary voltage shock occurs when touching a part of the electrode circuit, perhaps a damaged area on the electrode cable and another part of the body touches both sides of the welding circuit (electrode and work or welding earth) at the same time.

Most welding equipment is unlikely to exceed OCVs of 100V, but electric shock, even at this level can be serious, so the welding circuit should be fitted with low voltage safety devices to minimise the potential of secondary electric shock.

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A correctly wired welding circuit should contain three leads:

1 Welding lead from one terminal of the power source to the electrode holder or welding torch.
2 Welding return lead to complete the circuit from the work to the other terminal of the power source.
3 Earth lead from the work to an earth point. The power source should also be earthed.

All three leads should be capable of carrying the highest welding current required.

To establish whether the capacity of any piece of current carrying equipment is adequate for the job, the visual/welding inspector can refer to the duty cycle of the equipment. All current carrying welding equipment is rated in terms of:

Duty cycle

All current carrying conductors heat up when welding current is passed through them. Duty cycle is a measure of the capability of the welding equipment in terms of the ratio of welding time to total time which can be expressed as:

$$\text{Duty cycle} = \frac{\text{Welding time}}{\text{Total time}} \times 100$$

By observing this ratio the current carrying conductors will not be heated above their rated temperature. Duty cycles are based on a total time of 10 minutes. For example: a power source has a rated output of 350A at 60% duty cycle. This particular power source will deliver 350A (it's rated output) for six minutes out of every ten minutes without overheating.

Failure to carefully observe the duty cycle of equipment can over-stress the part and with welding equipment cause overheating leading to instability and the potential for electric shock.

21.3 Heat and light

21.3.1 Heat

In arc welding electrical energy is converted into heat and light energies, both of which can have serious health consequences.

The welding arc creates sparks with the potential to cause flammable materials near the welding area to ignite and cause fires. The welding area should be clear of all combustible materials and the inspector should know where the nearest fire extinguishers are and the correct type to use if a fire does break out.

Welding sparks can cause serious burns so protective clothing, such as welding gloves, flame retardant coveralls and leathers must be worn around any welding operation to protect against heat and sparks.

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21.3.2 Light

Light radiation is emitted by the welding arc in three principal ranges:

Type	Wavelength, nanometres
Infrared (heat)	>700
Visible light	400-700
Ultraviolet radiation	<400

Ultraviolet radiation (UV)

All arc processes generate UV and excess exposure causes skin inflammation and possibly skin cancer or permanent eye damage. The main risk amongst welders and inspectors is inflammation of the cornea and conjunctiva, commonly known as arc eye or flash.

Arc eye is caused by UV radiation which damages the outmost protective layer of cells in the cornea. Gradually the damaged cells die and fall off the cornea exposing highly sensitive nerves in the cornea to the comparatively rough inner part of the eyelid, causing intense pain, usually described as sand in the eye which becomes even more acute if the eye is then exposed to bright light.

Arc eye develops some hours after exposure, which may not even have been noticed. The sand in the eye symptom and pain usually lasts for 12-24 hours but can be longer in more severe cases. Fortunately it is almost always a temporary condition. In the unlikely event of prolonged and frequently repeated exposures permanent damage can occur.

Treatment of arc eye is simply: rest in a dark room. A qualified person or hospital casualty department can administer various soothing anaesthetic eye drops which can provide almost instantaneous relief. Prevention is better than cure and wearing safety glasses with side shields will considerably reduce the risk of this condition.

Ultraviolet effects upon the skin

The UV from arc processes does not produce the browning effect of sunburn but results in reddening and irritation caused by changes in the minute surface blood vessels. In extreme cases, the skin may be severely burned and blisters form. The reddened skin may die and flake off in a day or so. With intense prolonged or frequent exposure skin cancers can develop.

Visible light

Intense visible light particularly approaching UV or blue light wavelengths passes through the cornea and lens and can dazzle and, in extreme cases, damage the network of optically sensitive nerves on the retina. Wavelengths of visible light approaching infrared have slightly different effects but can produce similar symptoms. Effects depend on the duration and intensity of exposure and to some extent the individual's natural reflex action to close the eye and exclude the incident light. Normally this dazzling does not produce a long-term effect.

Infrared radiation

Infrared radiation is of longer wavelength than the visible light frequencies and is perceptible as heat. The main hazard to the eyes is that prolonged exposure (over years) causes a gradual but irreversible opacity of the lens. Fortunately, the infrared radiation emitted by normal welding arcs causes damage only within a comparatively short distance from the arc. There is an immediate burning sensation in the skin surrounding the eyes should they be exposed to arc heat and the natural reaction is to move or cover up to prevent the skin heating, which also reduces eye exposure.

BS EN 169 specifies a range of permanent filter shades of gradually increasing optical density which limit exposure to radiation emitted by different processes at different currents. It must be stressed that shade numbers indicated in the standard and the corresponding current ranges are for guidance only.

21.4 Fumes and gases

21.4.1 Fumes

Because of the variables involved in fume generation from arc welding and allied processes (the welding process and electrode, base metal, coatings on the base metal and other possible contaminants in the air), the dangers of welding fume can be considered in a general way. Although health considerations vary according to the type of fume composition and individual reactions the following holds true for most welding fume.

The fume plume contains solid particles from the consumables, base metal and base metal coating. Depending on the length of exposure to these fumes, most acute effects are temporary and include symptoms of burning eyes and skin, dizziness, nausea and fever. Zinc fumes can cause metal fume fever, a temporary illness similar to flu. Chronic, long-term exposure to welding fumes can lead to siderosis (iron deposits in the lungs) and may affect pulmonary function. Cadmium, is a toxic metal found on steel as a coating or in silver solder. Cadmium fumes can be fatal even under brief exposure, with symptoms much like those of metal fume fever. These two should not be confused. Twenty minutes of welding in the presence of cadmium can be enough to cause fatalities, with symptoms appearing within an hour and death five days later.

21.4.2 Gases

The gases resulting from arc welding present a potential hazard. Most of the shielding gases (argon, helium and carbon dioxide) are non-toxic when released, but displace oxygen in the breathing air, causing dizziness, unconsciousness and death the longer the brain is denied oxygen.

Some degreasing compounds such as trichlorethylene and perchlorethylene can decompose from the heat and UV radiation to produce toxic gases. Ozone and nitrogen oxides are produced when UV radiation hits the air and can cause headaches, chest pains, irritation of the eyes and itchiness in the nose and throat.

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To reduce the risk of hazardous fumes and gases, keep the head out of the fume plume. As obvious as this sounds it is a common cause of fume and gas over-exposure because the concentration of fumes and gases is greatest in the plume. In addition, use mechanical ventilation or local exhaust at the arc to direct the fume plume away from the face. If this is not sufficient, use fixed or moveable exhaust hoods to draw the fume from the general area. Finally, it may be necessary to wear an approved respiratory device if sufficient ventilation cannot be provided. As a rule of thumb, if the air is visibly clear and the welder is comfortable, the ventilation is probably adequate.

To identify hazardous substances, first read the material safety data sheet for the consumable to see what fumes can be reasonably expected from use of the product. Refer to the Occupational Exposure Limit (OEL) as defined in the COSHH regulations which gives maximum concentrations to which a healthy adult can be exposed to any one substance. Second, know the base metal and determine if a paint or coating would cause toxic fumes or gases. Particular attention should also be made to the dangers of asphyxiation when welding in confined spaces. Risk assessment, permits to work and gas testing are some of the necessary actions required to ensure the safety of all personnel.

Noise

Exposure to loud noise can permanently damage hearing, cause stress and increase blood pressure. Working in a noisy environment for long periods can contribute to tiredness, nervousness and irritability. If the noise exposure is greater than 85 decibels averaged over an 8 hour period then hearing protection must be worn and annual hearing tests carried out.

Normal welding operations are not associated with noise level problems with two exceptions: Plasma arc welding and air carbon arc cutting. If either of these is to be performed then hearing protectors must be worn. The noise associated with welding is usually due to ancillary operations such as chipping, grinding and hammering. Hearing protection must be worn when carrying out or when working in the vicinity of these operations.

21.5 Summary

The best way to manage the risks associated with welding is by implementing risk management programmes. Risk management requires the identification of hazards, assessment of the risks and implementation of suitable controls to reduce the risk to an acceptable level.

It is essential to evaluate and review a risk management programme. Evaluation involves ensuring that control measures have eliminated or reduced the risks and review the aims to check that the process is working effectively to identify hazards and manage risks.

It is quite likely that the visual/welding inspector will be involved in managing the risks associated with welding as part of their duties.

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Welding Safety

Section 21

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Welding Safety Objective

When this presentation has been completed you should be very aware of the risks posed in welding and cutting operations.

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Welding Related Risks

- Fire and explosion.
- Fume and gases.
- Electrical shock.
- Eye injuries.
- Skin burns.
- Mechanical hazards.

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Fire and Explosion

Weld away flammable materials

- Secure gas cylinders.

Use flashback arrestors

- Protect the floor - layer of sand or fire retardant sheets.

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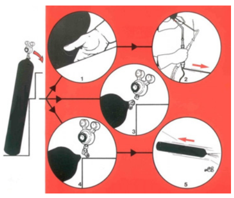
Fire and Explosion

Gas cylinders must be correctly secured, otherwise:



1. May cause direct injury.
2. May snatch hoses and blowpipe.
3. Regulator may break off escape of gas.
4. Valve may break off escape of gas.
5. Valve may break off cylinder accelerating by rocket action.

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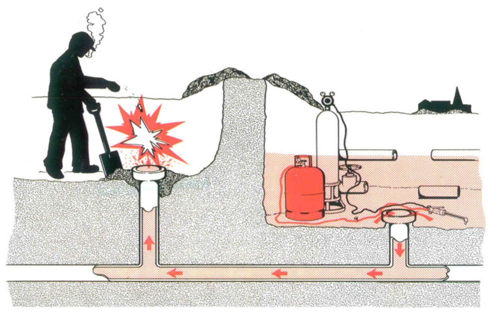
Fire and Explosion Hazard Onsite



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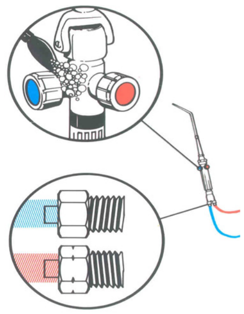
Checking Gas Cylinder for Leaks



- Leak testing.
- Acetylene screws are left handed!

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Welding Fume and Gases

Effect of welding fume and gasses on health:

- Fume - particulate and toxic: irritation of nose, throat, lungs, asphyxiation.
- Ozone - irritation of nose, throat lungs; excess mucous secretion, coughing.
- Nitrous oxide, hydrogen chloride, phosgene - delayed irritation and toxic effect on upper respiratory tract; excess fluid in lungs.
- Carbon monoxide - oxygen deficiency, drowsiness, headache, nausea; fatal oxygen starvation.
- Carbon dioxide - oxygen deficiency, asphyxiation.
- Argon, helium, nitrogen – asphyxiation.
- Hydrogen, other fuel gases - explosion, fire, asphyxiation.

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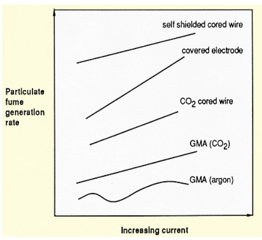
Welding Fume

Welding fume sources:

- Parent material. (Cr_6 thought to be carcinogenic!)
- Welding consumables. (filler, flux, gas).
- Action of heat/UV on air: Nitrous oxide and ozone.
- Surface treatments. (paint, plating, coatings).
- Cleaning fluids.



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Welding Fume

Things to be addressed:

- Composition of the fume.
- Concentration of the fume.
- Duration of exposure.

Fume health effects:

Respiratory tract irritation → Metal fume fever → Systemic poisoning → Chronic effects

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Welding Fume

Control of substances hazardous to health (COSHH) regulations set occupational exposure limits

	8hr TWA mg/m³	10min TWA mg/m³
Iron	5	10
Cr_6	0.5	
Ozone	0.2	0.6
Cadmium	0.05	0.05
Weld fume	5	
Aluminum	5	

TWA - Time waited average

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Welding Fume

COSHH regulations requires fume measurement:

a. In workshop.
b. In breathing zone.
c. Regular monitoring.
d. Regular auditing.

Note: COSHH regulations covers also **noise** exposure.

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Welding Fume

How to avoid welding fume exposure:

- Keep head out of fume.
- Work upwind of weld.
- Use local fume extraction.

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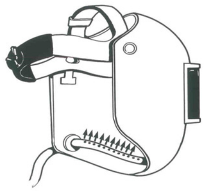
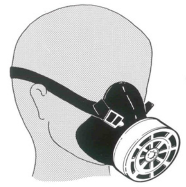
Welding Fume

How to avoid welding fume exposure:

- Use fresh air welding helmets.
- Use respirators as second line of defense.





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Respiratory Protective Equipment (RPE) Requirements

- Must be suitable for purpose.
- Must be approved by relevant organisations.
- Must be fully maintained.
- Must be safely stored.
- Must be correctly fitted.
- Selection, maintenance and fitting require trained staff.
- Users must be trained in its use.

RPE can adversely affect:

- Communication.
- Work rate.
- Mobility.
- Visibility.
- Use of other PPE.
- Tool use.

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Electrical Shock

Points to be considered:

O.C.V. :	for AC - 80V; for DC - 70V.
Modern equipment:	50V.
Plasma cutting:	over 100V.
TIG uses HF:	round 20,000V.

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Electrical Shock

Points to be considered:

Check weld connections and cable insulation.

Bad!

Good!

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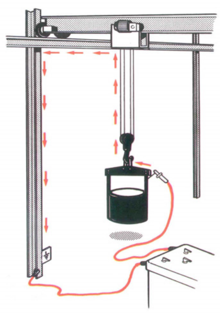
Electrical Shock



Welding current flows in crane hook, wire rope, crane bearings weakens and damage them.

Possibly burning out the crane electrics!

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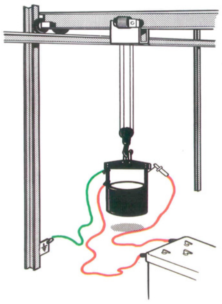
Electrical Shock



Welding return lead runs directly to the work: No damage.

Earth lead divert current from the crane: Supplementary safeguard.

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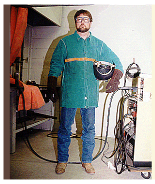
Eye Injuries and Skin Burns

Electric arc produces ultra violet/infra red light

Gives arc eye and skin burns!

Measures to be taken:

- Wear PPE.
- Choose shade of filter according to welding process.



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Eye Injuries and Skin Burns

- Wear safety goggles and visor during grinding.
- Wear ear defenders.

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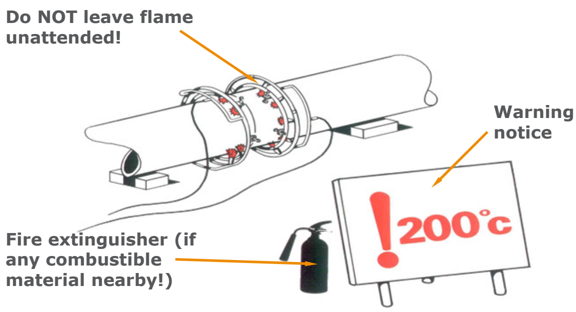
Skin Burns



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Work in Confined Spaces

Definition: Any place by virtue of its enclosed nature, there is a foreseeable risk of any specified occurrence.

Example: chambers, tanks, silos, pits, pipes, etc.

Specified occurrence:

- Fire or explosion.
- Loss of consciousness or asphyxiation due to gas, fumes, vapour or lack of oxygen.
- Drowning.
- Asphyxiation due to free flowing solid.
- Loss of consciousness due to high temperature.

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Summary

- Be aware of health and safety regulations for each specific application!
- Are the cables the right size for your job?
- Are they spread out or run neatly to prevent overheating?
- Is the work lead connected securely?
- Is there enough insulation between your body and the work piece?
- Are all connections tight, including the earth ground?
- Are electrode holder and welding cable in good conditions?
- Do not operate with power source covers removed!
- Disconnect input power before servicing!
- Do not touch electrically live parts or electrode with skin or wet clothing!
- Insulate yourself from work and ground!

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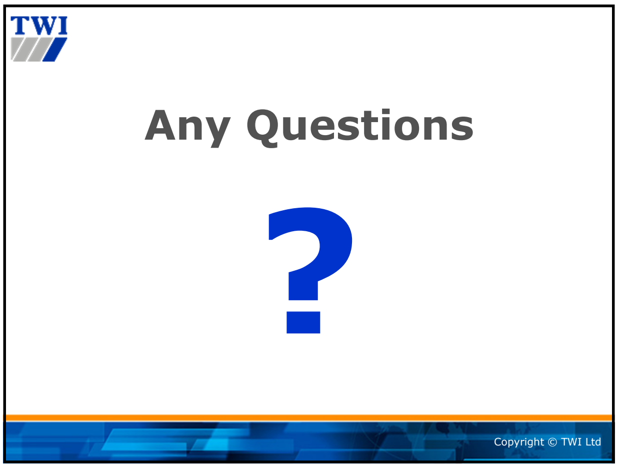
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Section 22

Calibration

22 Calibration

22.1 Introduction

BS EN 50504 - Code of practice for validation of arc welding equipment, is a standard that gives guidance to:

- Manufacturers about the accuracy required from output meters fitted to welding equipment to show welding current, voltage, etc.
- End users who need to ensure that output meters provide accurate readings.

The Standard refers to two grades of equipment, standard and precision:

- Standard: Suitable for manual and semi-automatic welding processes.

- Precision: Intended for mechanised or automatic welding because there is usually a need for greater precision for all welding variables as well as the prospect of the equipment being used for higher duty cycle welding.

22.2 Terminology

BS EN 50504 defines the terms it uses, such as:

Calibration	Operations for the purpose of determining the magnitude of errors of a measuring instrument, etc.
Validation	Operations for the purpose of demonstrating that an item of welding equipment, or a welding system, conforms to the operating specification for that equipment or system.
Accuracy	Closeness of an observed quantity to the defined, or true, value.

When considering welding equipment, those with output meters for welding parameters (current, voltage, travel speed, etc) can be calibrated by checking the meter reading with a more accurate measuring device and adjusting the readings appropriately.

Equipment that does not have output meters (some power sources for MMA, MIG/MAG) cannot be calibrated but can be validated to see the controls are functioning properly.

22.3 Calibration frequency

BS EN 50504 recommends re-calibration/validation at:

- Yearly intervals (following an initial consistency test at three monthly intervals) for standard grade equipment.
- Six monthly intervals for precision grade equipment.

The Standard also recommends that re-calibration/validation may be necessary more frequently. Factors that need to be considered are:

- Equipment manufacturer’s recommendations.
- User’s requirements.
- If the equipment has been repaired re-calibration should always be carried out.
- If there is a reason to believe the performance of the equipment has deteriorated.

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22.4 Instruments for calibration

Instruments used for calibration should:

- Be calibrated by a recognised calibrator using standards traceable to a national standard.
- Be at least twice and preferably five times more accurate than the accuracy required for the grade of equipment.
- For precision grade equipment it will be necessary to use instruments with much greater precision must be used for checking output meters.

22.5 Calibration methods

The Standard gives details about the characteristics of power source types, how many readings should be taken for each parameter and guidance on precautions that may be necessary.

For the main welding parameters, recommendations from the Standard are as follows:

Current

Details are given about the instrumentation requirements and how to measure pulsed current but there are requirements given, specified, or recommendations made, about where in the circuit current measurements should be made.

The implication is that current can be measured at any position in the circuit – the value should be the same.

Voltage

The standard emphasises that for processes where voltage is pre-set (on constant voltage the power sources) the connection points used for the voltage meter incorporated into the power source may differ from the arc voltage, which is the important parameter.

To obtain an accurate measure of arc voltage, the voltage meter should be positioned as near as practical to the arc.

This is illustrated by Figure 22.1 which shows the power source voltage meter connected across points 1 and 7.

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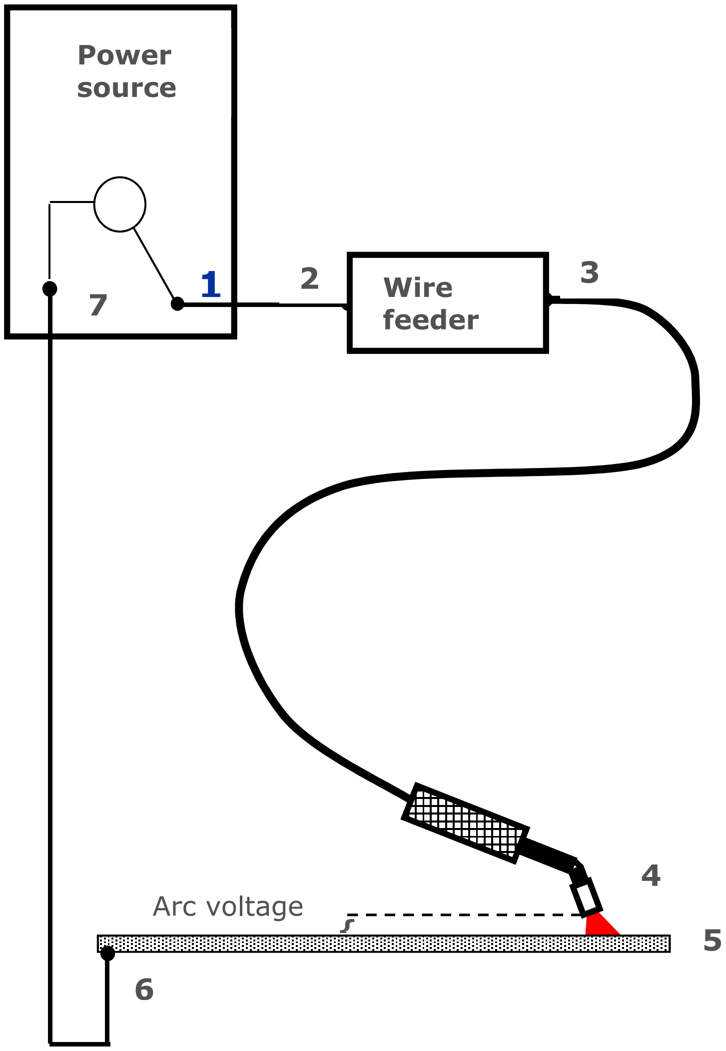

Figure 22.1 A welding circuit (for MIG/MAG).

However because there will be some voltage drops in sections 1-2, 3-4 and 6-7 due to connection points introducing extra resistance into the circuit, the voltage meter reading on the power source will tend to give a higher reading than the true arc voltage.

Even if the power source voltage meter is connected across points 3 and 7 (which it may be) the meter reading would not take account of any significant voltage drops in the return cable, section 6-7.

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The magnitude of any voltage drops in the welding circuit will depend on cable diameter, length and temperature and the Standard emphasises the following:

- It is desirable to measure the true arc voltage between points 4-5 but for some welding processes it is not practical to measure arc voltage so close to the arc.
- For MMA it is possible to take a voltage reading relatively close to the arc by connecting one terminal of the voltmeter through the cable sheath as close as ~2m from the arc and connect the other terminal to the workpiece (or to earth).
- For MIG/MAG the nearest practical connection points have to be 3-5 but a change from an air to a water-cooled torch or vice versa may have a significant effect on the measured voltage.
- Voltage drops between points 5-6 will be insignificant if there is a good connection of the return cable at point 6.

The Standard gives guidance about minimising any drop in line voltage by ensuring that the:

- Current return cable is as short as practical and is heavy, low resistance, cable.
- Current/return connector is suitably rated and firmly attached so does not overheat due to high resistance.

The Standard gives data for line voltage drops (DC voltage) according to current, cable cross-section and length (for both copper and aluminium cables).

Wire feed speed

For constant voltage (self-adjusting arc) processes such as MIG/MAG the standard recognises that calibration of the wire feeder is generally not needed because it is linked to current.

If calibration is required it is recommended that the time is measured (in seconds) for ~1m of wire to be delivered (using a stopwatch or an electronic timer). The length of wire should then be measured (with a steel rule) to an accuracy of 1mm and the feed speed calculated.

Travel speed

Welding manipulators, such as rotators and robotic manipulators, as well as the more conventional linear travel carriages, influence heat input and other properties of a weld and should be checked at intervals. Most of the standard devices can be checked using a stopwatch and measuring rule but more sophisticated equipment, such as a tacho-generator, may be appropriate.

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Calibration

Section 22

Materials Joining and Engineering Technologies
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Calibration Objectives

When this presentation has been completed you will have a greater understanding of why we need calibration and validation to monitor in process operations.

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Calibration/Validation

BS 7570: Covers the calibration and validation of welding equipment.

Grade 1 (general purpose equipment) all parameters should be +/- 10%.

Grade 2 (Automatic or automated equipment) parameters should be +/- 2.5% for current and +/- 5% for all other parameters.

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Calibration/Validation

Calibration can only be done on equipment with meters or gauges as theses can be adjusted.

Validation can be done on equipment with and without meters or gauges.

Oil fill transformers etc.

All equipment can be Validated but not all equipment can be Calibrated.

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Measuring in Welding

The purposes of measuring

- Demonstration of conformance to specified requirements
- Welding process control

Parameters to be measured:

- Welding current.
- Arc voltage.
- Travel speed.
- Shielding gas flow rate.
- Preheat/inter-pass temperature.
- Force/pressure.
- Humidity.

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Welding Current Measurement

Definition: The current delivered by a welding power source during welding.

- Measured with an ammeter.
- Measured in A.
- The ammeter may be connected at any point **in** the circuit.
- Due to its sensitivity, a shunt is needed.
- Indirect measurement: Tachogenerator and tong tester.

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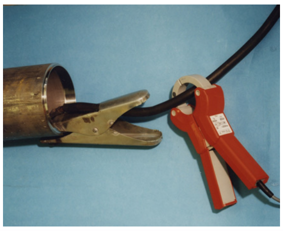
The Tong Tester

- Used for AC current
- No need to insert the meter into the circuit.



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Arc Voltage Measurement

Definition: The potential difference across the welding arc.

- Varies with the arc length.
- Measured with a voltmeter.
- Measured in V.
- The voltmeter may be connected only **across** the circuit (to the workpiece and as close as possible to the electrode).
- If the voltmeter is connected at the welding power source, a higher voltage will be recorded (due to potential drops across cables).
- Usually not required for MMA and TIG.

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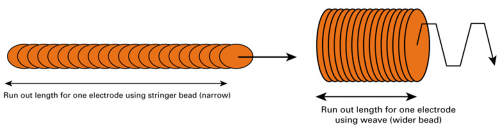
Travel Speed Measurement

Definition: The rate of weld progression.

- Measured in case of mechanised and automatic welding processes.
- In case of MMA can be determined using ROL and arc time.



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Gas Flow Rate Measurement

Definition: The rate at which gas is caused to flow.

Set with a gas regulator

Can be checked with a flowmeter

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Welding Temperatures Definitions

Preheat temperature

- Is the temperature of the workpiece in the weld zone immediately before **any** welding operation (including tack welding).
- Normally expressed as a minimum.

Interpass temperature

- Is the temperature in a multirun weld and adjacent parent metal immediately prior to the application of the next run.
- Normally expressed as a maximum.

Minimum interpass temperature = Preheat temperature

Preheat Maintenance temperature

- Is the minimum temperature in the weld zone which shall be maintained if welding is interrupted.
- Shall be monitored during interruption.

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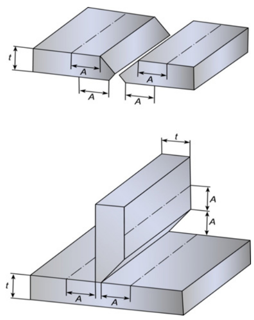
Welding Temperatures - Where?

Point of measurement - see BS EN ISO 13916

- If t ≤ 50mm - A = 4 x t but max. 50mm.
- The temperature shall be measured on the surface of the workpiece facing the welder.



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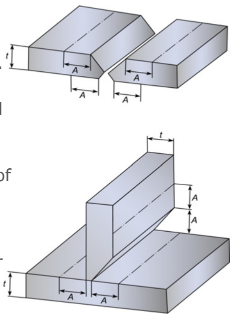
Welding Temperatures - Where?

Point of measurement - see BS EN ISO 13916

- If t > 50mm - A = min. 75mm.
- Where practicable, the temperature shall be measured on the face opposite to that being heated.
- Allow 2 min per every 25 mm of parent metal thickness for temperature equalisation.
- Interpass temperature shall be measured on the weld metal or immediately adjacent parent metal.



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Welding Temperatures - How?

Test equipment

- Temperature sensitive materials (TS)
- Contact thermometer (CT)
- Thermocouple (TE)
- Thermistor (CT)
- Optical/electrical devices for contactless measurement (TB)

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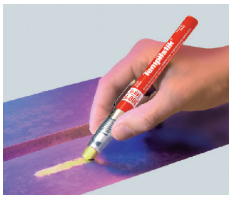
Temperature Test Equipment

Temperature sensitive materials:

- Crayons, paints and pills.
- Cheap.
- Convenient, easy to use.



Doesn't measure the actual temperature!

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Temperature Test Equipment

Thermocouple

- Based on measuring the thermoelectric potential difference between a hot junction (on weld) and a cold junction.
- Accurate method.
- Measures over a wide range of temperatures.
- Gives the actual temperature.
- Need calibration.

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Temperature Test Equipment

Thermistors

- Are temperature-sensitive resistors whose resistance varies inversely with temperature.
- Used when high sensitivity is required.
- Gives the actual temperature.
- Need calibration.
- Can be used up to 320°C.

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Temperature Test Equipment

Devices for contactless measurement

- IR radiation and optical pyrometer
- Measure the radiant energy emitted by the hot body.
- Contactless method - can be used for remote measurements.
- Very complex.
- For measuring high temperatures.

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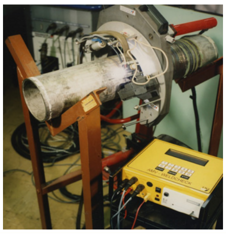
PAMS (Portable Arc Monitor System)

PAMS UNIT

The purposes of PAMS

For measuring and recording the welding parameters



For calibrating and validating the welding equipment

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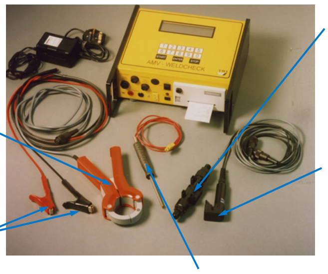
PAMS (Portable Arc Monitor System)

What does a PAMS unit measure?

Welding current (Hall effect device)

Arc voltage (connection leads)



Gas flow rate (heating element sensor)

Wire feed speed (tachometer)

Temperature (thermocouple)

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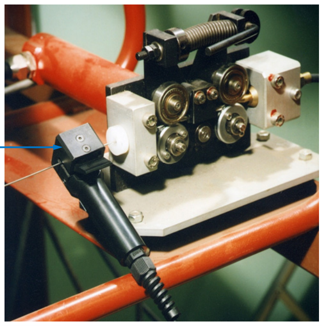
Use of PAMS

Wire feed speed monitoring

Incorporated pair of rolls connected to a tachogenerator



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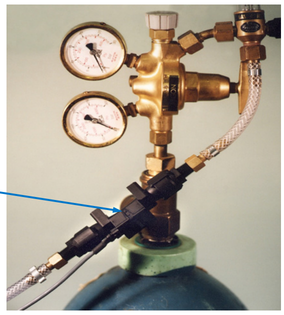
Use of PAMS

Shielding gas flow rate monitoring

Heating element sensor



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Calibration, Validation and Monitoring

Definitions:

- **Measurement** = set of operations for determining a value of a quantity.
- **Repeatability** = closeness between successive measuring results of the same instrument carried out under the same conditions.
- **Accuracy class** = class of measuring instruments that are intended to keep the errors within specified limits.
- **Calibration** = checking the errors in a meter or measuring device.
- **Validation** = checking the control knobs and switches provide the same level of accuracy when returned to a pre-determined point.
- **Monitoring** = checking the welding parameters (and other items) are in accordance with the procedure or specification.

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Calibration and Validation

When is it required?

- **Measurement** = set of operations for determining a value of a quantity.
- **Repeatability** = closeness between successive measuring results of the same instrument carried out under the same conditions.
- **Accuracy class** = class of measuring instruments that are intended to keep the errors within specified limits.
- **Calibration** = checking the errors in a meter or measuring device.
- **Validation** = checking the control knobs and switches provide the same level of accuracy when returned to a pre-determined point.
- **Monitoring** = checking the welding parameters (and other items) are in accordance with the procedure or specification.
- **See BS EN ISO 17662 for details!**

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Calibration and Validation

When it is **not** required?

- When verification of the process is not required.
- In case of small series and single piece production when all the following conditions are fulfilled:
  - Procedures are approved by procedure testing.
  - production is carried out by the same welding machine used during procedure testing.

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Calibration and Validation

When it is **not** required?

- In case of mass production when all the following conditions are fulfilled:
  - Production is controlled by pre-production testing, followed by testing of samples from production at regular intervals.
  - A statistical quality control system is used.
  - The process is stable between testing of samples.
  - Pre-production testing and sampling are performed separately for each production line (robotic cells).

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Welding Parameter Calibration/Validation

Which parameters need calibration/validation?

- Depends on the welding process.
- See BS EN ISO 17662 and BS 7570 for details.

How accurate?

- Depends on the application.
- Welding current - ±2.5%.
- Arc voltage - ±5%.
- Wire feed speed - ±2.5%.
- Gas flow rate - ±20% (±25% for backing gas flow rate).
- Temperature (thermocouple) - ±5%.

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Example 1 - MMA Elementary Monitoring

In theory any MMA operation could require monitoring of:

- Welding current.
- Arc voltage.
- R.O.L.
- Preheat/interpass temperature.
- Electrode treatment and storage.

In practice (depending on the application) only the welding current could require monitoring with a tongue test ammeter.

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Example 2 - High Integrity MMA Operation

In theory, this might require monitoring of all the activities previously mentioned.

The equipment thus required:

- Ammeter.
- Voltmeter.
- Stop watch. Or a PAMS
- Tape measure.
- Thermometer.
- Calculator.

All of the above equipment would require calibration; any meters fitted to the power source or electrode ovens would also require calibration.

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Example 3 - MIG/MAG Welding With a Robot

In theory, the following would require monitoring:

- Wire feed speed.
- Amperage.
- Voltage.
- Travel speed.
- Gas flow rate.
- Repeatability of the controls.

In practice, a data logger would be preferred to monitor all the parameters; also a PAMS would be required to check the repeatability of the control knobs.

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Summary

- A welding power source can only be calibrated if it has meters fitted.
- The inspector should check for calibration stickers, dates etc.
- A welding power source without meters can only be validated that the control knobs provide repeatability.
- The main role is to carryout in process monitoring to ensure that the welding requirements are met during production.

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Any Questions

?

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Section 23

Application and Control of Preheat

23 Application and Control of Preheat

23.1 General

Preheat is the application of heat to a joint immediately prior to welding and usually applied by a gas torch or induction system, although other methods can be used.

Preheat is used when welding steels for a number of reasons and it helps to understand why. One of the main reasons is to assist in removing hydrogen from the weld. Preheat temperatures for steel structures and pipework are calculated by taking into account the carbon equivalent (CEV) and thickness of the material and the arc energy or heat input (kJ/mm) of the welding process.

Standards such as BS EN 1011: Recommendations for welding of metallic materials for guidance on selection of preheat temperature ranges based on CEV, material thickness, arc energy/heat input and the lowest level of diffusible hydrogen required.

The welding inspector would normally find the preheat temperature for a particular application from the relevant WPS. In general, thicker materials require higher preheat temperatures, but for a given CEV and arc energy/heat input, they are likely to remain similar for wall thickness up to approximately 20mm.

23.2 Definitions

Preheat temperature

- Temperature of the workpiece in the weld zone immediately before any welding operation (including tack welding).
- Normally expressed as a minimum but can also be specified as a range.

Interpass temperature

- Temperature of the weld during welding and between passes in a multi-run weld and adjacent parent metal immediately prior to the application of the next run.
- Normally expressed as a maximum but should not drop below the minimum preheat temperature.

Preheat maintenance temperature

- Minimum temperature in the weld zone which should be maintained if welding is interrupted.
- Should be monitored during interruption.

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23.3 Application of preheat

Preheat

Local

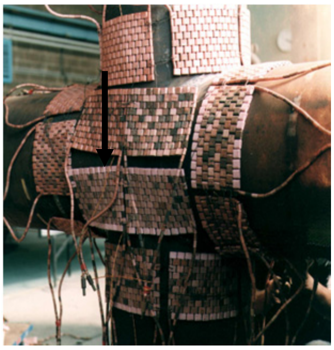
- Less energy required.
- Possible stresses due to non-uniform. Heating.

Global

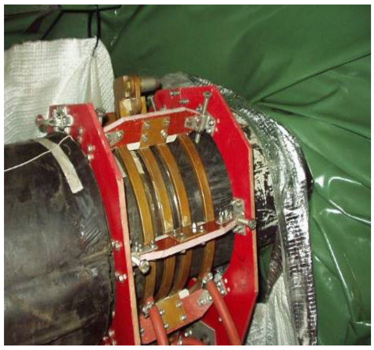
- More energy required.
- Uniform heating – no additional stresses.

Gas/electric oven

Resistive heating elements



HF heating elements



Flame applied preheat

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Gas/electric ovens

Generally used for PWHT but can be used for large sections of material to give a controlled and uniform preheat.

Resistive heating elements

Heating using electric current flowing through resistance coils.

High frequency heating elements

Heating effect is produced electrostatically providing uniform heating through a mass of material. Heat is generated by the agitation of the molecules in the material when subjected to a high frequency field.

Flame applied preheat

Probably the most common method of applying preheat using either torches or burners. Oxygen is an essential part of the preheating flame as it supports combustion but the fuel gases can be acetylene, propane or methane (natural gas).

With flame applied preheating sufficient time must be allowed for the temperature to equalise throughout the thickness of the components to be welded, otherwise only the surface temperature will be measured. The time lapse depends on the specification requirements.

23.4 Control of preheat and interpass temperature

When?

Immediately before passage of the arc.

Where?

Work piece thickness, t

$t \leq 50mm$	$t > 50mm$
■ A = 4 x t but maximum 50mm. ■ Temperature shall be measured on the surface of the work piece facing the welder.	■ A = minimum 75mm. ■ Where practicable temperature is measured on the face opposite that being heated. ■ Allow 2min per 25mm of parent metal thickness for temperature equalisation.

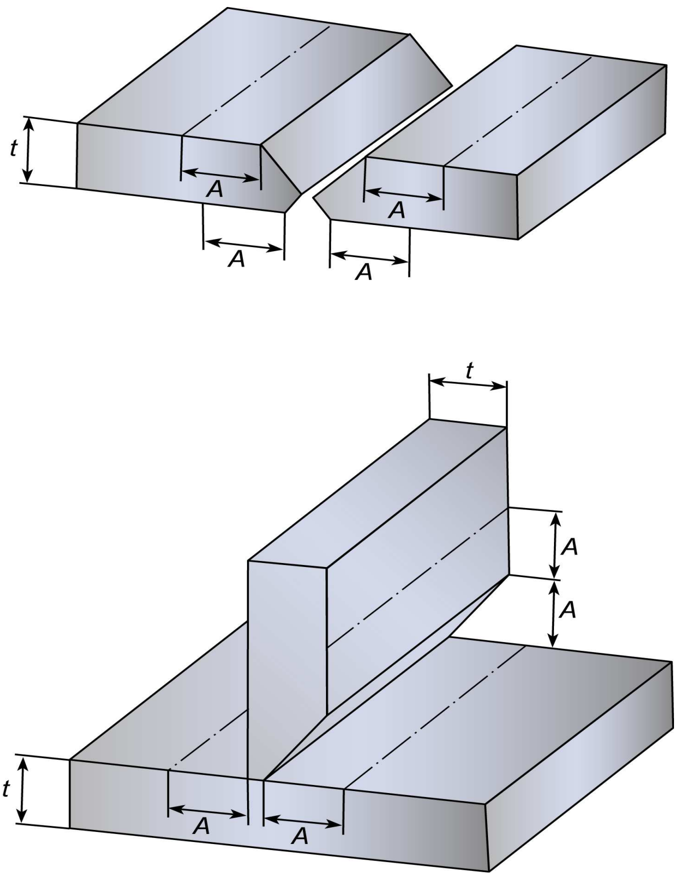

Figure 23.1 HAZ on the weld metal and parent metal.

Interpass temperature is measured on the weld metal or immediately adjacent parent metal.

Why?

Applying preheat has the following advantages:

- Slows down the cooling rate of the weld and HAZ, reducing the risk of hardened microstructures forming; allowing absorbed hydrogen more opportunity of diffusing out, thus reducing the potential for cracking.
- Removes moisture from the region of the weld preparation.
- Improves overall fusion characteristics during welding.
- Ensures more uniform expansion and contraction, lowering stresses between weld and parent material.

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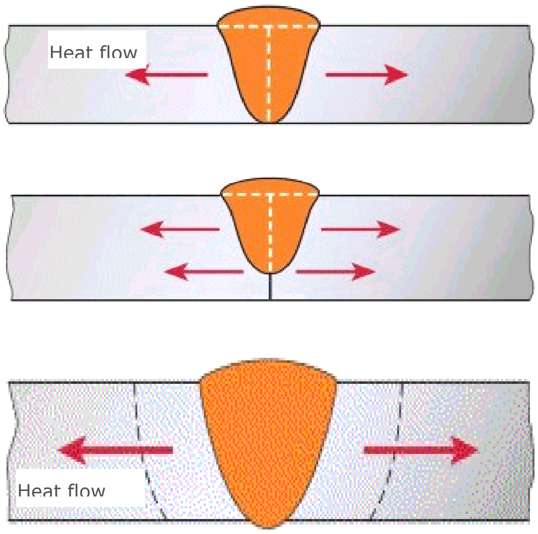

Figure 23.2 Two dimensional heat flow.

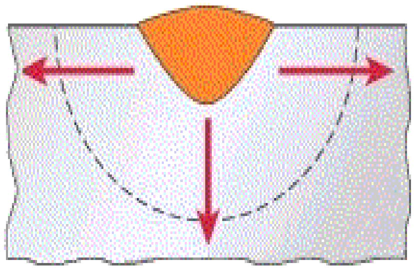

Figure 23.3 Three dimensional heat flow.

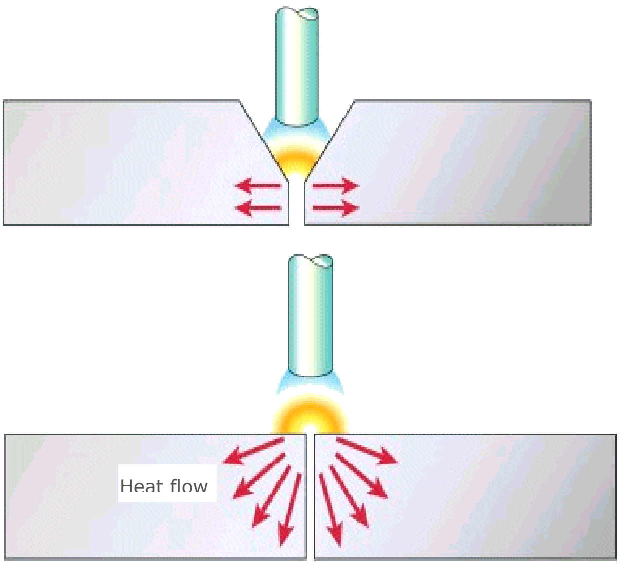

Figure 23.4 Head flow.

23.4.1 Temperature sensitive materials

- Made of a special wax that melts at a specific temperature (Tempilstik TM) or irreversible colour change (Thermochrome TM).
- Cheap, easy to use.
- Do not measure the actual temperature.

Figure 23.5 Examples of temperature indicating crayons and paste.

23.4.2 Contact thermometer

- Use either a bimetallic strip or a thermistor (ie a temperature-sensitive resistor whose resistance varies inversely with temperature).
- Accurate, gives the actual temperature.
- Need calibration.
- Used for moderate temperatures (up to 350°C).

Figure 23.6 Examples of a contact thermometer.

23.4.3 Thermocouple

- Based on measuring the thermoelectric potential difference between a hot junction (placed on the weld) and a cold junction (reference junction).
- Measures a wide range of temperatures.
- Accurate, gives the actual temperature.
- Can be used for continuous monitoring.
- Need calibration.

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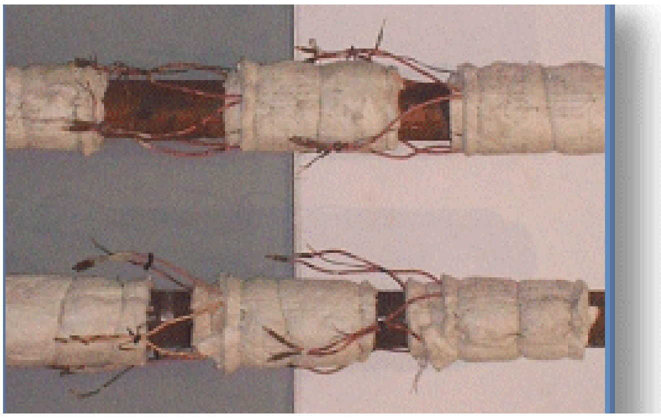

Thermister

Figure 23.7 Examples of thermocouples.

23.4.4 Optical or electrical devices for contactless measurement

- Can be infrared or optical pyrometers.
- Measure the radiant energy emitted by the hot body.
- Can be used for remote measurements.
- Very complex and expensive.
- Normally used for measuring high temperatures.

Figure 23.8 Example of contactless temperature measuring equipment.

23.5 Summary

The visual/welding inspector should refer to the WPS for both preheat and interpass temperature requirements. If in any doubt as to where the temperature measurements should be taken, the senior welding inspector or welding engineer should be consulted for guidance.

Both preheat and interpass temperatures are applied to slow down the cooling rate during welding, avoiding the formation of brittle microstructures (ie martensite) and thus preventing cold cracking.

Preheat temperatures can be calculated using different methods as described in various standards (eg BS EN 1011-2, AWS D1.1, etc) and are validated during the qualification of the welding procedure. According to BS EN ISO 15614 and ASME IX both preheat and interpass temperatures are considered essential variables hence any change outside the range of qualification requires a new procedure qualification.

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Section 24

Gauges

24 Gauges

Specialist gauges

Measure the various elements that need to be measured in a welded fabrication including:

- Hi-lo gauges for measuring mismatch and root gap.
- Fillet weld profile gauges for measuring fillet weld face profile and sizes.
- Angle gauges for measuring weld preparation angles.
- Multi-functional weld gauges for measuring many different weld measurements.

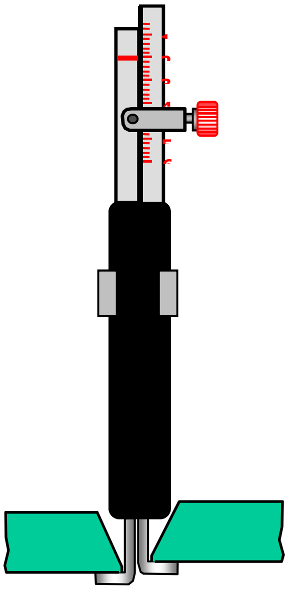

Figure 24.1 Hi-lo gauge used to measure linear misalignment.

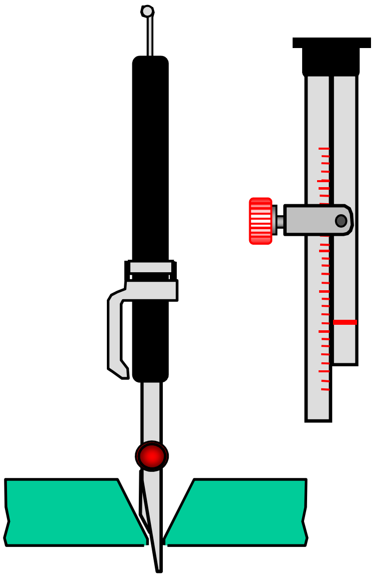

Figure 24.2 Hi-lo gauge can also be used to measure the root gap.

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Adjustable fillet gauge

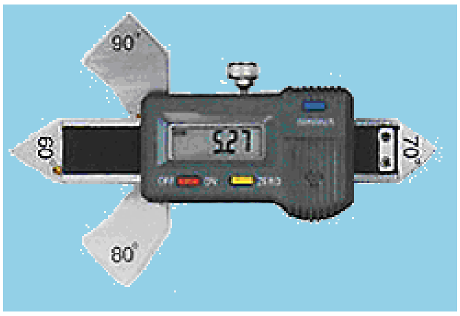
Measures fillet welds from 3-25mm ($^1/_8$-1 inch) with ±0.8mm ($^1/_{32}$ inch) accuracy. Uses an offset arm, which slides at 45 degrees to give fillet weld length measurements. Also measures weld throat thickness upto 1.5mm ($^1/_{16}$ inch).

Fillet weld gauge

Measures weld sizes from 3-25mm ($^1/_8$ to 1 inch).

Multi-purpose welding gauge

Rugged gauge fabricated in stainless steel measures the important dimensions of weld preparations and of completed butt and fillet welds. Intended for general fabrication work it rapidly measures the angle of preparation, excess weld metal, fillet weld leg length and throat size and misalignment in both metric and imperial.



Digital multi-purpose welding gauge

Measures the important dimensions of weld preparations and completed butt and fillet welds. Intended for general fabrication work and rapidly measures angle of preparation, excess weld metal, fillet weld leg length and throat size in both metric and imperial.

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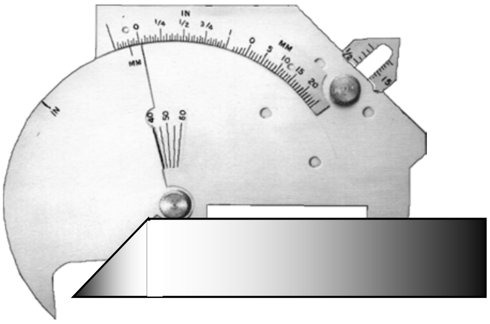
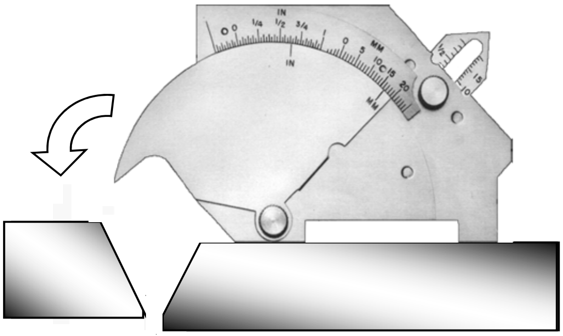
TWI Cambridge multi-purpose welding gauge



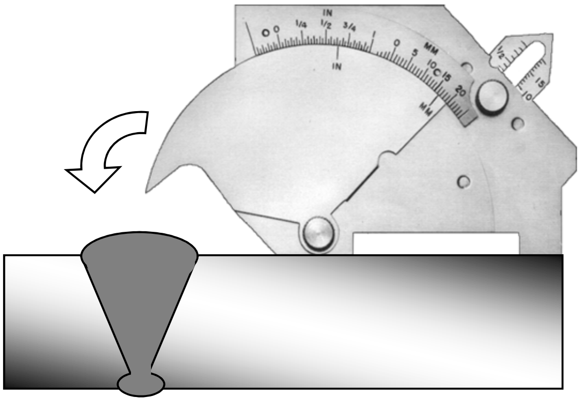
Angle of preparation

Scale reads 0-60 degree in 5 degree steps.The angle is read against the chamfered edge of the plate or pipe.



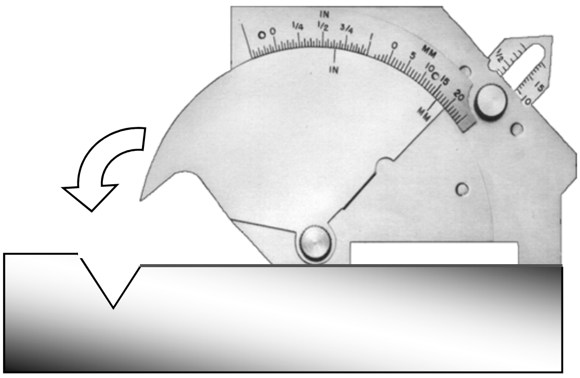
Linear misalignment

Can be used to measure misalignment of members by placing the edge of the gauge on the lower member and rotating the segment until the pointed finger contacts the higher member.



Excess weld metal root penetration

Scale used to measure excess weld metal height or root penetration bead height of single-sided butt welds by placing the edge of the gauge on the plate and rotating the segment until the pointed finger contacts the excess weld metal or root bead at its highest point.



Pitting/mechanical damage, etc

The gauge can measure defects by placing the edge of the gauge on the plate and rotating the segment until the pointed finger contacts the lowest depth.

The reading is taken on the scale to the left of the zero mark in metric or imperial.

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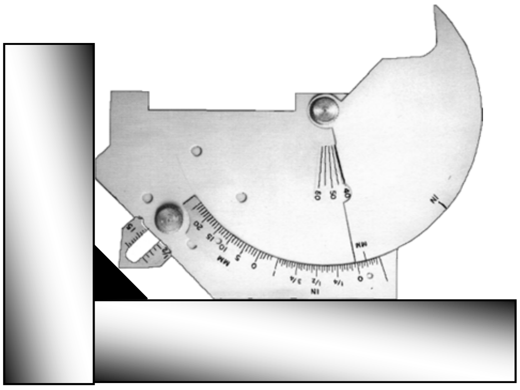
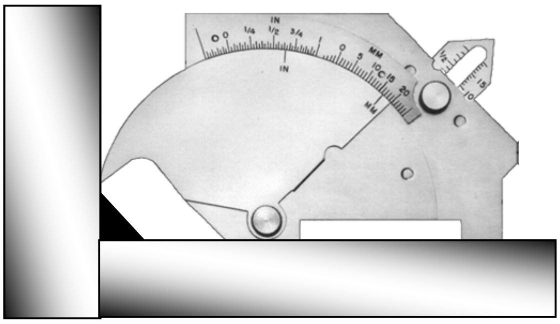


Fillet weld actual throat thickness

The small sliding pointer reads up to 20mm (¾ inch). When measuring the throat it is supposed that the fillet weld has a **nominal design throat** thickness as an **effective design throat** thickness cannot be measured in this manner.



Fillet weld leg length

The gauge can measure fillet weld leg lengths up to 20mm (1 inch), as shown on the left.

Excess weld metal can be easily calculated by measuring the leg length, and multiplying it by 0.7. This value is then subtracted from the measured throat thickness = excess weld metal.

Example: For a measured leg length of 10mm and a throat thickness of 8mm, 10 x 0.7 = 7 (throat thickness 8) - 7 = 1mm of excess weld metal.

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Appendix 1

Homework

Welding Inspection Level 2: Multiple Choice Questions

Paper 1 - MSR-WI-1a

Name: .... Date: ....

1 Which mechanical test can be used to measure the toughness of weld metal, HAZ and parent material?

a Macro.
b Nick break.
c Hardness.
d Charpy impact.

2 Which is the best destructive test for showing lack of sidewall fusion in a 25mm thickness butt weld?

a Nick break.
b Side bend.
c Charpy impact.
d Face bend test.

3 The principal purpose of a welder qualification test is to:

a Test the skill of the welder.
b Assess the weldability of the materials.
c Decide which NDT methods to use.
d Give the welder practice before doing production welding.

4 A fabrication procedure calls for the toes of all welds to be blended in by grinding. The reason for doing this is to:

a Make the welds suitable for liquid (dye) penetrant inspection.
b Improve the fatigue life.
c Reduce residual stresses.
d Improve the general appearance of the welds.

5 For full penetration single-sided butt joints, root bead penetration and profile are mainly influenced by:

a Root face.
b Bevel angle.
c Root gap.
d Included angle.

6 Which of the following would be cause for rejection by most fabrication standards when inspecting fillet welds with undercut, a small amount of?

a Depth.
b Length.
c Width.
d Sharpness.

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7 When visually inspecting the root bead of a single V-butt weld it should be checked for:

- a Lack of root penetration.
- b HAZ hardness.
- c Tungsten inclusions.
- d Slag.

8 The strength of a fillet weld is determined by:

- a Leg length.
- b Weld profile.
- c Weld width.
- d Throat thickness.

9 The European Standard for NDE of fusion welds by visual examination is:

- a EN 15614.
- b EN 2560.
- c EN 287.
- d EN 17637.

10 Visual inspection of a fabricated item for a high integrity application should cover inspection activities:

- a Before, during and after welding.
- b Before welding only.
- c After welding only.
- d During and after welding only.

11 Incomplete root penetration in a single V butt joint may be caused by:

- a Excessive root face.
- b Excessive root gap.
- c The current setting being too low.
- d Both **a** and **c**.

12 Incomplete root fusion in a single V butt weld may be caused by:

- a Linear misalignment.
- b Root gap being too large.
- c Root faces being too small.
- d Welding current too high.

13 When visually inspecting the face of a finished weld which of the following flaws would be considered the most serious:

- a Excess weld metal height.
- b Start porosity.
- c Spatter.
- d Arc strikes.

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14 A burn-through may occur if the:

- a Current is too low.
- b Root face is too large.
- c Root gap is too large.
- d Arc voltage is too high.

15 A Code of Practice is a:

- a Standard of workmanship quality only.
- b Set of rules for manufacturing a specific product.
- c Specification for the finished product.
- d Code for the qualification of welding procedures and welders qualifications.

16 A solid inclusion in a weld may be:

- a Entrapped slag.
- b Entrapped gas.
- c Lack of inter-run fusion.
- d None of the above.

17 Which of the following is a planar imperfection?

- a Lack of sidewall fusion.
- b Slag inclusion.
- c Linear porosity.
- d Root concavity.

18 For fillet welds it is normal practice in the UK and USA to measure:

- a Throat thickness.
- b Leg lengths.
- c Penetration depths.
- d Both **a** and **c**.

19 In a bend test, when the face of the specimen is in tension and root is in compression, the test is called a

- a Root bend.
- b Side bend.
- c Face bend.
- d Longitudinal bend.

20 Heavy porosity on the surface of some MMA welds made on a construction site is most likely to be caused by:

- a Use of the wrong class of electrodes.
- b Use of excessive current.
- c Moisture pick-up in the electrode covering.
- d A bad batch of electrodes.

21 Slag inclusions may be present in:

- a Manual metal arc welds.
- b Metal inert gas welds.
- c Metal active gas welds.
- d All welds.

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22 The main cause of undercut is:

- a Excessive amps.
- b Excessive OCV.
- c Excessive travel speed.
- d Current too low.

23 Which group of welders is most likely to require continuous monitoring by a welding inspector?

- a Concrete shuttering welders.
- b Overland pipeline welders.
- c Tack welders.
- d Maintenance welders.

24 Which of the following fillet welds is the strongest assuming they are all made using the same material and welded using the same WPS?

- a 8mm throat of a mitre fillet.
- b 7mm leg + 2mm excess weld metal.
- c Mitre fillet with 10mm leg.
- d Concave fillet with 11mm leg.

25 A typical included angle for MMA welding a full penetration pipe butt joint is:

- a 35°
- b 70°
- c 90°
- d Dependent on the pipe diameter.

26 A fillet weld has an actual throat thickness of 8mm and a leg length of 7mm, what is the excess weld metal?

- a 2.1mm
- b 1.8mm
- c 3.1mm
- d 1.4mm

27 The fusion boundary of a fillet weld is the:

- a Boundary between the weld metal and HAZ.
- b Boundary between individual weld runs.
- c Depth of root penetration.
- d Boundary between the HAZ and parent material.

28 If a Welding Inspector detects a type of imperfection not allowed by the application Standard he must:

- a Request further NDE.
- b Reject the weld.
- c Prepare a concession request.
- d Reject the weld if he considers it to be harmful.

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29 BS EN 17637 allows the use of a magnifying glass for visual inspection, but recommends that the magnification is:

- a x2.
- b x2 to x5.
- c x5 to x10.
- d Not greater than x20.

30 The majority of welder qualification tests are carried out using unbacked joints, because:

- a It is quicker and cheaper if back gouging is not required.
- b If the welding process is not TIG back purging is not required.
- c All welder qualification tests are done on small diameter pipe.
- d It requires more skill and increases the welders' qualification range.

31 Deflection of the arc by magnetic forces that can make welding difficult to control is commonly known as:

- a Arc initiation.
- b Arc misalignment.
- c Arc blow.
- d Arc constriction.

32 Which of the following electrode types is classified to EN ISO 2560?

- a E 38 3 R.
- b E 6013.
- c E 7018 - G.
- d E 51 33 B.

33 Which type of electrode is used for stovepipe welding for overland pipeline construction?

- a Rutile.
- b Cellulosic.
- c High recovery rutile.
- d Acid-rutile.

34 The three main types of MMA electrodes used for welding C and C-Mn steels are:

- a Basic, cellulosic and rutile.
- b Neutral, cellulosic and rutile.
- c Basic, cellulosic and neutral.
- d Rutile, low hydrogen and basic.

35 A WPS may specify a maximum width for individual weld beads (weave width) when welding C-Mn steels. If the width is exceeded it may cause:

- a Lack of inter-run fusion.
- b A reduction in HAZ toughness.
- c Lack of sidewall fusion.
- d Too low a deposition rate.

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36 You notice that MMA electrodes with the flux covering removed are being used as filler rods for TIG welding. This should not be allowed because:

- a It is wasteful.
- b The rod diameter may be too large.
- c The weld metal composition may be wrong.
- d The rod is too short.

37 In TIG welding a current slope-out device reduces:

- a Tungsten spatter.
- b Risk of crater cracking.
- c Risk of arc strikes.
- d Interpass temperature.

38 Which type of power source characteristic is normally used for manual welding?

- a Constant voltage.
- b Flat characteristic.
- c Constant current.
- d A motor generator.

39 In MMA welding penetration is principally controlled by:

- a Arc voltage.
- b Welding speed.
- c Ferro-silicon in the electrode coating.
- d Current.

40 Pipe bores of some materials must be purged with argon before and during TIG welding to:

- a Prevent linear porosity.
- b Prevent burn-through.
- c Prevent oxidation of the root bead.
- d Eliminate moisture pick-up in the root bead.

41 The chemical composition of the weld metal deposited by a C-Mn steel MMA electrode is usually controlled by:

- a Core wire composition.
- b Additions in the flux coating.
- c Iron powder in the flux coating.
- d Dilution from the base material.

42 Silicon is added to steel and the covering of MMA electrodes to:

- a Provide deoxidation.
- b Improve strength.
- c Improve toughness.
- d Provide more resistance to hydrogen cracking.

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43 A fusible insert for TIG welding helps:

- a Reduce porosity.
- b Give controlled root penetration.
- c Avoid the need for a back purge.
- d By acting as a backing for the root run.

44 According to AWS 2.4 a weld symbol for the other side is placed:

- a Above the dashed line.
- b Below the dashed line.
- c Above the solid line.
- d Below the solid line.

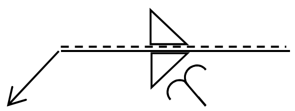
45 The term low hydrogen electrode is often used for certain electrodes. What type of covering will they have?

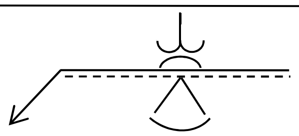
- a Cellulosic.
- b Rutile.
- c Acid.
- d Basic.

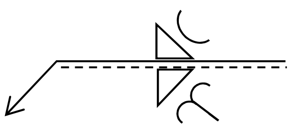
46 A hydrogen controlled MMA electrode can always be recognised by the:

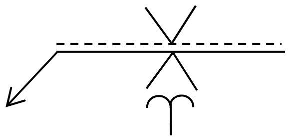
- a EN code letter (or AWS code number).
- b Electrode length.
- c Trade name.
- d Colour of the covering.

47 According to BS EN 22553 which of the following symbols requires weld toes to be smoothly blended on the other side?

a 

b 

c 

d 

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48 Which of the following units is used to express heat input?

a Joules.
b N/mm^2.
c J/mm^2.
d kJ/mm.

49 Which of the following elements is added to steel to give resistance to creep at elevated service temperatures?

a Nickel.
b Manganese.
c Molybdenum.
d Aluminium.

50 Nick break and fillet fracture tests are used for assessing:

a Weld quality.
b Weld metal ductility.
c Weld metal toughness.
d Resistance to fracture.

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Welding Inspector Level 2: Multiple Choice Questions

Paper 2 - MSR-WI-2a

Name: .... Date: ....

1 Lack of sidewall fusion:

a Is the most susceptible in double U butt welds.
b Is never found in single V butt welds.
c Is the most susceptible in double V butt welds.
d It is not normally a defect associated with the MMA welding process.

2 Leg length of a fillet weld is:

a The distance from the toe to face.
b The distance from the root to face centre.
c The distance from the root to the toe.
d It's 0.7 of the design throat thickness.

3 Throat thickness of a fillet weld (equal leg lengths) is:

a The distance from the toe to the face.
b The distance from the root to the face centre.
c The distance from the root to the toe.
d The distance from toe to toe.

4 Compound welds:

a Always contain full penetration butt welds.
b Joints which have combinations of welds made by different welding processes.
c Combinations between two different weld types.
d All of the above.

5 A duty not normally undertaken by a welding inspector is to:

a Check the condition of the parent material.
b Check the condition of the consumables.
c Measure residual stress.
d Check calibration certificates.

6 Crater pipe:

a Is another term for concave root.
b Is another term given for a burn through.
c Is a type of gas pore, found in the weld crater.
d Is a shrinkage defect, found in the weld crater.

7 Fillet welds:

a The strength is primarily controlled by the leg length.
b The strength is primarily controlled by the design throat thickness.
c The strength is primarily controlled by the actual throat thickness.
d Both **a** and **b**.

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8 Non planar defects:

- a Are always repaired.
- b Their existence will result in the removal of the entire weld.
- c They are not usually as significant as planar defects.
- d They can only be detected using radiography.

9 Welding Inspectors:

- a Should measure voltage as close to the welding arc as possible.
- b Should measure voltage anywhere along the welding cable.
- c Should always take the voltage reading from the voltmeter on the welding plant.
- d Don't normally take voltage readings, this is normally conducted by the welder.

10 Welding inspectors:

- a Normally supervise welders.
- b Are normally requested to write welding procedures.
- c Are sometimes requested to qualify welders.
- d All of the above.

11 Burn through:

- a Maybe caused by the root gap being too small.
- b Maybe caused by the travel speed being too fast.
- c Maybe caused by the welding current being too high.
- d All of the above.

12 In an arc welding process, which of the following is the correct term used for the amount of weld metal deposited per minute?

- a Filling rate.
- b Deposition rate.
- c Weld deposition.
- d Weld duty cycle.

13 When carrying out visual inspection from this list, which defect is most likely to be missed?

- a Linear misalignment.
- b Cap undercut.
- c Clustered porosity.
- d Cold lap.

14 The throat thickness of 19mm fillet weld is?

- a 27.5mm.
- b 24mm.
- c 13.3mm.
- d 12.5mm.

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15 Pre-heat for steel will increase if:

- a The material thickness reduces.
- b Faster welding speeds.
- c The use of a larger welding electrode.
- d A reduction in carbon content in the parent material.

16 Which of the following butt weld preparations is most likely to be considered for the welding of a 6mm thick plate?

- a Double V butt.
- b Asymmetrical double V butt.
- c Single U butt.
- d Single V butt.

17 A welding inspectors main attributes include:

- a Knowledge.
- b Honesty and integrity.
- c Good communicator.
- d All of the above.

18 What is the maximum allowable linear misalignment for 8mm material if the code states the following, '*Linear misalignment is permissible if the maximum dimension does not exceed 10% of t up to a maximum of 2mm*'?

- a 0.8mm.
- b 2mm.
- c 8mm.
- d None of the above, insufficient information provided.

19 When conducting a visual inspection on a butt weld you notice an excessive chevron shaped cap ripple. This may indicate which of the following?

- a Incorrect electrode.
- b Excessive travel speed.
- c Incorrect pre-heat applied.
- d That the welding has been carried out in the PF welding position.

20 Toe blending is generally carried out:

- a To reduce the possibility of fatigue failure.
- b To improve the toughness of the welded joint.
- c To increase the Ultimate Tensile Strength of the welded joint.
- d All of the above.

21 Arc strikes:

- a When associated with a welded joint may lead to hardening of the parent material.
- b When associated with a welded joint may lead to cracking.
- c When associated with a welded joint may cause a reduction in parent material thickness.
- d All of the above.

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22 Defects:

a Lack of inter run fusion would be considered more serious than answer c.
b Slag inclusions would be considered more serious than answer a.
c Lack of fusion (surface breaking) would be considered more serious than answer **a**.
d Both answer **a** and **c** would be considered to have the same seriousness as they are both lack of fusion defects.

23 ISO 17637:

a The minimum light illumination required for visual inspection is 350 Lux.
b The minimum light illumination required for visual inspection is 500 Lux.
c The minimum light illumination required for visual inspection is 600 Lux at not less than 30°.
d Doesn't specify any viewing conditions for visual inspection.

24 Flux cored wires may be advantageous over solid wires because:

a Higher deposition.
b Lower hydrogen contents in the deposited welds.
c Easy addition of alloying elements.
d Both **a** and **c**.

25 Movement of the arc by magnetic forces in an arc welding process is termed:

a Arc deviation.
b Arc misalignment.
c Arc blow.
d Stray arc.

26 A crack type most associated with the submerged arc welding process is:

a Hydrogen cracking in the HAZ.
b Solidification cracking.
c Lamellar tearing.
d Fatigue cracking.

27 MMA welding process:

a Uses a constant voltage.
b Uses a flat characteristic.
c Uses a drooping characteristic.
d Uses both **a** and **b**.

28 Which of the following electrodes and current types may be used for the TIG welding of nickel and its alloys?

a Cerium electrode, DC –ve.
b Zirconium electrode, AC.
c Thorium electrode, DC +ve.
d All of the above may be used.

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29 Travel speed:

- a If too fast may cause low toughness, slag inclusions and cap undercut.
- b If too fast may cause high hardness, slag inclusions and a narrow thin weld bead.
- c If too slow may cause high hardness, excessive deposition and cold laps.
- d None of the above.

30 MMA welding process:

- a Arc blow can be reduced or eliminated by a change from AC to DC current.
- b Arc blow can be reduced or eliminated by a change from DC to AC current.
- c Arc blow can be reduced or eliminated by a change from DC +ve to DC –ve.
- d Arc blow can be reduced or eliminated by a change from DC –ve to DC +ve

31 When considering the tungsten arc welding process what is the purpose of the down-slope (slope-out) control?

- a Ensure good penetration.
- b To prevent arc striking on the parent material.
- c To help prevent the formation of crater pipe and possible cracking.
- d To help prevent tungsten inclusions during welding.

32 Thermal cutting:

- a Local hardening can be reduced by increasing the cutting speed.
- b Local hardening can be reduced by the use of propane as a fuel gas.
- c Local hardening can be reduced by pre heating the material to be cut.
- d All of the above.

33 In a MMA welding process, which of the following statements is true?

- a An arc gap, which remains almost constant even if the welder varies the position of the electrode.
- b A voltage, which remains almost constant even if the welder, varies the arc gap.
- c A current, which remains almost constant even if the welder, varies the arc gap.
- d Both **a** and **b**.

34 When considering the MIG/MAG welding process which of the following metal transfer modes would be the most suited to the welding of thick plates over 25mm, flat welding position?

- a Dip transfer.
- b Pulse transfer.
- c Spray transfer.
- d Globular transfer.

35 TIG welding process:

- a For the welding of aluminium a DC –ve current is preferred.
- b For the welding of aluminium a DC +ve current is preferred.
- c For the welding of aluminium an AC is preferred.
- d All of the above.

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36 Which of the following statements is false?

- a In the MMA welding process AC current produces the deepest penetration.
- b DC electrode positive is used for the MAG welding of steel plate.
- c In the MAG welding process the wire feed speed remains constant during the welding operation.
- d All of the above.

37 When considering hydrogen, which of the following welding processes would produce the lowest levels in the completed weld? (under controlled conditions)

- a MMA.
- b SAW.
- c TIG.
- d FCAW.

38 In steel the element with the greatest effect on hardness is:

- a Chromium.
- b Manganese.
- c Carbon.
- d Nickel.

39 For a given voltage and current settings on a MMA welding plant, when the arc length is shortened, which of the following will be most affected?

- a The current will increase.
- b The current will decrease.
- c The voltage will decrease.
- d The voltage will increase.

40 Which of the following best describes a semi-automatic welding process?

- a The welder is responsible for maintaining the arc gap and travel speed.
- b The welder is responsible for travel speed only arc gap is kept constant by the welding plant.
- c Both travel speed and arc gap is controlled by the welding plant.
- d All of the above.

41 When calibrating a mechanised MAG welding plant, which of the following applies? (WFS = Wire feed speed)

- a Check – WFS, current, volts and wire diameter.
- b Check – WFS, joint set-up and gas flow rate.
- c Check – Gas flow rate, stick out length, WFS and current.
- d All of the above.

42 Which of the following fillet welded T Joints would have the highest resistance to fatigue fractures, assuming material, welding process, filler material to be the same?

- a A convex fillet weld throat thickness 10mm.
- b A mitre fillet weld throat thickness 8mm.
- c A concave fillet weld throat thickness 8mm.
- d Both **a** and **b** (throat thicknesses dimension the same).

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43 MAG welding process:

- a 1.2KJ/mm would be a typical heat input value.
- b 12KJ/mm would be a typical heat input value.
- c 1.2Jouls/mm would be a typical heat input value.
- d 6.5KJ/mm would be a typical heat input value.

44 During visual inspection of a fillet weld with even leg lengths of 15mm, the throat thickness is measured at 8.5mm, what is the fillet welds profile?

- a Convex.
- b Mitre.
- c Concave.
- d Both **a** and **b** are correct.

45 Which of the following welding parameters are the most difficult to control during the welding operation using a manual arc welding process?

- a Travel speed.
- b Deposition rate.
- c Current.
- d Arc length.

46 Brittle fractures:

- a The susceptibility in steels will increase with the formation of a fine grain structure.
- b The susceptibility in steels will increase with a reduction in the in-service temperature to sub-zero conditions.
- c The susceptibility in steels will increase with a slow cooling rate.
- d All of the above.

47 Which of the following are considerations for the selection of a preheat temperature?

- a Carbon equivalent, joint design, welding process and plate material quality.
- b All Joints over 25mm thick, hydrogen levels, welding process, carbon equivalent.
- c Arc energy, material thickness, hydrogen scale and carbon equivalent.
- d All of the above are considerations for the selection of a preheat temperature.

48 Mechanical testing:

- a Toughness can be measured with a macro test.
- b Toughness can be measured with a nick break test.
- c Toughness can be measured with a tensile test.
- d Toughness can be measured with a charpy V notch test.

49 Welds made with high heat inputs on C/Mn steels, show a reduction in one of the following properties?

- a Ductility.
- b Toughness.
- c Elongation.
- d Penetration.

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50 Which of the following elements, which may be added to steel, has the greatest effect on creep strength?

a Tungsten.
b Manganese.
c Carbon.
d Molybdenum.

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Welding Inspector Level 2: Multiple Choice Questions

Paper 3 - MSR-WI-3a

Name: .... Date: ....

1 Which of the following steels is considered non-magnetic?

a 18%Cr, 8%Ni.
b 2.25Cr 1Mo.
c 9%Cr,1Mo.
d 9%Ni.

2 Weld spatter during MMA welding is most likely to be caused by:

a Excessive current.
b Incorrect baking and storage of electrodes.
c Bad batch of electrodes.
d Too low an OCV.

3 A qualified Welding Procedure Specification is used to:

a Give instruction to the welder.
b Give information to the welding inspector.
c Give confidence that welds will have the specified properties.
d All of the above.

4 An arc strike (stray flash) on a steel component is regarded by some codes as unacceptable because:

a It will cause copper contamination.
b It may cause hard spots.
c It may give cracking.
d Both **b** and **c**.

5 In a transverse tensile test brittleness would be indicated if:

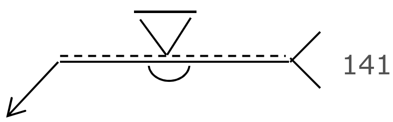
a There is a reduction in cross-section at the position of fracture.
b The fracture surface is flat and featureless but has a rough surface.
c Fracture occurred in the weld metal.
d The fracture face shows beach marks.

6 The surface of a fatigue crack will:

a Be rough and torn.
b Have sharp chevron markings.
c Be smooth.
d Have shear lips.

7 What does the number 141 refer to on this drawing?

a WPS number.
b Welding process.
c Filler material.
d Acceptance standard.



8 The current/polarity used for TIG welding all materials except aluminium and magnesium is:

a DC negative.
b DC positive.
c AC.
d Square wave AC.

9 A typical temperature range for baking basic coated electrodes is:

a 150-200°C.
b 200-250°C.
c 300-350°C.
d 400-450°C.

10 If welding travel speed is doubled but the current and voltage remain the same the heat input will be:

a Reduced by 50%.
b Increased by a factor of two.
c About the same.
d Reduced by approximately 25%.

11 Which type of submerged arc welding flux is susceptible to moisture pick-up?

a Neutral.
b Agglomerated.
c Fused.
d All about the same.

12 A large grain size in the HAZ of a C-Mn steel weld joint may have:

a Low ductility.
b Low toughness.
c High toughness.
d High tensile strength.

13 A STRA test is used to measure the:

a Tensile strength of the welded joint.
b Level of residual stress in butt joints.
c Fracture toughness of the HAZ.
d Through-thickness ductility of a steel plate (the Z direction).

14 The risk of hydrogen cracking is greater when MMA welding:

a C-Mn steels.
b Austenitic stainless steel.
c Low alloy steels for elevated temperature service.
d Low carbon steels for cryogenical service.

15 The property of a material which has the greatest influence on welding distortion is its:

a Yield strength.
b Coefficient of thermal expansion.
c Elastic modulus.
d Coefficient of thermal conductivity.

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16 Which of the following is a suitable shielding gas for FCAW of stainless steels?

- a 100% argon.
- b 70% argon + 30%He.
- c Argon + 5% hydrogen.
- d Argon + 20% CO_2.

17 The presence of iron sulphides in a weld bead may cause:

- a Solidification cracking.
- b Hydrogen cracking.
- c Lamellar tearing.
- d Weld decay.

18 A macrosection is particularly good for showing:

- a The weld metal HAZ microstructure.
- b Overlap.
- c Joint hardness.
- d Spatter.

19 Which of the following procedures would be expected to produce the least distortion in a 15mm straight butt weld?

- a TIG weld, single-sided, multi-pass.
- b MMA weld, single-sided, multi-pass.
- c MMA weld, double-sided, multi-pass.
- d SAW weld, 1 pass per side.

20 A suitable gas/gas mixture for GMAW of aluminium is:

- a 100%CO_2.
- b 100% Argon.
- c 80% argon + 20% CO_2.
- d 98% argon + 2% O_2.

21 Which of the following is associated with SAW more often than it is with MMA welds?

- a Hydrogen cracking in the HAZ.
- b Solidification cracking in the weld metal.
- c Reheat cracking during PWHT.
- d Lamellar tearing.

22 EN ISO 5817 (Level C) specifies that the limit for the diameter (D) of a single pore in a weld is:

$D \leq 0.3s$, but max.4mm where s = material thickness.
For which of the following situations is the pore acceptable?

- a s = 20mm, measured pore diameter = 5mm.
- b s = 15mm, measured pore diameter = 4.5mm.
- c s = 10mm, measured pore diameter = 3mm.
- d s = 10mm, measured pore diameter = 3.5mm.

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23 To measure arc voltage accurately it is recommended that the voltmeter should be connected:

a Across the arc and as near as practical to the arc.
b Across the power source terminals prior to arc initiation.
c Across the power source terminals during the welding operation.
d Anywhere in the circuit.

24 Lamellar tearing has occurred in a steel fabrication. What technique could have been used to find it before the weld was made?

a X-ray examination.
b Liquid penetrant examination.
c Ultrasonic examination.
d It could not have been found by any inspection method.

25 Preheating a low alloy steel prior to welding will minimise the risk of:

a Porosity.
b Excessive distortion.
c HAZ cracking.
d Lack of fusion.

26 Typical temperatures used for normalising a C-Mn steel plate are:

a 600-650°C.
b 1000-1100°C.
c 700-800°C.
d 880-920°C.

27 For GMAW the burn-off rate of the wire is directly related to:

a Stick out length.
b Wire feed speed.
c Arc voltage.
d Travel speed.

28 When MMA welding a 60mm wall nozzle to a 100mm wall vessel shell, preheat temperature should be checked:

a Before welding starts/re-starts.
b On the shell and nozzle.
c At points at least 75mm from the joint edge.
d All of the above.

29 A crack running along the centreline of a weld bead could be caused by:

a Use of damp flux.
b Lack of preheat.
c Arc voltage too high.
d Weld bead too deep and very narrow.

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30 To improve resistance to service failure caused by cyclic loading, it is good practice to:

a Use low heat input welding.
b Use steel with a low CEV.
c Ensure there are no features that give high stress concentration.
d PWHT the fabrication.

31 The use of low carbon austenitic stainless steels and stabiliser stainless steels will minimise the risk of:

a HAZ cracking.
b Weld decay.
c Weld metal cracking.
d Distortion.

32 Which type of SAW flux is susceptible to breaking down into fine particles during circulation?

a Fused.
b Neutral.
c Alloyed.
d Agglomerated.

33 The maximum hardness in the HAZ of a steel will increase if:

a Heat input is increased.
b CEV is increased.
c Joint thickness is decreased.
d Basic electrodes are used.

34 BS EN ISO 5817 (Level B) specifies the limit for excess weld metal (h) on a butt weld as:

$h \leq 1mm + 0.1b$, but max. 5mm, b = weld width.
In which of the following situations is the measured excess weld metal acceptable.

a b = 10 measured excess weld metal = 2.5mm.
b b = 20 measured excess weld metal = 3.5mm.
c b = 35 measured excess weld metal = 4.5mm.
d b = 45 measured excess weld metal = 5.5mm.

35 A C-Mn steel is being welded by MMA and the electrode run-out lengths that have been used are much shorter than specified by the WPS. This deviation may give:

a Increased risk of hydrogen cracking.
b Increased risk of solidification cracking.
c Lower values of HAZ toughness.
d Higher values of HAZ hardness.

36 The first procedure prepared for a Weld Procedure Qualification test weld is a:

a pWPS.
b WPS.
c WPQR.
d WPAR.

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37 Transfer of material identification by hard stamping is sometimes not allowed for high integrity applications because it:

- a Is too slow.
- b Can be a safety hazard.
- c May damage the material.
- d Causes problems with coating operations.

38 When welding thin plate distortion can be minimised by:

- a Welding from both sides.
- b Using U preparations rather than V types.
- c Using strongbacks.
- d Using back-step welding.

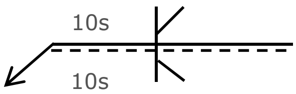
39 Which of the following would be considered to be high heat input welding?

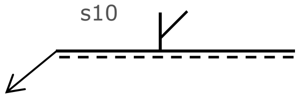
- a 550J/mm.
- b 55J/mm.
- c 5.5J/mm.
- d 5kJ/mm.

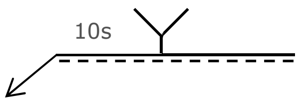
40 Initiation of a TIG arc using a high frequency spark may not be allowed because it:

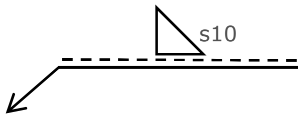
- a Often causes tungsten inclusions.
- b Can damage electronic equipment.
- c Is an electrical safety hazard.
- d Often causes stop/start porosity.

41 Which of these drawing symbols shows weld penetration depth in accordance with BS EN 22553?

a 

b 

c 

d 

42 BS EN 288 and BS EN ISO 15614 are specifications for:

a Welder approval testing.
b Welding equipment calibration.
c Welding procedure approval.
d Consumables for submerged arc welding.

43 What determines the penetrating power of gamma rays?

a Time.
b Type of isotope.
c Source-to-film distance.
d Source strength.

44 Which element has the greatest effect on the HAZ hardness of C-Mn steel?

a Molybdenum.
b Chromium.
c Titanium.
d Carbon.

45 Preheating a steel plate with a carbon equivalent value (CEV) of 0.48 may be required to:

a Drive moisture from the plate.
b Prevent excessive hardening in the HAZ.
c Prevent the formation of carbides.
d Improve the mechanical properties of the weld metal.

46 A welder approval certificate should be withdrawn if:

a He has not done any welding for four months.
b He has been absent from work for seven months.
c The repair rate for his welds exceeds 1%.
d His work has been examined by UT only.

47 In friction welding, the metal at the interface when the joining occurs is described as being in the:

a Liquid state.
b Intercritical state.
c Plastic state.
d Elastic state.

48 A penetrameter (IQI) is used to measure the:

a Size of discontinuity in a weld joint.
b Density of a radiographic film.
c Degree of film contrast.
d Quality of the radiographic technique.

49 Which of the following cutting methods is suitable for cutting stainless steel?

a Plasma.
b Oxy-acetylene.
c Oxy-propane.
d It depends upon the thickness.

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50 Which of the following would be classed as the most serious type of defect?

a A buried linear slag inclusion.
b Buried lack of inter-run fusion.
c Surface-breaking lack of sidewall fusion.
d Surface porosity.

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Welding Inspector Level 2: Multiple Choice Questions

Paper 4 - MSR-WI-4a

Name: .... Date: ....

1 What four criteria are necessary to produce hydrogen induced cold cracking?

- a Hydrogen, moisture, martensitic grain structure and heat.
- b Hydrogen, poor weld profiles, temperatures above 200°C and a slow cooling rate.
- c Hydrogen, a grain structure susceptible to cracking, stress and a temperature below 300°C.
- d Hydrogen, existing weld defects, stress and a grain structure susceptible to cracking.

2 In which of the following mechanical tests would show a change in the material from ductile to brittle with the use of a transition curve?

- a Tensile test.
- b Charpy test.
- c Fusion zone test.
- d All of the above.

3 Normalising:

- a Fast cooling from the austenite region when applied to steels.
- b Is slowly cooled from the austenite region to approximately 680°C and then cooled down in air.
- c Is slowly cooled down in air from below the lower critical limit.
- d None of the above.

4 Assuming that the welding process, material thickness, carbon equivalent and the welding parameters to be the same, which of the following joint types would normally require the highest preheat temperature?

- a Edge joint.
- b Lap joint.
- c Butt joint (single V).
- d T joint

5 Austenitic stainless steels are more susceptible to distortion when compared to ferritic steels this is because:

- a High coefficient of thermal expansion, low thermal conductivity.
- b High coefficient of thermal expansion, high thermal conductivity.
- c Low coefficient of thermal expansion, high thermal conductivity.
- d Low coefficient thermal expansion, low thermal conductivity,

6 Preheat temperature:

- a May be increased by an increase in travel speed.
- b May be increased by a reduction in material thickness.
- c May be increased by an increase in electrode diameter.
- d None of the above.

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7 Which of the following properties may be applicable to a carbon steel weld (CE 0.48) welded with a fast travel speed without preheat?

a Narrow heat affected zone and hardness value in excess of 350 HV.
b Broad heat affected zone and hardness values in excess of 350 HV.
c A very tough and narrow heat affected zone.
d Narrow heat affected zone and low hardness values.

8 Which of the following test pieces taken from a charpy test on a carbon-manganese steel weld, welded with a high heat input is most likely to have the lowest toughness?

a Test piece taken from parent metal.
b Test piece taken from weld metal.
c Test piece taken from HAZ.
d All of the above values will be the same.

9 Which is the correct arc energy for the following parameters, amps 350, volts 32 and the travel speed 310 mm/minute (MMA welding process)?

a 2.16 kJ/mm.
b 0.036 kJ/mm.
c 21.60 kJ/mm.
d 3.6 kJ/mm.

10 A multi-pass MMA butt weld made on carbon steel consists of 5 passes deposited using a 6mm diameter electrode. A 12-pass weld made on the same joint deposited using a 4mm diameter electrode on the same material will have:

a A lower heat input and a higher degree of grain refinement.
b A lower heat input and a coarse grain structure.
c A lower amount of distortion and a higher degree of grain refinement.
d A higher amount of distortion and a lower degree of grain refinement.

11 Transverse tensile test:

a Is used to measure the ultimate tensile strength of the joint.
b Is used to measure the elongation of a material.
c Is used to measure the yield strength of a material.
d All of the above.

12 Mechanical tests:

a Tensile tests are used to provide a quantitative measurement of weld zone ductility.
b Bend tests are used to provide a quantitative measurement of weld zone ductility.
c VPN tests are used to provide a qualitative measurement of weld zone ductility.
d All of the above could be used to provide a quantitative measurement of weld zone ductility.

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13 Bend tests:

a On a 25mm thick carbon steel butt weld a side bend would be the best for the detection of lack of inter-run fusion.
b On a 25mm thick carbon steel butt weld a face bend would be the best for the detection of lack of inter-run fusion.
c On a 25mm thick carbon steel butt weld a root bend would be the best for the detection of lack of inter-run fusion.
d On a 25mm thick carbon steel butt weld a Longitudinal bend would be the best for the detection of lack of inter-run fusion.

14 EN 287 standard refers to what:

a Welder approval.
b Welding procedure approval.
c Visual Inspection of fusion welds.
d Welding Inspection Personnel.

15 EN 2560 standard refers to which of the following?

a Welding terms and symbols.
b Covered electrodes for MMA.
c Filler wires for MIG/MAG and TIG.
d SAW Flux.

16 The main reason for qualifying a welding procedure is:

a Determine the welder's ability.
b Check whether the acceptance criteria specific to the project can be met.
c To show that the fabricator has good welding control.
d To show the welded joints meet the requirements of the specification.

17 Degreasing agents used on components are essential for quality welding, during and after welding some agents may:

a Cause corrosion problems.
b Leave residues.
c Give off toxic gases.
d All of the above.

18 In the welding of austenitic stainless steels, the electrode and plate materials are often specified to be low carbon content. The reason for this:

a To prevent the formation of cracks in the HAZ.
b To prevent the formation of chromium carbides.
c To prevent cracking in the weld.
d Minimise distortion.

19 Essential variable:

a In a WPS may change the properties of the weld.
b In a WPS may influence the visual acceptance.
c In a WPS may require re-approval of a weld procedure.
d All of the above.

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20 NDT:

a MPI can only detect surface breaking defects.
b DPI can only detect surface breaking defects.
c UT can only detect surface breaking defects.
d Both **a** and **b** are correct statements.

21 Radiographic testing:

a On a radiograph, slag inclusions and copper inclusion would both show up as light indications.
b On a radiograph, tungsten inclusions and excessive root penetration would both show up as light indications.
c On a radiograph, cap undercut and root piping would both show up as light indications.
d On a radiograph, excessive cap height and incomplete root penetration would both show up as dark indications.

22 Lamellar tearing:

a Can be prevented by the use of plate materials containing low levels of impurities.
b Can be prevented by the use of buttering runs.
c Is best prevented by post weld stress relief.
d Both **a** and **b** are correct.

23 When considering radiography using X-ray, which of the following techniques is most likely to be used for a pipe to pipe weld (circumferential seam), 610mm diameter with no internal access?

a SWSI.
b DWSI.
c DWDI.
d SWSI-panoramic.

24 Balanced welding techniques:

a Are used for controlling lamellar tearing.
b Are used to increasing weld toughness.
c Are used to reduce weld zone hardness.
d Are used to reduce distortion.

25 Radiographic testing:

a On a radiograph lack of root fusion would most likely show up as a dark straight line with a light root.
b On a radiograph lack of root fusion would most likely show up as a dark root with straight edges.
c On a radiograph lack of root fusion would most likely show up as a dark uneven line following the edge of the root.
d Lack of root fusion cannot be seen on a radiograph.

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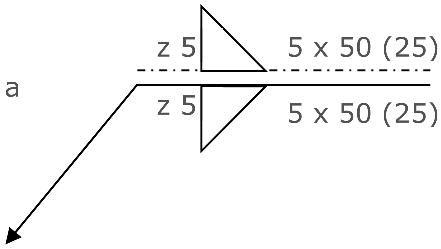
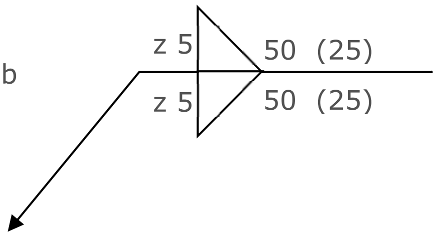
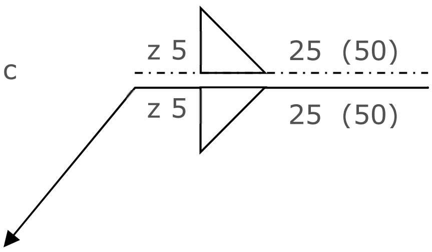
26 Is it permissible to allow a multi-pass butt weld to cool down between weld passes?

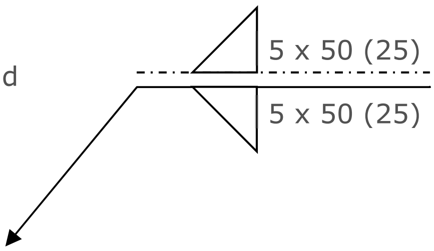
a It should be up to the welding inspector.
b No the weld must be kept hot at all times.
c It depends on the welder.
d It depends on the specification requirements.

27 A T joint on a support bracket is to be welded both sides using a 5mm leg length fillet weld, each weld is to be intermittent 50mm in total length, the gap between each weld is to be 25mm. Which of the following is the correct symbol in accordance with ISO 2553?

a


b


c


d


28 SAW welding process:

a The use of excessive voltages would result in insufficient flux melting.
b The use of excessive voltages would result in excessive flux melting.
c The use of excessive voltages would result in easy slag removal.
d The use of excessive voltages would result in excessive spatter.

29 Cellulose electrodes have which of the following properties?

a Viscous slag, large volumes of shielding gas and UTS values above 90,000psi.
b Large volumes of shielding gas, high spatter contents and hydrogen levels < 15ml per 100g of weld metal deposited.
c Large volumes of shielding gas, hydrogen contents > 15ml per 100g of weld metal deposited and should be never baked.
d High spatter contents, high deposition and large volumes of gas shield.

30 EN 2560, **E50 3 1Ni B 2 1 H5**, what does the **3** represent?

a A minimum charpy value of 30 joules.
b A maximum impact value of 47 joules.
c A minimum impact temperature of –30°C at a given joule value.
d None of the above.

31 Fatigue cracks:

a The fracture surface is rough and randomly torn.
b The fracture surface is smooth.
c The fracture surface has a step like appearance.
d The fracture surface is generally of a bright crystalline appearance.

32 E 6013:

a Would most probably be used for welding low pressure pipework.
b Would most probably be used for welding high pressure pipework.
c Are used in the vertical down welding position on storage tanks.
d Are used in a situation where low hydrogen welds are specified.

33 Which element in steel if present in significant amounts may lead to hot shortness?

a Phosphorus (P).
b Manganese (Mn).
c Silicon (Si).
d Sulphur (S).

34 Which of the following welding processes are commonly used for the welding of Aluminium?

a MIG and TIG.
b MAG and TIG.
c MMA and TIG.
d MMA and MIG.

35 Radiographic testing:

a Is most suited to the detection of volumetric flaws.
b Is most suited to the detection of all planar flaws.
c Both **a** and **b**.
d Is most suited to the detection of laminations in rolled plate materials.

36 Which of the following Isotopes may be used for a 25mm thick steel pipe to pipe weld DWSI (In accordance with EN 1435)?

a Ir 192.
b Co 60.
c ALR 75.
d Yb 169.

37 Increasing the carbon content of a steel will:

a Increase the hardness and toughness.
b Decrease the hardness and toughness.
c Increase hardness, decrease toughness.
d Decrease hardness, increase toughness.

38 Which of the following can be used to reduce the chances of solidification cracking?

a The use of a non-fluxed welding process and better quality materials.
b The use of better quality materials and the highest heat input process.
c The use of a low dilution process and wider joint preparation.
d The addition of silicon and a low hydrogen welding process.

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39 In an all weld metal tensile test, the original test specimens gauge length is 50mm. After testing the gauge length increased to 72mm, what is the elongation percentage?

- a 44%.
- b 144%.
- c 69.4%.
- d 2.27%.

40 Fillet welds:

- a 1 to 1 is the ratio between the leg length and design throat thickness on a mitre fillet weld with equal leg lengths.
- b 2 to 1 is the ratio between the leg length and design throat thickness on a mitre fillet weld with equal leg lengths.
- c 1.4 to 1 is the ratio between the leg length and design throat thickness on a mitre fillet weld with equal leg lengths.
- d All of the above could be applicable it depends upon the leg length size.

41 The toughness and yield strength of steel is reduced by:

- a Reducing the grain size.
- b Increasing the heat input.
- c Reducing the heat input.
- d Both **a** and **b**.

42 How can you tell the difference between an EN/ISO weld symbol and an AWS weld symbol?

- a The EN weld symbol will always have the arrow side weld at the top of the reference line.
- b The EN symbol has the elementary symbol placed on the indication line lying above or below the reference line to indicate a weld on the other side.
- c The EN symbol has the elementary symbol placed on the indication line lying above or below the reference line to indicate a weld on the arrow side.
- d The EN symbol has a fillet weld throat thickness identified by the letter z.

43 E7018:

- a Is a basic low hydrogen electrode containing iron powder.
- b Is a rutile electrode containing iron powder.
- c Is a cellulose electrode suitable for welding in all positions.
- d Is a basic electrode depositing weld metal yield strength of at least 70,000psi.

44 Ductile fracture:

- a Would have a rough randomly torn fracture surface and a reduction in area.
- b Would have a smooth fracture surface displaying beach marks.
- c Would have a step like appearance.
- d Would have a bright crystalline fracture surface with very little reduction in area.

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45 Which of the following under typical conditions using the MMA welding process would give the deepest penetration?

- a DC –ve.
- b DC +ve.
- c AC.
- d Both **a** and **b**.

46 Cold shortness:

- a Is mainly caused by the presence of sulphur (S).
- b Is mainly caused by the presence of phosphorous (P).
- c Is mainly caused by the presence of manganese (Mn).
- d Is mainly caused by the presence of silicon (Si).

47 When considering the advantages of site radiography over conventional ultrasonic inspection which of the following applies?

- a A permanent record, good for detecting lamellar tearing and defect identification.
- b A permanent record produced, good for the detection of all surface and sub-surface defects and assessing the through thickness depths of defects.
- c Permanent record produced, good for defect identification and not as reliant upon surface preparation.
- d No controlled areas required on site, a permanent record produced and good for assessing pipe wall thickness reductions due to internal corrosion.

48 HICC:

- a In Carbon Manganese steel is most susceptible in the weld zone.
- b Micro alloyed steel (HSLA) is most susceptible in the weld zone.
- c Austenitic steel is most susceptible in the weld zone.
- d Both **a** and **b** are correct statements.

49 Lamellar tearing:

- a Is a product defect caused during the manufacturing of certain steels.
- b Is a crack type, which occurs in the parent material due to welding strains acting in the short transverse direction of the parent material.
- c Is a type of hot crack associated with impurities (sulphur, carbon and phosphorous).
- d Is a type of crack that occurs in the weld or parent material due to cyclic stresses.

50 A welding process where the welding plant controls the travel speed and the arc gap but under constant supervision using a shielding gas mixture of 80% argon – 20% carbon dioxide is termed:

- a A manual MAG process.
- b A semi-automatic MAG process.
- c A mechanised MIG process.
- d A mechanised MAG process

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Appendix 2

Plate Reports and Questions

CSWIP 3.1 Training Questions for Plate Butt Weld 1

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a Equal to or less than 0mm.
b 1-4mm.
c 5-6mm.
d 7-8mm.
e Accept.
f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a None observed.
b 50-75mm.
c 10-30mm.
d 80-110mm.
e Accept.
f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 50-65mm.
b 22-35mm.
c None observed.
d 8-18mm.
e Accept.
f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

a Smooth intermittent.
b Sharp but less than 1mm deep.
c None observed.
d Sharp but more than 1mm deep.
e Accept.
f Reject.

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5 Crater pipes in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a The area is between 10-15mm^2.
b The pore is greater than 1mm dia.
c None observed.
d The pore is less than 1mm dia.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 70-90mm.
b 30-60mm.
c None observed.
d 5-10mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3 areas.
b 4 areas.
c None observed.
d 1 area.
e Accept.
f Reject.

9 Sharp indications of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels.

a 4 areas.
b 1 area.
c None observed.
d 3 areas.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

- a 1-2mm.
- b 3-4mm.
- c None observed.
- d Greater than 5mm.
- e Accept.
- f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a 3-5mm.
- b 1-2mm.
- c None.
- d Greater than 5mm.
- e Accept.
- f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

- a 35-40mm.
- b 20-25mm.
- c None observed.
- d 1-10mm.
- e Accept.
- f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 28-35mm.
- b 1-10mm.
- c None observed.
- d 15-23mm.
- e Accept.
- f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 31-39mm.
- b 18-22mm.
- c None observed.
- d 40-60mm.
- e Accept.
- f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 15-30mm.
b 5-8mm.
c None observed.
d 1-2mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 1-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp indications of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total and would you accept or reject you findings to the given acceptance levels?

a 2 items observed.
b 1 item observed.
c None observed.
d 3 or more.
e Accept.
f Reject.

18 Crater pipes in the weld root area: Which answer best matches your assessment of the total accumalitive areas and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn-through in the root area: Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1 area.
b 2 areas.
c None observed.
d 3 areas.
e Accept.
f Reject.

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20 Angular distortion: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge).

a 3-5mm.
b 6-8mm.
c None observed.
d 1-2mm.
e Accept.
f Reject.

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Visual Inspection Plate Report – Weld face

Name [Block capitals]______________________ **Signature** ____________________ **Test piece identification** ________

Code/Specification used ______________________ **Welding process** ________________ **Joint type**__________________

Welding position____________ **Length and thickness of plate** ___________________ **Date** _____________

Notes: Excess weld metal = linear misalignment = toe blend = weld width =

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Visual Plate Report
Weld Root

MEASURE FROM THIS DATUM ONLY

Notes: Excess weld metal = Toe blend = weld width =

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WI 3.1

EXAM VERSION

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-	O	O	O	O	O	O	O

INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
O	O	O	O	O

CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

D	D	M	M	Y	Y

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CANDIDATE NUMBER FOR OFFICE USE ONLY

GENERAL THEORY

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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

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TECHNOLOGY THEORY

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CSWIP 3.1 Training Questions for Plate Butt Weld 2

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a Equal to or less than 0mm.
b 1-4mm.
c 5-6mm.
d 7-8mm.
e Accept.
f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a None observed.
b 45-80mm.
c 0-40mm.
d 100-120mm.
e Accept.
f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 60-70mm.
b 20-30mm.
c None observed.
d 5-18mm.
e Accept.
f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

a 60mm in length.
b Sharp but less than 1mm deep.
c None observed.
d Sharp but more than 1mm deep.
e Accept.
f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a The area is between 10-15mm^2.
b The area is greater than 100mm^2.
c None observed.
d The area is between 70-90mm^2.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 35-45mm.
b 15-25mm.
c None observed.
d 5-10mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3.
b 4.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp indications of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels.

a 4 areas.
b 1 area.
c None observed.
d 3 areas.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

- a 1-2mm.
- b 3-4mm.
- c 0-1mm.
- d Greater than 5mm.
- e Accept.
- f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a 4-5mm.
- b 2-3mm.
- c None.
- d Greater than 5mm.
- e Accept.
- f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 35-40mm.
- b 15-25mm.
- c None observed.
- d 1-10mm.
- e Accept.
- f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 28-35mm.
- b 1-10mm.
- c None observed.
- d 13-20mm.
- e Accept.
- f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels.

- a 31-39mm.
- b 18-22mm.
- c None observed.
- d 40-60mm.
- e Accept.
- f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 15-30mm.
- b 5-8mm.
- c None observed.
- d 1-2mm.
- e Accept.
- f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 10-17mm.
- b 1-4mm.
- c None observed.
- d 5-8mm.
- e Accept.
- f Reject.

17 Sharp indications of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total number and would you accept or reject your findings to the given acceptance levels?

- a 3 or more items observed.
- b 1 item observed.
- c None observed.
- d 2 items observed.
- e Accept.
- f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

- a Individual pore diameter between 1-2mm.
- b Individual pore diameter between 2-3mm.
- c None observed.
- d Individual pore diameter greater than 3mm.
- e Accept.
- f Reject.

19 Burn-through in the root area: Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

- a 1 area.
- b 2 areas.
- c None observed.
- d 3 areas.
- e Accept.
- f Reject.

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20 Angular distortion: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels, measure from the weld centreline to the plate edge.

a 3-5mm.
b 6-8mm.
c None observed.
d 1-2mm.
e Accept.
f Reject.

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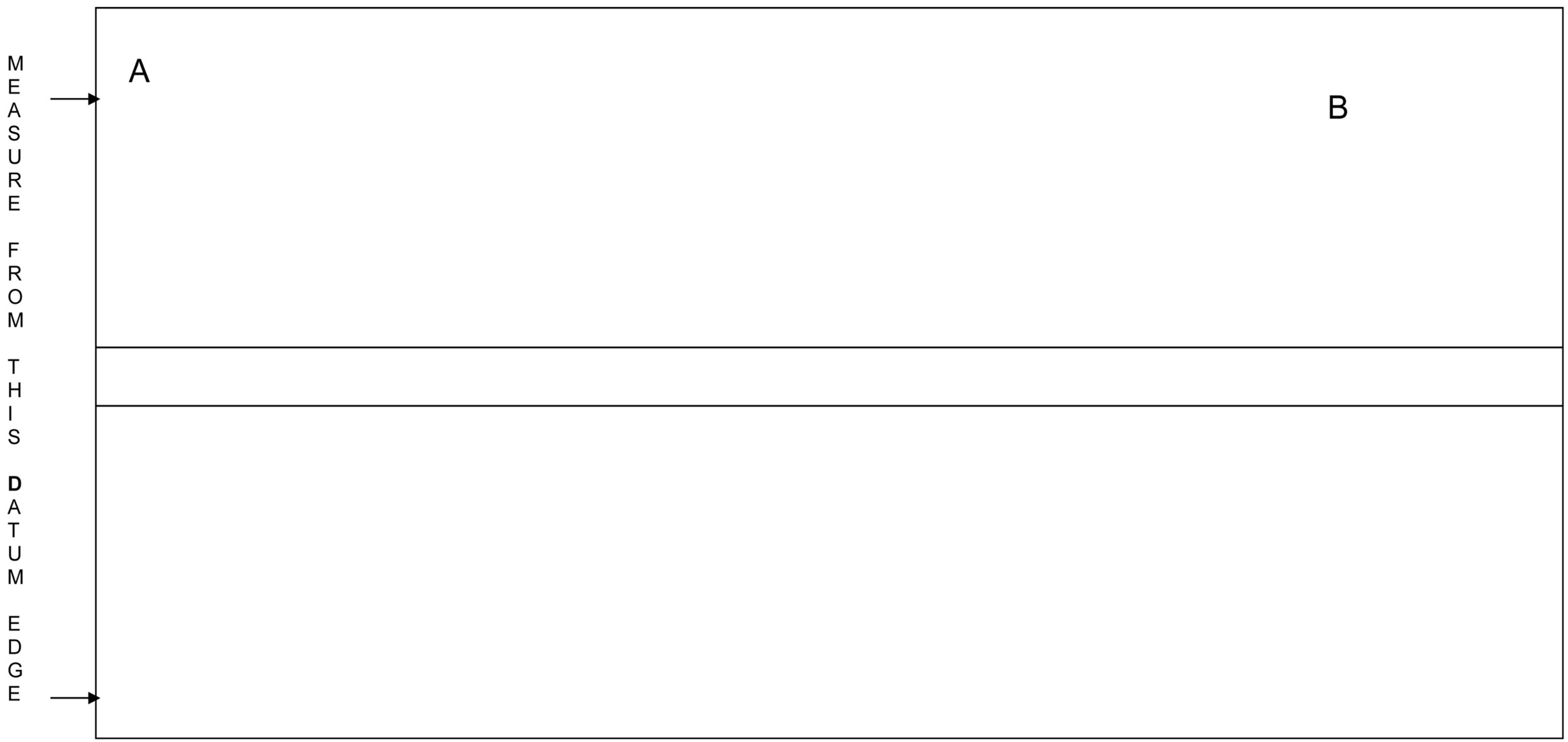
Visual Inspection Plate Report – Weld face

Name [Block capitals]______________________ **Signature** ____________________ **Test piece identification** ________

Code/Specification used ______________________ **Welding process** ________________ **Joint type**__________________

Welding position____________ **Length and thickness of plate** ____________________ **Date**____________



Notes: Excess weld metal = linear misalignment = toe blend = weld width =

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Visual Plate Report

Weld Root

Notes: Excess weld metal = Toe blend = weld width =

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WI 3.1

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EXAM -	O	O	O	O	O	O	O
VERSION -	O	O	O	O	O	O	O

INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

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Date of Birth

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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
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I agree with the terms and conditions of this examination	Tick Box

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TECHNOLOGY THEORY

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CSWIP 3.1 Training Questions for Plate Butt Weld 3

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a Equal to or less than 0mm.
- b 1-4mm.
- c 5-6mm.
- d 7-8mm.
- e Accept.
- f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a None observed.
- b 40-60mm.
- c 1-30mm.
- d 75-100mm.
- e Accept.
- f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a 60-70mm.
- b 20-30mm.
- c None observed.
- d 5-18mm.
- e Accept.
- f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

- a 50mm in length.
- b Sharp but less than 1mm deep.
- c None observed.
- d Sharp but more than 1mm deep.
- e Accept.
- f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a The area is between 15-25mm^2.
b The area is greater than 100mm^2.
c None observed.
d The area is between 70-90mm^2.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 70-90mm.
b 30-60mm.
c None observed.
d 91-100mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3 total.
b 4 total.
c None observed.
d 1 total.
e Accept.
f Reject.

9 Sharp areas of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels.

a More than 2 areas.
b 1 area.
c None observed.
d 2 areas.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

a 2-3mm.
b 4-5mm.
c 0-1.
d Greater than 5mm.
e Accept.
f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a 2-3mm.
b 1-2mm.
c None.
d Greater than 5mm.
e Accept.
f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 40-55mm.
b 25-35mm.
c None observed.
d 1-10mm.
e Accept.
f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 30-45mm.
b 1-15mm.
c None observed.
d 16-29mm.
e Accept.
f Reject.

14 Root concavity or shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels.

a 31-39mm.
b 18-22mm.
c None observed.
d 40-60mm.
e Accept.
f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 40-60mm.
b 5-8mm.
c None observed.
d 2-4mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 1-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp indications of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the total number of items and would you accept or reject your findings to the given acceptance levels?

a 2 observed.
b 1 item observed.
c None observed.
d 3 or more items observed.
e Accept.
f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn-through in the root area: Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 Angular distortion: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge).

a 3-4mm.
b 5-6mm.
c None observed.
d 1-2mm.
e Accept.
f Reject.

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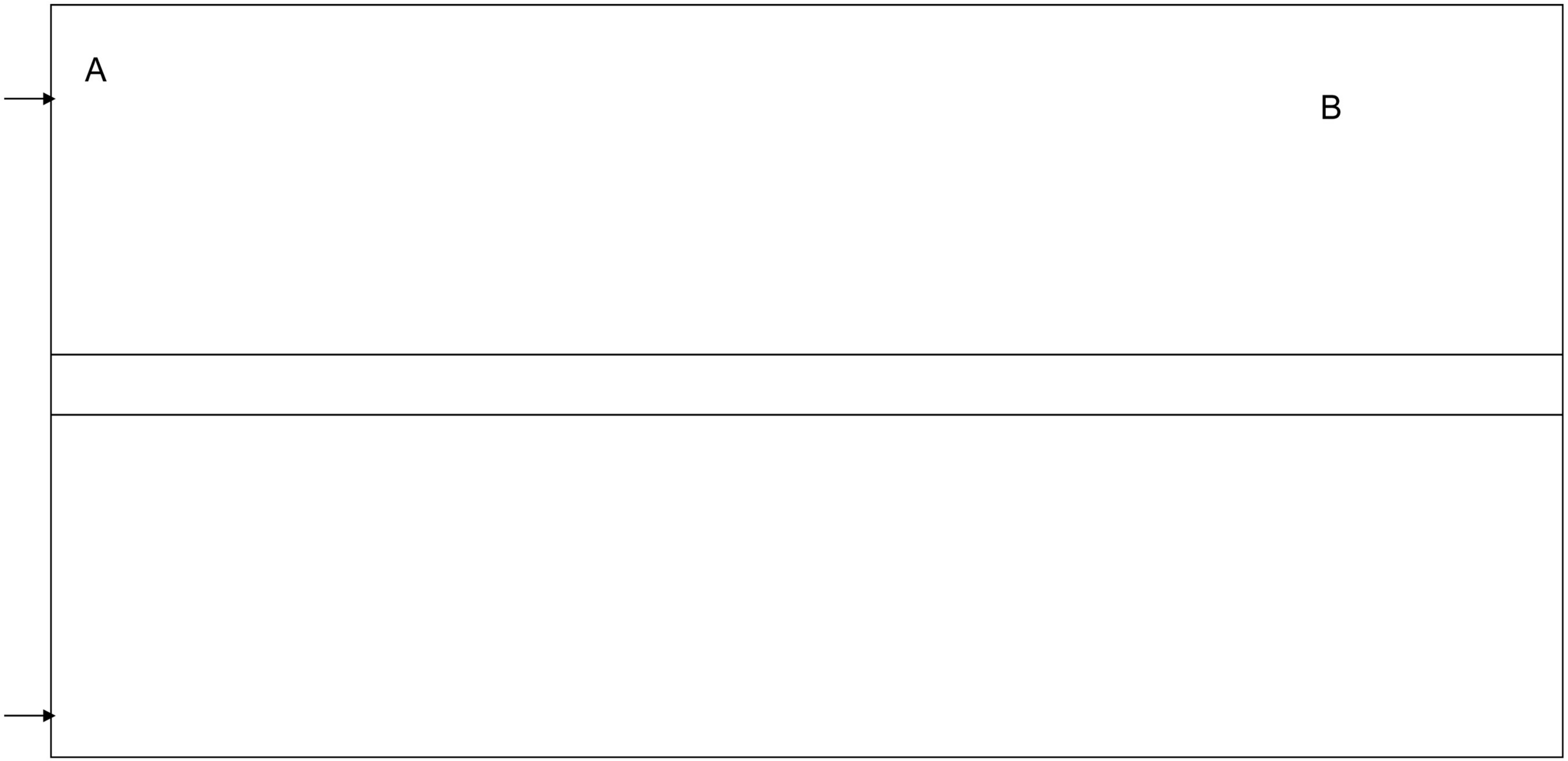
Visual Inspection Plate Report – Weld face

Name [Block capitals]______________________ **Signature** ___________________ **Test piece identification** ________

Code/Specification used _____________________ **Welding process** _______________ **Joint type**_________________

Welding position___________ **Length and thickness of plate** __________________ **Date**____________

MEASURE FROM THIS **D**ATUM EDGE



Notes: Excess weld metal = linear misalignment = toe blend = weld width =

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Visual Plate Report
Weld Root

Notes: Excess weld metal = Toe blend = weld width =

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VERSION -	O	O	O	O	O	O	O

INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	**INVIGILATOR SIGNATURE:**
EXAM DATE:	**EVENT CODE**
CANDIDATE NAME:	**CANDIDATE SIGNATURE:**

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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CANDIDATE NUMBER FOR OFFICE USE ONLY

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TECHNOLOGY THEORY

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MACRO A

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CSWIP 3.1 Training Questions for Plate Butt Weld 4

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a Equal to or less than 0mm.
- b 1-4mm.
- c 5-6mm.
- d 7-8mm.
- e Accept.
- f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a None observed.
- b 30-50mm.
- c 1-25mm.
- d 100-120mm.
- e Accept.
- f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a 12-18mm.
- b 8-10mm.
- c None observed.
- d 2-6mm.
- e Accept.
- f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

- a 10-20mm in length.
- b Sharp but less than 1mm deep.
- c None observed.
- d Sharp but more than 1mm deep.
- e Accept.
- f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a The area is between 0.5-5mm^2.
b The pore is greater than 45-60mm^2.
c None observed.
d The pore is between 20-30mm^2.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 30-39mm.
b 40-55mm.
c None observed.
d 5-10mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 2.
b 3.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp areas of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels.

a 4 areas.
b 1-2 areas.
c None observed.
d 3 areas.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

a 0.5-1mm.
b 1.5-2mm.
c None observed.
d Greater than 5mm.
e Accept.
f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a 3-5mm.
b 1-2mm.
c None.
d Greater than 5mm.
e Accept.
f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 35-40mm.
b 20-25mm.
c None observed.
d 1-10mm.
e Accept.
f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 28-35mm.
b 1-10mm.
c None observed.
d 15-23mm.
e Accept.
f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels.

a 31-39mm.
b 18-22mm.
c None observed.
d 40-75mm.
e Accept.
f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 15-30mm.
b 5-8mm.
c None observed.
d 40-50mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 1-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp indications of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

a 2-3 items observed.
b 1 item observed.
c None observed.
d 4 or more items observed.
e Accept.
f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn-through in the root area: Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 With refrence to cluster porosity which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels.

a 20-30mm^2.
b 31-40mm^2.
c None observed.
d 12-18mm^2.
e Accept.
f Reject.

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Visual Inspection Plate Report – Weld face

Name [Block capitals]______________________ **Signature** ____________________ **Test piece identification** ________

Code/Specification used ______________________ **Welding process** ________________ **Joint type**__________________

Welding position____________ **Length and thickness of plate** ____________________ **Date** _____________

Notes: Excess weld metal =	linear misalignment =	toe blend =	weld width =

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Visual Plate Report
Weld Root

MEASURE FROM THIS DATUM ONLY

Notes: Excess weld metal = Toe blend = weld width =

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EXAM VERSION	1	2	3	4	5	6	7
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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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TECHNOLOGY THEORY

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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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CSWIP 3.1 Training Questions for Plate Butt Weld 5

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a Equal to or less than 0mm.
b 1-4mm.
c 5-6mm.
d 7-8mm.
e Accept.
f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a None observed.
b 16-29mm.
c 1-15mm.
d 40-50mm.
e Accept.
f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 60-70mm.
b 20-30mm.
c None observed.
d 5-12mm.
e Accept.
f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

a 60-70mm in length.
b Sharp but less than 1mm deep.
c None observed.
d Sharp but more than 1mm deep.
e Accept.
f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a 1-15mm^2.
b Greater than 100mm^2.
c None observed.
d The area is between 70-90mm^2.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 40-60mm.
b 20-39mm.
c None observed.
d 5-10mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3.
b 4.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp areas of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels.

a 4.
b 1-2.
c None observed.
d 3.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

a 1-2mm.
b 3-4mm.
c None observed.
d Greater than 5mm.
e Accept.
f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a 2-3mm.
b 0.5-1.5mm.
c None.
d Greater than 5mm.
e Accept.
f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 30-40mm.
b 20-25mm.
c None observed.
d 1-10mm.
e Accept.
f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 28-40mm.
b 1-10mm.
c None observed.
d 15-23mm.
e Accept.
f Reject.

14 Root concavity or shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels.

a 31-39mm.
b 18-25mm.
c None observed.
d 40-75mm.
e Accept.
f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 15-30mm.
b 5-8mm.
c None observed.
d 1-2mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 1-4mm.
c None observed.
d 5-8mm.
e Accept
f Reject.

17 Sharp indications of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the total number of items and would you accept or reject your findings to the given acceptance levels?

a 2 items observed.
b 1 item observed.
c None observed.
d 3 or more items observed.
e Accept.
f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 0-0.5mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn-through in the root area: Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 Angular distortion: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge).

a 2-4mm.
b 6-8mm.
c None observed.
d 0.5-1mm.
e Accept.
f Reject.

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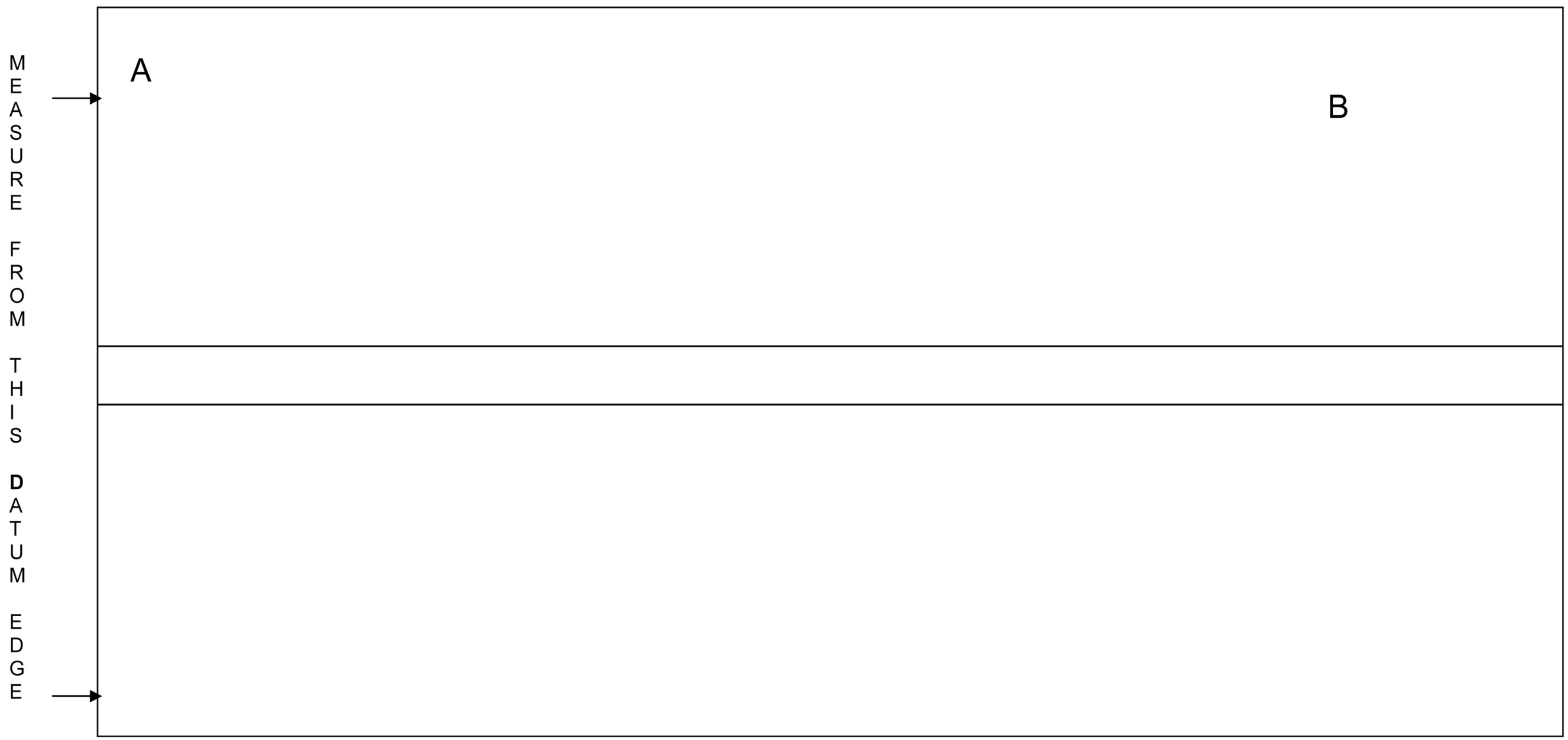
Visual Inspection Plate Report – Weld face

Name [Block capitals]______________________ **Signature** ___________________ **Test piece identification** ________

Code/Specification used _____________________ **Welding process** _______________ **Joint type**_________________

Welding position____________ **Length and thickness of plate** ____________________ **Date**____________



Notes: Excess weld metal = linear misalignment = toe blend = weld width =

Visual Plate Report

Weld Root

Notes: Excess weld metal = Toe blend = weld width =

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EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

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Table number	Defect type	Acceptance levels plate and pipe		Acceptance levels macro only
		Remarks	**Maximum allowance**	**Remarks**
1	**Excess weld metal**	At no point shall the excess weld metal fall below the outside surface of the parent material. All weld runs shall blend smoothly.	Excess weld metal will not exceed H = 2mm in any area on the parent material, showing smooth transition at weld toes.	As for plate and pipe
2	**Slag/silica inclusions**	Slag inclusions are defined as non-metallic inclusions trapped in the weld metal or between the weld metal and the parent material.	The length of the slag inclusion shall not exceed 50mm continuous or intermittent. Accumulative totals shall not exceed 50mm	Slag and silica not permitted
3	**Undercut**	Undercut is defined as a grove melted into the parent metal, at the toes of the weld excess metal, root or adjacent weld metal.	No sharp indications Smooth blend required. The length of any undercut shall not exceed 50mm continuous or intermittent. Accumulative totals shall not exceed 50mm. Max D = 1mm for the cap weld metal. Root undercut not permitted.	No sharp indications Smooth blend required
4	**Porosity or Gas Cavities**	Trapped gas, in weld metal, elongated, individual pores, cluster porosity, piping or wormhole porosity.	Individual pores $\leq$ 1.5 max. Cluster porosity maximum 50^{2}mm total area. Elongated, piping or wormholes 15mm max. L continuous or intermittent.	Cluster porosity not permitted. Individual pores acceptable.
5	**Cracks or Laminations**	Transverse, longitudinal, star or crater cracks.	Not permitted	Not permitted
6	**Lack of fusion Laps Cold lap**	Incomplete fusion between the weld metal and base material, incomplete fusion between weld metal. (lack of inter-run fusion)	Surface breaking lack of side wall fusion, lack of inter-run fusion continuous or intermittent not to exceed 15mm. Accumulative totals not to exceed 15mm over a 300mm length of weld.	Not permitted
7	**Arc strikes**	Damage to the parent material or weld metal, from an unintentional touch down of the electrode or arcing from poor connections in the welding circuit.	Not permitted	Not permitted
8	**Mechanical damage**	Damage to the parent material or weld metal, internal or external resulting from any activities.	No stray tack welds permitted Parent material must be smoothly blended General corrosion permitted. Max. D = 1.5mm. Only 1 location allowed	Not permitted
9	**Misalignment**	Mismatch between the welded or unwelded joint.	Max H = 1.5mm	As for plate and pipe
10	**Penetration**	Excess weld metal, above the base material in the root of the joint.	Max H ≤ 3mm	As for plate and pipe
11	**Lack of root penetration**	The absence of weld metal in the root area, two root faces showing.	Not permitted	Not permitted
12	**Lack of root fusion**	Inadequate cross penetration of (one) root face.	Lack of root fusion, not to exceed 50mm total continuous or accumulative.	Not permitted
13	**Burn through**	Excessive penetration, collapse of the weld root	Not permitted	Not permitted
14	**Angular distortion**	Distortion due to weld contraction	5mm max. Plate only	Accept
15	**Root concavity**	Weld metal below the surface of both parent metals	50mm maximum length 3mm maximum depth	Accept

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Practical Plate Inspection

Materials Joining and Engineering Technologies
Training and Examination Services

Practical Sessions Objective

When these presentation have been completed you will have a greater understanding of the examination requirement and how to identify and plot weld defects around real life welds and the classroom specimens on which you will be examined.

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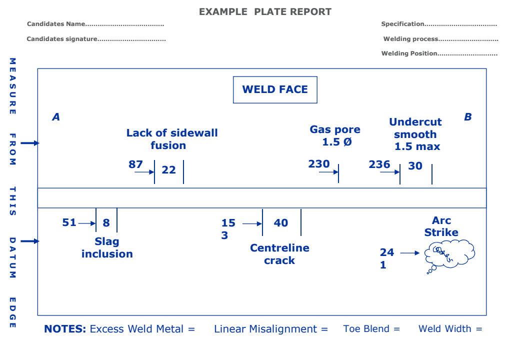
Example of Weld Face



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Example of Plate Root

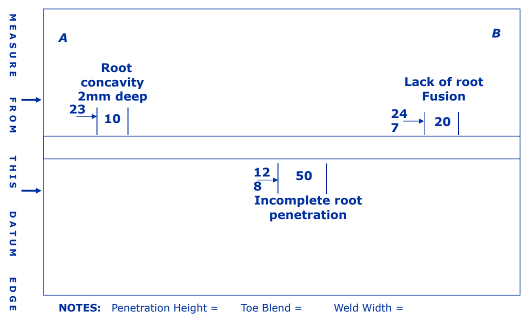

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Plate Inspection Examination

1. **Read the Questions and compare with your thumb print.**

With reference to penetration height, which of the below best reflects your assessment and would you accept or reject your findings to the given acceptance levels?

a. 4-6mm
b. 2-4mm
c. 0-1mm
d. 5mm
e. Accept
f. Reject

2. **Compare to acceptance standard.**

3. **Mark the answer in the OMR grid in pencil and accept or reject accordingly. When you are sure about your answer mark the OMR grid in BLACK PEN.**

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Any Questions

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Appendix 3

Pipe Reports and Questions

CSWIP 3.1 Training Questions for Pipe Butt Weld 1

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height. (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a Equal to or less than 0mm.
b 4-5mm.
c 1-3mm.
d 7-8mm.
e Accept.
f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a None observed.
b 30-50mm.
c 0-28mm.
d 55-70mm.
e Accept.
f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 13-19mm.
b 20-30mm.
c None observed.
d 8-12mm.
e Accept.
f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

a Smooth intermittent.
b Sharp but less than 1mm deep.
c None observed.
d Sharp but more than 1mm deep.
e Accept.
f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a Area is 10-15mm$^{2.}$
b Area 190-210mm$^{2.}$
c None observed.
d Area 130-160mm$^{2.}$
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 70-90mm.
b 30-60mm
c None observed.
d 5-25mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3.
b 4.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp indications of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of area and would you accept or reject your findings to the given acceptance levels?

a 4.
b 1.
c None observed.
d 2.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

- a 1-2mm.
- b 3-4mm.
- c None observed.
- d Greater than 5mm.
- e Accept.
- f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a 3-5mm.
- b 1-2mm.
- c None.
- d Greater than 5mm.
- e Accept.
- f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 35-40mm.
- b 20-25mm.
- c None observed.
- d 0-10mm.
- e Accept.
- f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 28-35mm.
- b 0-10mm.
- c None observed.
- d 15-23mm.
- e Accept.
- f Reject.

14 Root concavity or shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 31-39mm.
- b 5-12mm.
- c None observed.
- d 40-60mm.
- e Accept.
- f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 60-70mm.
b 71-80mm.
c None observed.
d 1-15mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 0-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp areas of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total number of items and would you accept or reject your findings to the given acceptance levels?

a 2-3.
b 1.
c None observed.
d 4-5.
e Accept.
f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn through in the root area: Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

20 Cluster porosity: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge).

a 3-5mm^{2}.
b 26-88mm^{2}.
c None observed.
d 12-20mm^{2}.
e Accept.
f Reject.

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Visual Inspection Pipe Report

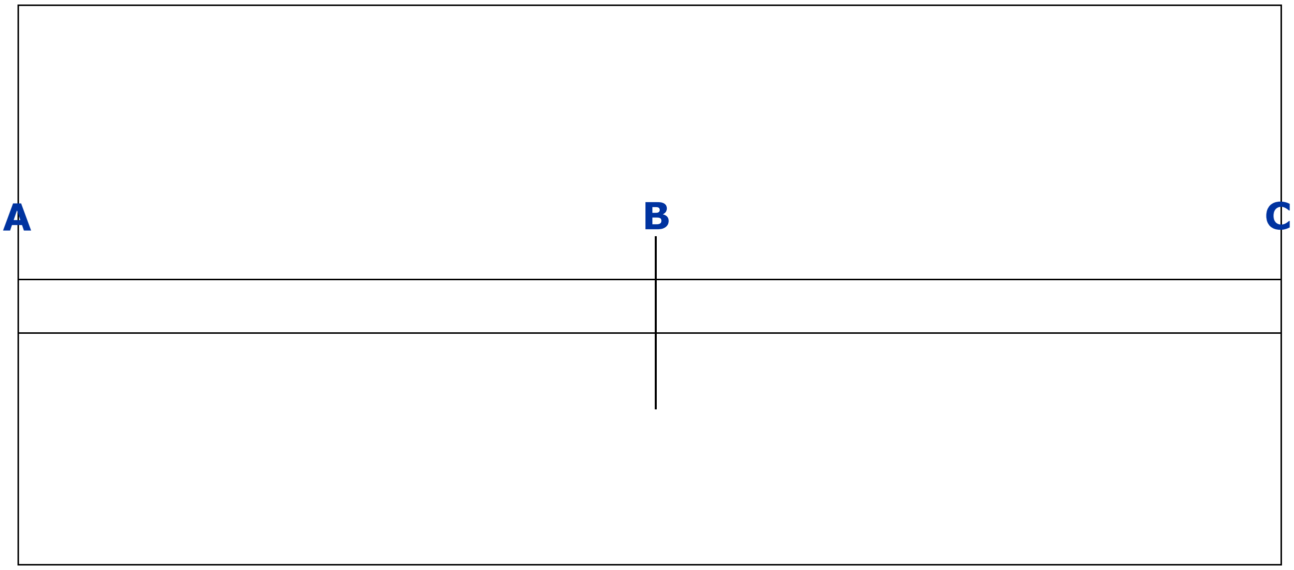
Name [Block capitals] ____

Signature ____________________________________ Pipe Ident# ___________

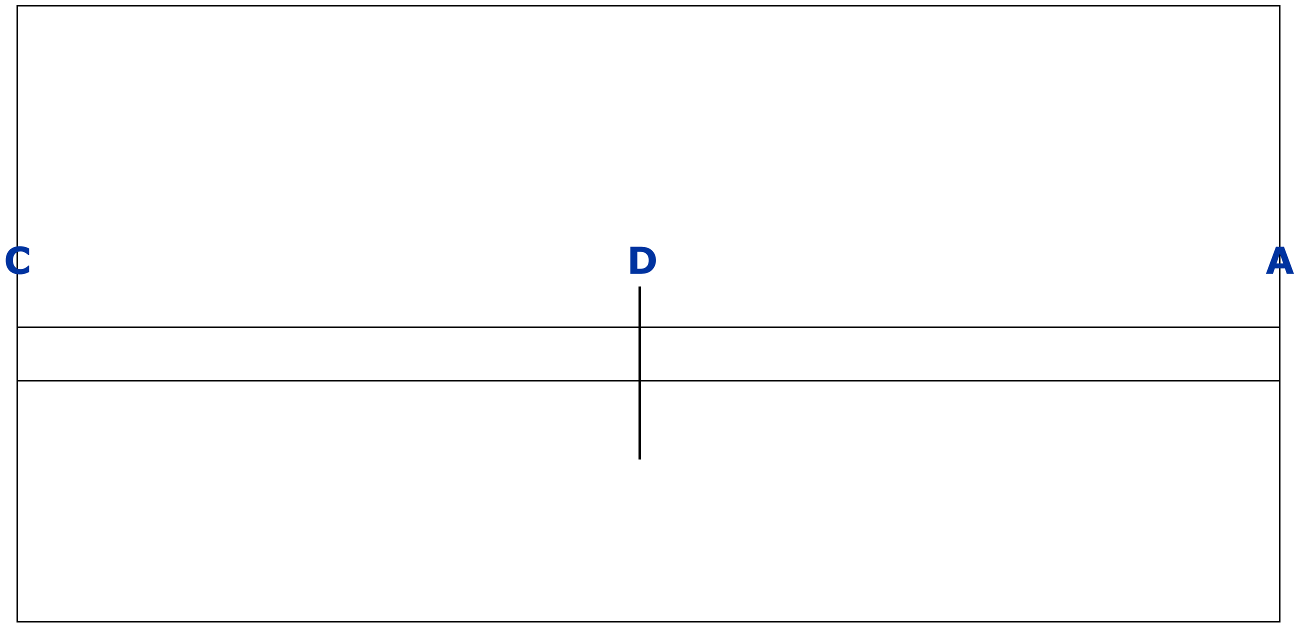
Code/Specification used ________ Welding Process ___________ Joint type ______

Welding position __________ OutsideØ and Thickness _________ Date __________

Weld face



Notes:
Excess weld metal height = Misalignment = Weld width = Toe blend =



Notes:
Excess weld metal height = Misalignment = Toe blend = Weld width =

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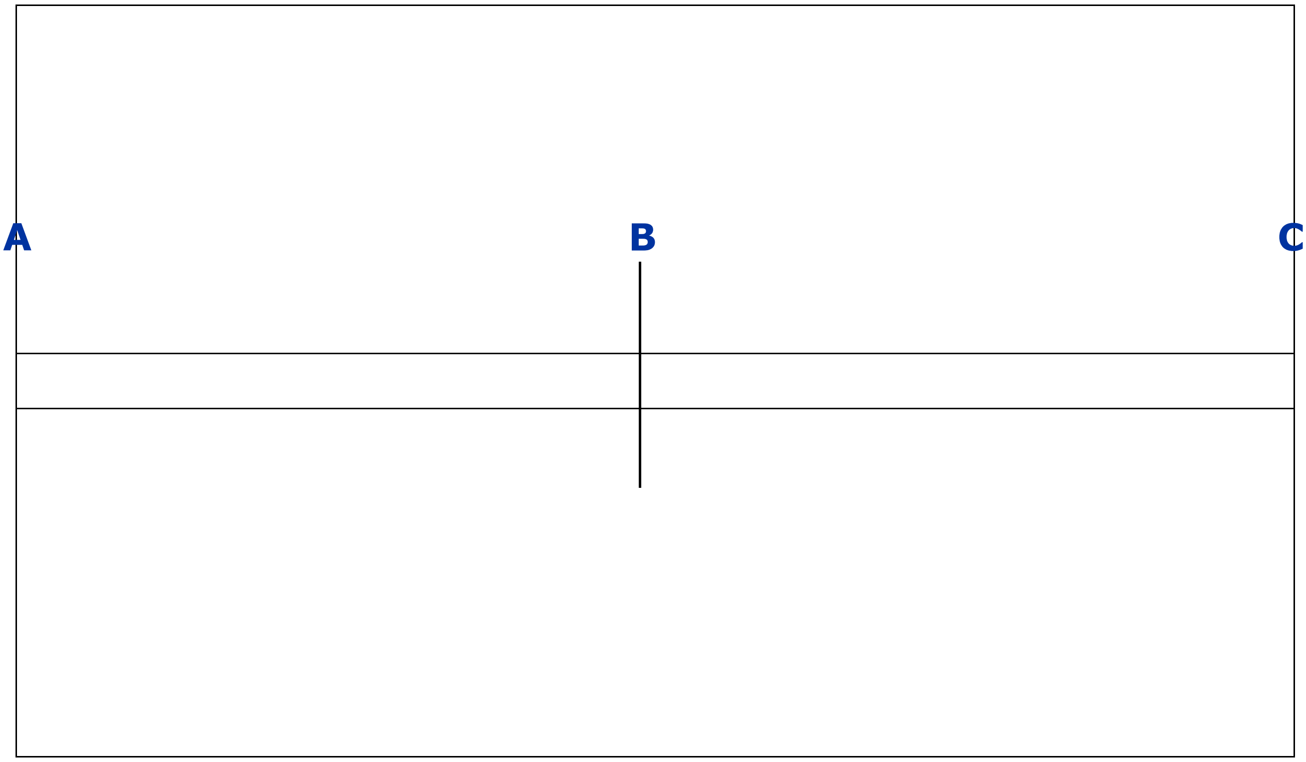
Pipe Root Face



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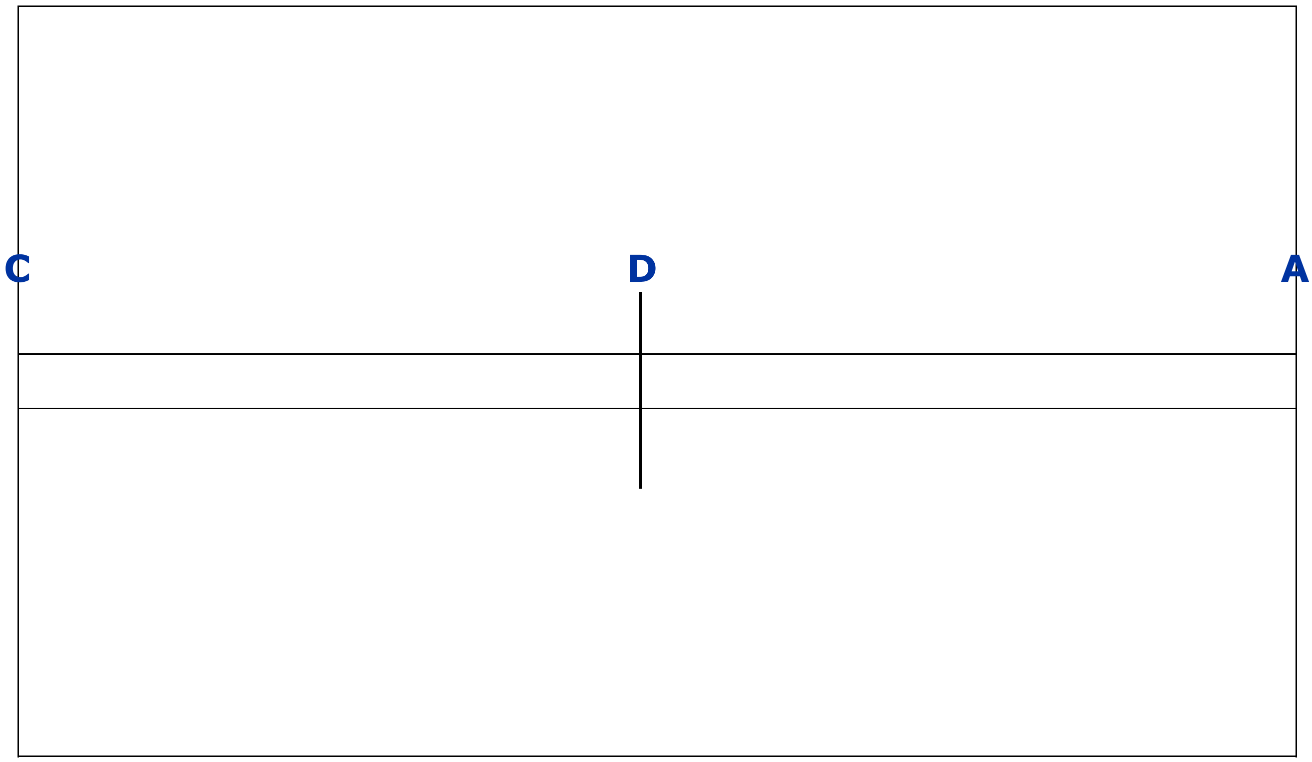

Notes:
Excess penetration height = Toe blend =

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MACRO B

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CSWIP 3.1 Training Questions for Pipe Butt Weld 2

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height: (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a Equal to or less than 0mm.
- b 1-4mm.
- c 5-6mm.
- d 7-8mm.
- e Accept.
- f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a None observed.
- b 30-60mm.
- c 0-25mm.
- d 100-120mm.
- e Accept.
- f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a 60-70mm.
- b 20-30mm.
- c None observed.
- d 8-12mm.
- e Accept.
- f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

- a 25mm in length.
- b Sharp but less than 1mm deep.
- c None observed.
- d Sharp but more than 1mm deep.
- e Accept.
- f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a 10-15mm^{2}.
b Greater than 100mm^{2}.
c None observed.
d 40-65mm^{2}.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 40-90mm.
b 30-60mm.
c None observed.
d 5-10mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3.
b 4.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp areas of mechanical damage: (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels?

a 4.
b 1.
c None observed.
d 3.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

a 1-2mm.
b 3-4mm.
c None observed.
d Greater than 5mm.
e Accept.
f Reject

11 Root penetration height: (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a 3-5mm.
b 1-2mm.
c None.
d Greater than 5mm.
e Accept.
f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 65-75mm.
b 45-60mm.
c None observed.
d 110-135mm.
e Accept.
f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 35-55mm.
b 10-30mm.
c None observed.
d 65-90mm.
e Accept.
f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels.

a 45-55mm.
b 73-90mm.
c None observed.
d 60-70mm.
e Accept.
f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 30-40mm.
b 5-8mm.
c None observed.
d 0-2mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 0-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp areas of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 2-3.
b 1.
c None observed.
d 4-5.
e Accept.
f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn through in the root area: Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 Porosity: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge)?

- a 35-45mm^2.
- b 60-80mm^2.
- c None observed.
- d 12-22mm^2.
- e Accept.
- f Reject.

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Visual Inspection Pipe Report

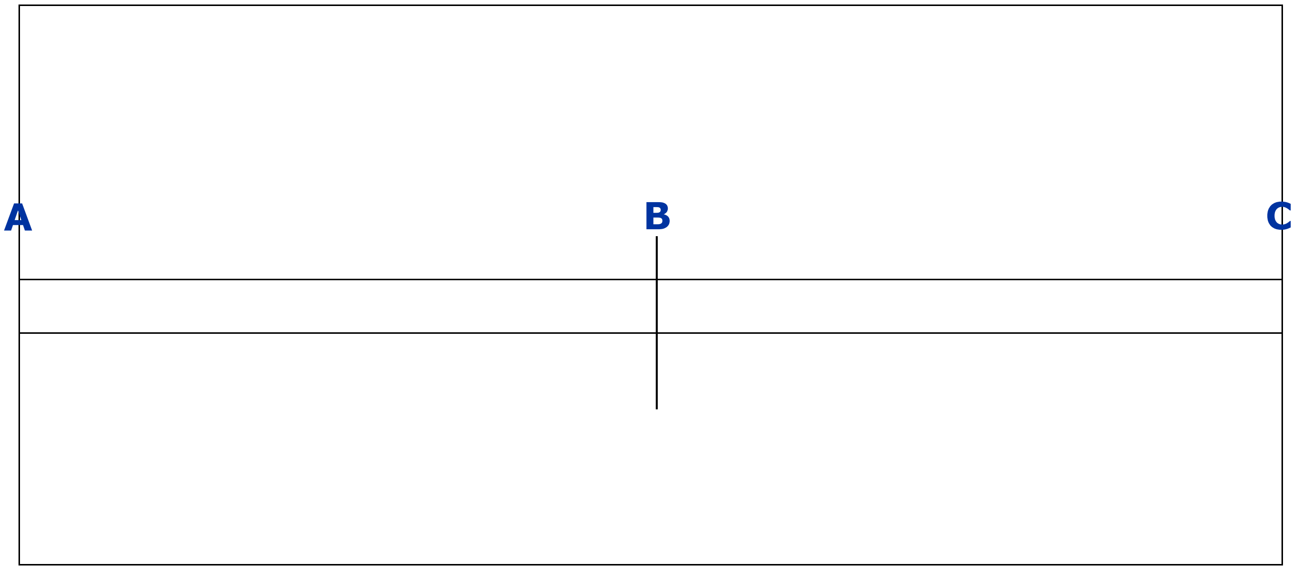
Name [Block capitals] ____

Signature ________________________________ Pipe Ident# __________

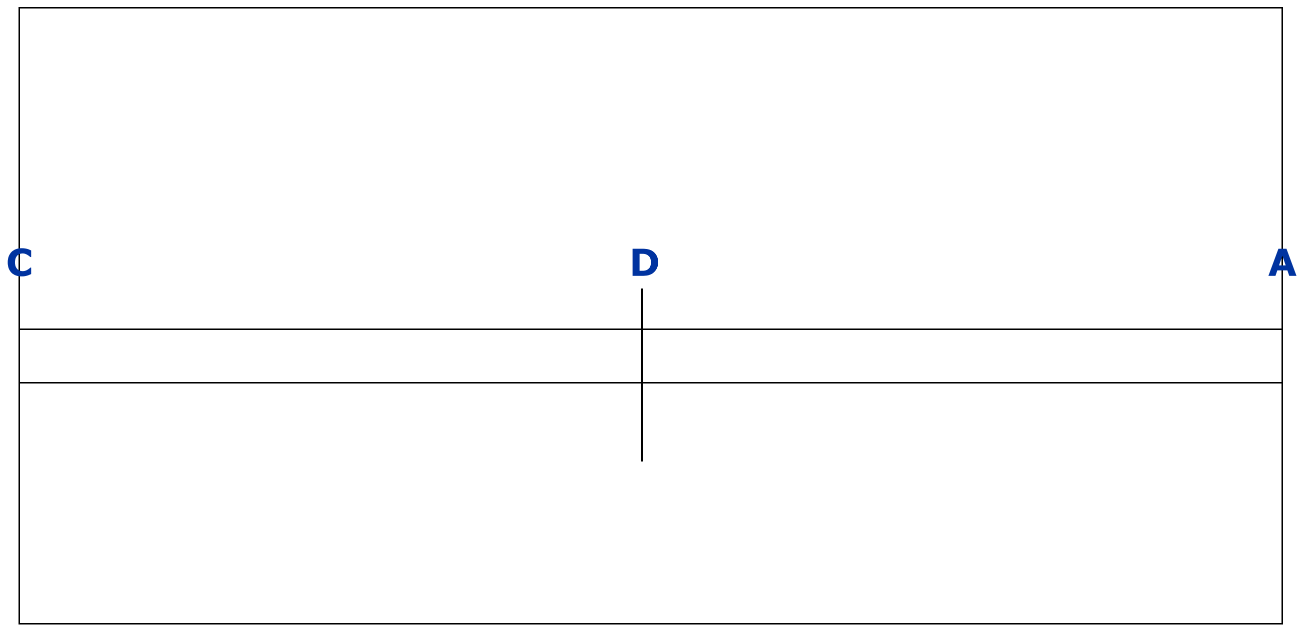
Code/Specification used _______ Welding Process __________ Joint type ______

Welding position ________ OutsideØ and Thickness ________ Date ________

Weld face



Notes:
Excess weld metal height = Misalignment = Weld width = Toe blend =



Notes:
Excess weld metal height = Misalignment = Toe blend = Weld width =

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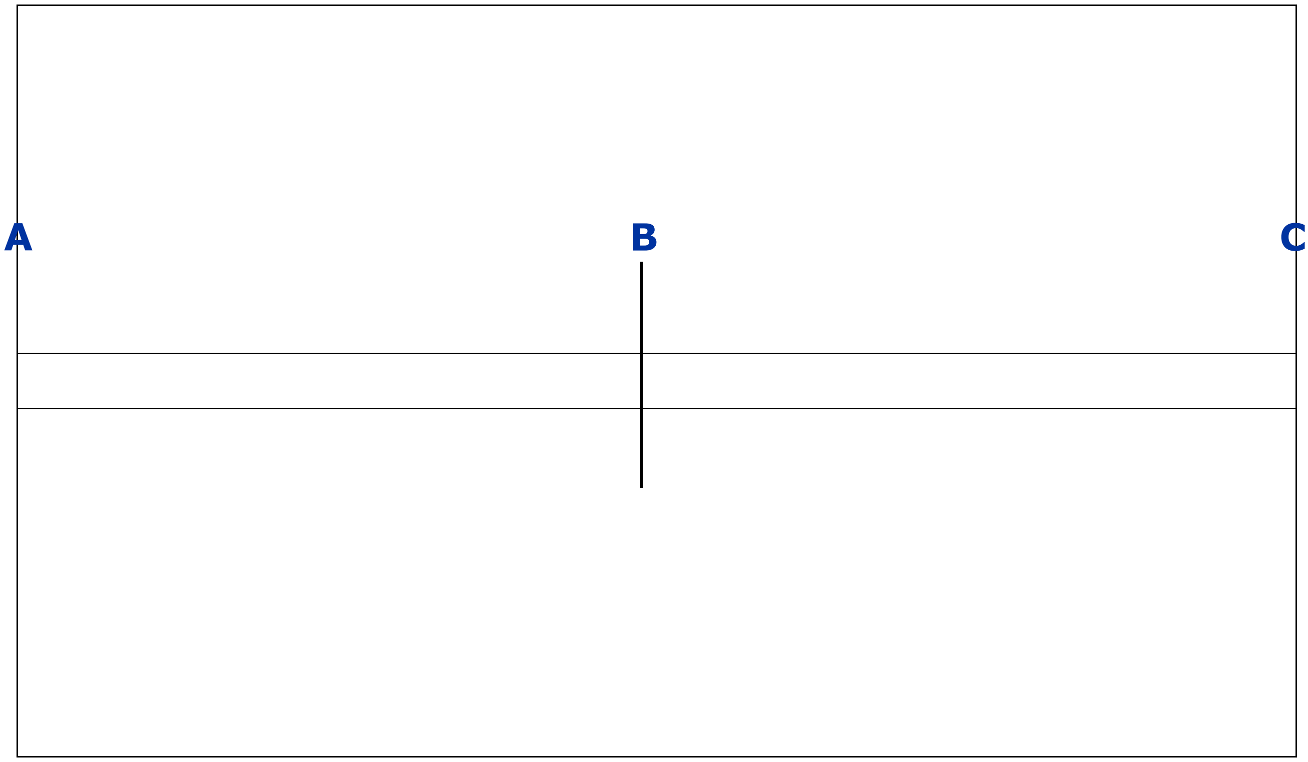
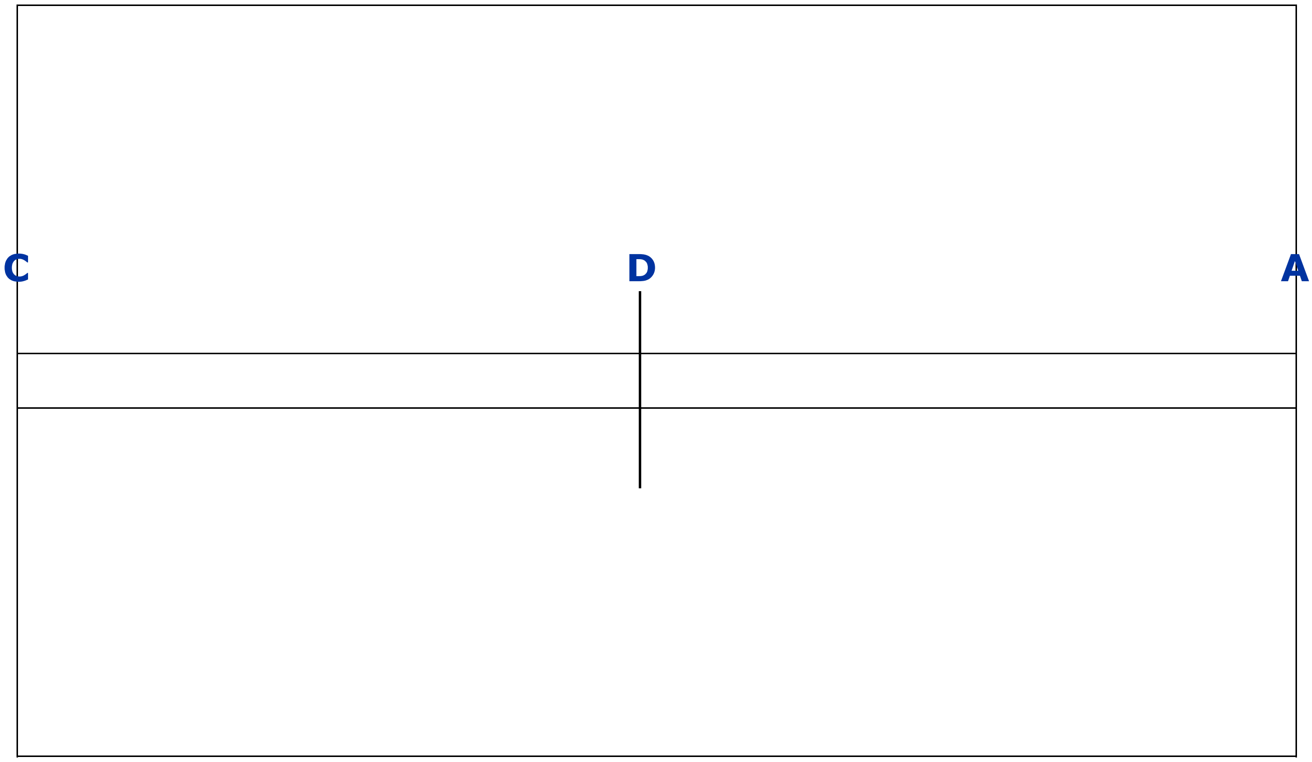
Pipe Root Face



Notes:
Excess penetration height = Toe blend =



Notes:
Excess penetration height = Toe blend =

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WI 3.1

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EXAM -	O	O	O	O	O	O	O
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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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TECHNOLOGY THEORY

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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
O	O	O	O	O

CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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CANDIDATE NUMBER FOR OFFICE USE ONLY

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TECHNOLOGY THEORY

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PIPE

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MACRO A

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MACRO B

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CSWIP 3.1 Training Questions for Pipe Butt Weld 3

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a Equal to or less than 0mm.
b 1-4mm.
c 4-5mm.
d 7-8mm.
e Accept.
f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a None observed.
b 65-80mm.
c 10-25mm.
d 100-120mm.
e Accept.
f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 60-70mm.
b 20-30mm.
c None observed.
d 5-12mm.
e Accept.
f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

a 50mm in length.
b Sharp but less than 1mm deep.
c None observed.
d Sharp but more than 1mm deep.
e Accept.
f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a 0-5mm^2.
b Greater than 100mm^2.
c None observed.
d 70-90mm^2.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 68-80mm.
b 45-60mm.
c None observed.
d 30-40mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 3.
b 4.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp indications of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels?

a More than 2.
b 1.
c None observed.
d 2.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

- a 1-2mm.
- b 3-4mm.
- c None observed.
- d Greater than 5mm.
- e Accept.
- f Reject.

11 Root penetration height (Highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a 3-5mm.
- b 1-2mm.
- c None.
- d Greater than 5mm.
- e Accept.
- f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 40-60mm.
- b 20-35mm.
- c None observed.
- d 0-10mm.
- e Accept.
- f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

- a 28-35mm.
- b 0-15mm.
- c None observed.
- d 15-23mm.
- e Accept.
- f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels.

- a 31-39mm.
- b 8-16mm.
- c None observed.
- d 40-60mm.
- e Accept.
- f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 15-30mm.
b 5-8mm.
c None observed.
d 0-2mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 0-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp areas of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

a 2-3 items observed.
b 1 item observed.
c None observed.
d 4-5 items observed.
e Accept.
f Reject.

18 Porosity in the weld root area: Which of the following answers best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn through in the root area: Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 Porosity: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge)?

a $30\text{-}50mm^2$.
b $60\text{-}80mm^2$.
c None observed.
d $10\text{-}20mm^2$.
e Accept.
f Reject.

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Visual Inspection Pipe Report

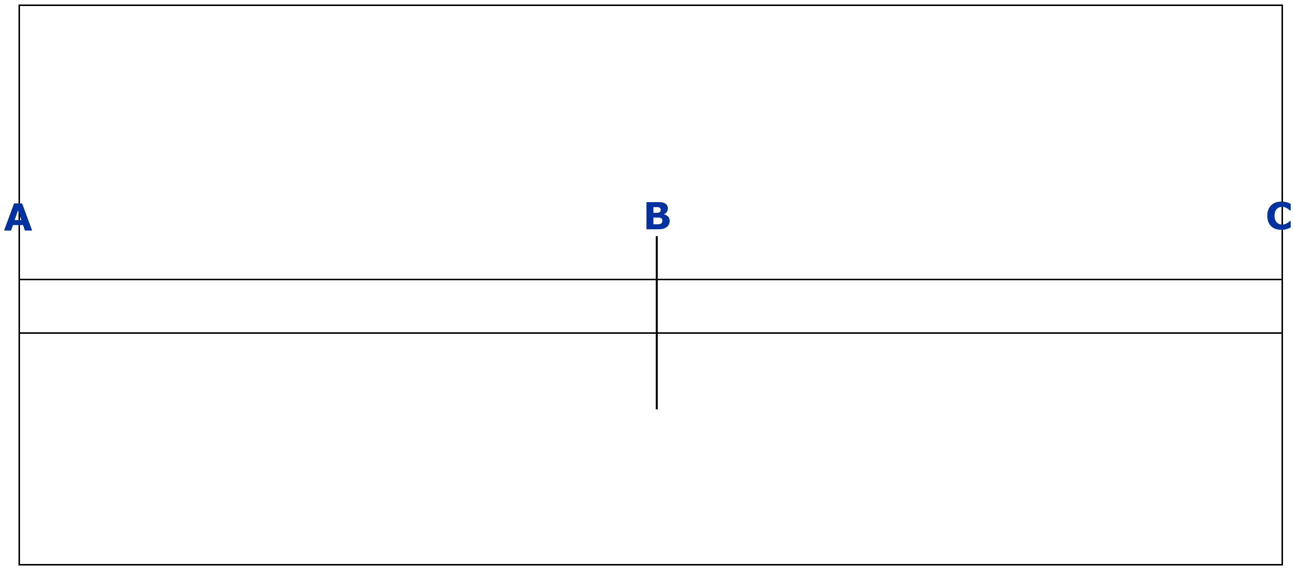
Name [Block capitals] ____

Signature ____ Pipe Ident# ______________

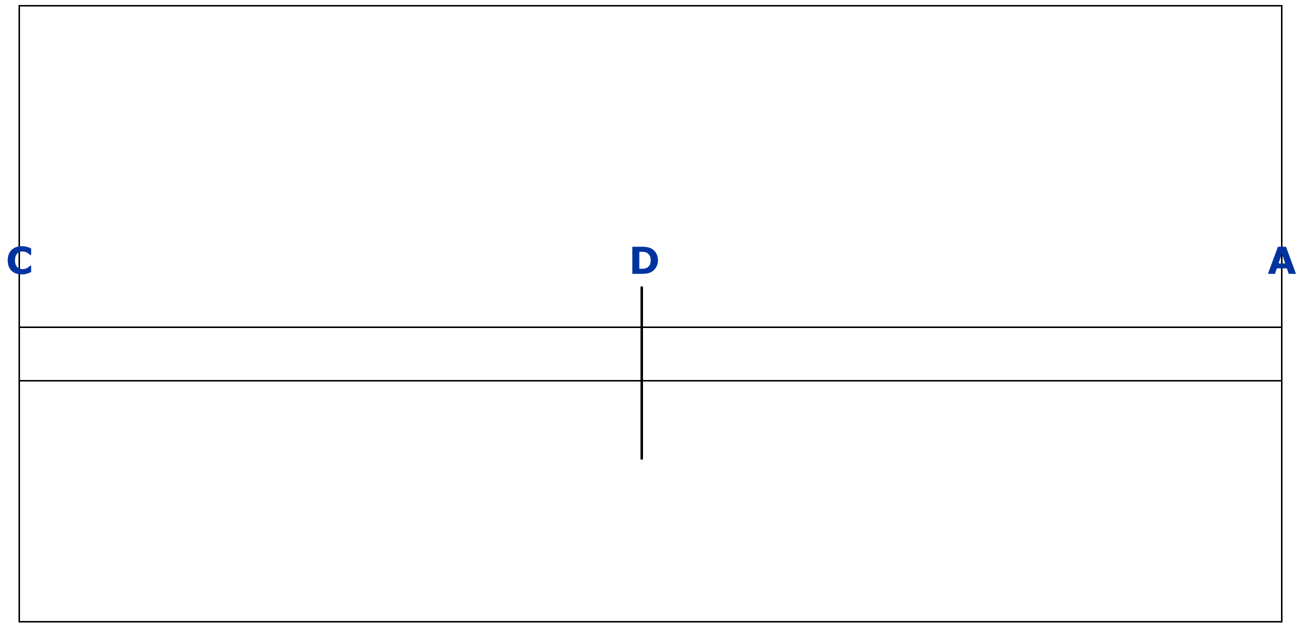
Code/Specification used __________ Welding Process ______________ Joint type ________

Welding position ____________ OutsideØ and Thickness ___________ Date ____________

Weld face



Notes:
Excess weld metal height = Misalignment = Weld width = Toe blend =



Notes:
Excess weld metal height = Misalignment = Toe blend = Weld width =

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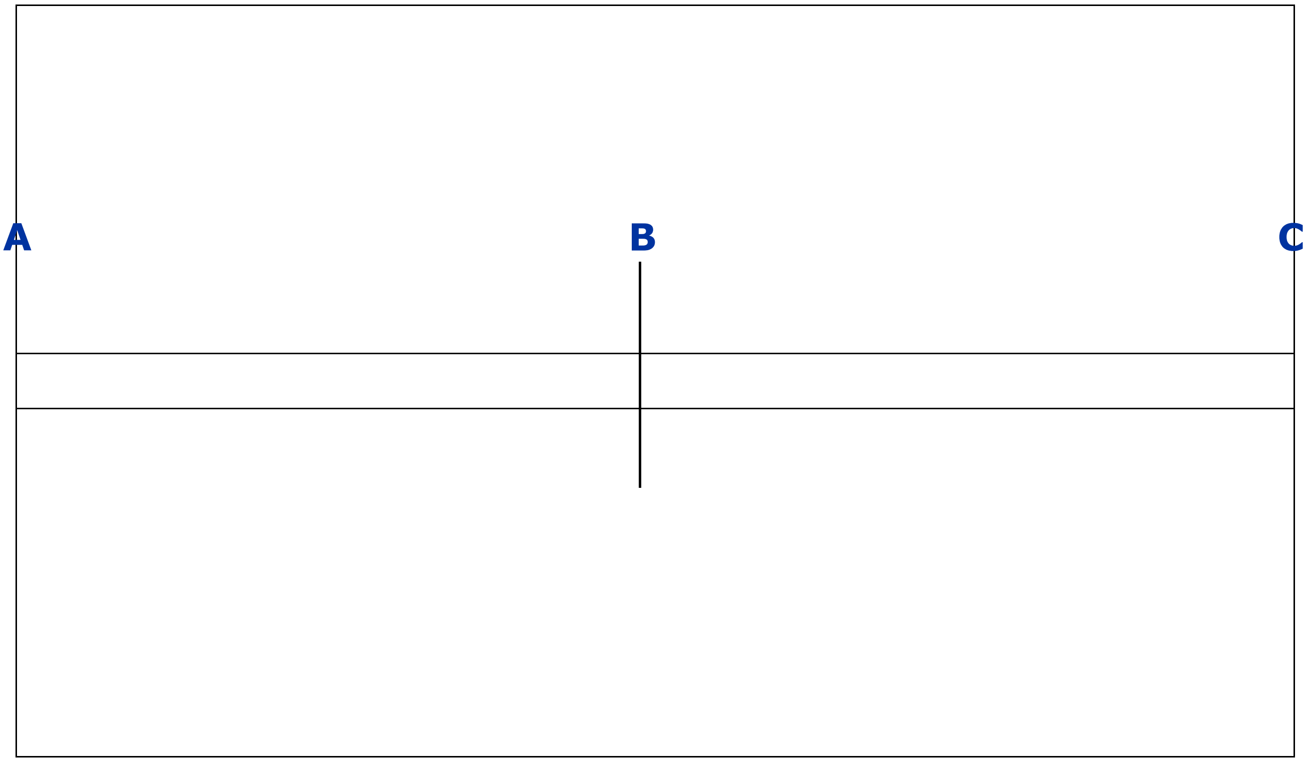
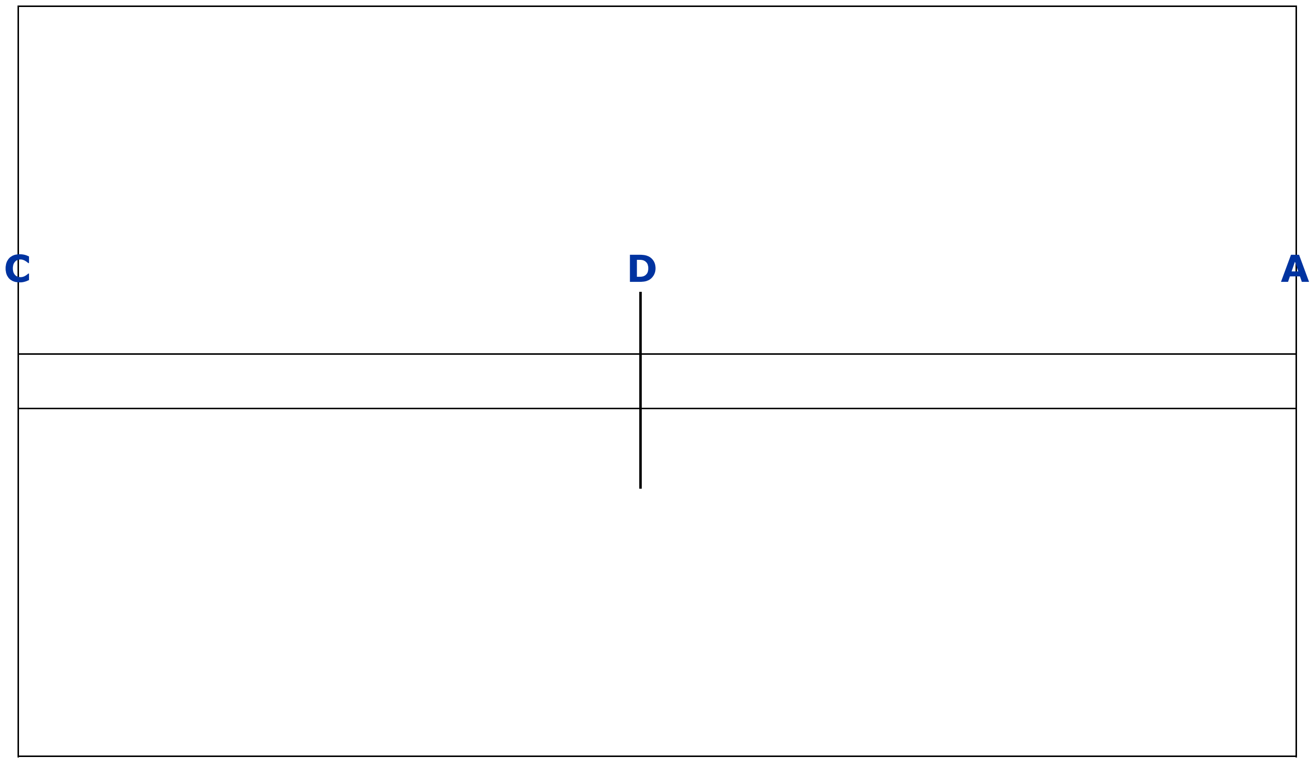
Pipe Root Face



Notes:
Excess penetration height = Toe blend =



Notes:
Excess penetration height = Toe blend =

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EXAM	O	O	O	O	O	O	O
VERSION	O	O	O	O	O	O	O

INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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CANDIDATE NUMBER FOR OFFICE USE ONLY

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TECHNOLOGY THEORY

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VERSION	O	O	O	O	O	O	O

INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

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Date of Birth

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GENERAL THEORY / TECHNOLOGY THEORY

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PLATE / PIPE

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MACRO A

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CSWIP 3.1 Training Questions for Pipe Butt Weld 4

Answers to be indicated on the Candidate Answer Template.

Weld Face

1 Maximum excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a Equal to or less than 0mm.
- b 3-4mm.
- c 5-6mm.
- d 7-8mm.
- e Accept.
- f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a None observed.
- b 80-100mm.
- c 135-150mm.
- d 110-130mm.
- e Accept.
- f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a 60-70mm.
- b 20-50mm.
- c None observed.
- d 2-6mm.
- e Accept.
- f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

- a 20-30mm in length.
- b Sharp but less than 1mm deep.
- c None observed.
- d Sharp but more than 1mm deep.
- e Accept.
- f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a 35-45mm^2.
b Greater than 55-80mm^2.
c None observed.
d 20-30mm^2.
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 110-130mm.
b 95-105mm.
c None observed.
d 65-85mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 2.
b 3.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp areas of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels.

a 4.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

a 1-2mm.
b 3-4mm.
c None observed.
d Greater than 5mm.
e Accept.
f Reject

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a 3-5mm.
b 1-2mm.
c None.
d Greater than 5mm.
e Accept.
f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 35-40mm.
b 20-25mm.
c None observed.
d 0-10mm.
e Accept.
f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 28-35mm.
b 0-10mm.
c None observed.
d 15-23mm.
e Accept.
f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

a 8-12mm.
b 18-22mm.
c None observed.
d 20-40mm.
e Accept.
f Reject.

15 Root undercut: Which answer best matches your assessment of the accumulative total l and would you accept or reject your findings to the given acceptance levels?

a 15-25mm.
b 35-45mm.
c None observed.
d 50-60mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 0-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp areas of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total number of items and would you accept or reject your findings to the given acceptance levels?

a 2-3.
b 1 item.
c None observed.
d More than 4 items.
e Accept.
f Reject.

18 Porosity in the weld root area: Which answer best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn through in the root area: Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 Cluster porosity: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels. (measure from the weld centreline to the plate edge)?

a 3-5mm^2.
b 6-8mm^2.
c None observed.
d 1-2mm^2.
e Accept.
f Reject.

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Visual Inspection Pipe Report

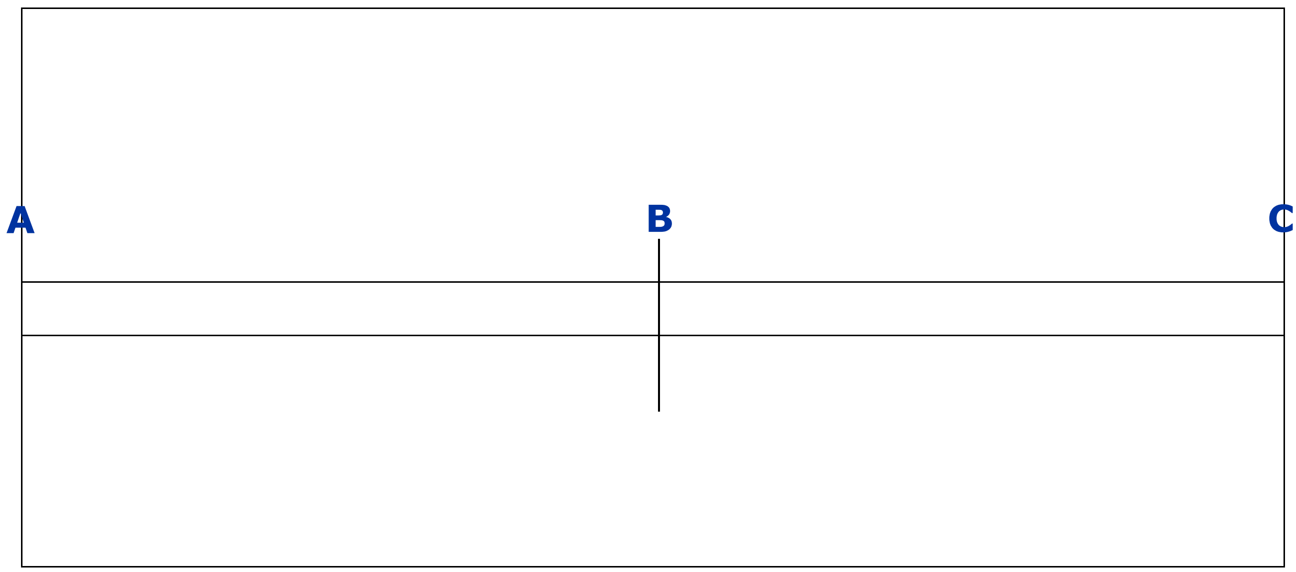
Name [Block capitals] ____

Signature _______________________________________ Pipe Ident# ____________

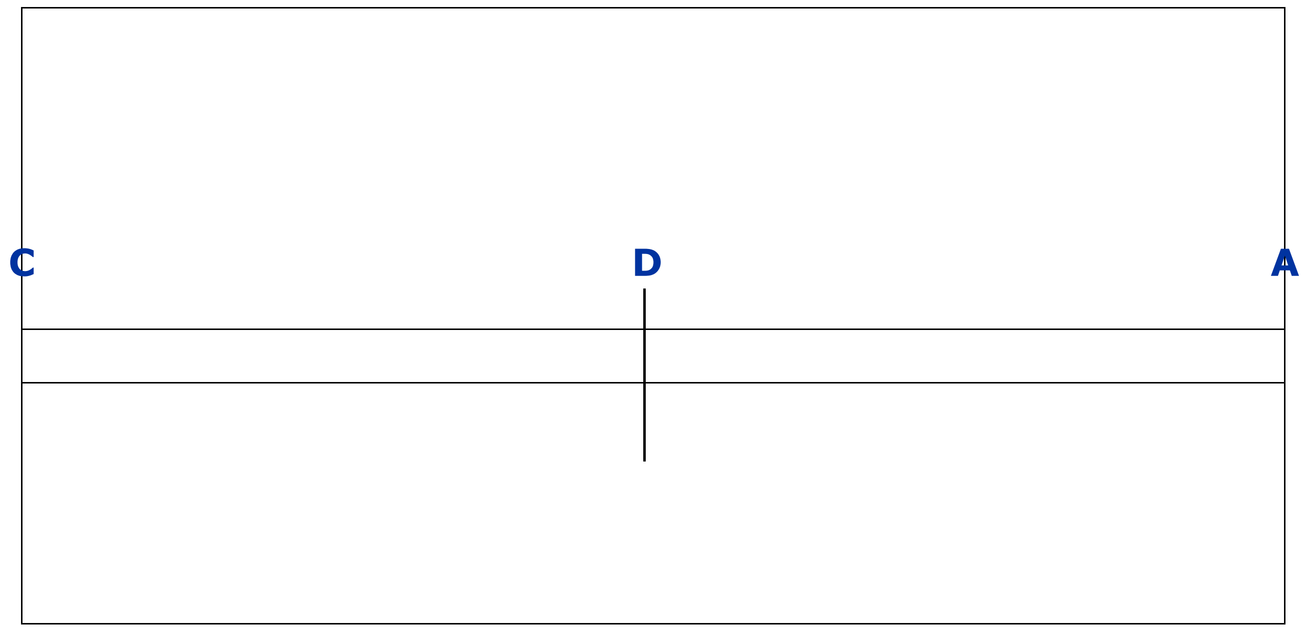
Code/Specification used ________ Welding Process ____________ Joint type ______

Welding position __________ OutsideØ and Thickness __________ Date __________

Weld face



Notes:
Excess weld metal height = Misalignment = Weld width = Toe blend =



Notes:
Excess weld metal height = Misalignment = Toe blend = Weld width =

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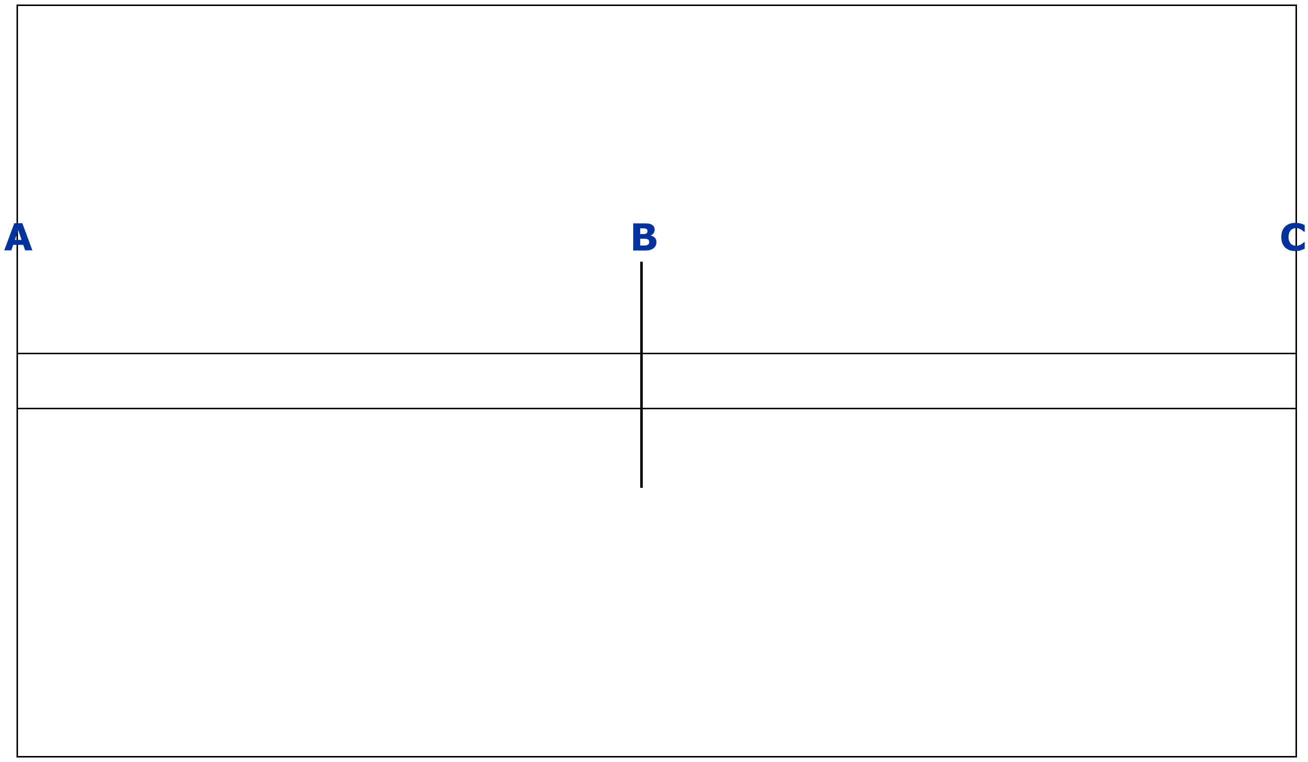
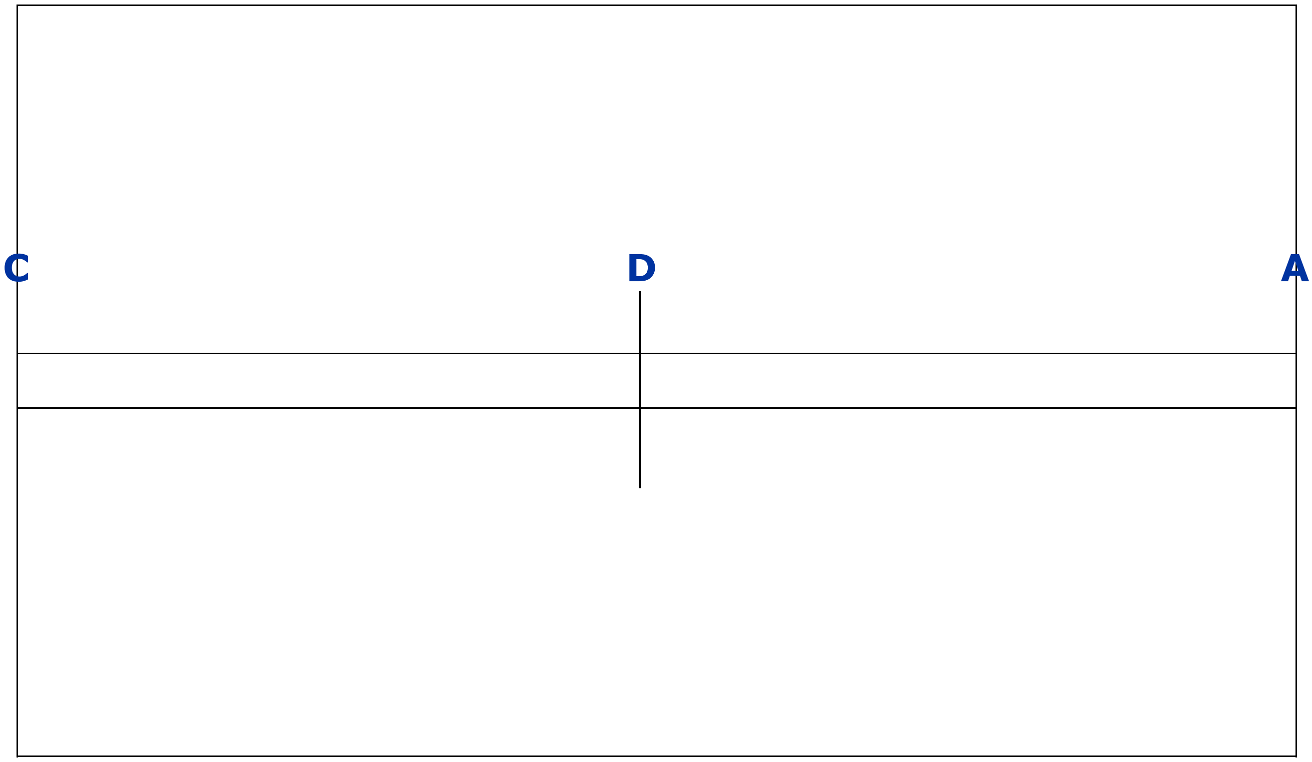
Pipe Root Face



Notes:
Excess penetration height = Toe blend =



Notes:
Excess penetration height = Toe blend =

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EXAM VERSION	1	2	3	4	5	6	7
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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	**INVIGILATOR SIGNATURE:**
EXAM DATE:	**EVENT CODE**
CANDIDATE NAME:	**CANDIDATE SIGNATURE:**

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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EXAM DATE:	EVENT CODE
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MACRO A

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CSWIP 3.1 Training Questions for Pipe Butt Weld 5

Answers to be indicated on the Candidate Answer Template

Weld Face

1 Excess weld metal height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

- a Equal to or less than 0mm.
- b 3-4mm.
- c 5-6mm.
- d 7-8mm.
- e Accept.
- f Reject.

2 Incomplete fill: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a None observed.
- b 40-55mm.
- c 30-40mm.
- d 60-70mm.
- e Accept.
- f Reject.

3 Slag inclusions: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

- a 60-70mm.
- b 20-50mm.
- c None observed.
- d 5-12mm.
- e Accept.
- f Reject.

4 Undercut: Which answer best matches your assessment of the imperfection and would you accept or reject your findings to the given acceptance levels?

- a Smooth intermittent.
- b Sharp but less than 1mm deep.
- c None observed.
- d Sharp but more than 1mm deep.
- e Accept.
- f Reject.

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5 Porosity in the weld: Which answer best matches your assessment of the total accumulative area and would you accept or reject your findings to the given acceptance levels?

a 0-20mm^2.
b Greater than 30-50mm^2.
c None observed.
d 60-70mm$^{2.}$
e Accept.
f Reject.

6 Cracks: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 2-3mm transverse crack.
b 15mm longitudinal crack.
c None observed.
d 9-14mm longitudinal crack.
e Accept.
f Reject.

7 Lack of fusion: Which answer best matches your assessment of the total accumulative length and would you accept or reject your findings to the given acceptance levels?

a 30-40mm.
b 45-55mm.
c None observed.
d 60-70mm.
e Accept.
f Reject.

8 Arc strikes: Which answer best matches your assessment of the total number and would you accept or reject your findings to the given acceptance levels?

a 2.
b 4.
c None observed.
d 1.
e Accept.
f Reject.

9 Sharp indications of mechanical damage (excluding hard stamping and pop marks): Which answer best matches your assessment of the total number of areas and would you accept or reject your findings to the given acceptance levels?

a 4.
b 1-2.
c None observed.
d 3.
e Accept.
f Reject.

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Weld Root

10 Misalignment: Which answer best matches your assessment of the maximum value and would you accept or reject your findings to the given acceptance levels?

a 1-2mm.
b 3-4mm.
c None observed.
d Greater than 5mm.
e Accept.
f Reject.

11 Root penetration height (highest individual point measured): Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels?

a 3-5mm.
b 1-2mm.
c None .
d Greater than 5mm.
e Accept.
f Reject.

12 Lack of root penetration: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 30-40mm.
b 21-29mm.
c None observed.
d 41-50mm.
e Accept.
f Reject.

13 Lack of root fusion: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 28-35mm.
b 0-10mm.
c None observed.
d 15-26mm.
e Accept.
f Reject.

14 Root concavity or root shrinkage: Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

a 31-39mm.
b 18-22mm.
c None observed.
d 40-60mm.
e Accept.
f Reject.

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15 Root undercut: Which answer best matches your assessment of the accumulative total and would you accept or reject your findings to the given acceptance levels?

a 35-45mm.
b 20-30mm.
c None observed.
d 50-60mm.
e Accept.
f Reject.

16 Cracks in the root: Which answer best matches your assessment of the accumulative total length and would you accept or reject your findings to the given acceptance levels?

a 10-17mm.
b 0-4mm.
c None observed.
d 5-8mm.
e Accept.
f Reject.

17 Sharp indications of mechanical damage in the root area weld and parent material (excluding hard stamping): Which answer best matches your assessment of the accumulative total number of items and would you accept or reject your findings to the given acceptance levels?

a 2-3.
b 1.
c None observed.
d 4-5.
e Accept.
f Reject.

18 Porosity in the weld root area: Which of the following answers best matches your assessment of the accumulative total area and would you accept or reject your findings to the given acceptance levels?

a Individual pore diameter between 1-2mm.
b Individual pore diameter between 2-3mm.
c None observed.
d Individual pore diameter greater than 3mm.
e Accept.
f Reject.

19 Burn through in the root area: Which answer best matches your assessment of the accumulative total number of areas and would you accept or reject your findings to the given acceptance levels?

a 1.
b 2.
c None observed.
d 3.
e Accept.
f Reject.

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20 Cluster porosity: Which answer best matches your assessment and would you accept or reject your findings to the given acceptance levels (measure from the weld centreline to the plate edge)?

a 30-50mm^2.
b 60-80mm^2.
c None observed.
d 12-22mm^2.
e Accept.
f Reject.

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Visual Inspection Pipe Report

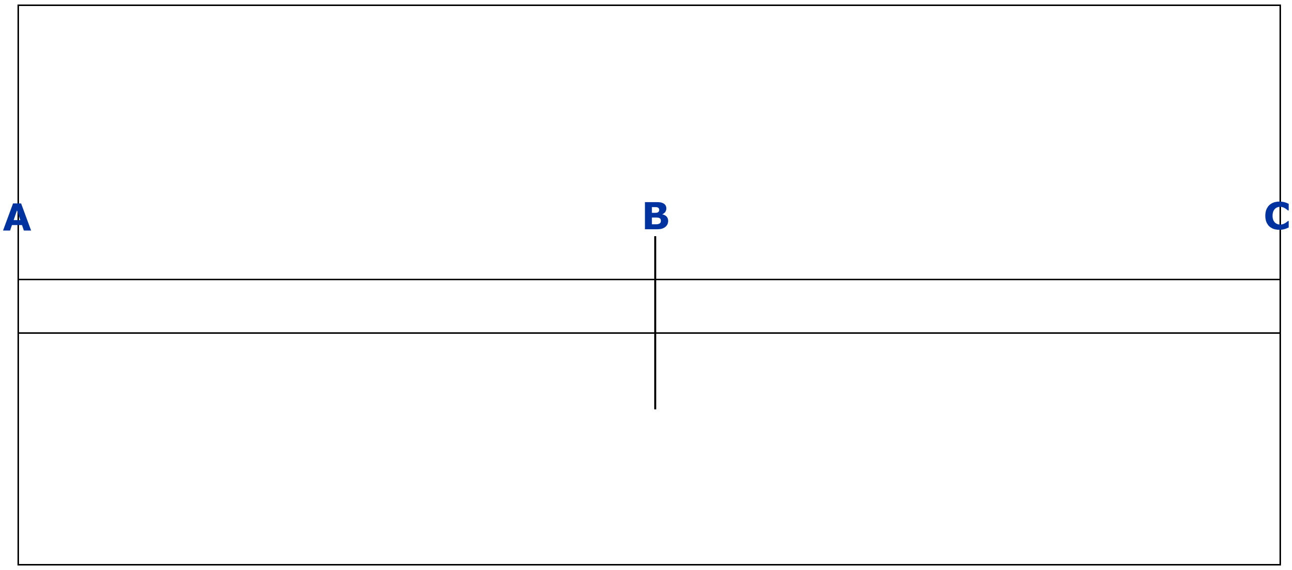
Name [Block capitals] ____

Signature ____________________________________ Pipe Ident# ___________

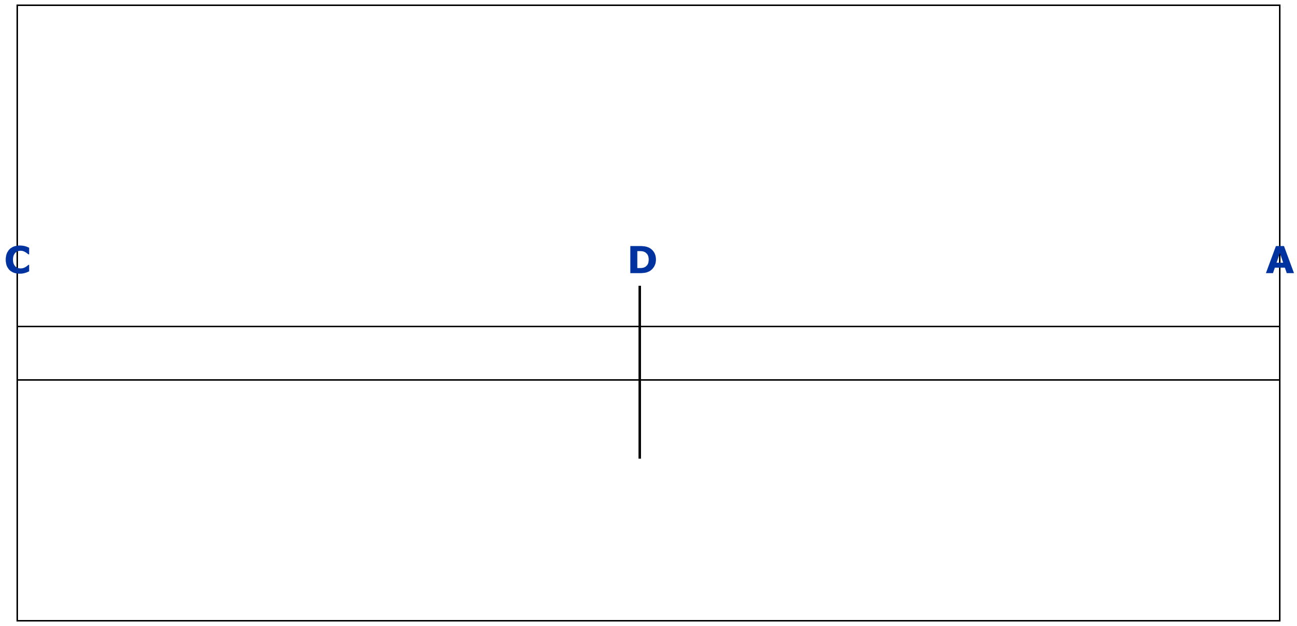
Code/Specification used ________ Welding Process ___________ Joint type ______

Welding position __________ OutsideØ and Thickness _________ Date __________

Weld face



Notes:
Excess weld metal height = Misalignment = Weld width = Toe blend =



Notes:
Excess weld metal height = Misalignment = Toe blend = Weld width =

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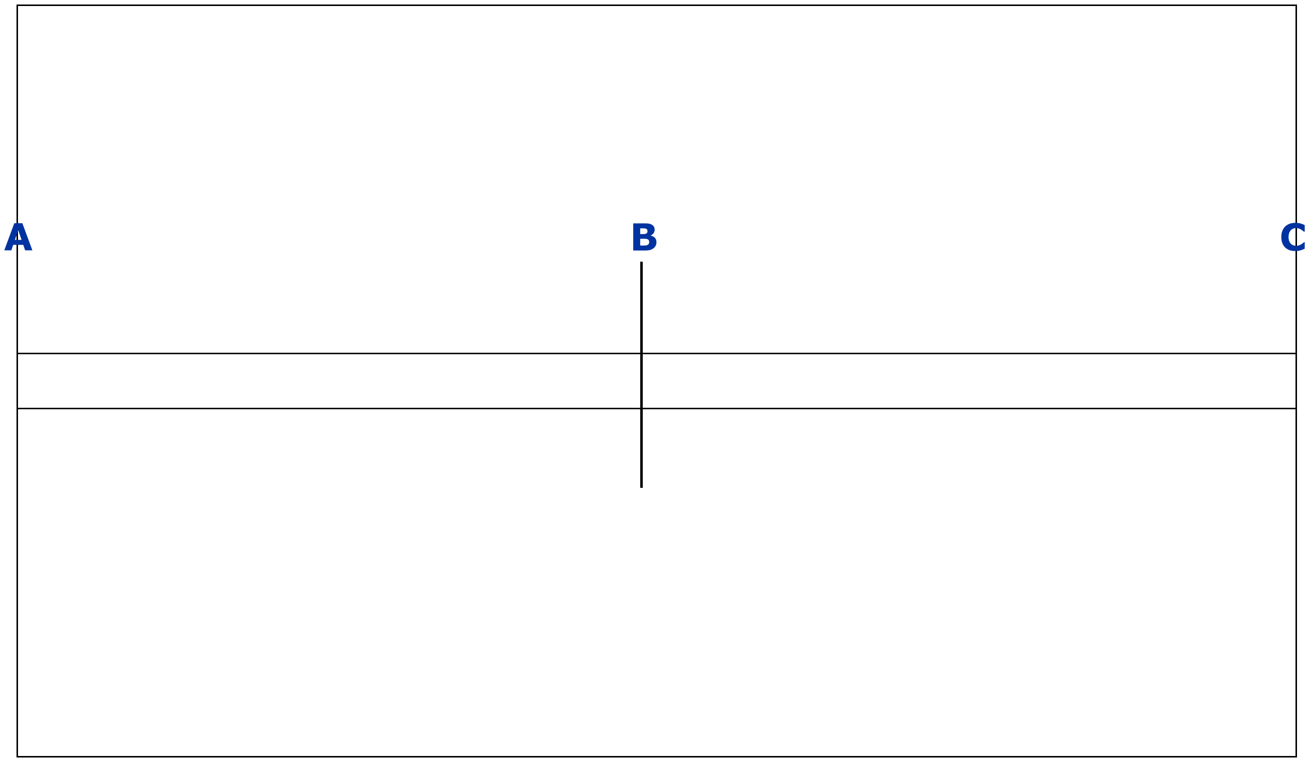
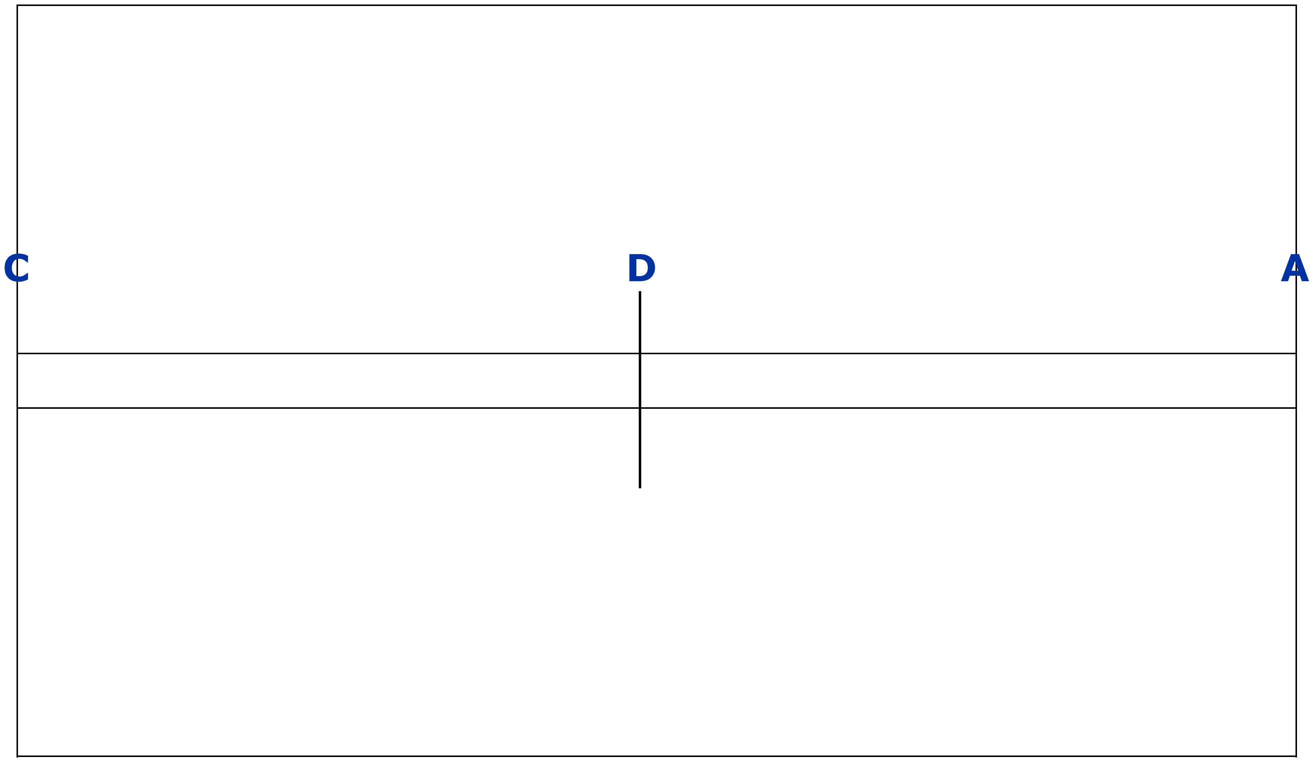
Pipe Root Face



Notes:
Excess penetration height = Toe blend =



Notes:
Excess penetration height = Toe blend =

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WI 3.1

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INITIAL	RETEST 1	RETEST 2	10 YR INITIAL	10 YR RETEST
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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

Date of Birth

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CANDIDATE TO FILL ALL BOXES INDICATED IN BLUE

INVIGILATOR NAME:	INVIGILATOR SIGNATURE:
EXAM DATE:	EVENT CODE
CANDIDATE NAME:	CANDIDATE SIGNATURE:

I agree with the terms and conditions of this examination	Tick Box

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Table numbers	Defect type	Acceptance levels plate and pipe		Acceptance levels macro only
		Remarks	**Maximum allowance**	**Remarks**
1	**Excess weld metal**	At no point shall the excess weld metal fall below the outside surface of the parent material. All weld runs shall blend smoothly.	Excess weld metal will not exceed H = 2mm in any area on the parent material, showing smooth transition at weld toes.	As for plate and pipe
2	**Slag/silica inclusions**	Slag inclusions are defined as non-metallic inclusions trapped in the weld metal or between the weld metal and the parent material.	The length of the slag inclusion shall not exceed 50mm continuous or intermittent. Accumulative totals shall not exceed 50mm	Slag and silica not permitted
3	**Undercut**	Undercut is defined as a grove melted into the parent metal, at the toes of the weld excess metal, root or adjacent weld metal.	No sharp indications Smooth blend required. The length of any undercut shall not exceed 50mm continuous or intermittent. Accumulative totals shall not exceed 50mm. Max D = 1mm for the cap weld metal. Root undercut not permitted.	No sharp indications Smooth blend required
4	**Porosity or Gas Cavities**	Trapped gas, in weld metal, elongated, individual pores, cluster porosity, piping or wormhole porosity.	Individual pores ≤ 1.5 max. Cluster porosity maximum 50^2mm total area. Elongated, piping or wormholes 15mm max. L continuous or intermittent.	Cluster porosity not permitted. Individual pores acceptable.
5	**Cracks or Laminations**	Transverse, longitudinal, star or crater cracks.	Not permitted	Not permitted
6	**Lack of fusion Laps Cold lap**	Incomplete fusion between the weld metal and base material, incomplete fusion between weld metal. (lack of inter-run fusion)	Surface breaking lack of side wall fusion, lack of inter-run fusion continuous or intermittent not to exceed 15mm. Accumulative totals not to exceed 15mm over a 300mm length of weld.	Not permitted
7	**Arc strikes**	Damage to the parent material or weld metal, from an unintentional touchdown of the electrode or arcing from poor connections in the welding circuit.	Not permitted	Not permitted
8	**Mechanical damage**	Damage to the parent material or weld metal, internal or external resulting from any activities.	No stray tack welds permitted Parent material must be smoothly blended General corrosion permitted. Max. D = 1.5mm. Only 1 location allowed	Not permitted
9	**Misalignment**	Mismatch between the welded or unwelded joint.	Max H = 1.5mm	As for plate and pipe
10	**Penetration**	Excess weld metal, above the base material in the root of the joint.	Max H ≤ 3mm	As for plate and pipe
11	**Lack of root penetration**	The absence of weld metal in the root area, two root faces showing.	Not permitted	Not permitted
12	**Lack of root fusion**	Inadequate cross penetration of (one) root face.	Lack of root fusion, not to exceed 50mm total continuous or accumulative.	Not permitted
13	**Burn through**	Excessive penetration, collapse of the weld root	Not permitted	Not permitted
14	**Angular distortion**	Distortion due to weld contraction	5mm max. Plate only	Accept
15	**Root concavity**	Weld metal below the surface of both parent metals	50mm maximum length 3mm maximum depth	Accept

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Practical Pipe Inspection

Materials Joining and Engineering Technologies
Training and Examination Services

Practical Sessions Objective

When these presentation have been completed you will have a greater understanding of the examination requirement and how to identify and plot weld defects around real life welds and the classroom specimens on which you will be examined.

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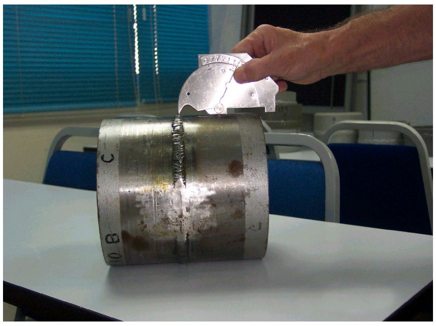
Pipe Inspection



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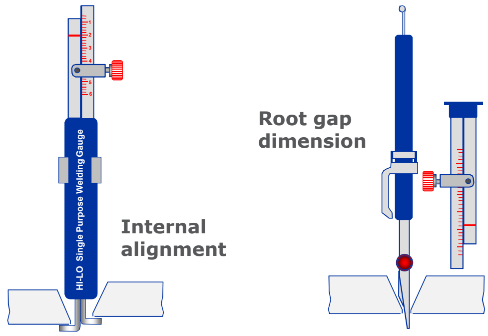
Hi-Low and Root Gap Measurements



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Pipe Inspection Examination

- After you have observed an imperfection and determined its type, you must be able to take measurements and complete the thumb print report sketch.
- The first thumb print report sketch should be in the form of a repair map of the weld. (ie all observations are Identified sized and located).
- The thumb print report sketch used in CSWIP exam will look like the following example.
- The thumb print is to used in conjunction with the multiple choice questions during the examination .

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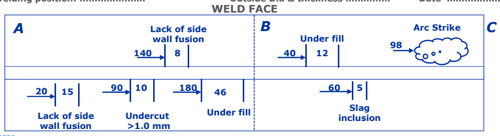
Pipe Inspection Examination

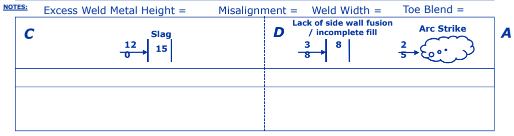
EXAMPLE PIPE REPORT

Name: [Block capitals] .... Signature: ....
Date........................
Code/Specification used: .... Welding process: .... Joint type: ....
Welding position: .... Outside Dia & thickness .... Date ....

WELD FACE



NOTES: Excess Weld Metal Height = Misalignment = Weld Width = Toe Blend =



NOTES: Excess Weld Metal Height = Misalignment = Weld Width = Toe Blend =

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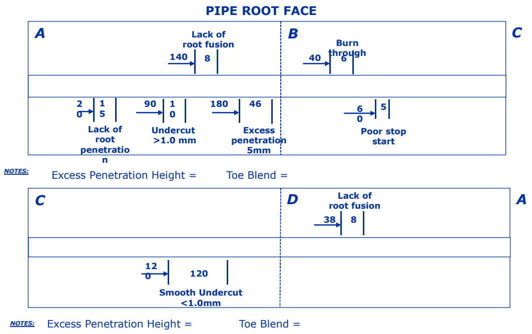
Pipe Inspection Examination



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Pipe Inspection Examination

1. Read the Questions and compare with your thumb print.

With reference to penetration height, which of the below best reflects your assessment and would you accept or reject your findings to the given acceptance levels?

a. 4-6mm
b. 2-4mm
c. 0-1mm
d. 5mm
e. Accept
f. Reject

2. Compare to acceptance standard.

3. Mark the answer in the OMR grid in pencil and accept or reject accordingly. When you are sure about your answer mark the OMR grid in BLACK PEN.

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Any Questions

?

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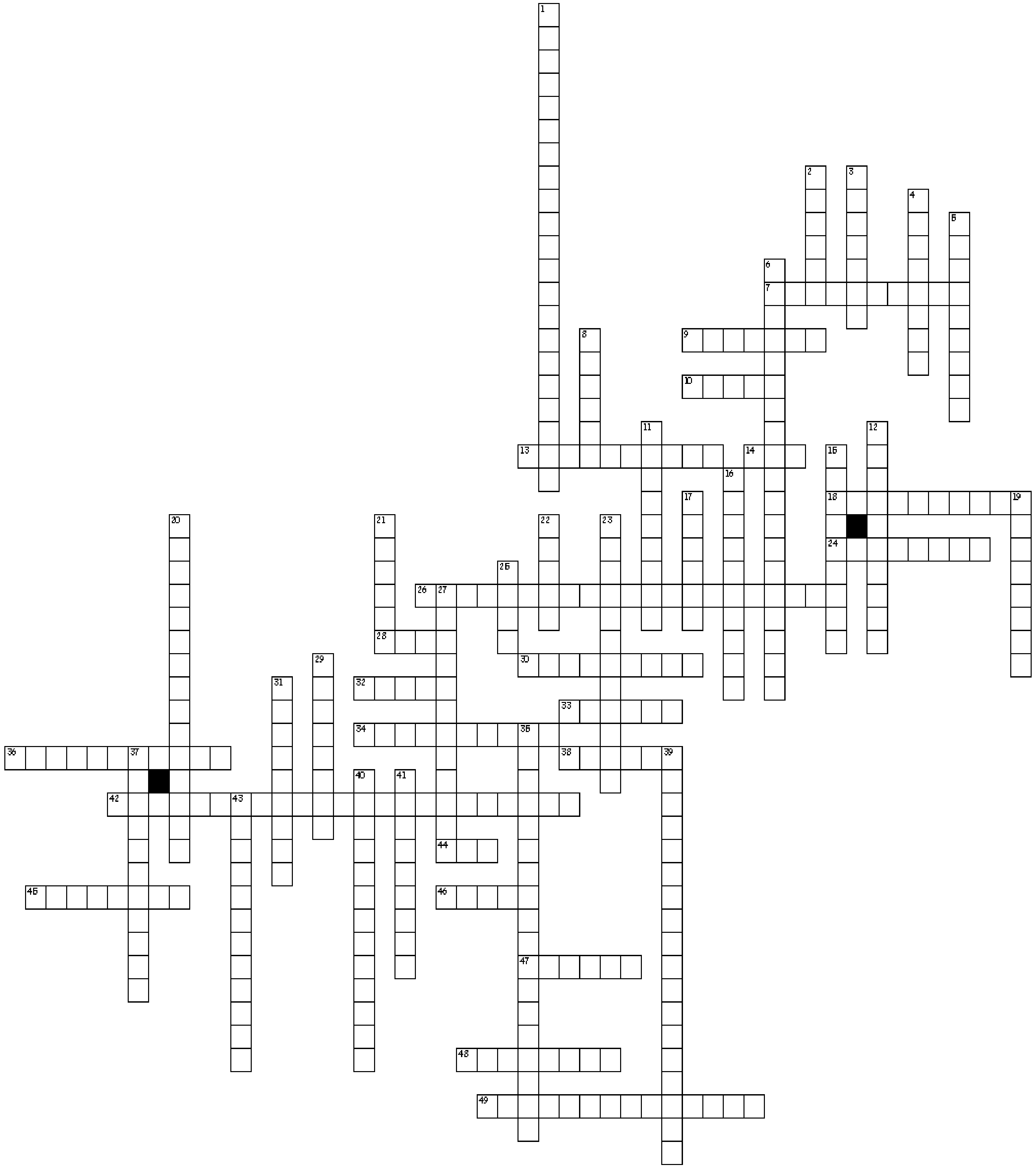
Appendix 4

Crossword



Across

7 For stovers (10)
9 The forces of magnetism on the weld pool (3,4)
10 An electrode with good toughness (5)
13 For creep resistance (10)
14 L in 316L (3)
18 Without filler wire (10)
24 I am often clustered (8)
26 CEV (6,10,5)
28 A solid inclusion (4)
30 Carelessness in welding causes me (3,6)
32 Used to examine grain structure (5)
33 I add strength and hardness (6)
34 A very hard and brittle microstructure (10)
36 Slope out to prevent me (6,5)
38 I can cut anything (6)
42 UTS (8,7,8)
44 A mode of transfer used in all positions (3)
45 Constant in GTAW (8)
46 Common gas used for GTAW (5)
47 Used for radiography over 50mm (6)
48 I may be essential or not (8)
49 When welding I must never go below this (7,7)

Down

1 IQI (5,7,9)
2 Used for weld detail (6)
3 I have a half life of 74.4.days (7)
4 Technique used to minimise distortion (4,4)
5 Can be caused by excess purge pressure (9)
6 Polarity for carbon GTAW (1,1,9,8)
8 10 x 10 x 55 long (6)
11 I suffer from this when depleted of chromium (4,5)
12 I am caused by unbalanced expansion and contraction (10)
15 This word is generally associated with rejection by most codes (9)
16 Only applicable in dip transfer (10)
17 Keeps rods at 70 degrees on site (6)
19 Used in mechanical testing over 12mm (4,4)
20 A step-like crack (8,7)
21 Preheating can minimise my chances (6)
22 SAW flux (5)
23 You can get me by 0.7 of your leg (6,6)
25 Used to apply a magnetic field (4)
27 A SAW flux easily crushed (12)
29 If my root is in compression this is me (4,4)
31 My purging powers prevent this (9)
35 Can be caused by an increased vertex angle (8,10)
37 All equipment should have this (11)
39 Polarity for welding aluminium with GTAW (11,7)
40 An electronic hazard (4,9)
41 If you slow down I go up (4,5)
43 Below this I turn molecular (5,7)

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Appendix 5

Macro and Micro Vidual Inspection

Macro and Micro Visual Inspection

Macro-examination

Macro-etching a specimen is etched and evaluated macrostructurally at low magnifications, is frequently used for evaluating carbon and low alloy steel products such as billets, bars, blooms and forgings as well as welds. There are several procedures for rating a steel specimen by a graded series of photographs showing the incidence of certain conditions and is applicable to carbon and low alloy steels. A number of different etching reagents may be used depending upon the type of examination. Steels react differently to etching reagents because of variations in chemical composition, method of manufacture, heat treatment and many other variables.

Macro-examinations are also performed on a polished and etched cross-section of a welded material. During the examination a number of features can be determined including weld run sequence, important for weld procedure qualifications tests. Any defects on the sample will be assessed for compliance with relevant specifications: Slag, porosity, lack of weld penetration, lack of sidewall fusion and poor weld profile are among the features observed. Such defects are looked for either by standard visual examination or at magnifications up to 5X. It is routine to photograph the section to provide a permanent record, a photomacrograph.

Micro-examination

Performed on samples either cut to size or mounted in a resin mould. The samples are polished to a fine finish, normally one micron diamond paste and usually etched in an appropriate chemical solution prior to examination on a metallurgical microscope. Micro-examination is performed for a number of purposes, assess the structure of the material and examine for metallurgical and anomalies such as third phase precipitates, excessive grain growth, etc. Many routine tests such as phase counting or grain size determinations are performed in conjunction with micro-examinations.

Metallographic weld evaluations can take many forms. In its most simplest, a weld deposit can be visually examined for large scale defects such as porosity or lack of fusion defects. On a microscale, it can be phase balance assessments from weld cap to weld root or a check for non-metallic or third phase precipitates. Examination of weld growth patterns is also used to determine reasons for poor mechanical test results. For example, an extensive central columnar grain pattern can cause a plane of weakness giving poor Charpy results.

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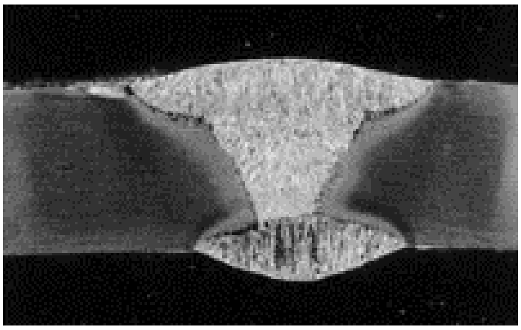

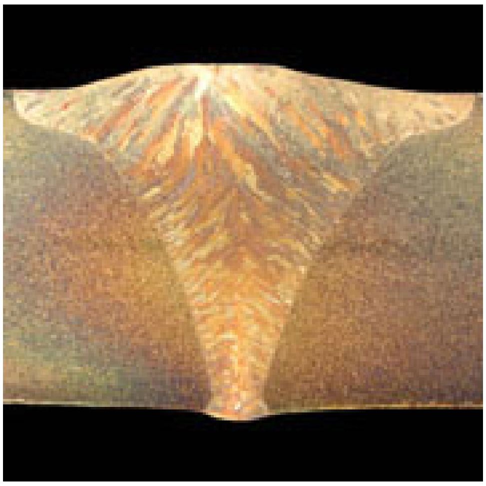

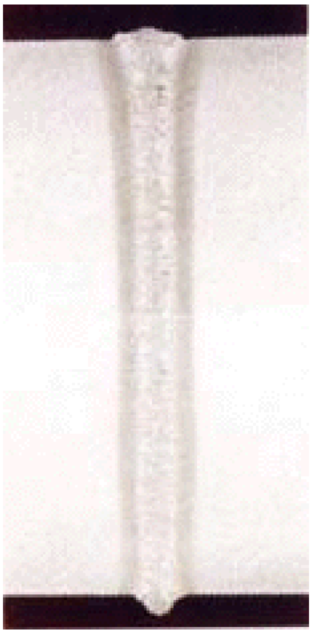

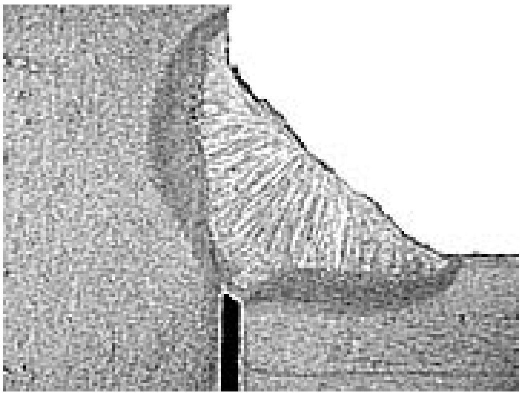

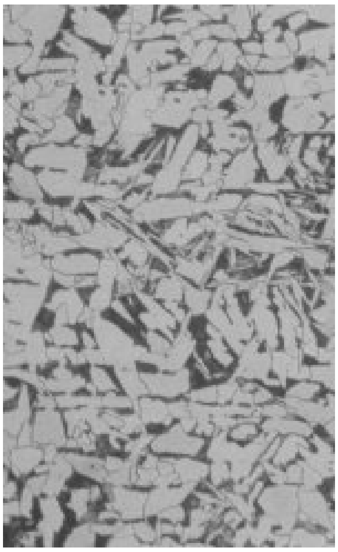

Photomacrographs

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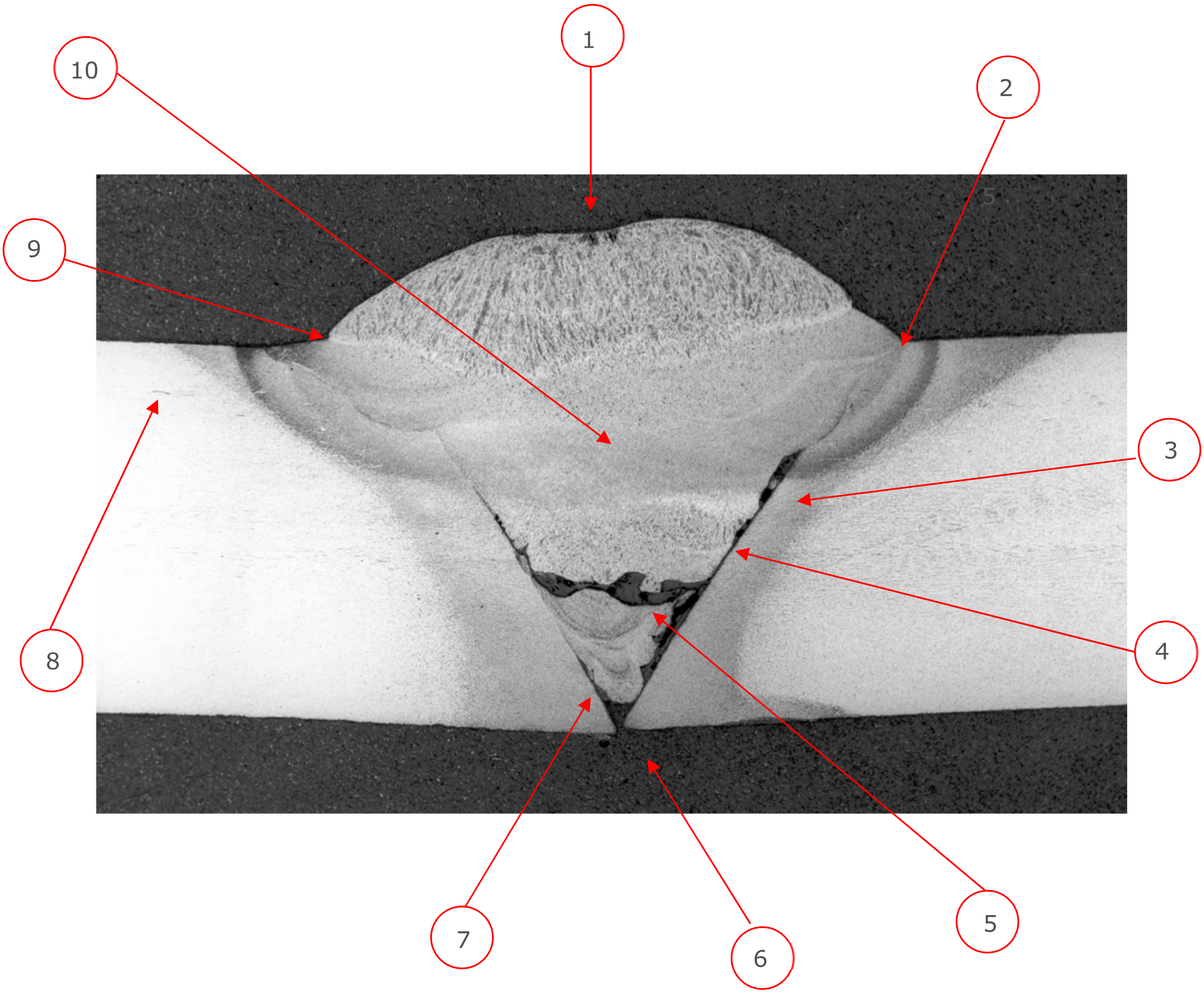
Training

Macroscopic

Training Macro 1

Welding process used MMA (SMAW)



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These questions are to be used with training macro 1

1 What is the indication at position 1 and would you accept or reject the indication to the given acceptance levels?

a Slag inclusions.
b Porosity.
c Excessive grain size.
d Tungsten inclusions.
e Accept.
f Reject.

2 The area identified at position 2 is the?

a Fusion zone.
b Fusion boundary.
c Toe of the weld.
d Undercut.

3 The area identified at position 3 is the?

a Fusion boundary.
b Acid marks.
c Polished area.
d Heat affected zone.

4 What is the indication at position 4 and would you accept or reject the indication to the given acceptance levels?

a Lack of inter-run fusion.
b Fusion boundary.
c Lack of sidewall fusion.
d Linear crack.
e Accept.
f Reject.

5 What is the indication at position 5 and would you accept or reject the indication to the given acceptance levels?

a Gas cavity.
b Lack of sidewall fusion.
c Slag trapped at the toes of the weld.
d Lack of inter-run fusion and slag.
e Accept.
f Reject.

6 What is the indication at position 6 and would you accept or reject the indication to the given acceptance levels?

a Slag inclusion.
b Lack of root fusion.
c Lack of root penetration.
d Burn-through.
e Accept.
f Reject.

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7 What is the indication at position 7 and would you accept or reject the indication to the given acceptance levels?

a Lack of inter-run fusion.
b Lack of sidewall fusion.
c Crack.
d Porosity in the root.
e Accept.
f Reject.

8 What is the indication at position 8 and would you accept or reject the indication to the given acceptance levels?

a Lamellar tearing.
b Hydrogen cracks.
c Laminations.
d Stress cracks.
e Accept.
f Reject.

9 What is the indication at position 9 and would you accept or reject the indication to the given acceptance levels?

a Overlap.
b Toe of the weld with good transition.
c Toe of the weld with poor transition.
d Undercut at the toe of the weld.
e Accept.
f Reject.

10 Which term best describes this welded joint?

a Square edge butt joint.
b Double V butt joint.
c Single V butt joint.
d T butt fillet weld.

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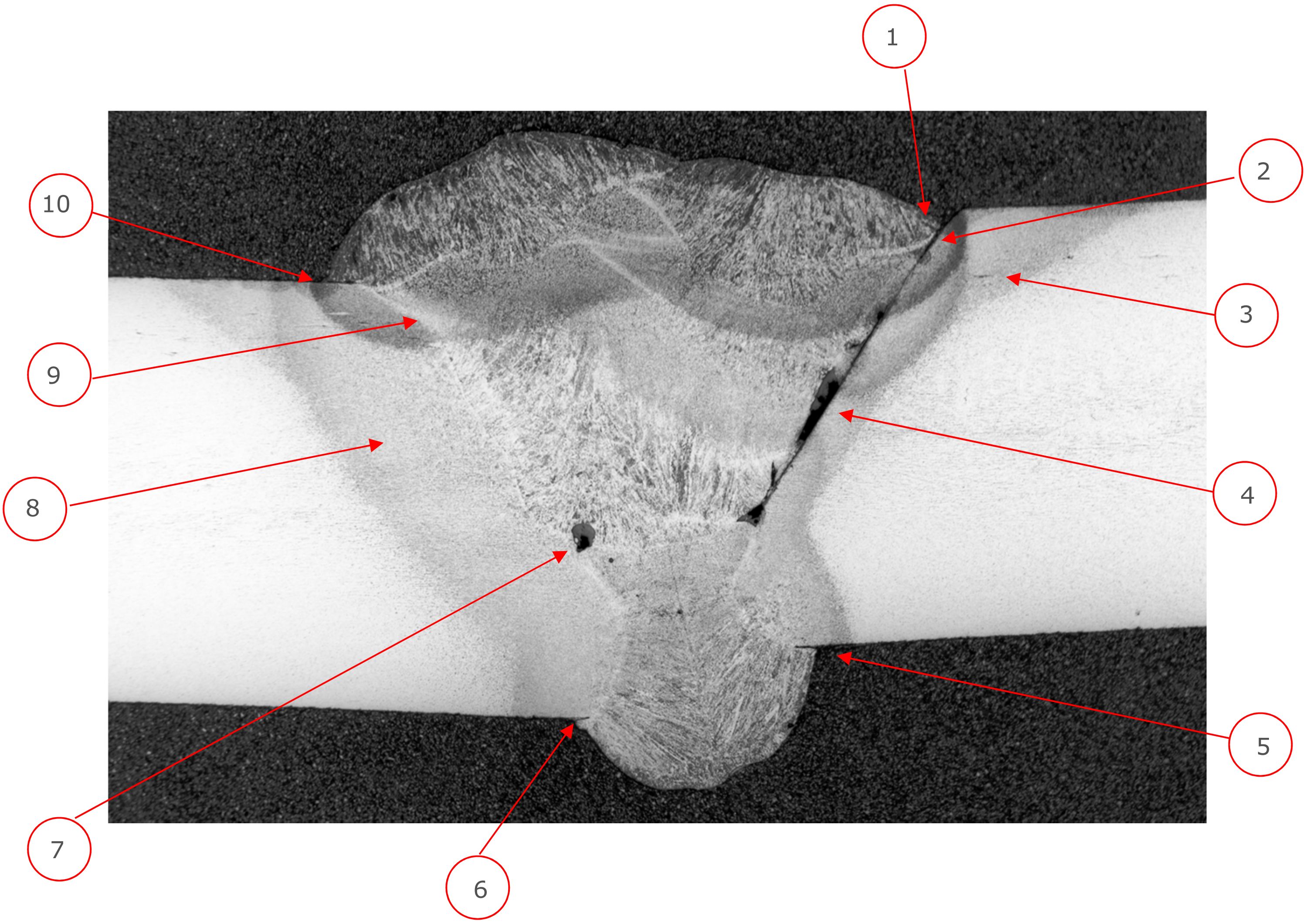
Training Macro 2

Welding process used MMA (SMAW)



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These questions are to be used with training macro 2

1 What is the indication at position 1 and would you accept or reject the indication to the given acceptance levels?

a Poor toe blend.
b Undercut.
c Lack of fusion.
d Underfill.
e Accept.
f Reject.

2 What is the indication at position 2 and would you accept or reject the indication to the given acceptance levels?

a Undercut.
b Poor toe blend.
c Underfill.
d Lack of sidewall fusion.
e Accept.
f Reject.

3 What is the indication at position 3 and would you accept or reject the indication to the given acceptance levels?

a Lamellar tearing.
b Corrosion crack.
c Hydrogen crack.
d Lamination.
e Accept.
f Reject.

4 What is the indication at position 4 and would you accept or reject the indication to the given acceptance levels?

a Lack of inter-run fusion.
b Lack of sidewall fusion and slag.
c Weld boundary.
d Lack of sidewall fusion and silicon.
e Accept.
f Reject.

5 What is the indication at position 5 and would you accept or reject the indication to the given acceptance levels?

a Toe crack.
b Hydrogen crack.
c Overlap.
d Lamellar tear.
e Accept.
f Reject.

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6 What is the indication at position 6 and would you accept or reject the indication to the given acceptance levels?

- a Spatter.
- b Lap.
- c Overlap.
- d Hydrogen crack.
- e Accept.
- f Reject.

7 What is the indication at position 7 and would you accept or reject the indication to the given acceptance levels?

- a Gas cavity.
- b Silicon inclusion.
- c Slag inclusion.
- d Copper inclusion.
- e Accept.
- f Reject.

8 The area identified at position 8 is referred to as the?

- a Heat affected zone.
- b Fusion boundary.
- c Fusion zone.
- d Polished area.

9 The area identified at position 9 is referred to as the?

- a Heat affected zone.
- b Fusion boundary.
- c Fusion zone.
- d Polished area.

10 What is the indication at position 10 and would you accept or reject the indication to the given acceptance levels?

- a Slag line.
- b Overlap.
- c Lamination.
- d Lamellar tear.
- e Accept.
- f Reject.

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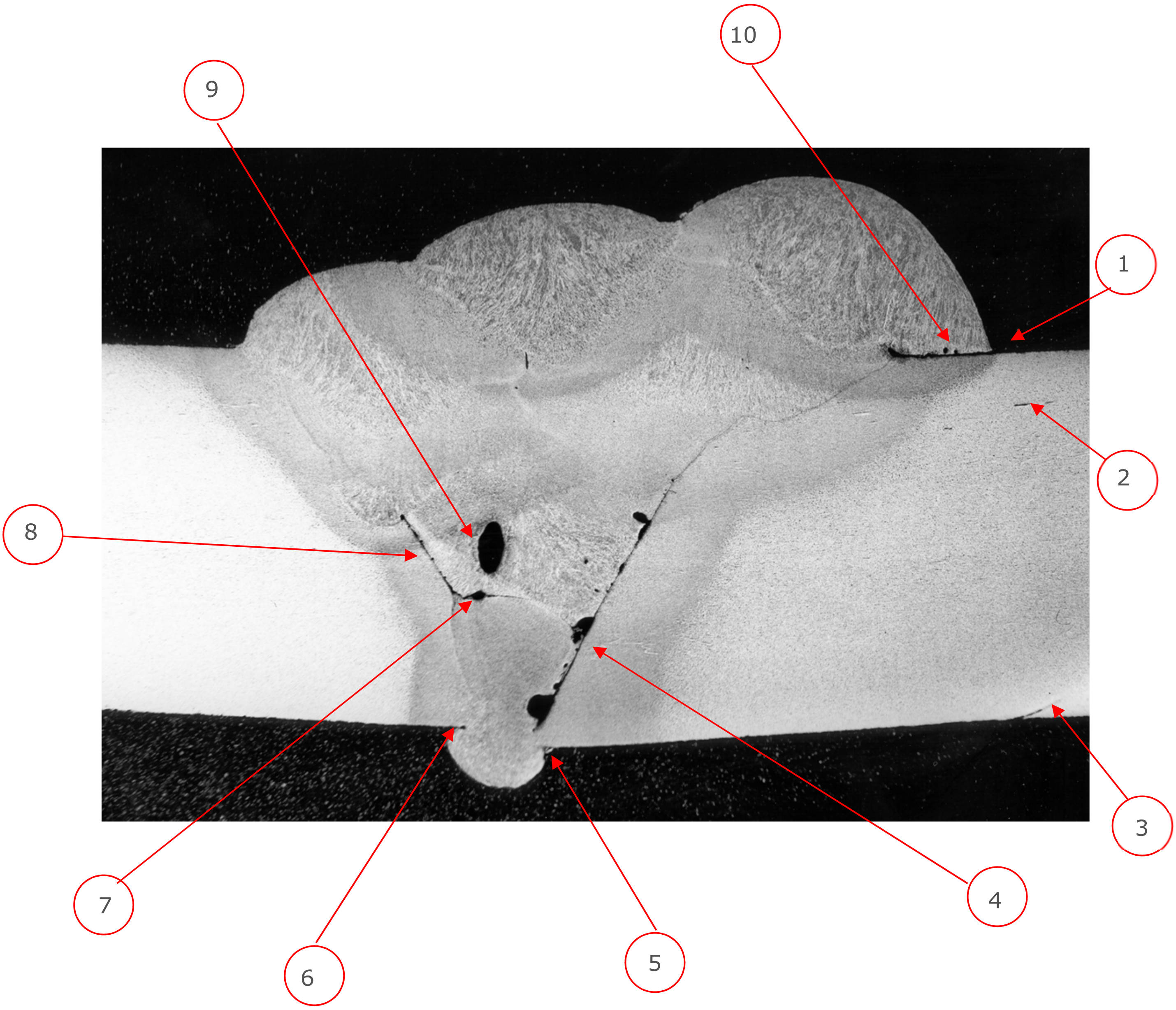
Training Macro 3

Welding process used MIG/MAG (GMAW)



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These questions are to be used with training macro 3

1 What is the indication at position 1 and would you accept or reject the indication to the given acceptance levels?

- a Linear crack.
- b Overspill.
- c Overlap.
- d Lamination.
- e Accept.
- f Reject.

2 What is the indication at position 2 and would you accept or reject the indication to the given acceptance levels?

- a Saw marks.
- b Lamellar tear.
- c Segregation bands.
- d Laminations.
- e Accept.
- f Reject.

3 What is the indication at position 3 and would you accept or reject the indication to the given acceptance levels?

- a Mechanical damage.
- b Lap.
- c Arc strike.
- d Lamellar tear.
- e Accept.
- f Reject.

4 What is the indication at position 4 and would you accept or reject the indication to the given acceptance levels?

- a Lack of sidewall fusion and slag.
- b Hydrogen crack.
- c Lack of sidewall fusion and gas cavity.
- d Linear sidewall crack.
- e Accept.
- f Reject.

5 What is the indication at position 5 and would you accept or reject the indication to the given acceptance levels?

- a Slag.
- b Silicon.
- c Spatter.
- d Copper.
- e Accept.
- f Reject.

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6 What is the indication at position 6 and would you accept or reject the indication to the given acceptance levels?

a Overlap.
b Crack.
c Incomplete root penetration.
d Incomplete root fusion.
e Accept.
f Reject.

7 What is the indication at position 7 and would you accept or reject the indication to the given acceptance levels?

a Transverse crack.
b Transverse hydrogen crack.
c Lack of inter-run fusion.
d Shrinkage crack.
e Accept.
f Reject.

8 What is the indication at position 8 and would you accept or reject the indication to the given acceptance levels?

a Lack of inter-run fusion.
b Crack.
c Linear slag line.
d Lack of sidewall fusion.
e Accept.
f Reject.

9 What is the indication at position 9 and would you accept or reject the indication to the given acceptance levels?

a Slag inclusion.
b Silicon inclusion.
c Gas cavity.
d Shrinkage defect.
e Accept.
f Reject.

10 What is the indication at position 10 and would you accept or reject the indication to the given acceptance levels?

a Porosity.
b Slag inclusion in weld metal.
c Silicon inclusions in weld metal.
d Tungsten inclusions in weld metal.
e Accept.
f Reject.

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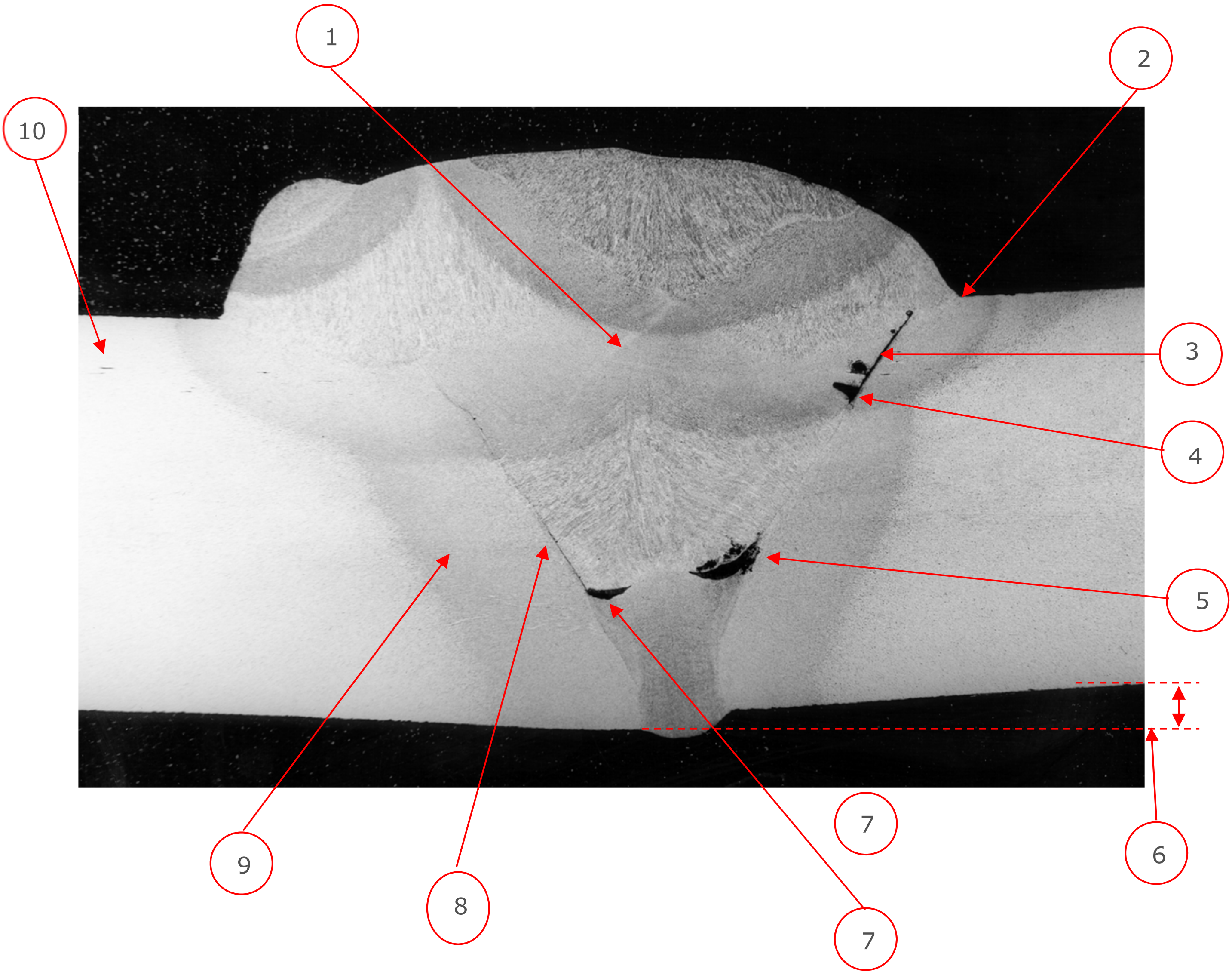
Training Macro 4

Welding process used MMA (SMAW)



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These questions are to be used with training macro 4

1 Which term best describes this welded joint?

a Square edge butt joint.
b Double V butt joint.
c Single V butt joint.
d T butt fillet weld.

2 What is the indication at position 2 and would you accept or reject the indication to the given acceptance levels?

a Overlap.
b Toe of the weld with good transition.
c Toe of the weld with poor transition.
d Undercut at the toe of the weld.
e Accept.
f Reject.

3 What is the indication at position 3 and would you accept or reject the indication to the given acceptance levels?

a Undercut.
b Poor toe blend.
c Underfill.
d Lack of sidewall fusion.
e Accept.
f Reject.

4 What is the indication at position 4 and would you accept or reject the indication to the given acceptance levels?

a Lack of inter-run fusion.
b Lack of sidewall fusion and slag.
c Weld boundary.
d Lack of sidewall fusion and silicon.
e Accept.
f Reject.

5 What is the indication at position 5 and would you accept or reject the indication to the given acceptance levels?

a Silicon inclusion.
b Slag inclusion, lack of sidewall fusion and lack of inter-run fusion.
c Gas cavity.
d Gas cavity and lack of sidewall penetration.
e Accept.
f Reject.

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6 Which term best describes the area indicated at position 6?

a Shrinkage.
b Linear distortion.
c Short transverse distortion.
d Angular distortion.
e Accept.
f Reject.

7 What is the indication at position 7 and would you accept or reject the indication to the given acceptance levels?

a Silicon inclusion.
b Slag inclusion.
c Slag inclusion, lack of inter-run fusion and lack of sidewall fusion.
d Elongated gas pore.
e Accept.
f Reject.

8 What is the indication at position 8 and would you accept or reject the indication to the given acceptance levels?

a Crack.
b Lack of inter-run fusion.
c Lack of sidewall fusion.
d Fusion boundary line.
e Accept.
f Reject.

9 The area identified at position 9 is referred to as the?

a Heat affected zone.
b Fusion boundary.
c Fusion zone.
d Polished area.

10 What is the indication at position 10 and would you accept or reject the indication to the given acceptance levels?

a Lamellar tearing.
b Hydrogen cracks.
c Laminations.
d Stress cracks.
e Accept.
f Reject.

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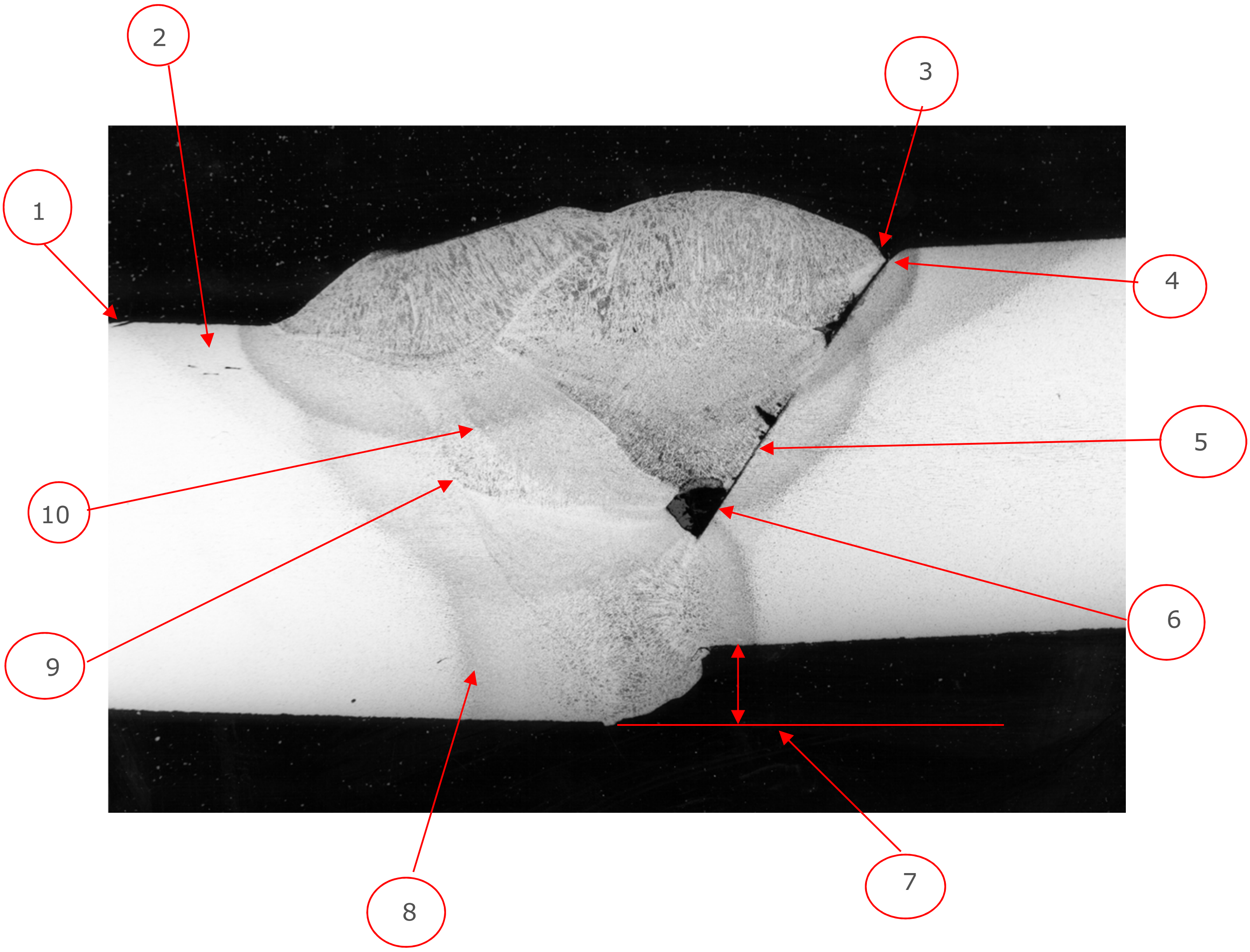
Training Macro 5

Welding process used MMA (SMAW)



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These questions are to be used with training macro 5

1 What is the indication at position 1 and would you accept or reject the indication to the given acceptance levels?

a Mechanical damage.
b Lap.
c Arc strike.
d Lamellar tear.
e Accept.
f Reject.

2 What is the indication at position 2 and would you accept or reject the indication to the given acceptance levels?

a Lamellar tearing.
b Hydrogen cracks.
c Laminations.
d Stress cracks.
e Accept.
f Reject.

3 What is the indication at position 3 and would you accept or reject the indication to the given acceptance levels?

a Undercut.
b Poor toe blend.
c Underfill.
d Lack of sidewall fusion.
e Accept.
f Reject.

4 What is the indication at position 4 and would you accept or reject the indication to the given acceptance levels?

a Undercut.
b Poor toe blend.
c Underfill.
d Lack of sidewall fusion.
e Accept.
f Reject.

5 What is the indication at position 5 and would you accept or reject the indication to the given acceptance levels?

a Lack of inter-run fusion.
b Fusion boundary.
c Lack of sidewall fusion.
d Linear crack.
e Accept.
f Reject.

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6 What is the indication at position 6 and would you accept or reject the indication to the given acceptance levels?

a Lack of sidewall fusion and slag.
b Hydrogen crack.
c Lack of sidewall fusion and gas cavity.
d Linear sidewall crack.
e Accept.
f Reject.

7 Which term best describes the area indicated at position 7?

a Shrinkage.
b Linear misalignment.
c Short transverse distortion.
d Transition weld set-up.
e Accept.
f Reject.

8 The area identified at position 8 is referred to as the?

a Fusion boundary.
b Acid marks.
c Polished area.
d Heat affected zone.

9 The area identified at position 9 is referred to as the?

a Heat affected zone.
b Fusion boundary.
c Fusion zone.
d Polished area.

10 Which term best describes this welded joint at position 10?

a Square edge butt joint.
b Double V butt joint.
c Single V butt joint.
d T butt fillet weld.

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Training Macro Answer Sheet

Macro 1						
1	1a	1b	1c	1d	1e	1f
2	2a	2b	2c	2d	2e	2f
3	3a	3b	3c	3d	3e	3f
4	4a	4b	4c	4d	4e	4f
5	5a	5b	5c	5d	5e	5f
6	6a	6b	6c	6d	6e	6f
7	7a	7b	7c	7d	7e	7f
8	8a	8b	8c	8d	8e	8f
9	9a	9b	9c	9d	9e	9f
10	10a	10b	10c	10d	10e	10f

Macro 2						
1	1a	1b	1c	1d	1e	1f
2	2a	2b	2c	2d	2e	2f
3	3a	3b	3c	3d	3e	3f
4	4a	4b	4c	4d	4e	4f
5	5a	5b	5c	5d	5e	5f
6	6a	6b	6c	6d	6e	6f
7	7a	7b	7c	7d	7e	7f
8	8a	8b	8c	8d	8e	8f
9	9a	9b	9c	9d	9e	9f
10	10a	10b	10c	10d	10e	10f

Macro 3						
1	1a	1b	1c	1d	1e	1f
2	2a	2b	2c	2d	2e	2f
3	3a	3b	3c	3d	3e	3f
4	4a	4b	4c	4d	4e	4f
5	5a	5b	5c	5d	5e	5f
6	6a	6b	6c	6d	6e	6f
7	7a	7b	7c	7d	7e	7f
8	8a	8b	8c	8d	8e	8f
9	9a	9b	9c	9d	9e	9f
10	10a	10b	10c	10d	10e	10f

Macro 4						
1	1a	1b	1c	1d	1e	1f
2	2a	2b	2c	2d	2e	2f
3	3a	3b	3c	3d	3e	3f
4	4a	4b	4c	4d	4e	4f
5	5a	5b	5c	5d	5e	5f
6	6a	6b	6c	6d	6e	6f
7	7a	7b	7c	7d	7e	7f
8	8a	8b	8c	8d	8e	8f
9	9a	9b	9c	9d	9e	9f
10	10a	10b	10c	10d	10e	10f

Macro 5						
1	1a	1b	1c	1d	1e	1f
2	2a	2b	2c	2d	2e	2f
3	3a	3b	3c	3d	3e	3f
4	4a	4b	4c	4d	4e	4f
5	5a	5b	5c	5d	5e	5f
6	6a	6b	6c	6d	6e	6f
7	7a	7b	7c	7d	7e	7f
8	8a	8b	8c	8d	8e	8f
9	9a	9b	9c	9d	9e	9f
10	10a	10b	10c	10d	10e	10f

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Practical Macro Inspection

Materials Joining and Engineering Technologies
Training and Examination Services

Macro Objective

When this presentation has been completed you will have a greater understanding of Macro examination and assessment to the acceptance criteria.

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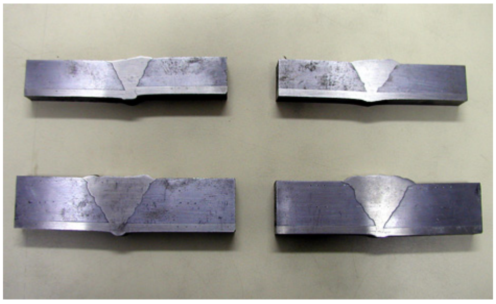
Macro Inspection Examination



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Macro Inspection Examination

For CSWIP 3.1 Welding Inspectors examination you are required to conduct a visual examination of two macro samples.

Time allowed 45 minutes

Acceptance Levels TWI 09

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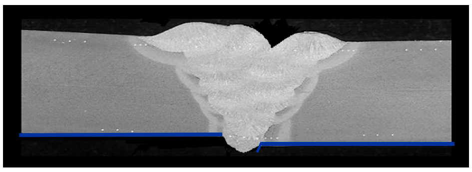
Macro Defects



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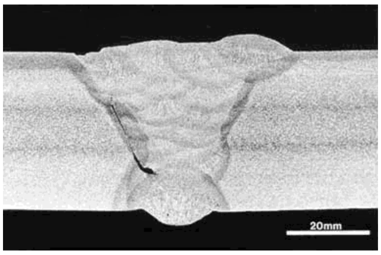
Macro Defects



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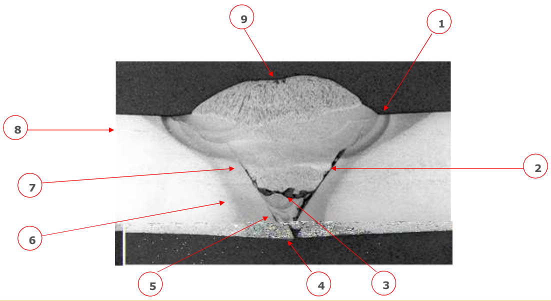
Macro Inspection

Welded with SMAW



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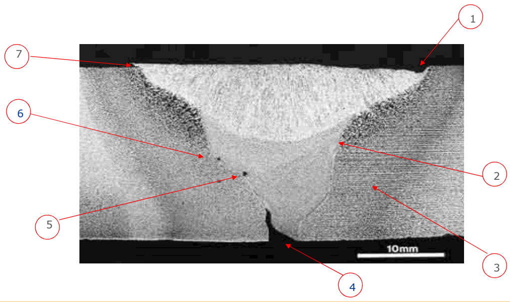
Macro Inspection

Welded with SMAW



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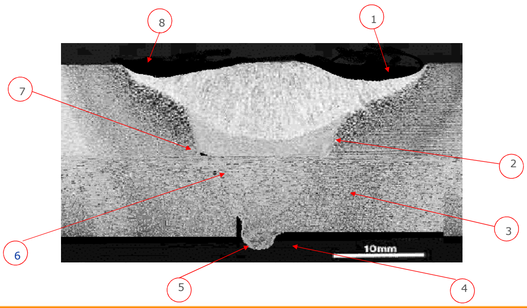

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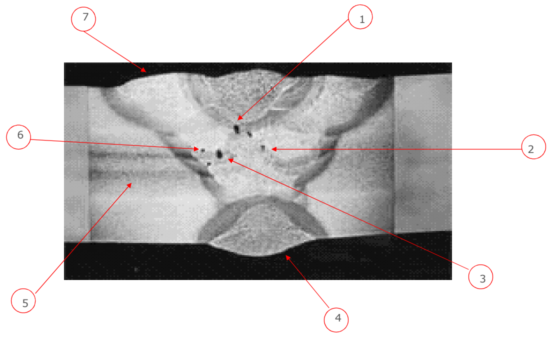

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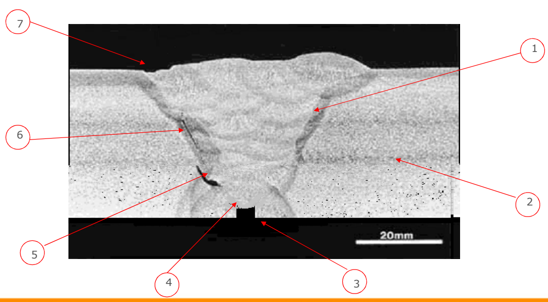

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Macro Inspection

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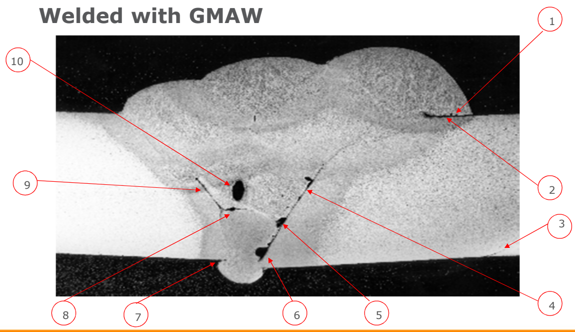

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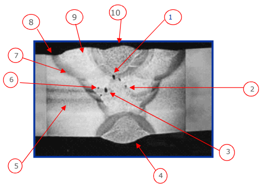
Macro Inspection Examination

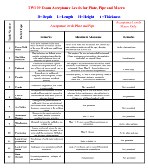
1. **Examine the Macro Photograph**



2. **Read the Questions**

1. What is the defect at position 1 and would you accept or reject the defect to the given acceptance levels?
   a. Poor toe blend
   b. Underfill
   c. Undercut
   d. Lack of fusion
   e. Accept
   f. Reject

3. **Compare Against Acceptance Levels**



4. **Mark the answer in the OMR grid in pencil and accept or reject accordingly. When you are sure about your answer mark the OMR grid in BLACK PEN**

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Any Questions

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