TWI

WELDING INSPECTION - STEELS

COURSE REF: WIS.5

The Welding Institute
Training Services Group
Abington Hall, Abington
Cambridge CB1 6AL

CSWIP WELDING INSPECTOR

THEORY A - 30 QUESTION MULTICHOICE - 30 MINUTES

THEORY B - MANDATORY QUESTION
"DUTIES OF A WELDING INSPECTOR" TO YOUR CHOICE OF CODE
(NO MORE THAN 30 MINUTES ON THIS QUESTION) APPROX. 300 WORDS.

4 FROM 6 TECHNOLOGY QUESTIONS
1 HR 15 MINUTES

PRACTICAL A:

INSPECTION AND SENTENCING OF A PIPE TO YOUR CODE
1 HR 45 MINUTES

INSPECTION OF A PLATE TO CSWIP ACCEPTANCE LEVELS
1 HR 15 MINUTES

PRACTICAL B:

BEND & MACROS (3 OFF)
45 MINUTES

ORAL:

10 QUESTIONS ON YOUR CODE RE APPLICATION
10-20 MINUTES

WELDING INSPECTION - STEELS

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CONTENTS

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COURSE DETAIL

ALL COURSE MEMBERS PLEASE READ CAREFULLY

1. The general working programme is attached.
2. Any alterations will be announced by the course tutor.
3. The lectures and tutorials etc are supported by the course text, please read as appropriate.
4. Question papers will be used to reinforce most sessions please attempt the questions, these will be discussed or marked at the discretion of the lecturer/tutor.
5. The end of course assessments are marked and the results recorded.

KEY KNOWLEDGE FOR WELDING INSPECTION PERSONNEL

The information contained in this course text supplements the lectures given in the course WIS 5.

Terminology given in the test is that recommended in BS 499 Pt 1: 1983; Weld Symbols to BS 499 Pt 2 : 1980. To supplement this further, however, an indication of both International (ISO) and American standards is given.

The sections are written in general terms and do not include all of the conditions that may apply to a specific fabrication or product.

SECTION 1

TERMINOLOGY

Use of the correct terminology is important. This course uses BS 499.

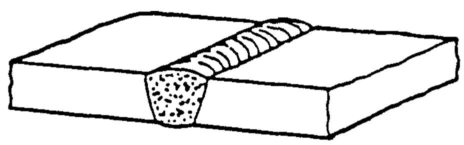
GENERAL TERMINOLOGY

WELDS and JOINTS

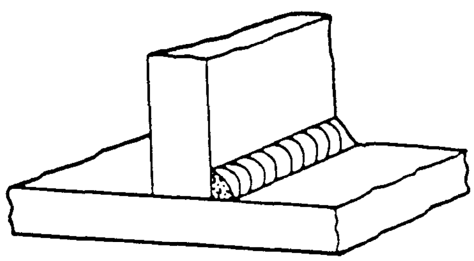
Frequently the terms 'weld' and 'joint' are used incorrectly. Exact definitions are given in BS 499 'Welding terms and symbols'.

TYPES OF WELD

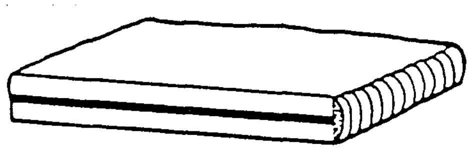
BUTT WELD



FILLET WELD



EDGE WELD



SPOT WELD

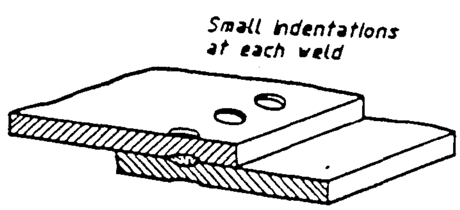


Illustration depicts resistance weld. Spot welds can be made with MIG or TIG processes.

TYPES OF JOINT

The four basic welds can be used to join various types of joints.

The following are some typical joints

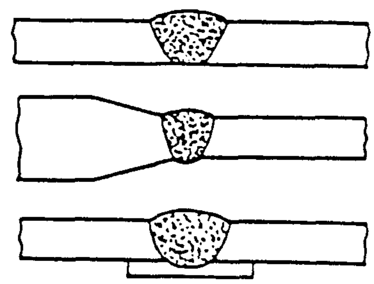
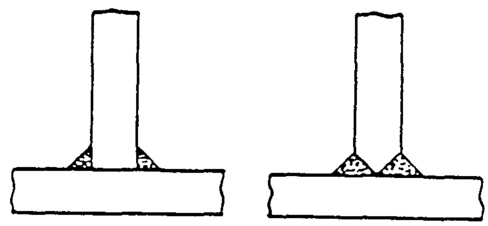
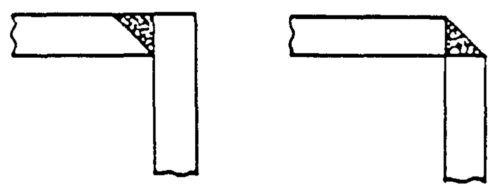
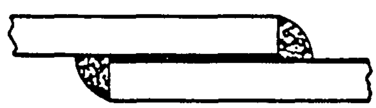
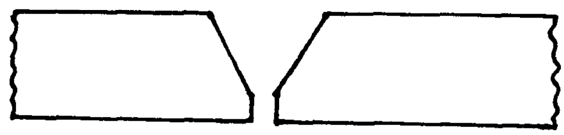
TYPE OF JOINT	EXAMPLES
BUTT	
TEE	
CORNER	
LAP	

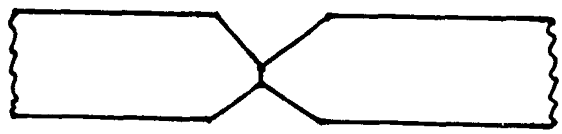
PLATE EDGE PREPARATION FOR BUTT WELDS

The illustrations show standard terminology for the various features of plate edge preparations.

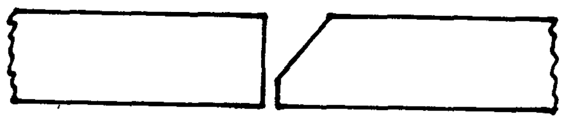
Single – V



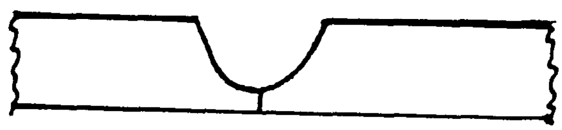
Double – V



Single bevel

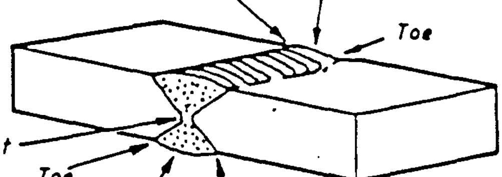


Single – U



FEATURES OF COMPLETED WELD

A butt weld in a plate, made by welding from both sides, has two weld faces, four toes. In a full penetration weld made from one side, the protruding weld on the underside is the penetration bead.



If a weld is sectioned, polished and etched, the fusion boundary can be established. Metal lying between the two fusion boundaries is weld metal, a mixture of deposited metal and plate material that has been melted. Adjacent to the fusion boundary is the heat affected zone (HAZ), in which the plate material has a metallurgical structure modified by the heat of welding.

Fillet welds also have

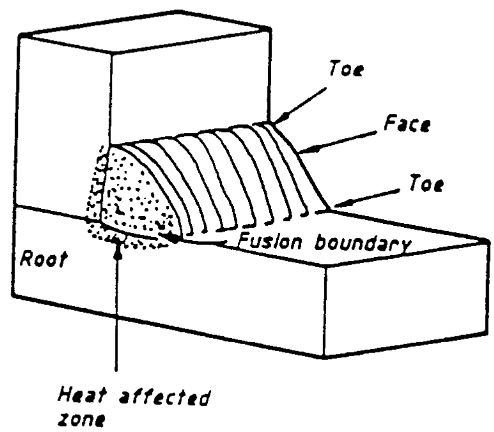
Toes

A weld face

A root

A fusion boundary

A heat affected zone

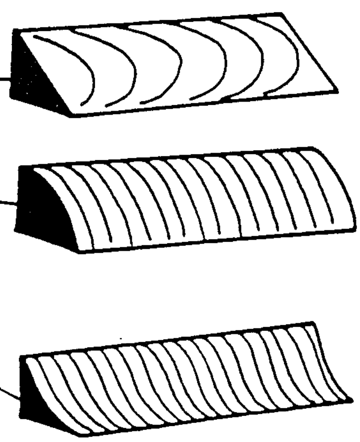


The shape of a fillet weld in cross-section is described by three terms

Mitre fillet

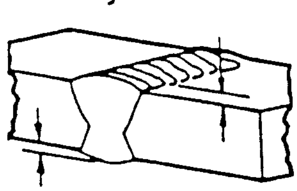
Convex fillet

Concave fillet



Fillet ① mitre ② Concave ③ Convex

Excess weld metal, as illustrated, is often referred to as 'weld reinforcement'. This does not necessarily mean it strengthens a joint.

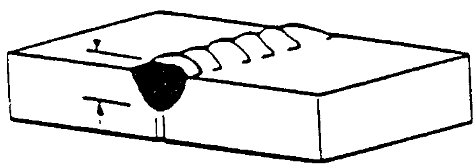


SIZE OF WELDS

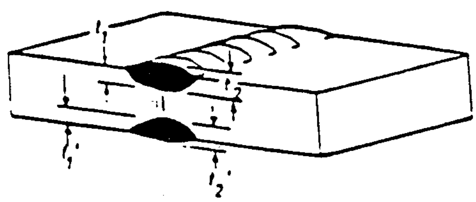
For full penetration butt welds, the general rule is: design throat thickness, t_1 = thickness of the thinner part joined.

Partial penetration butt welds

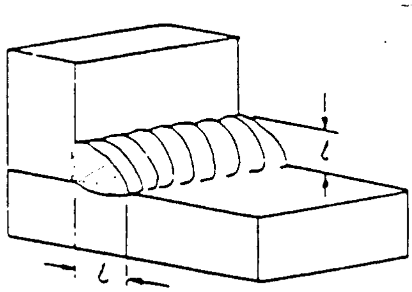
The term partial penetration strictly implies butt welds that are designed to have less than full penetration. Failure to achieve full penetration when it is wanted should be listed as the defect INCOMPLETE PENETRATION.



The throat thickness of a partial penetration weld made from both sides is $t_2 + t_2$, and the design throat thickness $t_1 + t_1$. Note that the degree of penetration must be known.

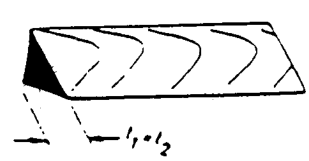


Fillet weld sizes are calculated by reference to allowable shear stress on the throat area, i.e. throat area = design throat thickness x length of weld. The size required is specified on drawings in terms of leg length (l).



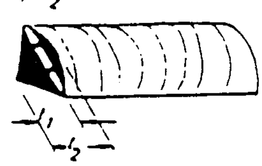
throat area = Design throat thickness x weld length.

For fillet welds with equal leg lengths:

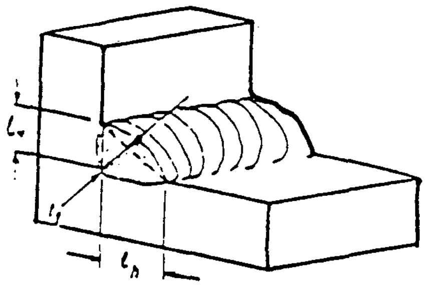


$$l = 1.4t_1$$?

where t_1 is as defined for mitre and convex fillets.



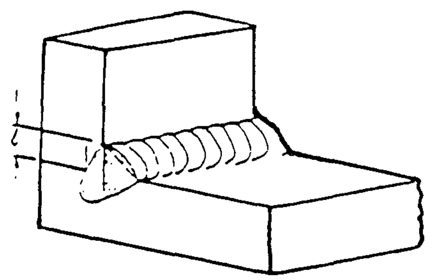
If an asymmetrical fillet weld is required, both leg lengths are specified and t_1 is taken as the minimum throat dimension.

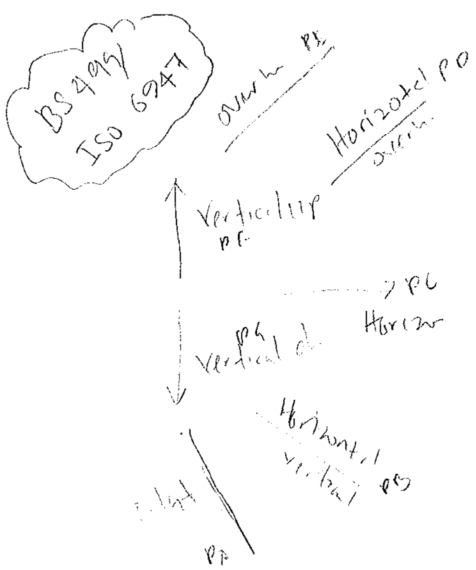


Deep penetration fillet weld

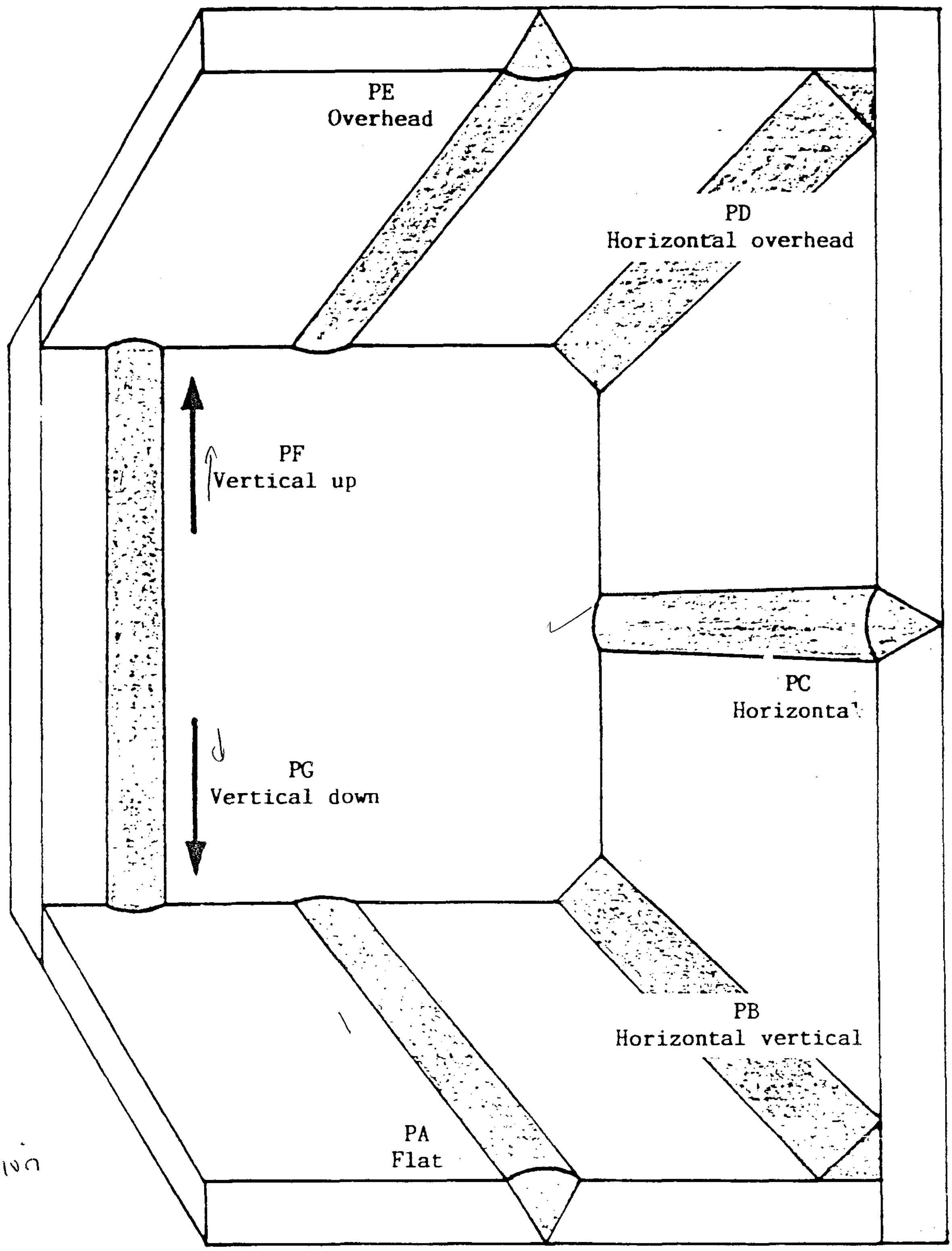
With high current density processes, e.g. submerged arc and MIG (spray). penetration along the joint line can be produced.

This gives an increase in throat thickness with no change in leg length.





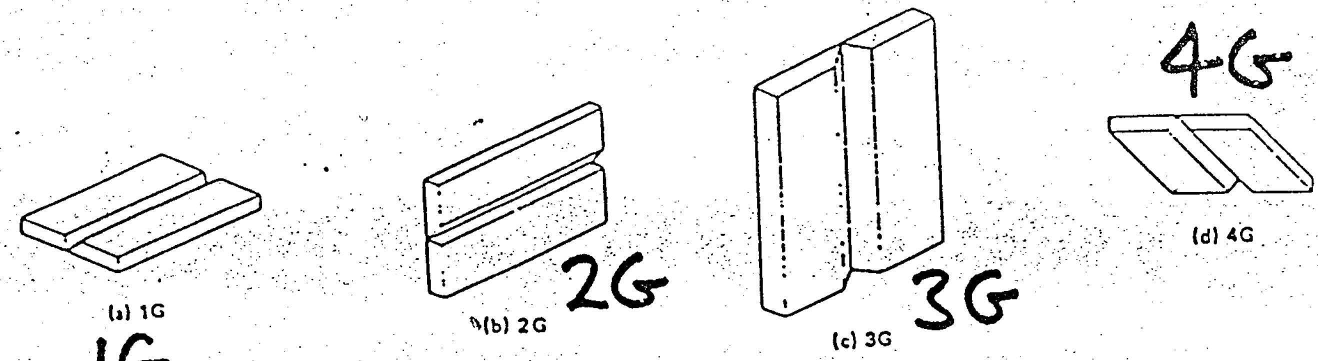
WELDING POSITIONS (BS 499:1991/ISO 6947)



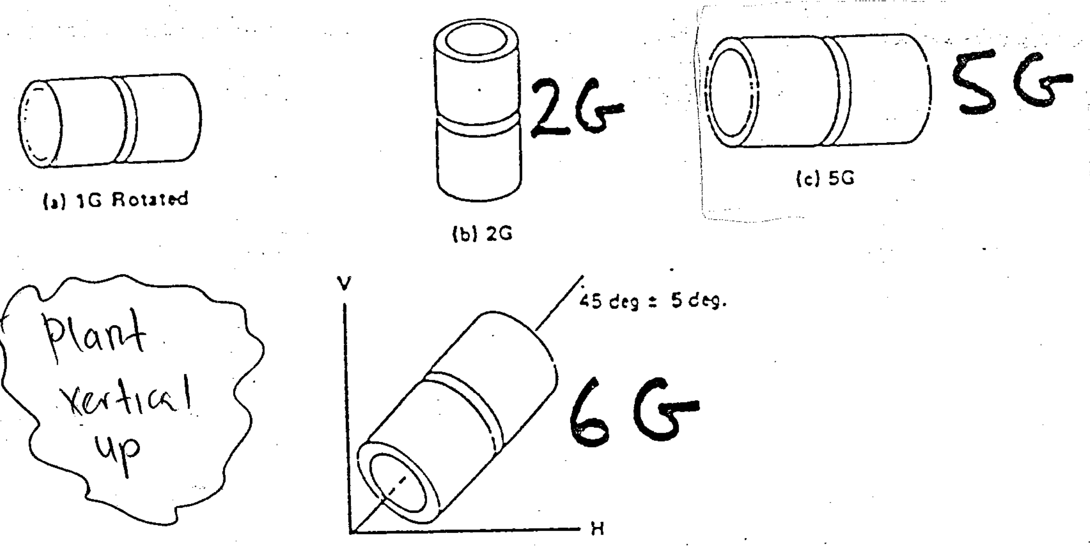
P - Position

NOTE: To avoid confusion with existing abbreviations, eg F for flat, in principle the letter 'P' (for position) has been placed in front of the symbol to indicate 'main position'

QW-461 Positions (Cont'd)



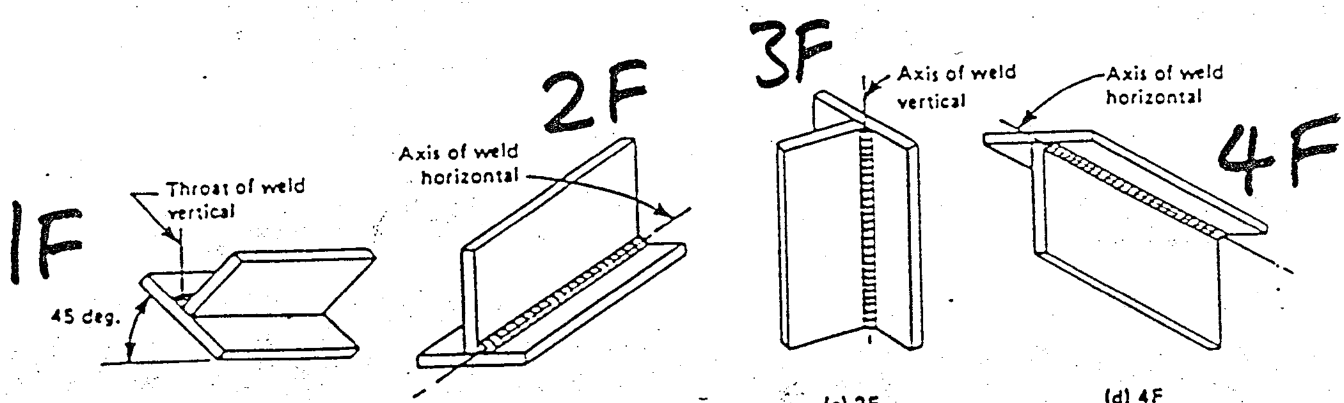
QW-461.3 GROOVE WELDS IN PLATE — TEST POSITIONS



Pipeline vertical down

Plant vertical up

QW-461.4 GROOVE WELDS IN PIPE — TEST POSITIONS



QW-461.5 FILLET WELDS IN PLATE — TEST POSITIONS

* 3G & 4G cannot weld pipe

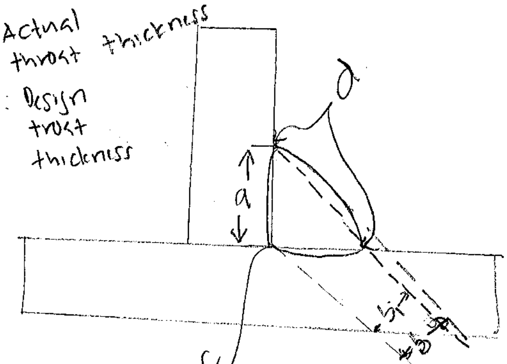
QUESTIONS

TERMINOLOGY

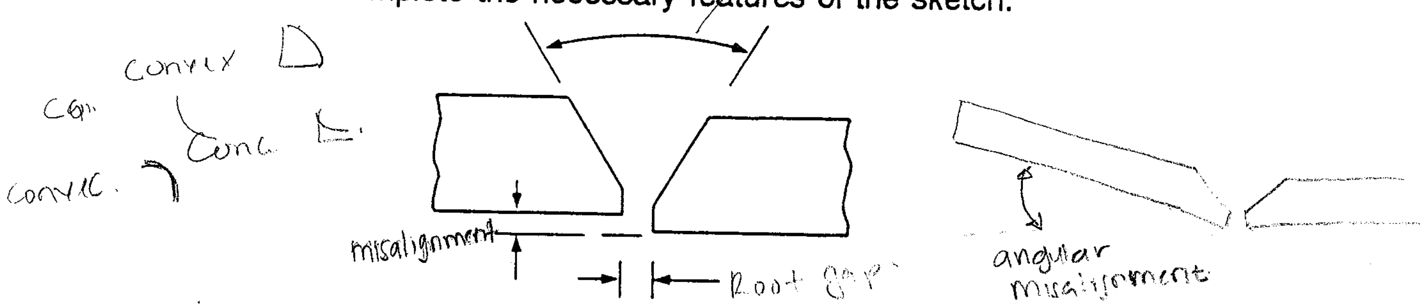
Q1. Sketch a single vee butt joint and a single bevel butt joint

Q2. Sketch a tee joint and indicate for fillet welds:

a) leg length
b) throat thickness
c) root
d) toes



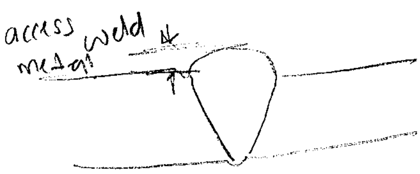
Q3. Complete the necessary features of the sketch:

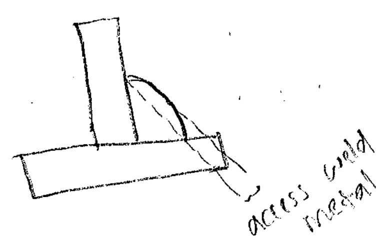


Q4. Describe the three (3) types of fillet weld shape.

(1) mitre weld ✓
(2) concave weld ✓ good toe blend
(3) convex weld ✓ not good toe blend

Q5. What is 'excess weld metal'?





SECTION 2

THE DUTIES OF THE WELDING INSPECTOR

VISUAL INSPECTION

At any point in the course of welding, i.e. tacking, root pass, filler pass or capping pass, but particularly for the root and cap, a detailed inspection may be required. British Standard 5289 : 1976 gives guidance on tools and responsibilities together with sketches of typical defects.

The inspector at this point must – BS 5289. Guideline for tools & responsibility

a) observe, identify and perhaps record the features of the weld.

b) decide whether the weld is acceptable in terms of the particular levels which are permitted; defect levels may be 'in–house' or National Codes of Practice.

When the defect size is in excess of the permitted level then either a concession must be applied for (from a competent person) or the weld rejected.

CODE OF PRACTICE FOR VISUAL INSPECTION

A code of practice for an inspection department could take the form outlined below. It is appreciated that full implementation of the code would be extremely costly and therefore it may be necessary to reduce the amount of inspection to less than is theoretically required.

AIDS OF VISUAL INSPECTION

Illumination: Good lighting is essential

Inspection lenses: The magnification should not exceed 2–2½ diameters. If higher magnification is required use a binocular microscope.

Optical viewing devices area progressive development from the use of a hand torch and mirror, frequently with the addition of a magnifier and light source.

In order to achieve accessibility probe units are available down to a diameter, properties for which are:

1. Large field of vision.
2. Freedom from distortion of image.
3. Accurate preservations of colour values.
4. Adequacy of illumination.

VISUAL INSPECTION PRACTICE

The inspector should be familiar with the following:

1. All applicable documents.
2. Workmanship standards.
3. All phases of good workshop practice.
4. Tools and measuring devices.

INSPECTION BEFORE WELDING

Before assembly:

Check:

1. Application standard
2. Welding procedure sheets
3. Drawings
4. Welder qualifications
5. Material composition
6. Condition of material
7. Type of edge preparation, method and finish
8. Consumables, i.e. type of electrodes, filler wires, fluxes, shielding and backing gases (composition) and special drying requirements for electrodes
9. Welding process.processes

After assembly:

Check:

1. Clearance dimensions, tolerances, type of backing (if any)
2. Alignment, tack welds, bridging pieces, etc.
3. Cleanliness
4. Preheat (if any)

Note: Good inspection prior to welding could eliminate conditions that lead to the formation of defects.

INSPECTION DURING WELDING

Check:
1. Welding process
2. Preheat and interpass temperatures
3. Inter-run cleaning
4. Joint preparation
5. Filler metals
6. Control of distortion
7. Root and subsequent runs
8. Welding current and voltage
9. Chipping, grinding, gouging
10. Fluxes and shielding gases
11. Compliance with weld procedure sheet and application standard

AFTER WELDING

Check:
1. Dimensional accuracy
2. Conformity of drawings and standard requirements
3. Acceptability of welds regarding appearance
4. Post-heat treatment (if any)
5. Repairs

REPAIRS

1. Mark out area positively and clearly.
2. Use a method established and understood by all inspection and repair personnel.
3. Check when partially removed (visual and NDT).
4. Check when fully removed (visual and NDT).
5. Check rewelding.
6. Reinspect.

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QUESTIONS

RESPONSIBILITIES AND DUTIES OF A WELDING INSPECTOR

Q1. Give three (3) main responsibilities of a welding inspector

(1) comply with standard/code

(2) workmanship control

(3) Documentation control

Q2. Give three (3) attributes which all welding inspectors must possess

(1) knowledgeable

(2) Honest

(3) Physically fit.

(4) ~~Common~~ Good communicator

Q3. What documents or records should be referred to by the welding inspector?

(1) ~~code~~ Relevant International code & Standard

(2) Client's specification

(3) Client's WI

(4) WPS

(5) mill certificates

(6) Welder Qualification Record

To observe, measure and identify activities, before, during and after welding

Q4. What are the duties of the welding inspector?

Before welding

(1) Read & understand relevant code

(2) " WPS

(3) Isometric drawing

(4) check material certificate

(5) Check Consumable certificate

(6) Edge preparation

(7) Preheat temperature

(8) Check temperature gauge certificate

(9) Welders Qualification

(10) Weather condition

During welding

(1) Check current

(2) Check voltage

(3) Check interpass temperature

(4) Check welding speed

(5) Inter pass cleaning

(6) Flux & shielding gas

(7) Weather condition

After welding

- Dimensional accuracy
- Conformity to drawing & standard
- Visual inspection
- Post heat treatment

Q5. Should the most up to date code or specification be used?

⇒ No.

SECTION 3

CODES AND STANDARDS

CLASS OF WORK

There are many types of work which require engineering materials to be joined by welding, for example:

pressure vessels
bridges
oil rigs
earth moving equipment
aero-engines
ventilation systems
storage tanks
heavy vehicle chassis
car bodies
food processing plant

The quality requirements of the joints in these fabrications depend on their fitness-for-purpose and differ significantly from one application to the next.

Pressure vessels require welds which can withstand the stresses and high temperatures experienced in operation.

Bridges must take into account the effect of differing vehicle loads and wind loading.

Oil rigs are designed to withstand the effect of wave formation and wind loads.

Earth moving equipment has to accommodate differences in terrain and earth conditions and is subject to fatigue loading.

Welds in food processing plants must withstand corrosion by hot acidic liquors.

On the next page some typical Codes of practice and Standards which cover various types of constructions being fabricated by welding are listed.

Note: Throughout this text, the term Code is used to cover Code of Practice, Standard and Specification.

Code	Class of Work
BS 5500	Unfired fusion welded pressure vessels
ASME VIII	American boiler and pressure vessel code
BS 2633	Class 1 Arc welding of ferritic steel pipework for carrying fluids
BS 4515	Process of welding steel pipelines on land and offshore
BS 5950	Structural use in steelwork in building
AWS D1.1	Structural welding code (American)
BS 5400	Steel concrete and composite bridges
BS 6235	Code of Practice for fixed offshore structure
API 1104	Standard for welding pipelines and related facilities

These documents can also provide a useful source of data for applications where Codes do not exist. It should be remembered, however, that the principal criterion in the Codes listed is the quality of the joint in relation to the service conditions. There are other applications where success is judged by different criteria, such as dimensional accuracy.

Another important consideration is controlling the cost of welding. Variations in weld times and quantities of consumables can readily result if the method of making a weld is left to the welder to decide.

The continuous and satisfactory performance of weldments made to various Codes requires that specific guidelines are laid down to cover materials, design of joints, welding processes, welding consumables, acceptance criteria and inspection techniques.

These guidelines are usually grouped under the general heading of a Weld Procedure.

QUESTIONS

CODES AND STANDARDS

Q1. List the typical items to be found in a Code of Practice

(1) Material
(2) Scope
(3) Welder Qualification test
(4) Inspection & Testing

Q2. Explain the meanings of the terms:

a) 'Shall' — mandatory requirement - refer to API 1104 - clause 8.2.16
b) 'Should' - good to have/do it precommend practice.

Q3. What is meant by the term 'concession'?

A variation/change from the drawings or spec in writing with agreement & client approval.

Q4. Does a Code of Practice contain all relevant information?

No,
Need also drawing & client spec.

Q5. State the three (3) parties generally mentioned in Codes or Standards

(1) Company (owner of the project)
(2) Manufacturer
(3) Third party Inspection

SECTION 4

THE WELDING PROCEDURE

The task of collecting the data and drafting the documentation is often referred to as *writing* a weld procedure. In many ways this is an unfortunate term as the writing of documents is the last in a sequence of tasks.

Producing a weld procedure involves:

- planning the tasks
- collecting the data
- writing a procedure for use or for trial
- making test welds
- evaluating the results of the tests
- approving the procedure of the relevant Code
- preparing the documentation

In each Code reference is made to how the procedures are to be devised and whether approval of these procedures is required. In most Codes approval is mandatory and tests to confirm the skill of the welder are specified. Details are also given of acceptance criteria for the finished joint.

The approach used depends on the Code, for example:

BS 2633 : (Class 1 arc welding of ferritic steel pipework for carrying fluids) provides general comments on various aspects of a suitable weld procedure.

AWS D.1.1 (Structural welding code – steel) favours more specific instructions for different joints and processes which are, in effect, pre-qualified procedures.

Other Codes do not deal specifically with the details of the weld procedure but refer to published documentation, e.g. BS 5135 'process of arc welding carbon and carbon manganese steels'.

COMPONENTS OF A WELD PROCEDURE

Items to be included in the procedure can be some of the following:

1. Parent metal
   - 1.1 Type
   - 1.2 Thickness (for pipe this includes outside diameter)
   - 1.3 Surface condition
   - 1.4 Identifying marks

2. Welding process
   - 2.1 Type of process (MMA, TIG, MAG etc)
   - 2.2 Equipment
   - 2.3 Make, brand, type of welding consumables
   - 2.4 When appropriate the temperature and time adopted for drying and baking of electrode/consumables

3. Joint design
   - 3.1 Welding position
   - 3.2 Edge preparation
   - 3.3 Method of cleaning, degreasing etc
   - 3.4 Fit up of joint
   - 3.5 Jigging or tacking procedure
   - 3.6 Type of backing

4. Welding position
   - 4.1 Whether shop or site welding
   - 4.2 Arrangement of runs and weld sequence
   - 4.3 Filler material, composition and size (diameter)
   - 4.4 Welding variables – voltage, current travel speed
   - 4.5 Weld size
   - 4.6 Back gouging
   - 4.7 Any specific features, e.g. heat input control, run-out length

5. Thermal treatment
   - 5.1 Preheat and interpass temperatures including method and control
   - 5.2 Post weld treatment including method and control

APPROVING THE PROCEDURE

When the data has been collected, the procedure must be validated by producing and testing a trial weld.

If the procedure is to be used on a fabrication which has been designed to meet the requirements of a Code, the test weld is done under the supervision of an independent witness. The detailed arrangements for the test are subject to agreement between the contracting parties.

A number of British Standards make cross reference to another Standard which covers approval testing.

Other Codes of practice include their own weld procedure/welder approval information.

In general they include a standard format which can be used to report the results of an approval test.

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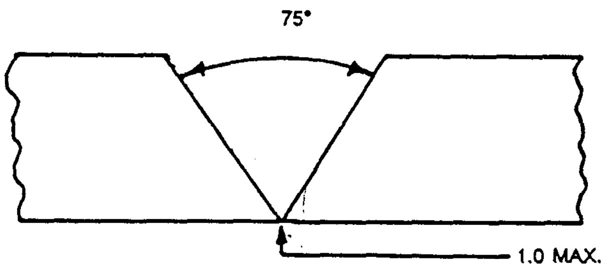
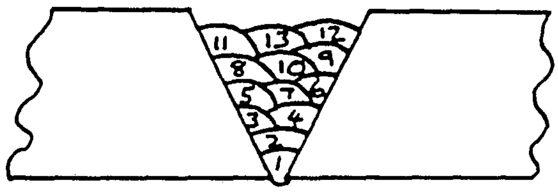
MANUFACTURER'S WELDING PROCEDURE SPECIFICATION (WPS)

(see EN 288-2)

Location: ....TWI TRAINING WORKSHOP..
Manufacturer's Welding Procedure: ....pWPS 001/A...
Reference No: ....41920...
WPAR No: ....0223..
Manufacturer : ....FRED BLOGGS INDUSTRIES..............................

Welder's Name: ....A N OTHER..
Welding Process: ....141(TIG ROOT)/111(MMA FILL & CAP)..................
Joint Type: ....SINGLE VEE BUTT..

Examiner or test body:......B.D.I LTD...........................
Method of Preparation and Cleaning:......DEGREASE & MACHINE...
Parent Material Specification: ..316L STAINLESS STEEL
C .03% Cr 17% Mn 1.5% Mo 2.5%
Ni 11% Si 0.5% + Residuals
Material Thickness (mm): 15mm
Outside Diameter (mm):......155mm............................
Welding Position: ......HL045.......................................

Weld Preparation Details/Joint Design (Sketch)*	Welding Sequences
	

Welding Details

Run	Process	Size of Filler Metal	Current A	Voltage V	Type of current/ Polarity	Wire Feed Speed	Travel Speed*	Heat input*
1	141	AUTOGENEOUS	60-70	10-12	DCEN	-	40mm/mn	1.0KJ/mm
2-4	111	3.2mm	110-120	20-22	DCEP	-	140mm ROL	1.0KJ/mm
5-10	111	3.2mm	95-110	20-22	DCEP	-	130mm ROL	1.0KJ/mm
10 to	111	2.5mm	70-90	20-22	DCEP	-	100mm ROL	1.0KJ/mm
completion		2.5mm	70-90	20-22	DCEP	-	100mm ROL	1.0KJ/mm
-	-	-	-	-	-	-	-	-

Filler Metal Classification and trade name:......SOUDOMETAL SUPERCROM 316L to ISO 3581-E19:12:3:LR23..............................
Any Special Baking or Drying: ......DRY AT 100°C FOR 2 HOURS QUIVER AT 75°C..
Gas/Flux: shielding: ......ARGON - COMMERCIAL PURITY ....
backing : ......ARGON - COMMERCIAL PURITY ....
Gas Flow Rate - Shielding: ......8 LITRES/MINUTE...
Backing: ....4 LITRES/MINUTE...
Tungsten Electrode Type/Size: ......2% THORIUM 2.5 ϕ.......................................
Details of ~~Back Gouging~~/Backing: ......RETAIN UNTIL RUN 5 ONWARD..
Preheat Temperature: ......NONE...
Interpass Temperature: ......150°C MAXIMUM...

Other information*:..
e.g. weaving (maximum width of run): .....2 x ϕ......
Oscillation: amplitude, frequency, dwell time: ....as required
Pulse welding details: ......NOT REQUIRED ....
Stand off distance: ....NOT REQUIRED ....
Plasma welding details: ......NOT REQUIRED ....
Torch angle: .TILT 90° SLOPE 70°..........................

Post-Weld Heat Treatment and/or Ageing: ......NONE....................................
Time, Temperature, Method: ......NOT REQUIRED..
Heating and Cooling Rates*: ......AS PROCEDURE...

Manufacturer

Name ......FREDERICK BLOGGS.......................................
Date .00-00-199-..
Signature ....Frederick Bloggs...

Examiner or test body

Name ......I.C. ITCANBE...................................
Date ......00-00-199.......................................
Signature ....I C Itcanbe...

The Welding Institute Cambridge

TWI

THE WELDING INSTITUTE

WELDING PROCEDURE APPROVAL RECORD FORM (WPAR)

TO EN 288

WELDING PROCEDURE APPROVAL – TEST CERTIFICATE

Manufacturer's Welding Procedure Reference No. ....41920/001/A..

Examiner or test body BDI LTD..................
Reference No. .BDI 71000/25 ....

Manufacturer: ...FRED BLOGGS INDUSTRIES ....

Address ....375 LONDON ROAD, CAMBRIDGE UK. ....

....

Code/Testing Standard:......EN 288 ....

Date of Welding: ......00–00–199– ....

EXTENT OF APPROVAL

Welding Process: .....141 TIG ROOT 111 MMA FILL & CAP ....

Joint Type : .....ANY BUTT JOINT IN PIPE OR PLATE/FILLET WELDS IN PIPE/PLATE & T BUTT WELDS ....

Parent metal(s): .....AUSTENITIC STAINLESS STEELS.................................. **Conditions of tempered:** .NOT APPLICABLE.........

Metal thickness (mm): .....12mm – 16.5mm ....

Outside Diameter (mm): .....78mm – 310mm ....

Filler Metal type : ......316L SOUDOMETAL SUPERCROM TO ISO E19:12:3:L R 2:3 ONLY ....

Shielding Gas/Flux: ......ARGON ....

Type of Welding Current: ......DIRECT CURRENT 141 DCEN 111 DCEP ....

Welding Positions: ......ALL POSITIONS EXCEPT P.G. (VERTICAL DOWN) ....

eheat: ......NOT REQUIRED..

Post-Weld Heat Treatment and/or ageing: ....NOT REQUIRED..

Other Information: ......TACK WELDING NOT PERMITTED LINE UP CLAMPS ONLY ....

....

....

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

Location .... **Date of Issue** .00–00–199– .... **Examiner or test body**

Name... B.D.I. LTD – I.C. ITCANBE

Date...00–00–199– ....

Signature I C Itcabe ....

Page 1 of 3

DETAILS OF WELD TEST

Location: ....SHOP – TWI TRAINING WORKSHOP......................................

Examiner or test body: ....B.D.I. LTD......

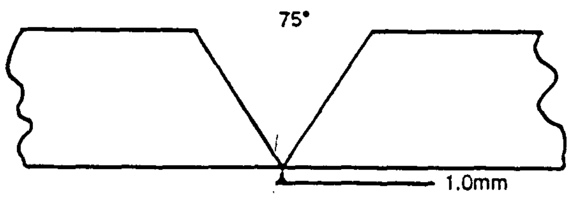
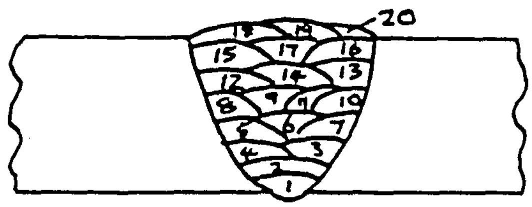
Manufacturer's Welding Procedure
Reference No.: ......41920 ....

WPAR No: ......WPAR 001/A..

Method of Preparation and Cleaning: ..M/C & DEGREASE
Parent Material Specification: ..316L STAINLESS STEEL

Manufacturer: ......FRED BLOGGS INDUSTRIES ....
Welder's Name:......A N OTHER ....
Welding Process: ......141 (TIG) 111 (MMA)...
Joint Type : ......SINGLE VEE BUTT...
Weld Preparation Details (Sketch)*: ....NO ROOT FACE.....................

Material Thickness (mm): ....15mm ....
Outside Diameter (mm) : ....155mm ....
Welding Position : ..hl045 ....

Joint Design	Welding Sequence
	

Welding Details

Run	Process	Size of Filler Metal	Current A	Voltage V	Type of current/ Polarity	Wire Feed Speed	Travel Speed*	Heat input* KJ/mm
1	141	AUTOGENEOUS	65	11	DCEN	–	45mm	0.95
2–4	111	32.mm	115	21	DCEP	–	150mm	0.96
5–10	111	3.2mm	105	21	DCEP	–	150mm	0.88
10 to	111	3.2mm	80	21	DCEP	–	110mm	0.96
completion		3.2mm	80	21	DCEP	–	110mm	0.96

Filler Metal Classification and trade name: ....SOUDOMETAL SUPERCROM 316L ....
Any Special Baking or Drying:....DRIED AT 100°C – 2 HRS. ....
Gas/Flux: **shielding:** ......BOC ARGON..
backing: ......BOC ARGON..
Gas Flow Rate – Shielding: ....6 LITRES/MIN.......................................
Backing: ......4 LITRES/MIN...
Tungsten Electrode Type/Size: ......2% THORIUM 2.5mm...................
Details of Backing: ......RETAINED UNTIL RUN 6.................................
Preheat temperature: ....NONE APPLIED..
Interpass Temperature: ....MAXIMUM 130°C...

Other information*:
e.g. weaving (Maximum width of run): ..NONE..
Oscillation: amplitude, frequency, dwell time
Pulse welding details: ...NONE ....
Stand off distance:....NONE ....
Plasma welding details: ...NONE..........
Torch angle: ....AS REQUIRED ....

Post-Weld Heat Treatment and/or Ageing:......NONE ....
Time, Temperature, Method: ....NONE..
Heating and Cooling Rates*: ....NONE..

MANUFACTURER

Name: ....FREDERICK BLOGGS.......................
Date: ....00-00-199– ....
Signature: .... Frederick Bloggs

Examiner or test body

Name: ....I C ITCANBE ....
Date: ....00-00-199- ....
Signature: .... I C Itcanbe

The Welding Institute Cambridge

DOCUMENTATION

The objectives of a procedure or welder approval test are:

a) to prove the procedure meets the necessary requirements with reference to feasibility, mechanical strength etc

b) to prove the welders are competent to work in a particular job

If a customer queries it, evidence can and would be supplied to prove validity, even though the approval tests might have been some considerable time ago.

Approval Test Specifications call for a paper record which can be know as either:

procedure/welder approval certificate
procedure/welder approval record
procedure/welder approval report

The following records should also be kept:

a) NDT reports
b) records of visual examination or mechanical testing
c) test pieces from destructive testing

Other records which are equally important are:

a) PROOF of regular employment on a job
b) for scheduling re-tests
c) to avoid duplication on procedure approval

TEST CERTIFICATE

Should state clearly that it is a welder approval; and not a PROCEDURE approval, and, depending on the particular Standard, should contain the following:

a) welder's name and identity number - could be his/her clock or payroll number, or possibly a photograph
b) date of the test
c) Standard of Code in full, i.e. BRITISH STANDARD 4872 PT 1 : 1982
d) testpiece details including material specification
e) equipment and consumable details: welding equipment, type of filler etc
f) extent of approval
g) sketch of run sequence, preparation and dimensions

h) other factors, operating parameters etc
i) the test results (visual, NDT, DT etc)
j) remarks
k) witnessed by
l) test supervisor
m) location

Most Standards give an example of the test certificate.

SIGNATURES ON CERTIFICATES MUST BE ENDORSED WITH COMPANY STAMP.

STORAGE AND RETRIEVAL

Most companies prefer to store the records in a conventional filing system. With larger companies it may be useful to use a computer filing system or register which could automatically give an indication of re-approval.

TWI

WELDER APPROVAL TEST CERTIFICATE

[redacted] THE WELDING INSTITUTE

Manufacturer's Welding Procedure Specification..........41920 ....

Reference No.(If applicable)........... 0223 ....

Welder's Name: ....P COCK ....

Identification: .... 54321 ....

Method of Identification: .... PASSPORT ....

Date and place of birth: ....25 DECEMBER 1952 ....

Employer: ....FRED BLOGGS INDUSTRIES ....

Code/Testing Standard: .... EN 287 ....

Examiner or test body ......BDI LTD. ....

Reference No. ....0223 ....

Photograph

(If required) NOT REQUIRED

Job Knowledge: Acceptable/~~Not tested~~ (Delete as necessary)

	Weld test details	Range of approval
Welding process	141 (TIG) 111 (MMA)	141 TIG / 111 MMA
Plate or pipe	PIPE	PIPE & PLATE
Joint type	SINGLE VEE BUTT	ANY BUTT OR FILLET WELD
Parent metal group(s)	W11	W01/W02/W03/W04/W011/
Filler metal type/Designation	ISO 3581 E19:12:3:LR23	ABOVE APPROVAL USING SPECIFIED FILLER
Shielding gases	ARGON	ARGON
Auxiliaries	ARGON BACKING	ARGON
Test piece thickness (mm)	15mm	5mm AND GREATER
Pipe outside diameter (mm)	155mm ϕ	GREATER THAN 0.5 ϕ
Welding position	HL045	ALL POSITIONS EXCEPT VERTICAL DOWN
Gouging/~~backing~~	NOT REQUIRED	REQUIRED ON DOUBLE PREPS

Additional information is available on attached sheet and or welding procedure specification No.: 00-00-199-

Type of test	Performed and acceptable	Not required
Visual	✓	
Radiography	✓	
Magnetic particle		✓
Dye penetrant	✓	
Macro		✓
Fracture	✓	
Bend	✓	
Additional Tests*		✓

* Append separate sheet if required

Name, date and signature I C ITCANBE I C Icanbe

Examiner or test body BDI LTD

Date of issue 00-00-199-

Location TWI TRAINING WORKSHOP

Validity of approval until 00-00-199-

Prolongation for approval by examiner or test body
for the following 2 years (refer to 10.2)

Date	Signature	Position or title

Prolongation for approval by employer/coordinator
for the following 6 months (refer to 10.2)

Date	Signature	Position or title

QUESTIONS

WELD PROCEDURE & WELDER APPROVAL

Q1. State six (6) essential variables

(1) welding process
(2) Joint Design.
(3) Type of base material
(4) filler metal.
(5) welding position.
(6) welding technique.
(7) Electrical characteristic.
(8) Polarity
(9) Heat treatment.

Q2. State the meaning of 'extent of approval' and give five (5) examples

area of scope for PQR

(1) Diameter of pipe
(2) welding position
(3) Joint configuration.
(4) Base material
(5) Filler metal

Q3. Explain the difference between a welding procedure specification, a procedure qualification record and a welder approval certificate

welding procedure specification - a list of essential variables when altered will effect the mechanical, metallurgical properties of the weldment. WPQR is a certificate that demonstrates the WPS is fit for use.
welder approval certificate is the piece of paper that illustrates the welder is competent to perform the welding for a particular job.

Q4. Why are procedures and welders approved?

to build confidence

WPS - to proof that the WPS meet the necessary requirements with reference to feasibility, mechanical strength etc.
Welders - to proof that the welder is competent to perform the welding activity in a particular job.

Q5. State two (2) reasons for re-approval of:

a) A weld procedure
b) A welder

change in essential variable i.e. parent metal chemical composition & Joint Design.

change in pipe size (out of the range)
failure rate
change in welding process.
time lapes

SECTION 5

DESTRUCTIVE TESTING

Destructive tests on welded joints are usually made as part of the approval of a welding procedure or a welder.

The test pieces are cut from the test weld and their location is often specified in the standard.

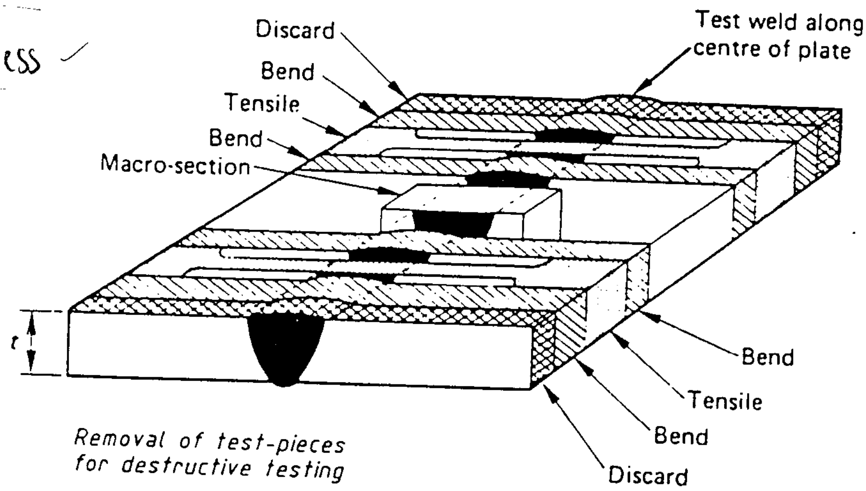
British Standards for Testing of Welds
BS 709: 1983 Methods of testing fusion welded joints and weld metal in steel

BS709 : 1983 - methods of testing fusion welded joints and weld metal in steel

Commonly used destructive tests are:

- Bend
- Tensile
- Charpy
- Fracture tests
- Macro section
- Hardness

BS709 : methods of testing fusion welded joints & weld metal in steel



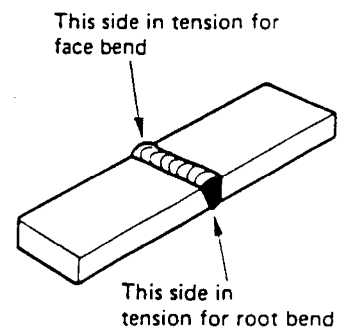
Removal of test-pieces for destructive testing

BEND TESTS (transverse and longitudinal)

Object

To determine the soundness of weld metal, heat affected zone and weld zone.

These tests may also be used to give some measure of the ductility of the weld zone. It is not usual to use longitudinal and transverse bend tests for the same application.



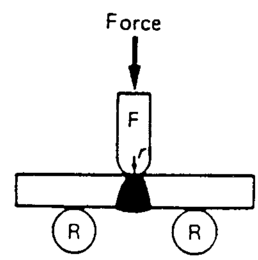
Test-piece for face or root bend

Surface in contact with former is ground flat

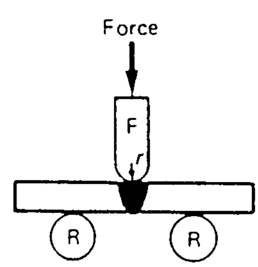
Method

The specimen is bent by the movement of a former of prescribed diameter, the relevant side of the specimen to be placed in tension. Angle of bend and diameter of former should be as specified in the appropriate application standard.

- excess weld metal to be removed



(a) Face bend



(b) Root bend

R = Roller support
F = Former of specified radius (r) at end

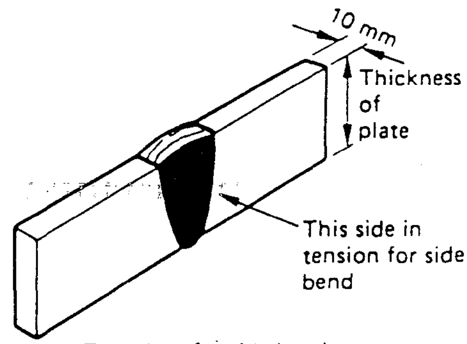
Reporting Results

1. Thickness of specimen
2. Direction of bend (root or face)
3. Angle of bend
4. Diameter of former
5. Appearance of joint after bending, e.g. type and location of flaws.

SIDE BEND TEST

Object

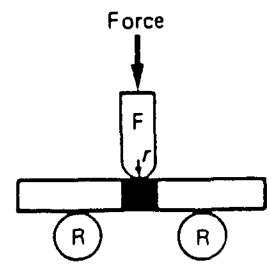
To determine the soundness of a welded joint in a cross section. This may be preferred to the transverse bend test on thick materials.



Test-piece for side bend

Method

The testing method is the same as that used for transverse bends.



(c) Side bend

R = Roller support
F = Former of specified radius (r) at end

Reporting Results

1. Width and thickness of specimen
2. Angle of bend
3. Diameter of former
4. Appearance of joint after bending e.g. type and location of flaws

max tear allowable <3 mm - API 1104

TRANSVERSE TENSILE TEST – measure the strength of the weldment

Object

- parent metal
- HAZ
- weld

Used to measure the transverse tensile strength under static loading of a butt joint employing butt welds.

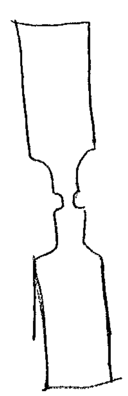
The test is not designed to give the tensile strength of the weld metal.

Method

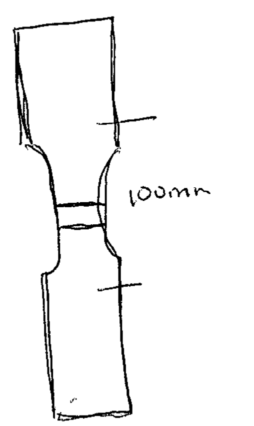
The testpiece is clamped at each end and a load is applied by a hydraulic or screw mechanism. The load is increased until fracture occurs.

Reporting Results

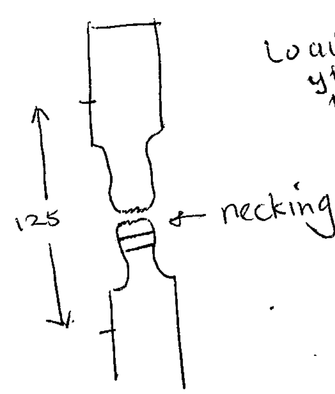
1. Type of specimen (e.g. reduced section)
2. Whether excess weld metal is removed or not remove
3. Tensile strength in N/mm^2, is calculated from maximum load and original cross sectional areas. When excess weld metal is not removed the cross sectional area shall be the product of the parent metal thickness and the width of the specimen.
4. Location of fracture, whether in parent metal, heat affected zone or weld metal. If the fracture is in the parent metal, the distance from the weld zone shall be stated.
5. Location and type of any flaws present on the fracture surfaces.

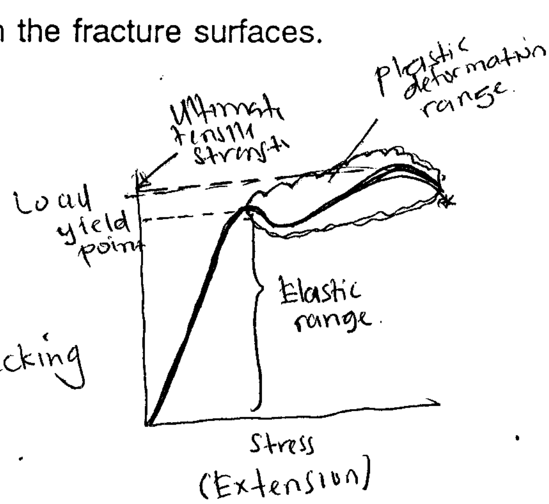


Radius reduced transverse tensile test



Reduced transverse tensile test.





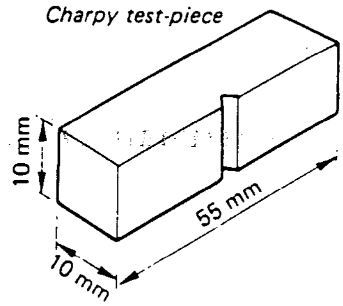
(1) Bend test
(2) ~~Hte~~ Br Trasverse tensile test
(3) Charp V Notch

CHARPY V NOTCH IMPACT TEST - measure of toughness

BS131

Object

To determine the amount of energy absorbed in fracturing a standardised testpiece at a specified temperature.

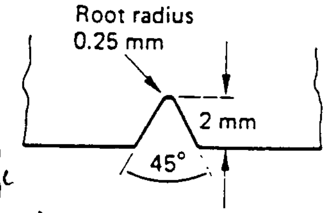


BS131: part 2:

Method

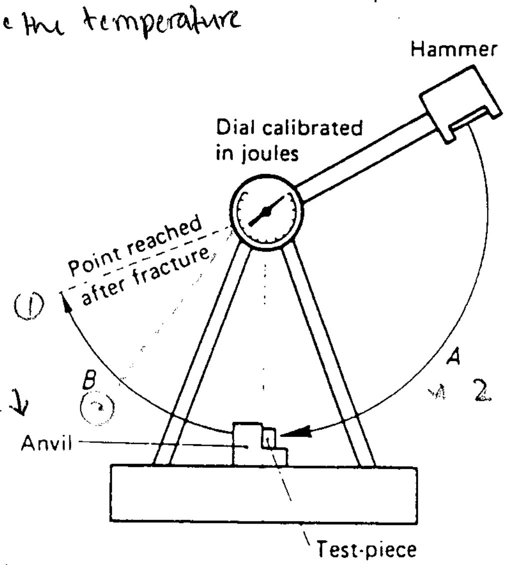
A machined, notched specimen is broken by one blow from a pendulum. Because scatter occurs in the results, at least three specimens are used to assess the joint represented.

* take 3 reading and average



Testing is carried out at a temperature specified in the appropriate application standard in accordance with BS 131: Pt 2: 1972.

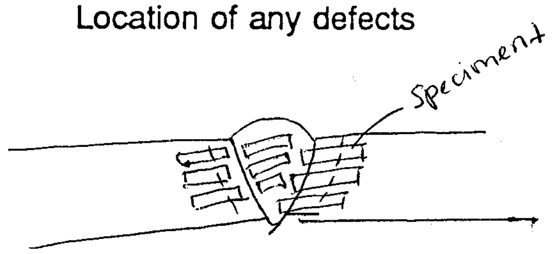
* take the temperature

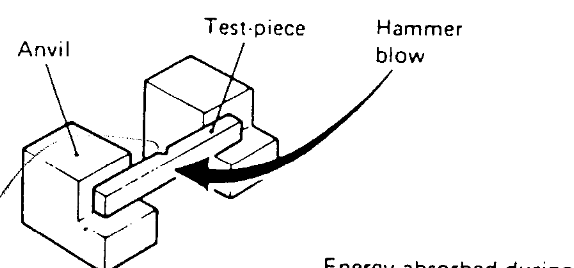


Charpy impact machine

Reporting Results

1. Location and orientation of the notch
2. Testing temperature - temperature ↓ impact value ↓
3. Energy absorbed
4. Description of fracture appearance - Flat ~~brack~~ surface ⇒ brittle
5. Location of any defects





V-notch face away from hammer

Test-piece in position on anvil

Energy absorbed during fracture is proportional to $(A-B)$

FILLET WELD FRACTURE TEST – to check for penetration of fillet weld.

Object

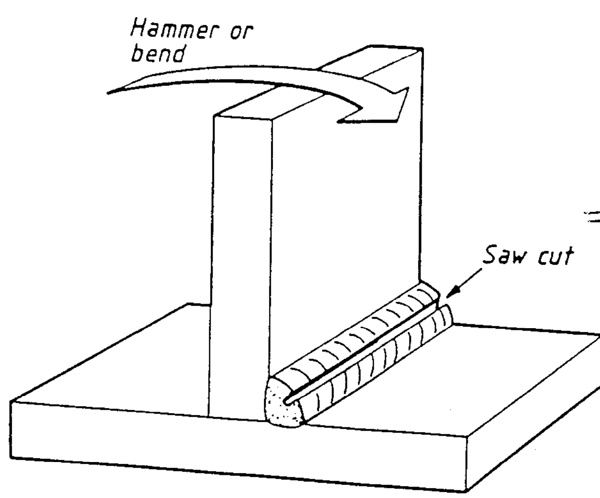
To break the joint through the weld to permit examination of the fracture surfaces.

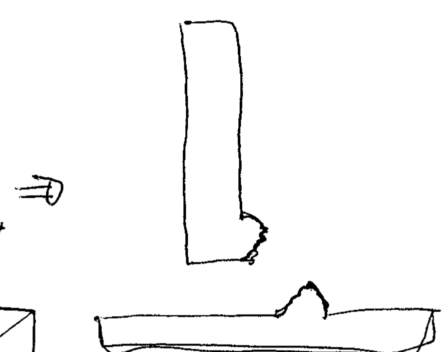
Method

The specimen is cut to length and a saw cut, normally 2mm deep, is made along the centre of the weld face. The specimen is fractured by bending or by hammer blows.

Reporting Results

1. Thickness of parent metal
2. Throat thickness and leg length
3. Location of fracture
4. Appearance of joint after fracture
5. Depth of penetration/lack of penetration or fusion





① Side bend test
② Transverse tensile test
③ Charpy V-notch test
④ Fillet weld Fracture test
⑤ Nick break test

'NICK' BREAK TEST – Test for quality of weld metal. – for butt weld.

Object

As for fillet weld fracture

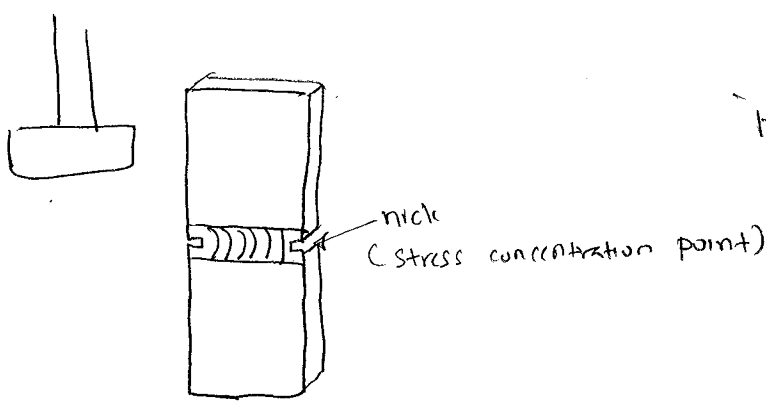
Method

The specimen is cut transversely to the weld, and a saw cut is applied along the centre of the weld face. The specimen is fractured by bending or by hammer blows.

Reporting Results

1. Thickness of material
2. Width of specimen
3. Location of fracture
4. Appearance of joint after fracture

'Nick'-Break test



QUESTIONS

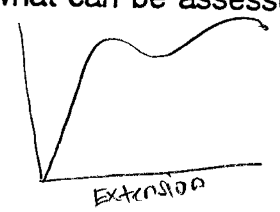
MECHANICAL TESTING OF WELDMENTS

Q1 From a tensile test the following items were progressively recorded

a) load
b) extension

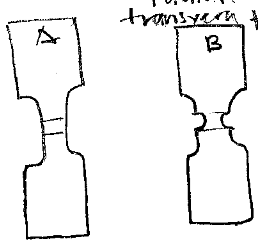
If the original length is also known, state what can be assessed.

(1) ~~Tensile Strength~~
(2) ultimate strength
(3) yield point
(4) Elongation



reduced transverse tensile test

radius reduced transverse tensile test



Q2 State the objectives of:

a) a reduced transverse tensile test – ~~for~~ ~~par~~
b) a radius reduced transverse tensile test

a) To check the tensile for entire weldment
b) weld metal only

Q3 What is the purpose of a Charpy test?

Indication of toughness of a material at a set temperature
- toughness: ability to withstand impact

Q4 What is the purpose of :

a) face bend test – To determine the soundness / and defect on or near the face of the weld
b) root bend test – to determine the soundness / and defect on ~~or~~ near root of the weld
c) side bend test ? → To determine the soundness of a welded joint in a cross section.

Q5 What is the purpose of the 'nick' in a nick bend test ?

To guide the fracture (stress concentration point)

– 1

* Hardness: ability to withstand penetration.

SECTION 6

WELD SPECIFICATIONS

Welds must be specified by clear instructions and all staff including production personnel must understand the weld symbols specified.

It may only be necessary to specify the weld size and electrode to be used.

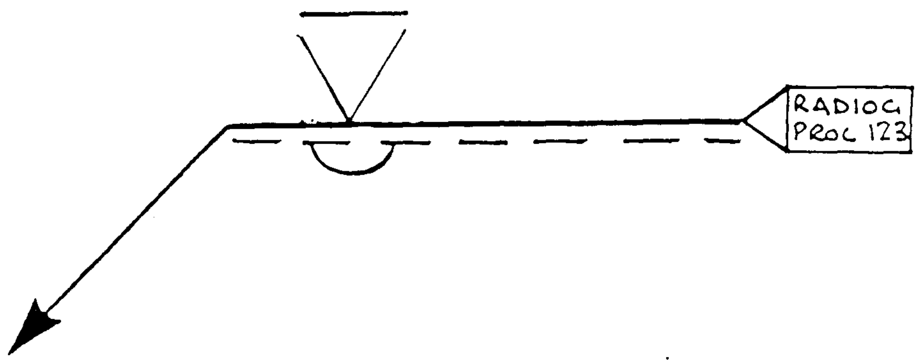
Or, the full details of a weld procedure may be needed.

Three methods are commonly used to specify a weld:

Written statement

'Weld AZ321 is to be a single V butt welded from the outside of the vessel. The surface of the weld is to be ground flush. The root is to be sealed with a weld run deposited from inside the vessel. The completed weld is to be radiographed.'

Symbols on a drawing



STANDARDS FOR WELD SYMBOLS

Although the main features of weld symbols are international, variations in detail occur from country to country. Symbols are specified by National Standards.

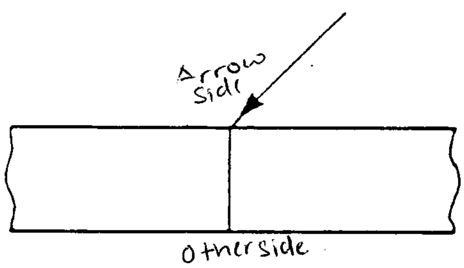
ISO 2553

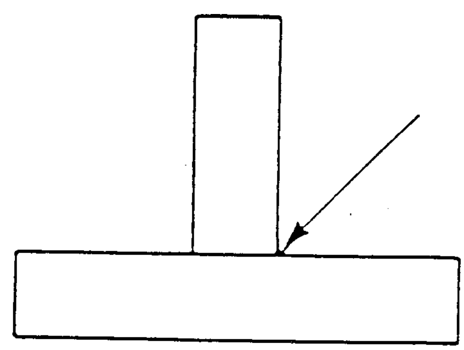
Iso 2553
UK .... BSEN 22553 = ISO 2553.
USA AWS2.4

In this text, symbols are in accordance with BSEN 22553 which supercedes BS499 and is identical to those in ISO 2553

Indicating Joint Position

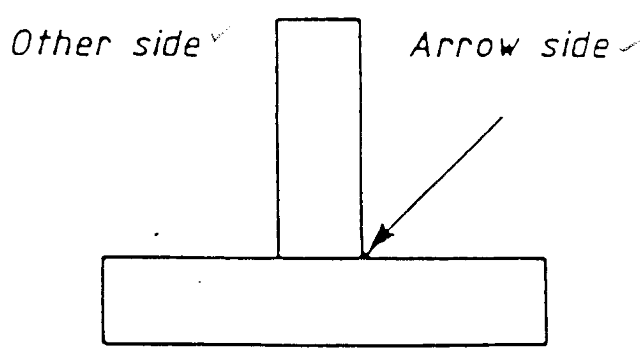
The position of the joint is indicated by an arrow.





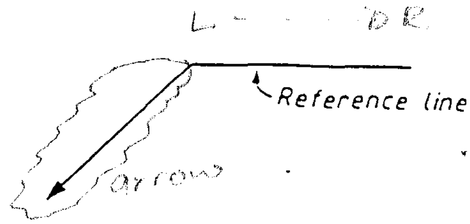
The arrow points to one side of the joint.
This is called the ARROW SIDE.

The side remote from the arrow is the OTHER SIDE.



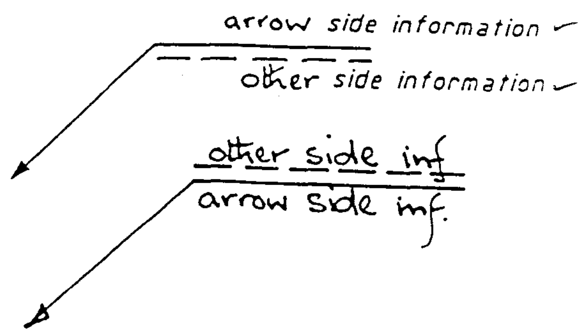
WELD DETAILS

Information about the weld is given on a reference line attached to the arrow. The reference line is always horizontal.

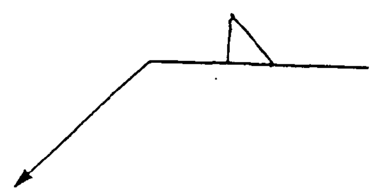


Details of the weld on the arrow side of the joint are given on the solid line.

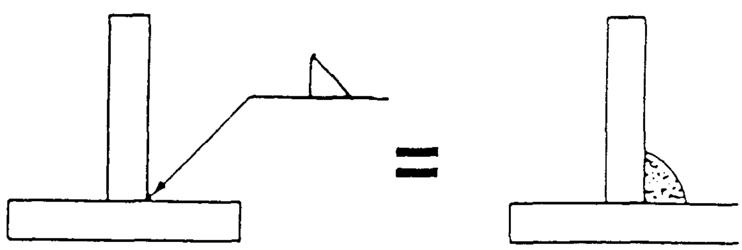
Other side information is on the dotted line, and can be shown above or below the solid line.



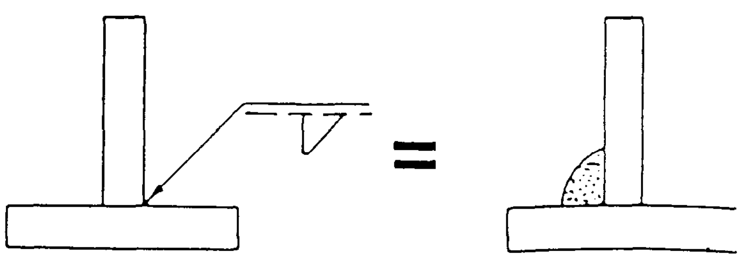
A fillet weld is indicated by a triangle placed on the reference line.

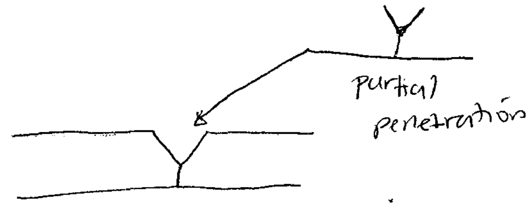


A triangle on the reference line specifies a fillet weld on the **arrow side** of the joint.



A triangle on the dotted line
A triangle **above** the line calls for a fillet weld on the **other side** of the joint.

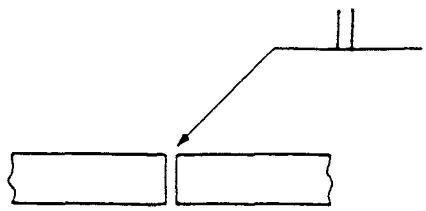




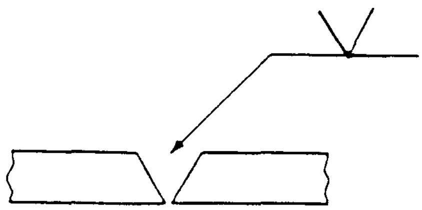
TYPES OF BUTT WELD

The common types of edge preparation associated with a butt weld are indicated as follows :

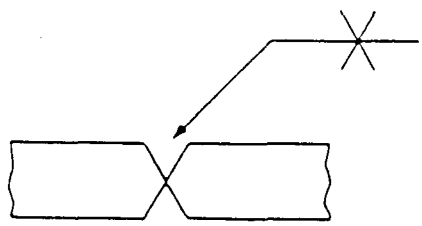
Square edge preparation



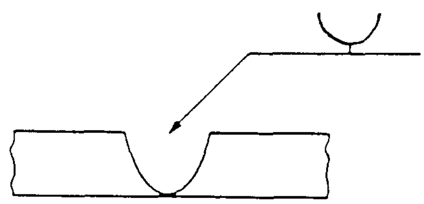
Single V preparation



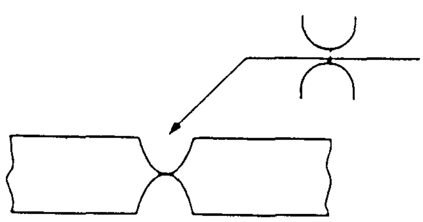
Double V preparation



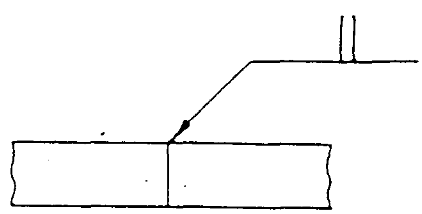
Single U preparation



Double U preparation

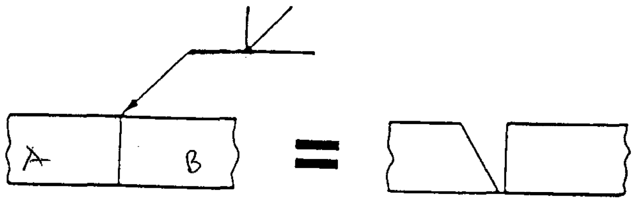


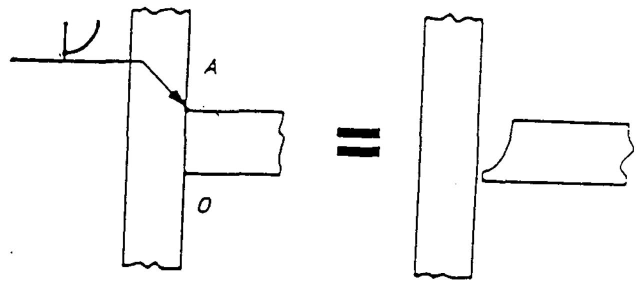
Using symbols it is not necessary to draw the shape of the edge preparation. The joint is shown as a single line.

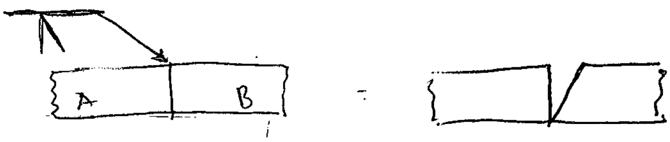


ASYMMETRICAL PREPARATIONS

In some joints, only one component is prepared, e.g. single bevel butt or single J butt.







A = Arrow side
O = Other side

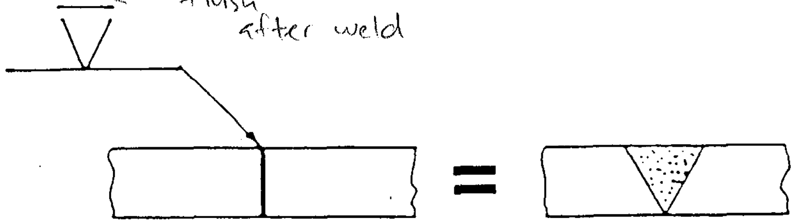
In these cases the arrow points at the edge which is to be prepared.

SURFACE PROFILE

The surface profile can be indicated by an extra symbol placed on the top of the weld symbol.

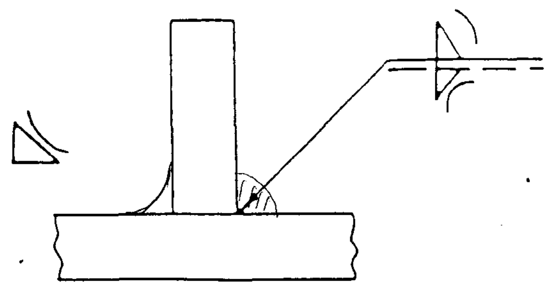
Single V butt weld with a flat surface. (Flushed after welding. Usually by grinding).

flush
after weld



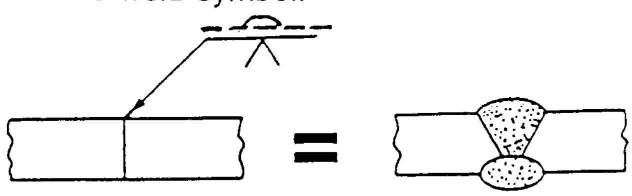
Convex fillet weld.

Concave fillet weld. (May be achieved by welding alone or by subsequent grinding).



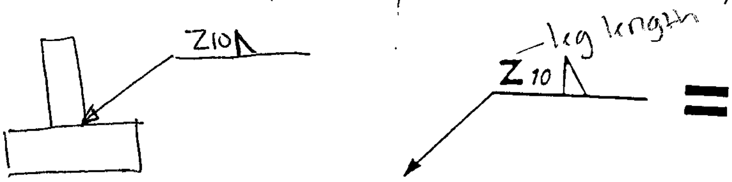
SEALING RUN

If the root of a butt weld is to be sealed the symbol is placed on the reference line, opposite the weld symbol.

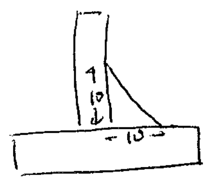


DIMENSIONING FILLET WELDS

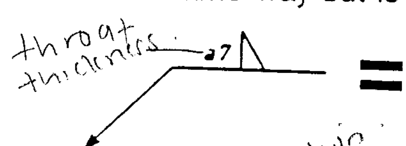
The leg length of a fillet weld is located in front of the weld symbol (triangle). (The dimension is in millimetres) preceded with the letter Z



10mm leg length
fillet weld

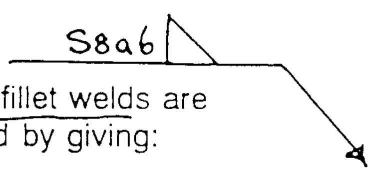


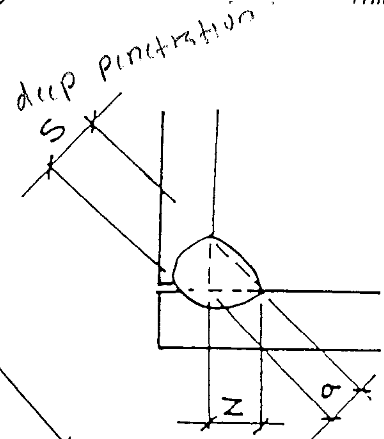
Throat thickness is indicated in the same way but is preceded by the letter 'a'.



fillet weld with
7mm design throat
thickness

For deep penetration fillet welds the dimensions are indicated for example:



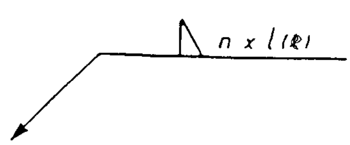


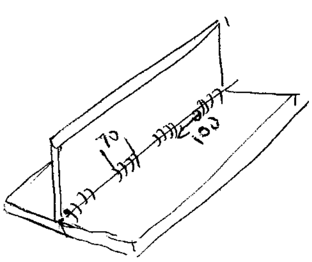
Intermittent fillet welds are dimensioned by giving:

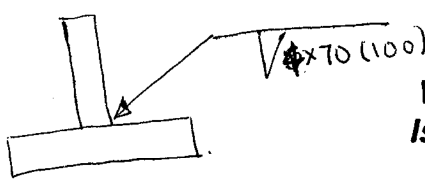
- number of weld elements (n).

- length of weld element (l).

- distance between weld elements (e).



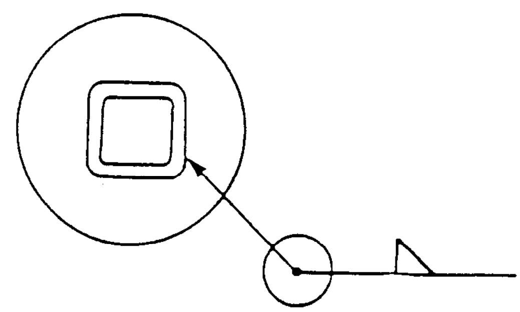




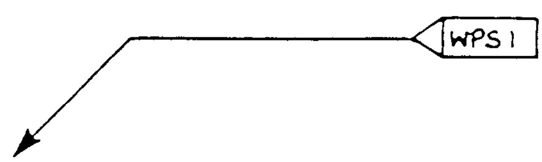
SUPPLEMENTARY SYMBOLS

Three supplementary symbols are in general use:

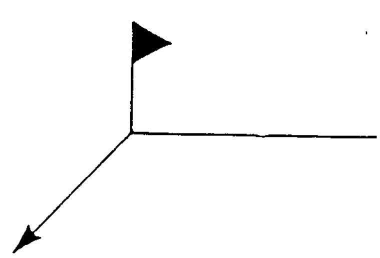
Weld all round the component



Inspect by NDT, Weld, Paint, etc.
the reference document can
be included in the box.



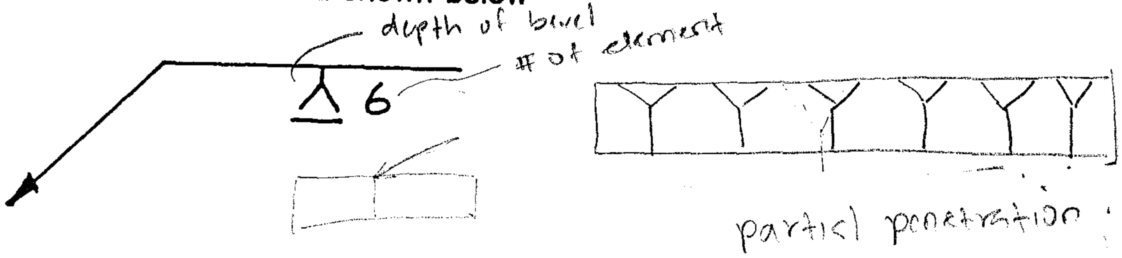
Weld this joint on site



QUESTIONS

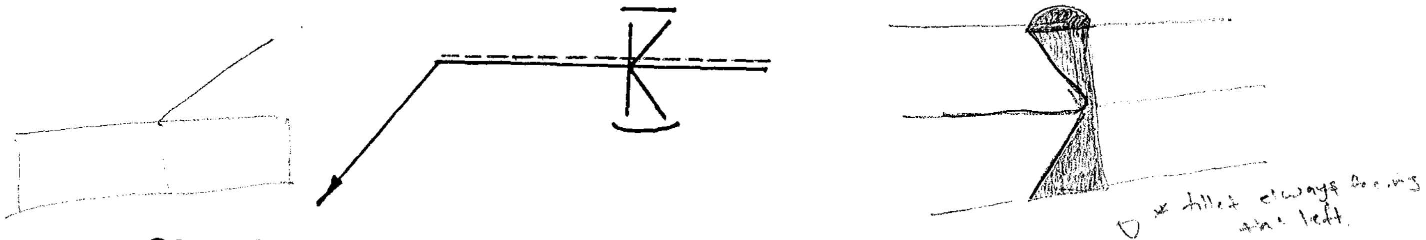
SYMBOLS FOR WELDING SPECIFICATION

Q1 Sketch/describe the weld shown below

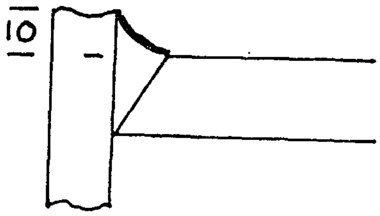


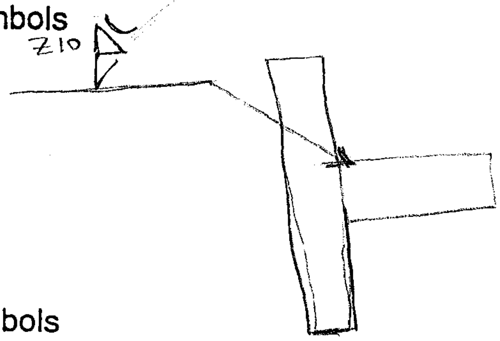
partial penetration

Q2 Sketch/describe the weld shown below

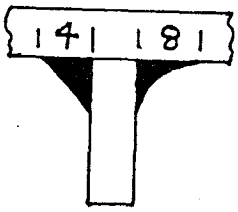


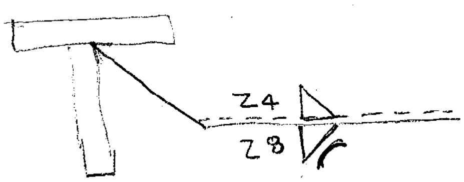
Q3 Specify the weld shown below by means of symbols



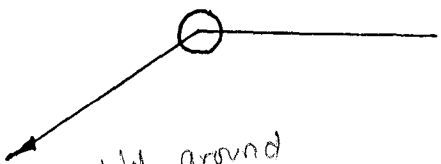


Q4 Specify the weld shown below by means of symbols

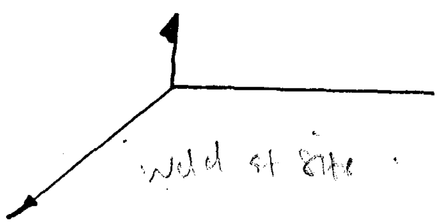




Q5 Describe the following:



weld around the component



weld at site

SECTION 7

REVIEW OF STEELS AND MATERIAL DEFECTS

The term 'steel' is used to describe many different metals, they are all alloys based on iron, but the alloying additions, such as carbon, manganese, silicon and chromium, etc., singly or in combination produce a range of metals with widely differing physical and mechanical properties as well as quite different weldability.

IRON	Fe – Basic ingredient of steel ⇒ pure state, soft, ductile
CARBON	C – Increase hardness & strength ⇒ side effect more than 0.4% carbon creat problem with hydrogen cracking
MANGANESE	Mn – add toughness and resistance to sulfur.
SILICON	Si – Dioxsidizer add via electrode & bring O_2 to surface while steel molten.
ALUMINIUM	Al – Dioxsidizer add to raw material
CHROMIUM	Cr – Corrossion resistance.
MOLYBDENUM	Mo – for high temp strength ⇒ combat creep (stress, streching & break)
TITANIUM	Ti – Stabilizer ⇒ combat weld decay.
NIOBIUM	Nb – Stabilizer ⇒ combat weld decay.
VANADIUM	V – add hardness, strength & toughness.
SULPHUR	S – Impurity ⇒ lead to hot shortness (when hot prone to break/crack). should be <0.03%
NICKEL	Ni – improve toughness.
COPPER	Cu – grain refinement, improve weathering (better to withstand corrossion)

RIMMING STEEL

Composition 0.09%C
0.9%Mn – toughness & resistence to sulfur.
\+ residuals

Weldability The weld pool will require to have added deoxidant via a filler rod.

LOW CARBON STEEL up to 0.25% CE

Composition 0.2%C
0.9%Mn – toughness & resistence to sulfur
\+ residuals

Weldability The general weldability is good but the level of residuals (S) may cause weld metal/heat affected zone cracking.

MEDIUM CARBON STEEL up to 0.55% CE

Composition 0.45%C
0.90%Mn
\+ residuals

Weldability The high carbon content induces hydrogen cracking in the HAZ as the section size increases.

HIGH CARBON STEEL

Composition 0.8%C
0.9%Mn
+ residuals

Weldability The weld pool is subject to solidification type cracking and the HAZ suffers hydrogen cracking.

CARBON–MANGANESE STEEL

Composition 0.2%C
1.5%Mn - add strength & combat sulfur
+ residuals
may also contain Ti, Nb and V - add hardness, strength & toughness
stabilizer & combat weld decay

Weldability These high Mn steels have good toughness, particularly the Ti, Nb and V grades, and the main weldability problem is to maintain these.

QUENCHED AND TEMPERED STEEL

Composition 0.4%C Heat treatment done
1.0%Mn
0.8%Cr corrosion resistance
0.3%Mo - High temp ⇒ combat creep
stabilizer + Ti or Al Dioxidiser
+ residuals

Weldability These steels are difficult to weld, and defect free welds with good mechanical properties are only attained by using the greatest care.

HIGH TEMP. STEEL

Composition 0.25–9%Cr corrosion resistance
0.25–3%Mo High temp character
etc.
high temperature & combat creep

Weldability The weldability of the low Cr is difficult.

LOW TEMP. STEEL

Composition 3.5–9%Ni improve toughness.
etc.

Weldability The higher Ni are subject to solidification cracking.

High Strength

MICRO ALLOYED STEEL (HSLA)

Composition
0.25%C – Strength & Hardness
1.5%Mn – toughness & resistence to sulfur
0.002%V
0.005%Nb min. – Dioxidise
0.003%Ti

add hardness strength & toughness

Weldability
These steels may suffer hydrogen cracking in the weld metal.

STAINLESS STEELS

1. MARTENSITIC SS – knife, fork

Composition
11%Cr – corrossion resister.
0.08%C
+ residuals

Weldability
Poor due to hydrogen cracking.

2. FERRITIC SS – knife

Composition
12–27%Cr – corrossion resistan.
0.08%C – Hardness & Strength
+ residuals

Weldability
Poor due to cracking, brittleness and temper embrittlement.

3. AUSTENITIC SS (NB NON-MAGNETIC) – 304, 309, 316

Composition
18–27%Cr – corrossion resister
8–22%Ni – improve toughn
0.08%C – hardness & strength
+ residuals

Weldability
Problems with solidification cracking and weld decay.

$\boxed{\text{Duplex}}$ – autenitic & Ferritic steel
no apply preheat

50mm

A great variety of materials may require to be inspected with a view to satisfactory welding.

Inspection points are:

Specification/supplier – to mill sheet or reference number.

Quantity:

Size	–	length, breadth, thickness, diameter
Distortion	–	flatness/ovality
Condition	–	rust/paint, heat treatment
Defects	–	laps, bands, laminations
Storage		

SPECIFICATION

It is not, in general, safe for the inspector to identify materials by composition from mill sheet, since very small variations or additions to the metal may give rise to significant changes in properties and weldability. However, limited selectivity is permissible, such as % carbon maximum, etc.

The procedure is for the mill sheet to be submitted for approval and then the inspector records and transfers the reference number.

SUPPLIER

This can be found on the Goods Inwards documents or the receipt documents, or occasionally on packaging or even marked on the metal.

QUANTITY

The quantity being inspected should always be noted as well as the sample size, if 100% inspection is not being employed.

SIZE

Sizes must be checked for secondary identification as well as conformance. The inspector will, as appropriate, be given tolerances on size which are permissible.

DISTORTION

A check is often required on the degree of distortion, i.e.

Flatness
squareness
straightness
ovality
consistent wall thickness

CONDITION

Rust, paint and grease on the surface of the metal are all harmful to welding and must usually be removed at least near to the actual weld. Guidance is normally given to the inspector regarding acceptable levels or the treatment which is required. An inspector should be alert to gradual changes, such as increased corrosion. Carefully maintained specimens showing acceptable conditions are often the best method. Heat treatment condition, annealed, normalised etc.

DEFECTS

In wrought products the most common defects are laps and laminations. Both these will normally be subsurface so unless NDE is being employed only, the edges of plate, and particularly cut edges, can be inspected. The lap/lamination will appear as a narrow black line parallel to the surface.

STORAGE

After inspection and approval for use it is essential that the metal is stored in such a way as to maintain its good condition. Protect from corrosion and mechanical damage.

Questions to be asked:

1. Do the markings on the material match those on the procedure sheet or drawing?
2. Are the dimensions correct?
3. Is the surface condition satisfactory for welding?

QUESTIONS:

REVIEW OF STEELS AND MATERIAL DEFECTS

Q1 Name two (2) wrought plate defects.

① lamination
② Lap (near surface material)
③ Segregation band

Q2 Give examples of composition

a) A rimming steel – 0.09% C, 0.9% Mn + Residual + Fe
b) A low carbon steel – 0.2% C, 0.9% Mn + residuals + Fe.
c) A tool steel – 1% C, 0.9% Mn balance Fe.

Q3 Give an example by composition of a stainless steel (austenite)

18% Cr
8% Ni
+ Fe.

Q4 What is the purpose of the increased Mn content of a carbon–manganese steel

add toughness and resistance to sulfur

Q5 State the features/defects which should be noted when inspecting wrought plate

① Size
② Type
③ Condition

SECTION 8

CONSUMABLES

Welding consumables are the:

Electrodes
Wire (lengths or rolls)
Fluxes
Gases.

Each consumable is critical in respect to –

Specification/supplier
Condition
Treatment (if any)

Take as an example a common MMA covered electrode. This will be to a specified type but an additional requirement may be that only one or two suppliers/manufacturers are acceptable. The electrode must be in good condition with regard to corrosion and mechanical damage and so storage and mechanical handling are important. If the electrode requires heat treatment for low hydrogen potential then the temperature, time and oven condition require attention. The issue of electrodes to the welder for use and the procedures for recycling and scrap must often be dealt with care.

There are many codes in existence which cover the various consumables. The only reasonable rule is to keep to what is specified unless (and only unless) a written order for variation is received.

Covered Electrodes

BS 639
AWS A5 1
ISO 2560
BS 2493
BS 2926

Gas-shielded wires

BS 2901, Part 1-5

Gases

BS 4365
BS 4105

Identification of covered electrodes

In the BS system for carbon and carbon manganese steels the electrode may be partially or completely specified by a letter/number.

The summary sheet gives details.

British Standards System

BS specification: BS 639: 1986

FIRST GROUP

Electrode designation	Tensile strength, N/mm²	Minimum yield stress, N/mm²
E43	430-550	330
E51	510-650	380

COVERING

B	basic
BB	high efficiency
C	cellulosic
O	oxidising
R	rutile (medium coated)
RR	rutile (heavy coated)
S	other types

EFFICIENCY

% recovery to nearest 10% (≥110)

(H)

Indicates hydrogen controlled (≤15ml/100g)

Tensile strength.

position

E 51 33 B 160 2 0 ✓ (H)

temperature at impact value of 28J & 47J

efficiency

SECOND GROUP

First digit	Temperature for impact value of 28J, °C
0	Not specified
1	+20
2	0
3	−20
4	−30
5	−40

Second digit	Temperature for impact value of 47J, °C
0	Not specified
1	+20
2	0
3	−20
4	−30
5	−40
6	−50
7	−60
8	−70

POSITION DIGIT

1	all positions
2	all positions except vertical down
3	flat and, for fillet welds, horizontal vertical
4	flat
5	flat, vertical down and, for fillet welds, horizontal vertical
9	any position or combination of positions not classified above

ELECTRICAL DIGIT

Code	Direct current	Alternating current
	Recommended electrode polarity	Minimum open-circuit voltage, V
0	Polarity as recommended by manufacturer	Not suitable for use on AC
1	+ or −	50
2	−	50
3	+	50
4	+ or −	70
5	−	70
6	+	70
7	+ or −	80
8	−	80
9	+	80

BRITISH STANDARD 639 1986

MANUAL METAL ARC WELDING CONSUMABLES FOR C.C/Mn STEELS

~~L000~~

Basic

E 51 33 B 160 2 0 (H)

COVERED ELECTRODE

Tensile
STRENGTH
(N/mm²) (10)

TOUGHNESS
Indication

COVERING

EFFICIENCY (%)

POSITIONAL CAPABILITY

ELECTRICAL CAPABILITY

LOW HYDROGEN POTENTIAL
≤ 15ml/100g

AMERICAN WELDING SOCIETY A5. 1-81
MANUAL METAL ARC WELDING
CONSUMABLES FOR
C. C/Mn STEELS

E 70 1 8 G

ARC WELDING ELECTRODE — E

TENSILE STRENGTH lb/"^{2} (PSI) — 70

WELDING POSITION — 1

1 = ALL POSITIONAL 2 = FLAT & HV FILLETS

FLUX COVERING CURRENT TYPE AND POLARITY — 8

A5.5-81 LOW ALLOY STEEL (ALLOY CONTENT) — G

Differen Code.

refer to Hand out.

TWI

THE WELDING INSTITUTE

QUESTIONS:

THE BRITISH STANDARD CLASSIFICATION OF MMA ELECTRODES

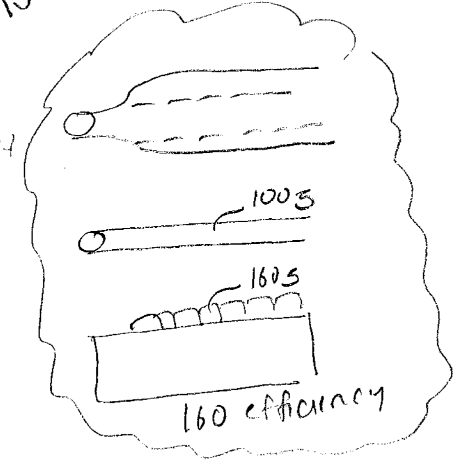
Q1. Explain the following factors:

electrical potential — low hydrogen

E 51 33 B 160 2 0 (H)

covering — all positions except vertical down

E ⇒ covered electrode
51 ⇒ 510N/m² (Tensile Strength)
33 ⇒ Impact toughness value at -20 is 28J
B ⇒ Basic covering — 160 - efficiency



Q2. What is the compulsory part?

E 51 33 B - covered

Q3. State the meaning of the following:

a) B = basic
b) R = Rutile.
c) AR = Acid Rutile
d) O = Oxidizing
e) C = Cellulosic
f) RR = Rutile (heavy coated)

Q4. When an electrode specification terminates with an (H), what is usually required in order to give the specified results?

Baking, Holding & quiver

Q5. What is the meaning of:

"S" size "T" time "C" condition

SECTION 9

THE FOUR ESSENTIAL FACTORS FOR ESTABLISHING A WELD

Welding is usually regarded as a joining process in which the work pieces are in atomic contact often with a filler metal of broadly similar properties.

Hence soldering and brazing are excluded but both solid-state and fusion welding are included. different material

Solid state processes include:

Forge welding — heat & hammer
Friction welding → ~~Strp~~ Stay & stir

Fusion welding processes include:

Oxy-acetylene
Manual metal arc (MMA)
Metal inert/active gas (MIG/MAG)
Submerged arc welding (SAW)
Electro-slag welding (ESW)

Fusion welding ① Oxy-acetylene ② manual metal arc ③ metal Inert/Active gas ④ Submerged arc ⑤

Fusion welding factors

similar properties of the base metal.

1. Fusion (melting)

   The metal must be melted which requires a high intensity heat source.

2. The process must remove any oxide and other contamination from the joint faces. — provide protection from surface contamination.

3. Contamination by the atmosphere must be avoided.

4. The welded joint must possess adequate properties.

mechanical properties
e.g. Tensile strength.

QUESTIONS:

FOUR FACTORS IN WELDING

Q1. State the four (4) factors which must be satisfied for good welds.

① Fusion
② Provide protection from surface contamination
③ " " " atmospheric contamination
④ Adequate Mech. properties

Q2. What ar the mechanical tests which are usually used to ensure compliance with adequate mechanical properties.

① Tensile test ✓
② Hardness test ✓
③ Bend test ✓
④ charpy test ✓

Q3. Name three (3) methods of protecting the molten metal from contamination.

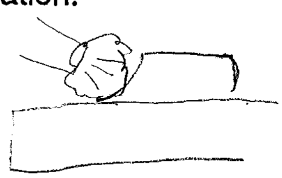
① Slug / Flux .
② Gasshield
③ Vacum .

Q4. Describe the metal cleaning requirements required when making high class stainless steel welds.

Acetone
① Chemically clean - clean steel
② Mechanically clean - remove residual from mechanical cleaning.
③ chemically clean

Q5. Name two methods of protecting the arc from contamination.

① Shielding Gas
② Flux



SECTION 10

(Wednesday)
30/05/07

EQUIPMENT

Welding inspection necessarily involves checking that the correct welding/cutting process is being used, that the equipment is in workable condition and that the welding parameters of amperes and volts are being adhered to. The following pages outline the constant current process and list the types of defects which are associated with them.

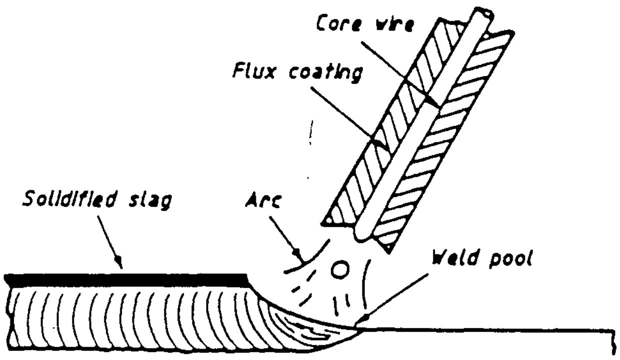
You will notice that the arc processes are divided into two (2) types ('drooping' and 'flat'). This refers to their volt-amp output characteristics.

The conventional machine is known as the constant current machine (drooping characteristic) and has for many years been used for manual metal arc and tungsten inert gas welding. By using drooping an alteration in arc length gives a very small change in current.

A 'DROOPING ARC' PROCESS (CONSTANT CURRENT)

MANUAL METAL-ARC (MMA)

Shielded metal-arc (US); Stick; Electric arc welding



Type of Operation
Manual.

Mode of Operation
Arc melts parent plate and electrode to form a weld pool which is protected by flux cover.

Operator adjusts electrode feed rate, *i.e.* hand movement, to keep arc length constant. Slag must be removed after depositing each bead. Normally a small degree of penetration, requiring plate edge preparation. Butt welds in thick plate or large fillets are deposited in a number of passes. The process can also be used to deposit metal to form a surface with alternative properties.

Typical defects associated with this process:

Overlap.

• Porosity.

• Slag inclusions.

• Excessive spatter.

Stray flash.

Incomplete penetration.

Excess penetration.

• Undercut.

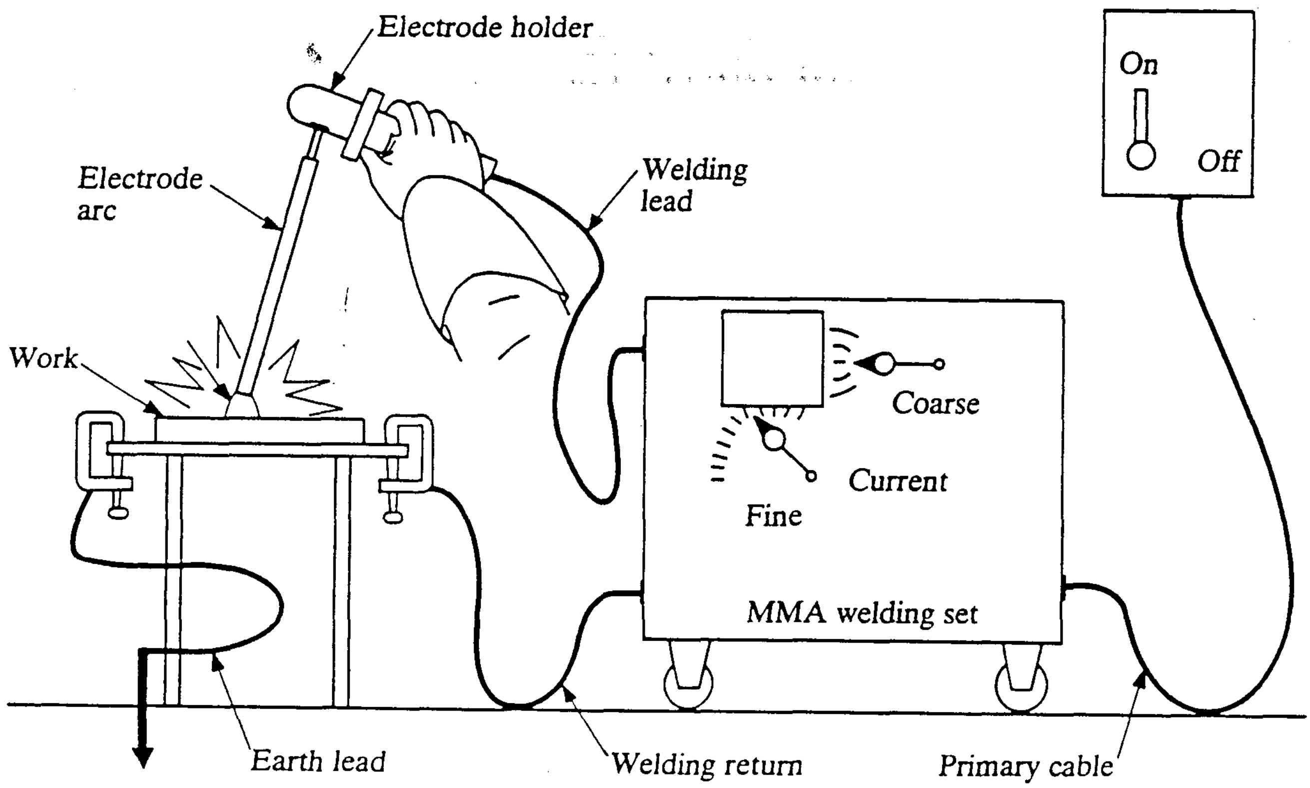
Crater cracks.

Lack of fusion.

WELDING EQUIPMENT

MANUAL METAL ARC

Welding sets



Manual metal arc sets are manufactured in a range of sizes, usually distinguished by current: note the duty cycle at which the current is quoted when comparing sets. Engine powered generators allow operation away from mains supplies.

Electrical input is single-phase at 240 volts for small sets, and 415 volts (2 live phases of a three-phase supply) for larger ones.

Output is AC or DC. AC only sets need an open circuit voltage of 80V to run all electrodes; 50V is safer and allows more current to be drawn, but is limited to general purpose rutile electrodes only.

A control on the set adjusts current; the current is shown either on a simple scale, or for accurate work on a meter.

MANUAL METAL ARC WELDING

INTRODUCTION

In manual metal arc welding the heat source is an electric arc which is formed between a consumable electrode and the parent plate. The arc is formed by momentarily touching the tip of the electrode onto the plate and then lifting the electrode to give a gap of 3.0mm (⅛") - 6.0mm (¼") between the tip and the plate. When the electrode touches the plate, current commences to flow and as it is withdrawn the current continues to flow in the form of a small spark across the gap, which will cause the air in the gap to become ionized, or made conductive. As a result of this the current continues to flow even when the gap is quite large. The heat generated is sufficient to melt the parent plate and also melt the end of the electrode; the molten metal so formed is transferred as small globules across the arc into the molten pool.

EQUIPMENT

1. Power Source

The welding machine consists of a power source with welding lead and an electrode holder.

The function of the power source is to provide the voltage necessary to maintain an arc between the electrode and the workpiece and the end of the electrode. The amount of current provided by the power source can be altered by a control to suit different welding conditions.

Power source may supply direct current (DC) or alternating current (AC) to the electrode. AC transformers and DC generators supply only one type of current, but transformer - rectifiers can be switched between AC or DC output.

2. Welding cables

The welding current is conducted from the power source to the work by multi-strand, insulated flexible copper or aluminium cables. A return cable is required to complete the welding circuit between the work and power source. The size of the cable must be sufficient for the maximum output of the welding power source.

The earth lead is a third cable and acts as a safety device in the event of an electrical fault.

3. **Electrode holder**

The holder should be relatively light, fully insulated and rated for at least maximum power source output.

4. **Return clamp**

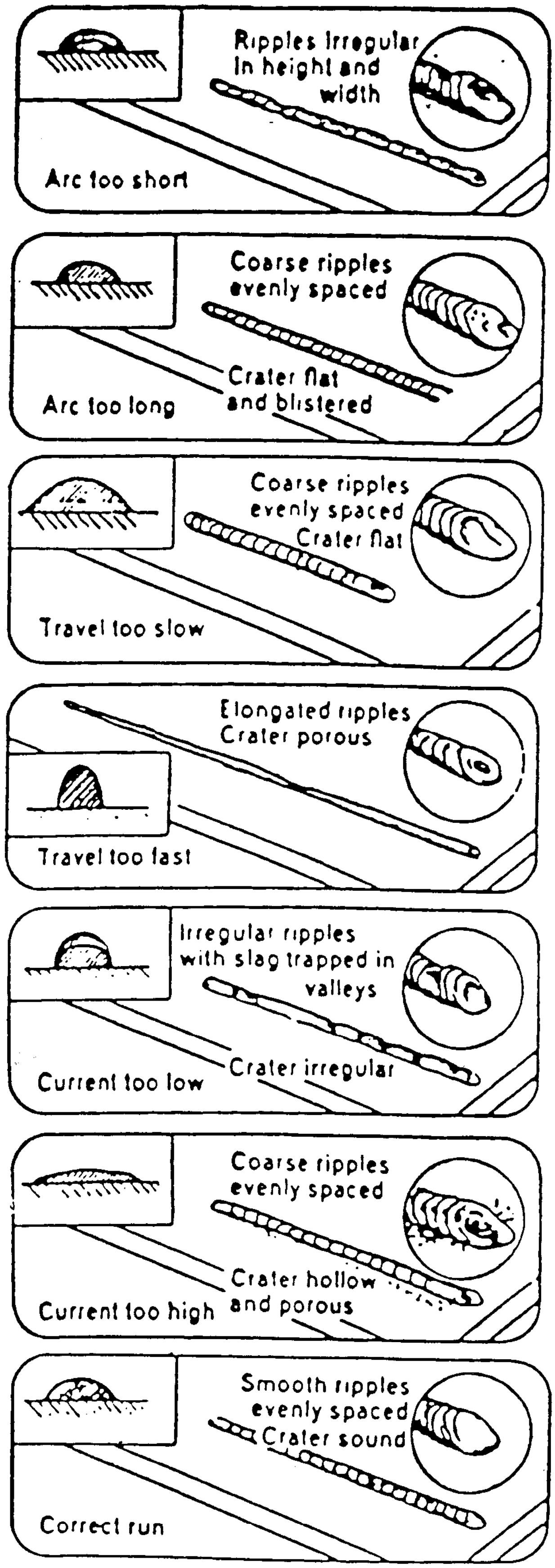
This is fastened to the work or bench on which the work is placed and completes the welding circuit. The surface clamped should be clean enough to allow good metal to metal contact.

5. **Welding shield or helmet**

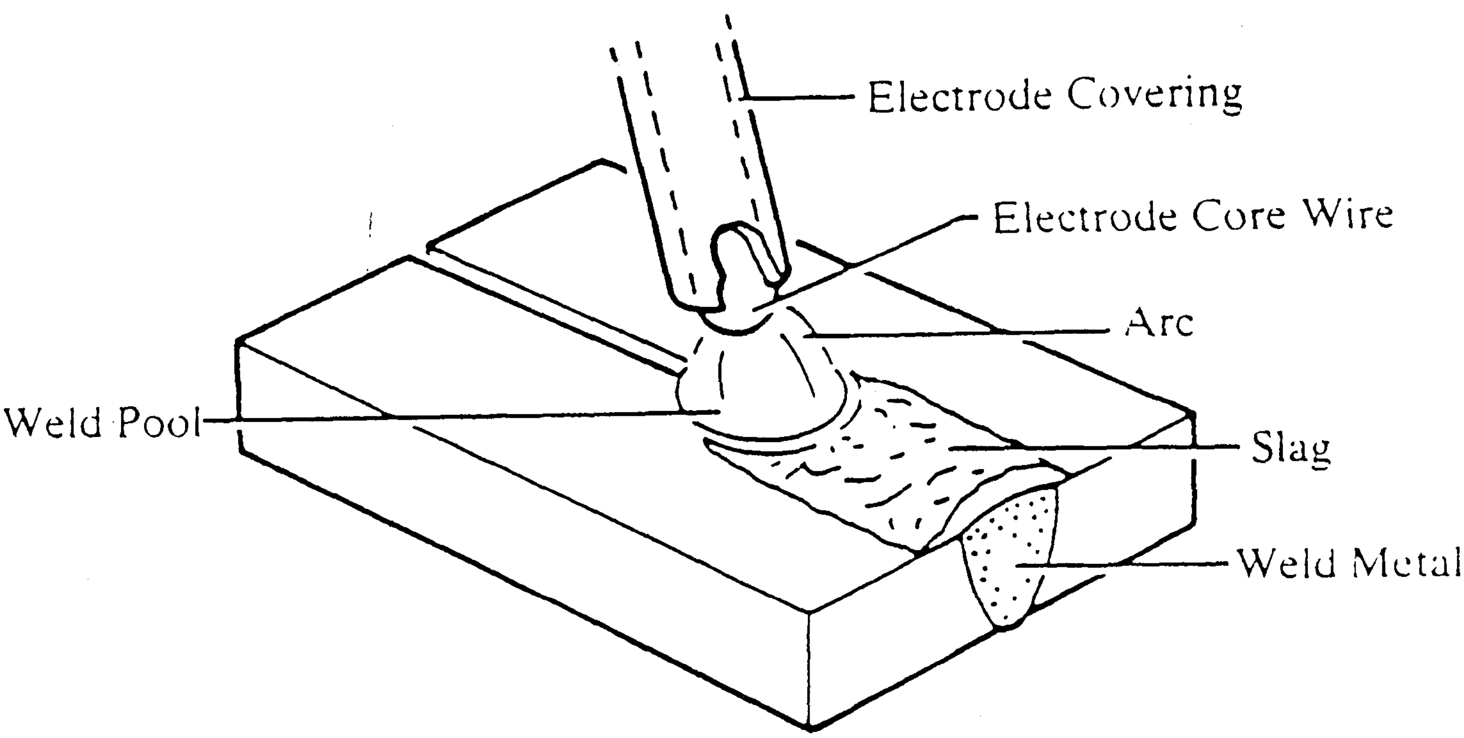
A welding shield or helmet is necessary for protection from arc ray and heat, and the spatter from the molten metal. The arc is viewed through a filter which reduces the intensity of the radiation, but allows a safe amount of light to pass for viewing the weld pool and end of the electrode.

EFFECT OF VARIATION IN PROCEDURE

1. Too short an arc length will cause irregular piling of the weld metal.
2. Too long an arc length will cause the deposit to be coarse rippled and flatter than normal.
3. A slow rate of travel gives a wider thicker deposit, shorter than normal length; too slow a rate of travel may allow the slag to flood the weld pool causing difficulty in controlling deposition.
4. A fast rate of travel gives a narrower, thinner deposit, longer than normal length; too fast a rate of travel may prevent adequate interfusion with the parent metal.
5. A low welding current tends to cause the weld metal to pile up without adequate penetration into the parent metal; too low a welding current makes the slag difficult to control.
6. A high welding current gives a deposit that is flatter and wider than normal with excessive penetration into the parent metal; too high a welding current causes considerable spatter.
7. With correct arc length, correct rate of travel, correct welding conditions and technique, the run deposited metal will be regular in thickness and width, with a neat finely rippled surface, free from porosity or any slag entrapment.



The shielded arc. Manual arc weld on steel base plate with a covered electrode.



QUESTIONS:

MANUAL METAL ARC

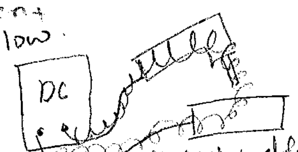
Q1. State the main three (3) welding parameters of the process.

a) Amperes
b) Run out length (travel speed)
c) Voltage

Q2. Explain two types of electrical supply and an advantage of each type.

① DC current
- ~~Stable~~ Stable.
- choice of polarity

② AC current
- No arc blow.



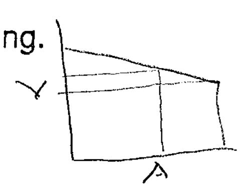
magnetic effect results droplet move around

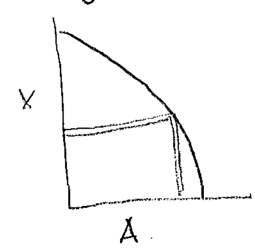
Q3. What type of power source characteristics is considered essential for MMA?

~~a)~~ Constant current ?
b) Constant voltage ?

WELDING MACHINES

FLUX CORED	TIG (GTAW)
MIG/MAG	MMA (SMAW)
CO_2	(manual)
(Semi-auto)	↓
↓	Constant current
Constant Voltage.	(Drooping characteristic)
(Flat characteristic)	





Q4. Give six functions of an electrode coating.

i) Provides a gas shield
ii) Helps start the arc.
iii) Help stabilize the arc
iv) provide alloying element (mechanical properties)
v) ~~Impro~~ Help shape the weld.
vi) Slow the cooling rate.

Provide deoxidiser to prevent porosity.
Provide Iron powder to increase deposition rate.

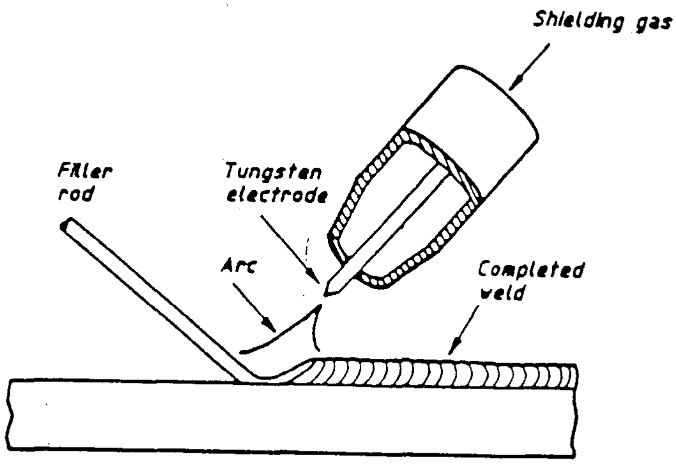
Q5. What is the usual composition of the core wire of an MMA electrode?
low carbon steel.

SECTION 11

A 'DROOPING' ARC PROCESS (CONSTANT CURRENT)

TUNGSTEN INERT GAS (TIG)

Tungsten arc gas shielded; Argon arc; Gas tungsten arc welding; GTAW (USA)



Type of Operation
Usually manual, but can be mechanised.

Mode of Operation
An arc is maintained between the end of a tungsten electrode and the work. The electrode is not consumed and the current is controlled by the power source setting. The operator must control the arc length and also add filler metal if needed to obtain the correct weld: consequently, a high degree of skill is needed for best results.

The arc is unstable at low currents. Special provision is made for starting (h.f. or surge injection) and for welding thin materials (pulse TIG).

In all cases the electrode and weld pool are shielded by a stream of inert gas. Filler rod is fed into the weld pool in some cases.

Typical defects associated with this process:

- Tungsten inclusions.
- Lack of fusion.
- Incomplete penetration.
- Undercut.
- Porosity.
- Burnthrough.
- Excess penetration.
- Oxide inclusions.
- Unequal leg length.

Consumables

TIG (GTAW)	MIG/MAG (GMAW)	MMA (SMAW)	SAW	OAW
shielding gas + Filler rod	shielding gas + filler wire	Electrod	Flux + Filler wire	Gas + Filler rod

TIG WELDING SETS

Sets are manufactured in a range of sizes, identified by current: also important is whether the output is DC only, DC/AC or AC only. AC is needed for most work on aluminium.

Electrical input may be single-phase at 240 or 415v, or three-phase at 415v. On the normal d.c. or a.c. output an 'h.f. unit' superimposes a high voltage high frequency supply to cause a spark from electrode to parent metal when the welder wants to start the arc: alternatively, an electronic control switches the current on just as the welder lifts the electrode off the work ('touch start'). The output has a drooping characteristic, so by switching off the h.f. unit it can be used for manual metal arc. Alternatively, an add-on h.f. unit can convert a manual metal arc set to TIG.

The welder often uses a foot switch wired to the set to switch on and off, and to give a fine control of current.

A 'slow-start' and 'current delay' controls allow current to rise and fall slowly at the beginning and end of a weld, for example welding round a pipe.

As for gas-shielded metal-arc sets a cylinder holder and/or a water-cooling unit for use with heavier guns, may be built in.

Accessories

Welding return cable (torch has its own built-in lead to stand up to high frequency supply).

Connectors to set.

Clamps or clips.

Torch and connecting hose assembly, to suit current.

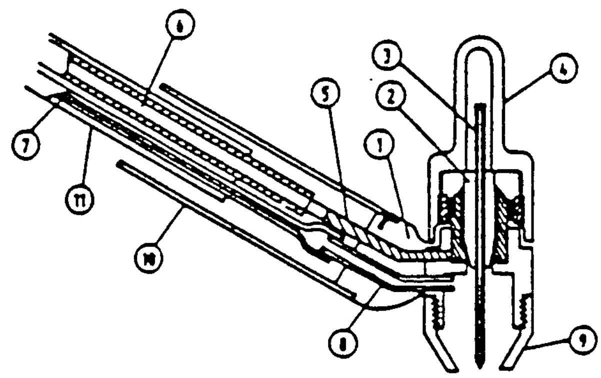
Gas hose.

Gas regulator.

Cylinder stand.

Typical air cooled TIG torch

1. Torch body, plastic with metal inserts
2. Collect, interchangeable to suit electrode diameter
3. Electrode
4. Insulating cap
5. Current connection
6. Welding cable
7. Gas hose
8. Gas pipe
9. Nozzle - ceramic
10. Handle
11. Outer flexible sleeve



Spares

Electrodes -

Collets - various sizes to clamp electrodes in torch

Electrode rear cover - various lengths to accommodate a long electrode, or short to work where space is restricted.

Gas-shielding nozzle - ceramic.

Silicone rubber ring seals joint between nozzle and torch body.

In DC welding, the electrode usually has negative polarity which reduces the risk of overheating which may otherwise occur with electrode positive. The ionised gas or plasma stream can attain a temperature of several thousand degrees centigrade. Consequently, within the normal range of welding currents (5–300A) rapid cooling can be effected.

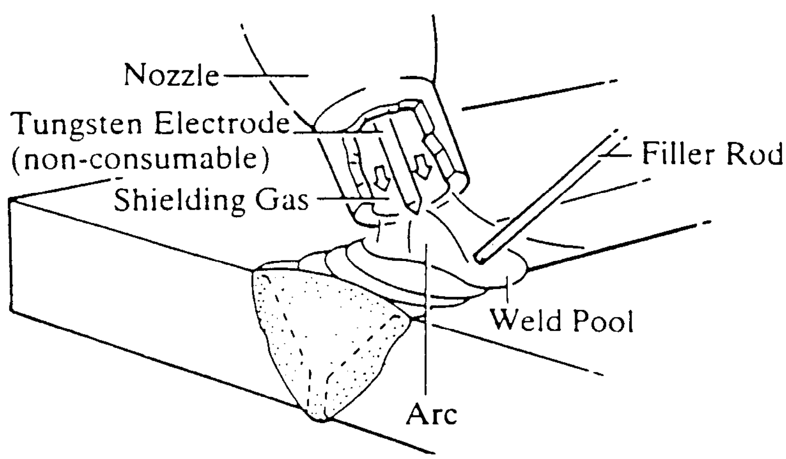
The gas supplied to the arc has two functions: it generates the arc plasma, and it protects the electrode, weld pool and weld bead from undesirable oxidation.

DC TIG

The TIG torch allows the electrode to extend beyond the shielding gas nozzle, as shown.

The arc is ignited to high voltage, high frequency (HF) pulses, or by short circuiting the electrode to the workpiece and withdrawing at a present low current. In DC welding, the arc is in the form of a cone, the size of which is determined by current, the electrode diameter and the vertex angle.

Arc size determined by
i) current
ii) electrode diameter
iii) vertex angle



Electrode

Selection of electrode composition and size is not completely independent and must be considered in relation to the operating mode and the current level. Electrodes for DC welding are pure tungsten or tungsten with 1 or 2% thoria, the thoria being added to improve electron emission which facilitates arc ignition. In AC welding, where the electrode must operate at a higher temperature, a pure tungsten or tungsten–zirconia electrode is preferred, as the rate of tungsten loss is somewhat less than with thoriated electrodes and the zirconia aids retention of the 'balled' tip.

Table 1. Recommended electrode diameter and vertex angle for TIG welding at various current levels

	DC electrode negative		AC
Welding current A	Electrode* diameter mm	Vertex angle, degrees	Electrodeτ > diameter, mm
<20	1.0	30	1.0 – 1.6
20 to 100	1.6	30 – 60	1.6 – 2.4
100 to 200	2.4	60 – 90	2.4 – 4.0
200 – 300≈	3.2	90 – 120	4.0 – 4.8
300 to 400≈	3.2	120	4.8 – 6.4

* Thoriated tungsten
τ Zirconiated tungsten, balled tip, electrode diameter depends on degree of balance on AC waveform.
≈ Use current slope–in to minimise thermal shock which may cause splitting of the electrode.

In DC welding, a small diameter, finely pointed approximately 30° electrode must be used to stabilise low current arcs at less than 20A. As the current is increased, it is equally important to readjust the electrode diameter and vertex angle. Too fine an electrode tip causes excessive broadening of the plasma stream, due to the high current density, which results in a marked decrease in the depth to width ratio of the weld pool. More extreme current levels will result in excessively high erosion rates and eventually in melting of the electrode tip. Recommended electrode diameters and vertex angles in argon shielding gases for the normal range of currents are given in Table 1.

Shielding gas

The shielding gas composition is selected according to the material being welded, and the normal range of commercially available gases is given in the Table below. In selecting a shielding gas it should be noted that:

1. The most common shielding gas is argon. This can be used for welding a wide range of material including mild steel, stainless steel, and the reactive aluminium, titanium and magnesium..
2. Argon-hydrogen mixtures, typically 2% and 5% H_2, can be used for welding austenitic stainless steel and some nickel alloys. The advantages of adding hydrogen are that the shielding gas is slightly reducing, producing cleaner welds, and the arc itself is more constricted, thus enabling higher speeds to be achieved and/or producing an improved weld bead penetration profile, i.e. greater depth to width ratio. It should be noted that the use of a hydrogen addition introduces the risk of hydrogen cracking (carbon and alloy steels) and weld metal porosity (ferritic steels, aluminium and copper), particularly in multipass welds.

3. Helium, and helium-argon mixtures, typically 75/25 helium/argon, have particular advantages with regard to higher heat input; the greater heat input is caused by the higher ionisation potential of helium, which is approximately 25eV compared with 16eV for argon.

4. As nitrogen is a diatomic gas, on re-association at the workpiece surface, it is capable of transferring more energy than monatomic argon or helium. Hence its addition to argon can be particularly beneficial when welding materials such as copper, which have high thermal conductivity; the advantages of nitrogen additions cannot be exploited when welding ferritic and stainless steels because nitrogen pick-up in the weld pool could cause a significant reduction in toughness and corrosion resistance.

Recommended shielding gases for TIG welding

	Shielding gas mixtures					
Metal	Argon	Argon +H_2	Helium	Helium-argon	Nitrogen	Argon-nitrogen
Mild steel	●					
Carbon steel	●			O		
Low alloy steel	●			●		
Stainless steel	●	●	O	O		
Aluminium	●		●	●		
Copper	●		●	●	O	O
Nickel alloys	O	●		O		
Titanium and magnesium	●		O			

● *most common gas*
O *also used*

The effectiveness of a gas shield is determined at least in part by the gas density. As the density of helium is approximately one tenth that of argon, difficulties can be experienced in protecting the weld pool, particularly when welding under draughty conditions or at high currents which may induce turbulence in the gas shielding stream.

However, effective shielding can be maintained by increasing the gas flow, typically by a factor of two. Shielding of the weld pool area can also be improved by use of a gas lens, which is inserted into the torch nozzle to ensure laminar flow. Adoption of this technique is strongly recommended when welding in positions other than the flat and for welding curved surfaces.

AC TIG

TIG welding is also practised with AC, the electrode polarity oscillating at 50Hz. The technique is used in welding aluminium and magnesium alloys, where the periods of electrode positive ensure efficient cathodic cleaning of the tenacious oxide film on the surface of the material. Compared with DC welding, the disadvantages of the technique lie in the low penetration capacity of the arc and, as the arc extinguishes at each current reversal, in the necessity for a high open circuit voltage, typically 100V and above, or continuously applied HF, to stabilise the arc. Low penetration results in particular from the blunt or "balled" electrode which is caused by the high degree of electrode heating during the positive half-cycle. Where deep penetration is required, use of DC with helium as the shielding gas, which does not suffer from these disadvantages and is somewhat tolerant to surface oxide, may be an alternative. Use of helium, however, is not particularly attractive because of its high cost and, in the absence of the cleaning action of the arc, the weld pool/parent metal boundaries can be somewhat indistinct, thus making it difficult to monitor and control the behaviour of the weld pool.

QUESTIONS:

TUNGSTEN INERT GAS

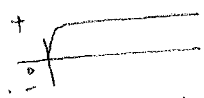
Q1. State the welding variables for TIG.

① ampher
② Polarity
③ travel speed
④ Voltage.
⑤ Flow rate

Q2. What is the type of current used for steels, and what is the electrode polarity ?

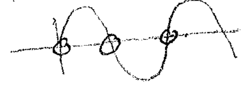
DC⁻, (DCEN) / or straight Polarity

Q3. What is the purpose of high frequency ?



a) For direct current - Helps start the arc.

b) For alternating current - Helps start and maintaine the arc.



H.F
OFF
START - for DC
CONTINUOUS - for AC

Q4. Name the two inert gases mainly used in TIG and give an advantage for each gas.

① Argon → cheap

② Helium → Higher arc voltage (more penetration)

Q5. Give an advantage and a disadvantage of the process.

advantages
① produce smooth clean welding.
② able to weld thin material
③ No slag - does not require cleaning
④ Weld root does not require backing.
⑤ able to weld array of material.

Disadvantages
① Slow deposition rate
② ~~Expensive.~~
③ Relatively expensive
④ Equipment is not relatively portable.
⑤ Require inert gas

SECTION 12

DEFECTS WHICH MAY BE DETECTED BY SURFACE INSPECTION

Defects which may be detected by visual inspection can be grouped under four headings.

1. Cracks

2. Surface irregularities

3. Contour defects

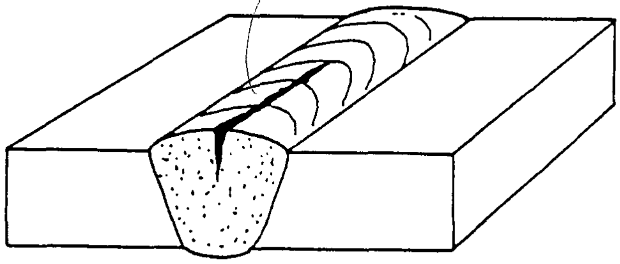
4. Root defects

Internal defects such as cavities

Solid inclusions will be dealt with during macroscopic examination

Surface Cracks

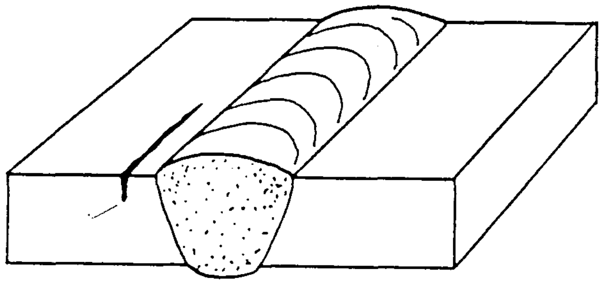
longitudinal crack (solidification crack)



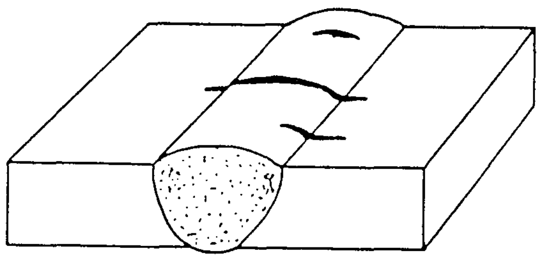
60 015* **Crack**
A linear discontinuity produced by fracture.

Cracks may be

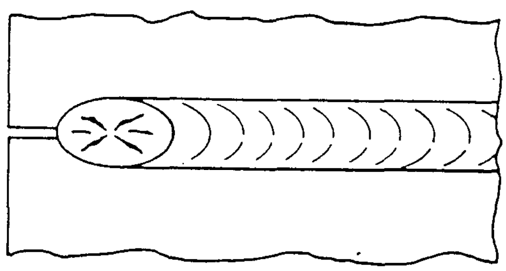
longitudinal, in the weld metal, *i.e.* centreline



longitudinal, in the parent metal
(H.A.Z)
Hydrogen induced crack.

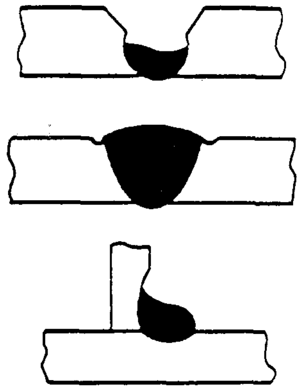


transverse
High tensile cracking



crater
(star cracking)
due to shrinking forces

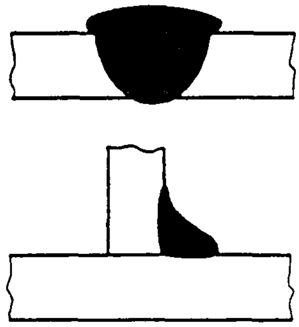
Surface Irregularities



60 006* **Undercut**
An irregular groove at a toe of a run in the parent metal or in previously deposited weld metal.

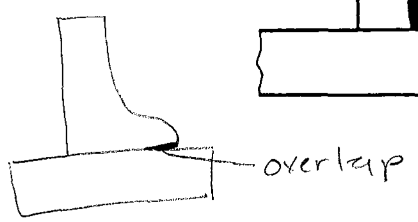
weld metal washed away the parent metal
⇒ induce crack
API 1104 < 0.4mm

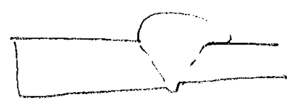
⇒ cause of under cut
① high current ✓
② Angle of electrode ✓
③ Too fast travel speed ✓
④ Arc length (too long) ✓



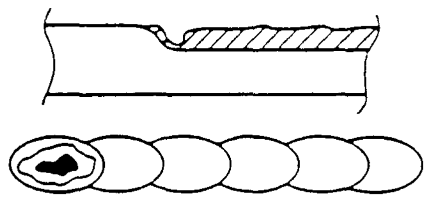
60 007* **Overlap**
An imperfection at the toe or root of a weld caused by metal flowing on to the surface of the parent metal without fusing to it.

⇒ cause
① Slow travel speed ✓
② low current ✓
③ Angle of electrode ✓





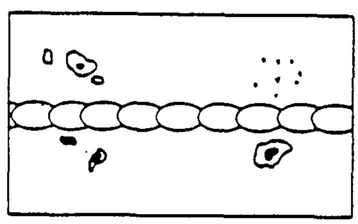
60 038 **Crater pipe**
A depression due to shrinkage at the end of a run where the source of heat was removed.
⇒ common defect for tig welding
⇒ cause
– taking the shielded gas away quickly



Crater pipe

10 031 **Spatter**

⇒ due to
① High current
② Arc length (too long)
③ damp electrode (exposed electrode)



32 104 **Stray flash**
(stray arcing) arc strike, arc burn

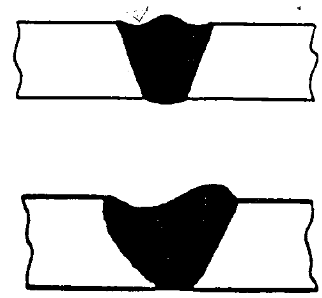
welder unintention electrode touch the parent metal
– the seriousness depends on parent material

Bulbous contour

Contour Defects

60 003 **Incompletely filled groove** /Lack of fill/under fill

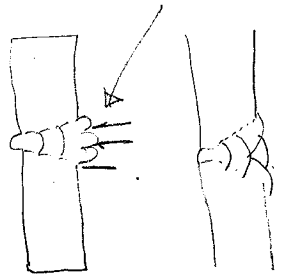
A continuous or intermittent channel in the surface of a weld, running along its length, due to insufficient weld metal. The channel may be along the centre or along one or both edges of the weld.

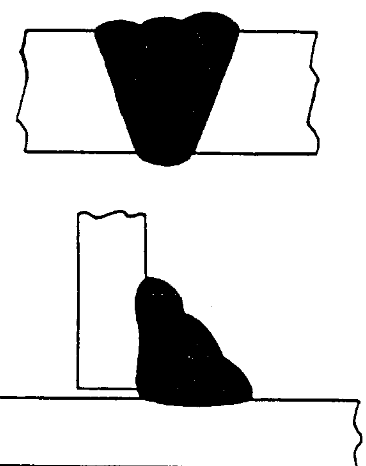


00 000* **Bulbous contour**
(not BS 499 term)

(poor Interweld blending)

Bulbous contour



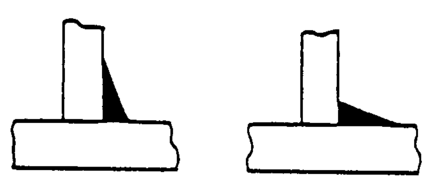


Bulbous contour

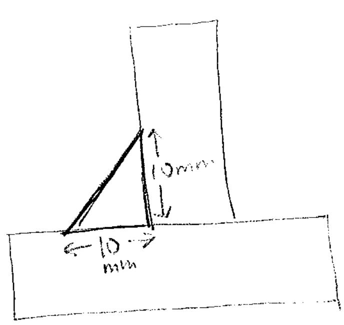
00 000* **Unequal legs**
(not BS 499 term)

Variation of leg length on a fillet weld. likely to happen in TIG process (GTAW)

N.B. Unequal leg lengths may be specified as part of the design — in which case they are not defects.



Acceptable range ±20%



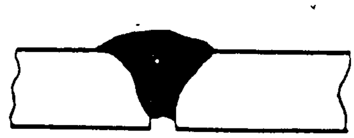
±2mm

10 – 15 l/min
2 – 3 l/min

ASME IX does not accept any root defect

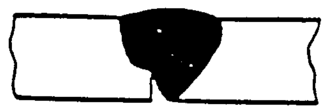
Root Defects

60 022* **Incomplete root penetration** (Lack of root pentration)
Failure of weld metal to extend into the root of a joint.



cause ⇒ ① too large root face ✓
② Amp too low ✓
③ Root Gap too small ✓
④ Speed too fast ✓
⑤ Arc length too long ✓

60 020 **Lack of root fusion**
Lack of union at the root of a joint. ⇒ one side does not fuse
① Electrode angle ④ Arc blow
② misalignment
③ Poor Joint preparation



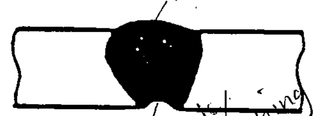
lack of side wall fusion
lack of root fusion.

60 001* **Excess penetration bead**
Excess weld metal protruding through the root of a fusion weld made from one side only.

cause ① current to high ④ Root face too thin
② Speed too slow
③ Root gap too big (Joint prep.)

60 002* **Root concavity** – under ASME IX – not acceptable
(suck-back; underwashing)

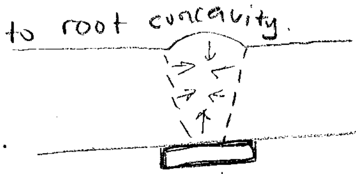
A shallow groove which may occur in the root of a butt weld.

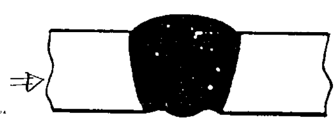


suck back / underwashing

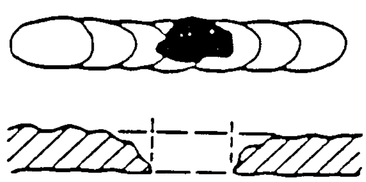
① Too high purging gas pressure. (TIG process)
② Hot pass sucking the root back
③ too long arc length.

004* **Shrinkage groove** – Simillar to root concavity.
A shallow groove caused by contraction in the metal along each side of a penetration bead.

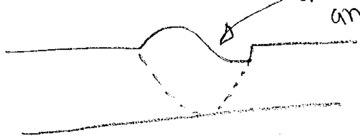




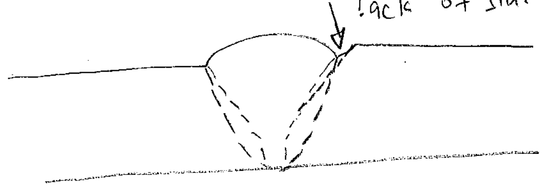
60 039 **Burnthrough**
(melt through)
A localised collapse of the molten pool due to excessive penetration, resulting in a hole in the weld run.



undefill and lack of side wall fusion



lack of side wall fusion.



QUESTIONS

REVIEW OF DEFECTS

Q1 Name two (2) crack/planar defects found within the weld metal.

(1) Solidification cracking ✓.
(2) Crate craking. ✓
(3) Lack of interrun fusion ✓.

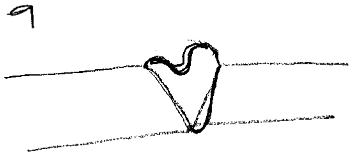
Q2 Give two (2) main causes of excess penetration

(1) ~~extra~~ high current
(2) Speed too slow
(3) Root gap to big.
(4) Root face to thin.

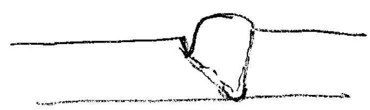
Q3 Sketch a) Incomplete filled groove

b) Lack of sidewall fusion at the weld toe

a



(b)



Q4 Give three (3) main causes of undercut

(1) High current
(2) Angle of electro
(3) Travel speed too fast

Q5 Give three possible causes of lack of side wall fusion

(1) low current
(2) Travel speed to fast
(3) Angle of electrode
(4) poor joint preparation *

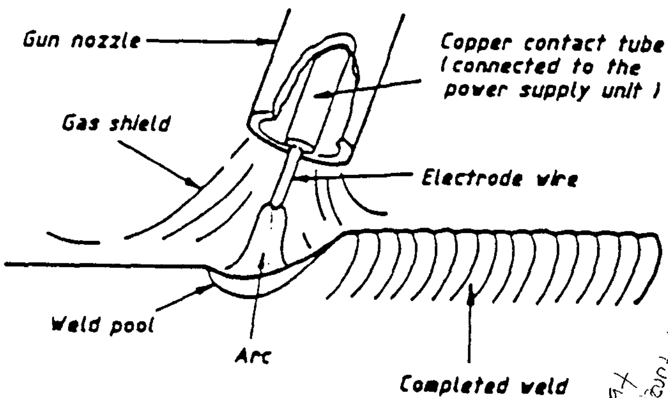
SECTION 13

With a 'flat' volts/amps characteristic an attempted alteration in arc length (volts) will have little effect, hence arc length (volts) remains constant but a significant change in current will result. This is often referred to as the "self-adjusting arc".

Metal Inert Gas -

A 'FLAT' ARC PROCESS (CONSTANT) VOLTAGE

METAL INERT GAS (MIG)



spray < flat / horizontal

Type of Operation
Manual, mechanised or automatic.

Mode of Operation
An arc is maintained between the end of the bare wire electrode and the work. The wire is fed at a constant speed, selected to give the required current, and the arc length is controlled by the power source. The operator is not therefore concerned with controlling the arc length and can concentrate on depositing the weld metal in the correct manner.

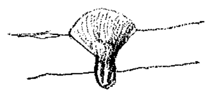
The process can be operated at high currents (250-500A) when metal transfer is in the form of a 'spray', but, except for aluminium, this technique is confined to welding in the flat and horizontal positions. For vertical and overhead welding special low-current techniques must be used, *i.e.* 'dip' transfer or pulsed arc. The arc and weld pool are shielded by a stream of gas.

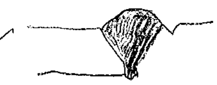
The electrode can be solid or flux cored.

Metal Active Gas (MAG); CO_2; Metal-arc gas shielded; GMAW (US)

Typical defects associated with this process:

Incomplete penetration. ✓ 

Excessive penetration. ✓ 

- Undercut. ✓ 

Excessive spatter. ✓

Cracking. ✓

- Porosity. ✓

- Lack of fusion. ✓

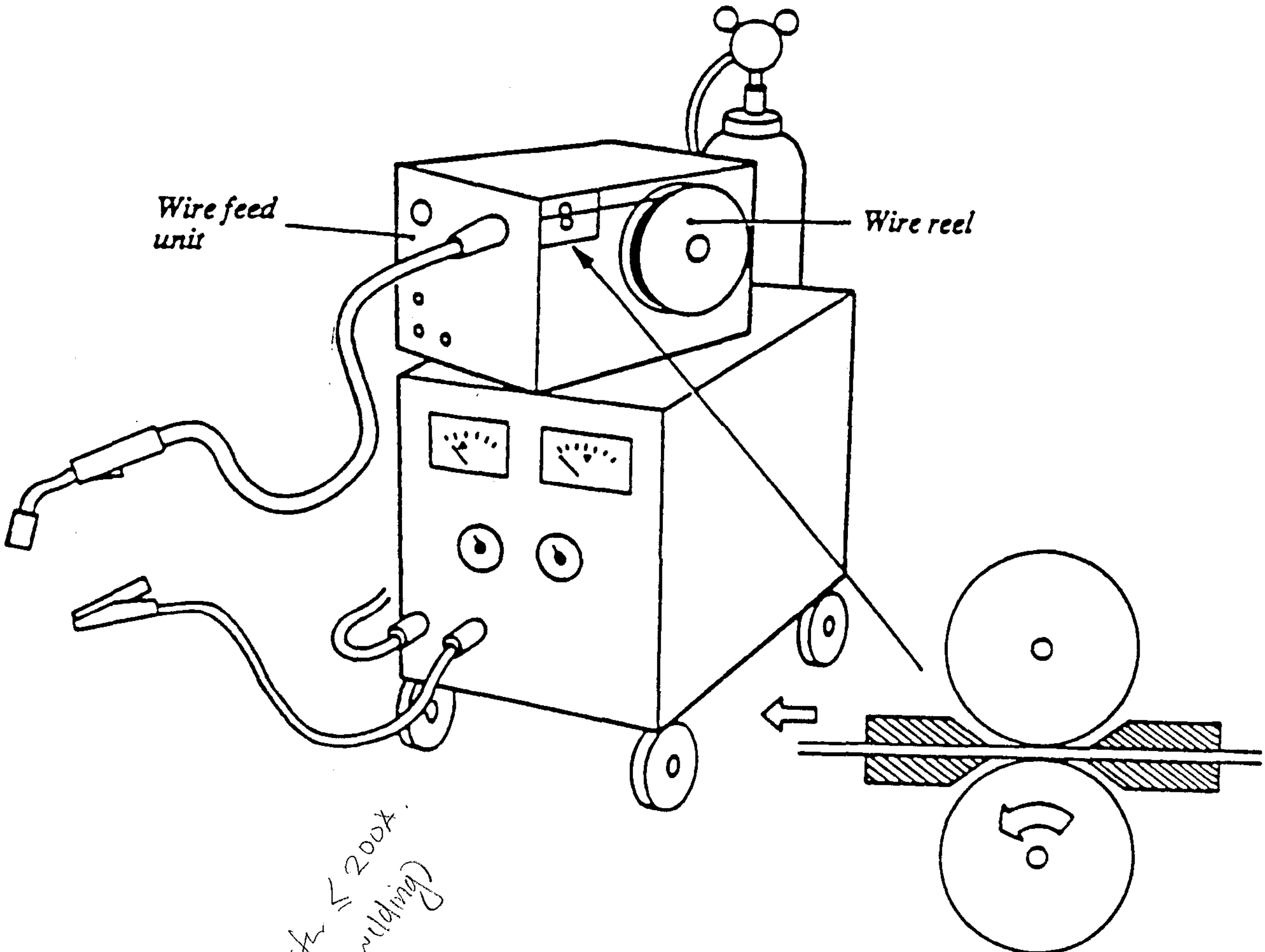
Stray flash. ✓

In mechanised MIG and submerged arc welding the process may also be operated using constant current or drooping arc characteristics.

dip transfer } vertical & overhead.
pulse arc. }
spray < flat / horizontals

GAS SHIELDED METAL ARC WELDING

Welding sets



Dip transfer ≤ 200A.
(Steel welding)

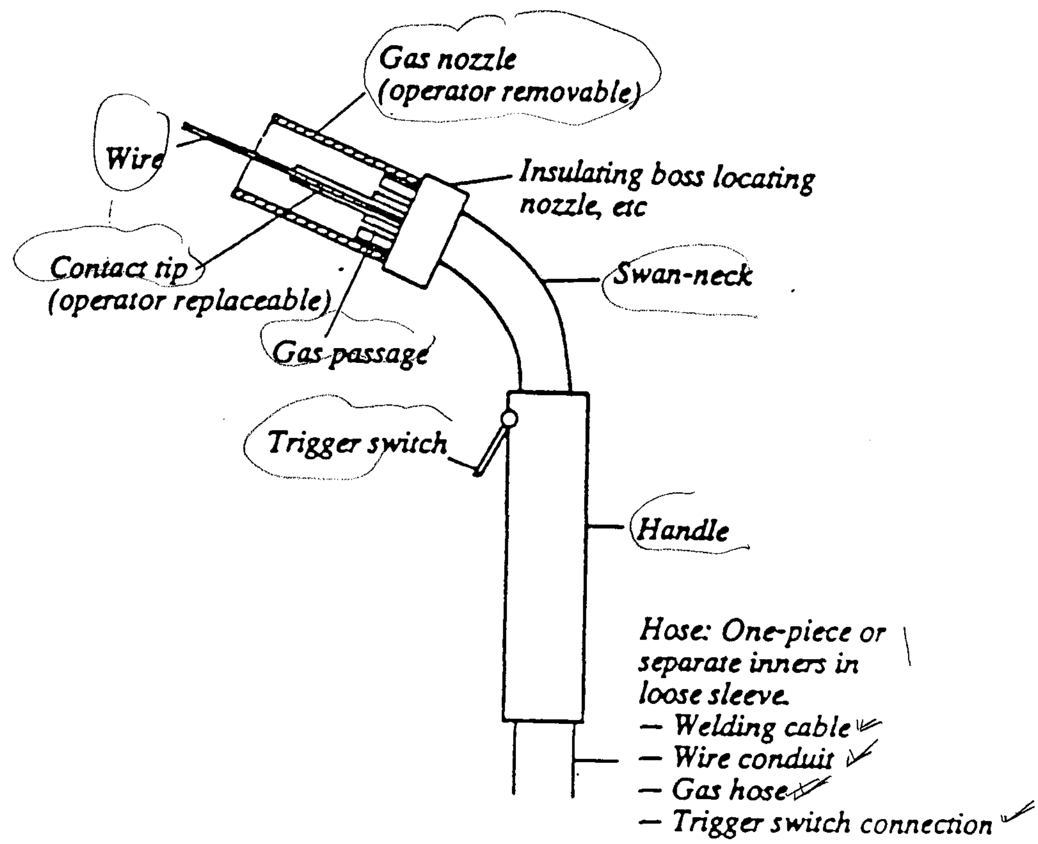
Sets are manufactured in a range of sizes, identified by current, similar to metal arc welding. Currents below 200A can only give 'dip transfer' operation, suitable for welding steel only.

Larger sets may have the wire reel and motor as a separate unit, so it can be placed near the job. Controls on the set adjust output voltage and may allow a choice of inductance: the wire speed control will be on the wire feed unit.

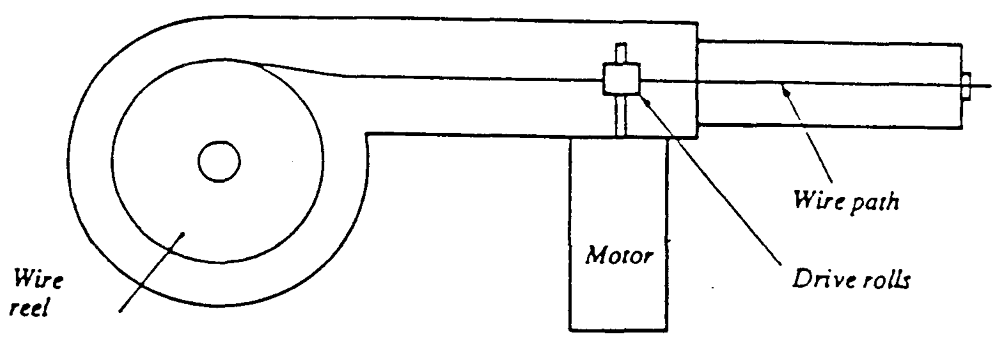
Electrical input is from single–phase 240V mains for small sets, or three–phase 415V for medium size upwards. Output is always DC with a flat output characteristic (semi automatic), drooping output (mechanised).
constant current

Sets often have a built–in holder for a gas cylinder.

A set will usually be supplied complete with a suitable gun: also see 'Accessories' below. Heavy duty guns may be water cooled, and the set may have a water tank and cooling radiator built in.



When welding aluminium, the wire is soft, and tends to kink when pushed through a hose – a gun carrying a small reel of wire – 'reel–on–gun' – obviates this.



Sets which supply current in pulses (at 40–200 per second) give improved results on some jobs: as this 'pulse–MIG' would increase the number of controls, an electronic 'synergic' control system varies all the parameters in step to simplify adjustments.

Accessories

Welding cables }
Connectors to set } similar to manual metal arc: one set usually included
Clamps or clips }

Gun and connecting hose assembly to suit current, usually supplied with set; also see 'spares' below.

Gas regulators and hose, connections to suit.

Vaporiser for carbon dioxide gas on industrial sets.

Cylinder stand

Spares

The following parts come into contact with the wire – spares are needed to replace worn parts, or if wire size or type is changed.

Inlet and outlet guides }
} on drive assembly
Drive rolls }

Wire conduit liner – spring steel coil, like curtain wire, for steel electrode wire, or plastic tube for aluminium.

Contact tip in gun – needs fairly frequent replacement.

Gas shielding nozzle for gun – various sizes to suit different jobs.

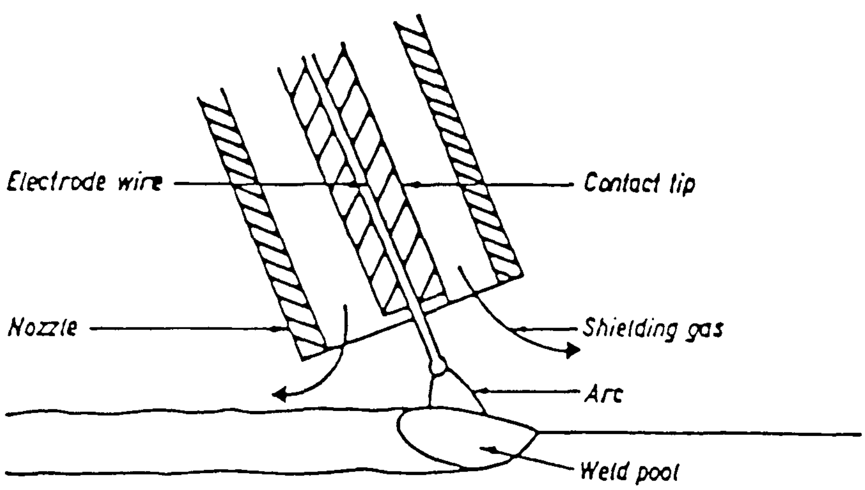
MIG/MAG WELDING

PROCESS CHARACTERISTICS

The heat source used to melt the parent metal is obtained from an electric arc which is formed between the end of a consumable electrode wire and the work-piece. The arc melts the end of the electrode wire which is transferred to the molten weld pool. The electrode wire is fed from a spool which is attached to the wire driving system and passes through a set of rolls which are driven by a variable speed electric motor. By varying the speed of the motor we can adjust the level of the welding current: high wire feed speed gives high welding current. The arc length can also be varied by altering the voltage: high voltages give longer arc lengths and vice versa.

In order to prevent the air reacting chemically with the molten metal a shielding gas of either CO_2 or argon/CO_2 mixture is passed over the weld zone from a nozzle attached to the welding gun or torch. This protects the molten droplets passing across the arc and the molten weld pool.

Electrical power for the process is a direct current which is obtained from a transformer-rectifier. The welding gun or torch is connected to the positive pole of the power supply unit and electrical contact to the wire is obtained as close to the arc as possible by means of a copper contact tip or tube.



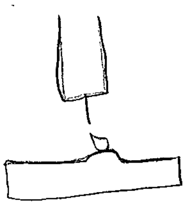
Metal transfer

The metal at the end of the electrode is melted and transferred to the molten weld pool.

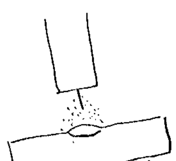
The type of metal transfer are:

1. Spray or globular transfer ✓
2. Short-circuiting or dip transfer ✓

Spray transfer/globular transfer – mid range



This type of metal transfer generally occurs at high current high arc voltage ranges, e.g. 250–600A at 28–40V. As the current is increased the rate at which the droplets are transferred across the arc increases and they become smaller in volume. The droplets can be seen on a high-speed cine film but cannot be distinguished with the naked eye. It appears as if there is a spray of metal.



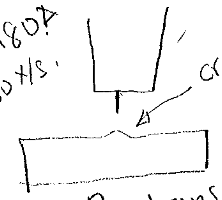
The type of shielding gas greatly affects the current rate at which the spray transfer occurs. The use of CO_2 as a shielding gas requires a much greater current density than argon to produce the same droplet rate.

With the use of high currents giving strong magnetic forces very directional arcs are produced. In argon shielding gases the action of these forces on the droplets is well-balances and transfer from wire to work is smooth with little or not spatter. However, in a CO_2 shield the forces tend to be out-of-balance giving rise to an arcing condition that is less smooth and spatter levels are heavier. Metal transfer under these conditions is normally called globular or free-flight.

The welding conditions which give spray or globular transfer are normally associated with high deposition rates on medium and thick sections and can only be used when welding in the flat position.

MIG.
(1) Dip transfer
(2) Globular
(3) Dip transfer/short circuit

60-180A
50-200+/s.



create a continuous explosive (short circuit)

Short-circuiting arc or dip-transfer

Dip transfer

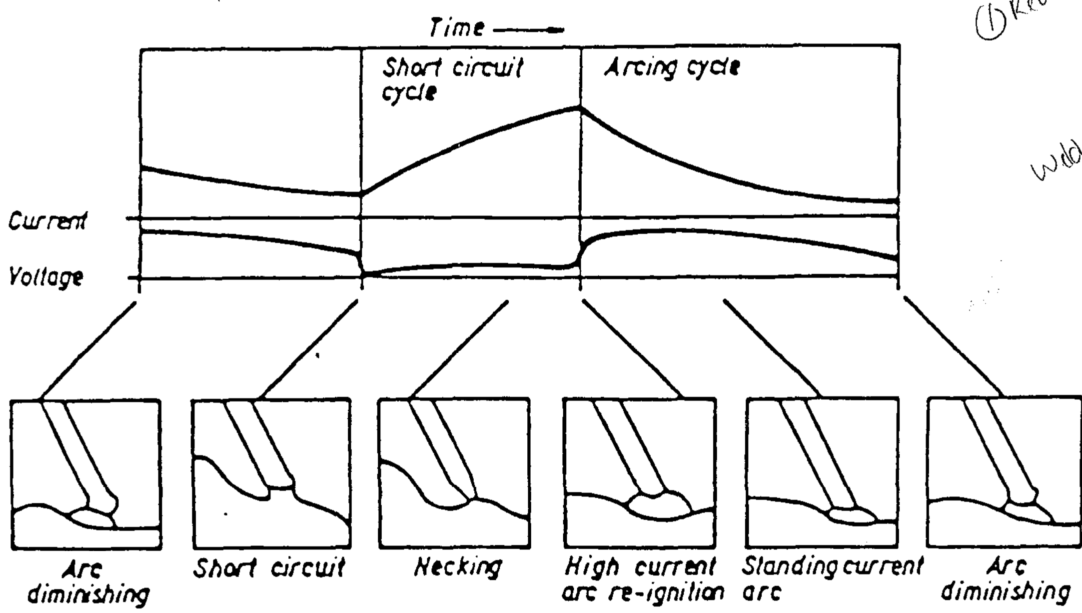
At lower arc voltages and currents, generally within the 16-26V, 60-180A ranges, metal transfer takes place during short circuits between the electrode and the weld pool. These follow a consistent sequence of alternate arcing and short-circuiting causing the end of the electrode wire to dip into the weld. As the wire touches the weld pool there is a rise of current, the resistance of the wire causes heating and the end of the electrode melts. The wire necks due to a magnetic pinch effect and the molten metal flows into the pool. During this short-circuit period the current delivered by the power source is much higher than during arcing, typically 1000-1500A. This creates high forces which have an explosive effect on the weld pool and spatter is considerable. To reduce this effect an inductance is connected in series with the power supply and the arc to reduce the rate of rise of current during the short-circuit period.

The short-circuit is cleared more slowly and gently, and the spatter is reduced to an acceptable level. Ideally an almost irregular dip/arc cycle takes place about 50-200 times a second. Too little inductance gives rise to unstable arcing conditions, excessive spatter and lack of fusion defects.

The dip transfer mode is used for the welding of thin sheet and medium plate, and for all thicknesses when welding in the vertical or overhead positions.

(1) Reduce the spatter)
for thin & medium plate

Weld position:
(1) Vertical.
(2) overhead.



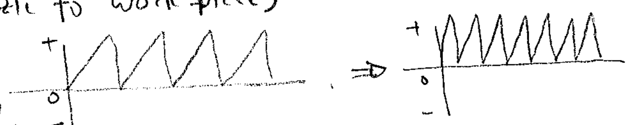
Short circuit cycle

QUESTIONS

MIG MAG AND CO_2 WELDING
(METAL INERT GAS WELDING)

Q1 State the main welding parameters and variables of the process.

a) current
b) volt
c) travel speed
d) wire feeding speed
e) Tilt angle
f) gas flow rate
g) stick out length (nozzle to work piece)
h) Inductance
(change # dip per minutes)



Q2 What polarity is normally used for welding applications ?

DCEP, DC+, Reverse Polarity (DCRP)

Q3 State the modes of transfer

a) Dip transfer
b) Globular transfer
c) Spray transfer
d) Pulse transfer

Q4 State three (3) items of importance when inspecting a wire to be used for MIG welding. (STC)

(1) Size
(2) Type
(3) Condition

Q5 Which defect can be quite common when using the short circuiting mode of transfer?

dip

relatively cool arc

60 - 180 Amp.

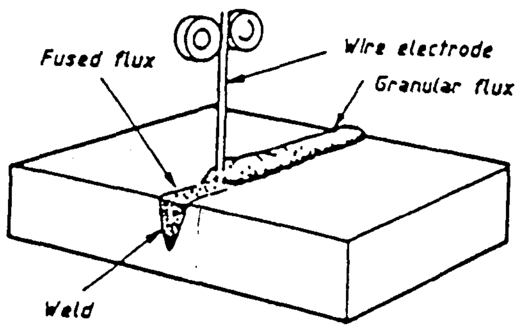
a) Lack of penetration
b) Undercut
c) Lack of fusion
d) Porosity

SECTION 14

A 'FLAT' ARC PROCESS (CONSTANT) VOLTAGE

SUBMERGED-ARC (SA)

SUBMERG ARC WELDING
'SAW'



Type of Operation
Mechanised, automatic or semi-automatic.

Mode of Operation
An arc is maintained between the end of a bare wire electrode and the work. As the electrode is melted, it is fed into the arc by a set of rolls, driven by a governed motor. Wire feed speed is automatically controlled to equal the rate at which the electrode is melted, thus arc length is constant. The arc operates under a layer of granular flux (hence 'submerged' arc). Some of the flux melts to provide a protective blanket over the weld pool; the remainder of the flux is unaffected and can be recovered and re-used provided it is dry and not contaminated.

A semi-automatic version is available in which the operator has control of a welding gun which carries a small quantity of flux in a hopper.

Typical defects associated with this process:

Porosity. ✓ – high speed / shallow flux covers

Cracking. ✓

• Slag inclusions. ✓

• Incomplete penetration. ✓

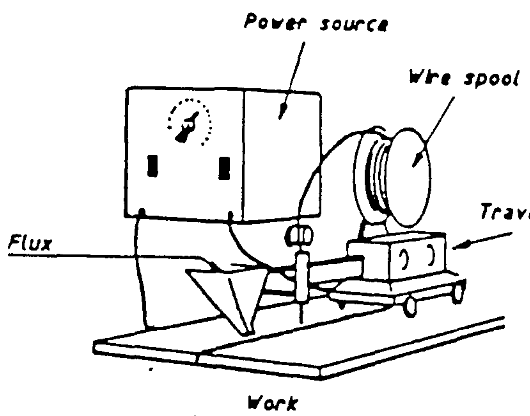
Excessive penetration. – low voltage
– to avoid use strip cladding

Weld profile defects. ✓

• Undercut. – high current, high speed
– trapping electrode angle.

Lack of fusion.

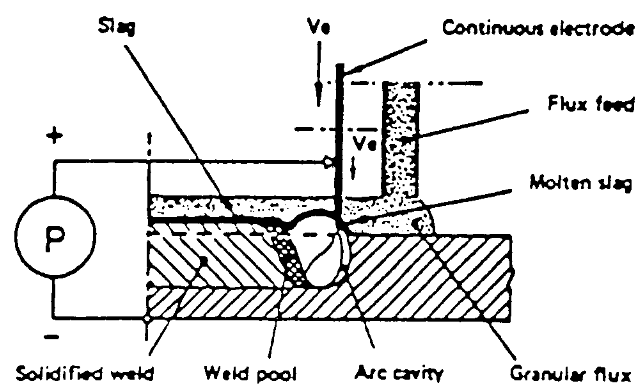
• Burn through – slow speed.



SUBMERGED ARC WELDING:

PROCESS AND EQUIPMENT FUNDAMENTALS

The principle of the submerged–arc process is shown schematically below. A power source P, is connected across the contact nozzle on the welding head and the workpiece. The power source can be a transformer for AC welding or a rectifier (or motor generator) for DC welding. The filler materials are an uncoated continuous electrode and a granular welding flux fed down to the joint by way of a hose from the flux hopper. To prevent the electrode overheating at high currents the welding current is transferred to the electrode at a point very close to the electric arc. The arc is burning in a cavity filled with gas (CO_2, CO, etc) and metal fumes. In front the cavity is walled in by unfused parent material, and behind the arc by solidifying weld metal. The covering over the cavity consists of molten slag. The diagram below also shows the solidified weld and the thin covering of solid slag which has to be detached after the completion of each run.



Since the arc is completely submerged by the flux there is none of the irritating arc radiation which is so characteristic of the open arc processes; welding screens are therefore unnecessary.

The welding flux is never completely consumed and the surplus quantity left can be collected either by hand or automatically and returned to the flux hopper to be used again.

Although semi-automatic submerged-arc welding equipment exists and is convenient for certain applications, most of the submerged-arc welding carried out today makes use of fully mechanised welding equipment. Indeed, one of the main virtues of the submerged-arc process is the ease with which it can be incorporated into fully mechanised welding systems to give high deposition rates and consistent weld quality. Weld metal recovery approaches 100% since losses through spatter are extremely small. Heat losses from the arc are also quite low owing to the insulating effect of the flux bed, and for this reason the thermal efficiency of the submerged-arc process can be as high as 60% compared with about 25% for manual metal-arc (MMA) welding.

Flux consumption is approximately equal to the wire consumption, the actual ratio – weight of wire consumed: weight of flux consumed – being dependent on the flux type and the welding parameters used.

Welding parameters are maintained at their set values by the arc control unit. A feed-back system is usually used to maintain a stable arc length so that a change in the arc length – corresponding to a change in arc voltage – will produce an increase or decrease in the wire feed speed until the original arc length is regained.

Joint preparation

Joint preparation depends on plate thickness, and type of joint, e.g. circumferential or longitudinal, and to some extent, on the standards to which the structure is being made.

Plates of up to 14mm thick can be butt welded without preparation with a gap not exceeding 1mm or 10% of the plate thickness, whichever is the greater. Thicker plates need preparation if full penetration is to be obtained. Variable fitup cannot be tolerated.

A welder using stick electrodes can adjust his technique to cope with varying joint gaps and root faces or varying dimensions. Not so an automatic welding head. If conditions are set up for a root gap of 0.5mm and this increases to 2 or 3mm, burnthrough will occur unless an efficient backing strip is used. In such circumstances a hand-welded root run using MIG or MMA electrodes is advisable. All plate edges must be absolutely clean and free from rust, oil, millscale, paint etc. If impurities are present and are melted into the weld, porosity and cracking can easily occur.

Time spent in minimising such defects by careful joint preparation and thorough inspection prior to welding is time well spent since cutting out weld defects and then rewelding is very expensive and time-consuming

Welding procedure

low heat input for stainless steel & because nickel alloy
a) poor thermal conductivity
b) high coefficient of expansion
may lead to distortion
prevention:
① multi passes
② small wire diameter

In general the more severe the requirements regarding low temperature notch toughness the lower the maximum welding current that can be used to minimise heat input, which means that a multipass technique is called for. When welding stainless steels the heat input should be kept low for other reasons: stainless steel has poor thermal conductivity and a high coefficient of expansion compared with mild steel. These two effects lead to overheating and excessive distortion if large diameter wires and high currents are used. Multirun welds using small diameter wires are therefore recommended for stainless steels and high nickel alloys such as Inconel.

Selection of welding conditions

Selection of the correct welding conditions for the plate thickness and joint preparation to be welded is very important if satisfactory joints free from defects such as cracking, porosity, and undercut are to be obtained. The process variables which have to be considered are:

Deep penetration

good surface appearance
bead shape
reduce porosity

a. electrode polarity ✓
b. welding current ✓
c. electrode diameter ✓
d. arc voltage ✓
e. welding speed ✓
f. electrode extension ✓
g. electrode angle ✓
h. flux depth ✓

These are the variables which determine bead size, bead shape, depth of penetration, and, in some circumstances, metallurgical effects such as incidence of cracking, porosity and weld metal composition.

a. electrode polarity

DCEP

The deepest penetration is usually obtained with DC reverse polarity (electrode +ve) which also gives the best surface appearance, bead shape, and resistance to porosity.

DCEN

?

Direct current straight polarity (electrode−ve) gives faster burnoff (about 35%) and decreased penetration since the maximum heat is developed at the tip of the electrode instead of at the surface of the plate. For this reason DC−ve polarity is often used when welding steels of limited weldability and when surfacing since, in both instances, penetration into the parent material must be kept as low as possible. The flux/wire consumption ratio is less with electrode −ve polarity than with electrode +ve so that alloying from the flux is reduced.

In changing from electrode +ve to −ve polarity some increase in arc voltage may be necessary to obtain a comparable bead shape. Alternating current gives a result about half way between DC electrode +ve and −ve polarity. It is particularly useful when arc blow is a problem and is often used in tandem arc systems, where a DC +ve electrode is used as the leading electrode and an AC electrode as the trail.

b. welding current

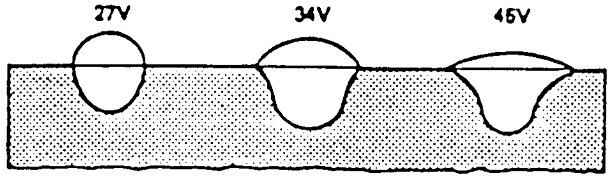
Increasing the wire feed speed increases the welding current so that the deposition rate increases as the welding current increases. The current density determines the depth of penetration: the higher the current density the greater the penetration. For a given flux, arc stability will be lost below a minimum threshold current density so that if the current for a given electrode diameter is too low arc stability is lost and a rugged irregular bead is obtained. Too high a current density also leads to instability because the electrode overheats. Undercutting may also occur.

c. electrode diameter

For given current, changing the electrode diameter will change the current density, which means in practice that a larger diameter will reduce penetration and the likelihood of burnthrough, but at the same time arc striking is more difficult and arc stability is reduced.

d. arc voltage ↑ dilution

The effect of arc voltage is often misunderstood because if affects dilution rather than penetration. Bead-on-plate welds and square edge close butt welds (no gap) have increased width and dilution as arc voltage increases, but **depth** of penetration remains the same.



Effect of arc voltage on bead shape

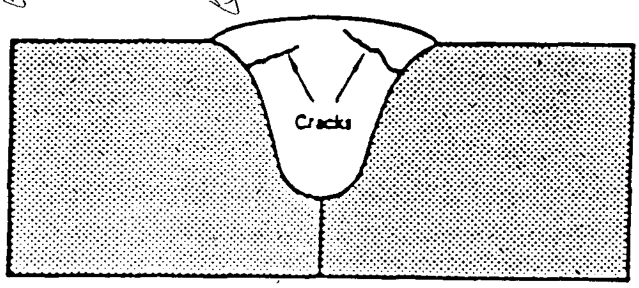
If the joint is 'open', as for example in a butt joint with rather small angled V preparation, increasing the arc voltage can decrease the penetration.

Increasing the arc voltage lengthens the arc so that weld bead width is increased, reinforcement is decreased, flux consumption is increased, and the probability of arc blow is also increased. When alloying fluxes are used arc length and hence arc voltage is very important, since at high arc voltages more flux is melted so that more alloying elements enter the weld metal. Thus arc voltage can affect weld metal composition.

e. welding speed

Bead size is inversely proportional to welding speed. Faster speeds reduce penetration and bead width, increase the likelihood of porosity and, if taken to the extreme, produce undercutting and irregular beads. At high welding speeds the arc voltage should be kept fairly low otherwise arc blow is likely to occur.

If the welding speed is too slow burn-through can occur. A combination of high arc voltage and slow welding speed can produce a mushroom-shaped weld bead with solidification cracks at the bead sides.



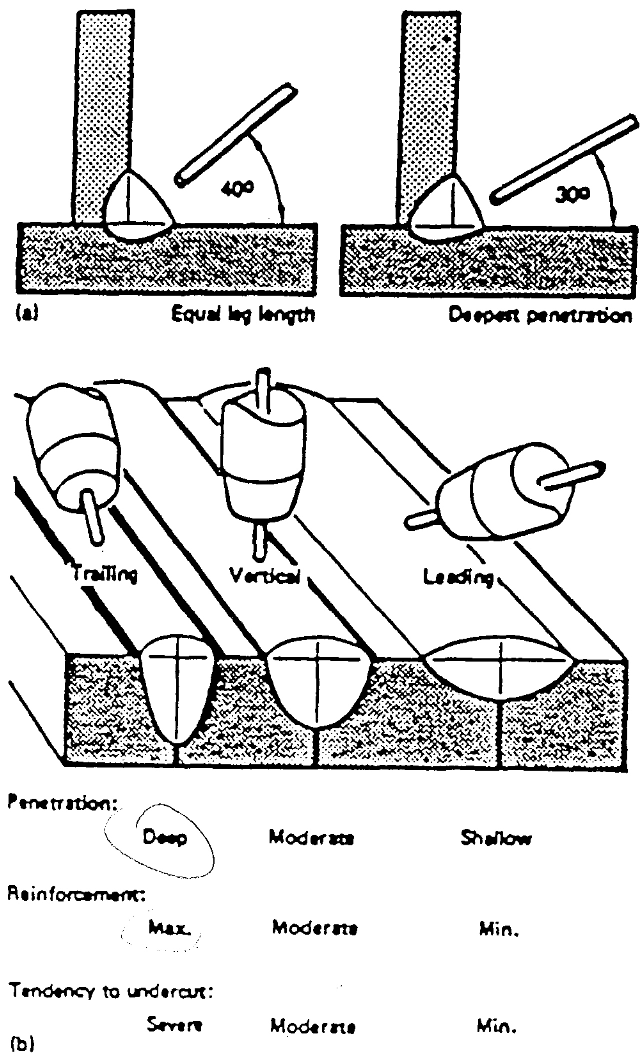
f. electrode extension (stickout)

Electrode extension is an important variable since it governs the amount of resistance heating which occurs in the electrode. If the extension is short the heating effect is small and penetration is deep. Increasing the extension increases the temperatures of the electrode but decreases the penetration. Deposition rate is increased. Increased extension is therefore useful in cladding and surfacing applications but steps have to be taken to guide the electrode otherwise it wanders.

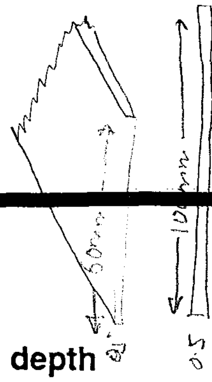
For normal welding the electrode extension should be 25-30mm for mild steel and rather less, say 20-25mm, for stainless. This is because the electrical sensitivity of stainless wire is appreciably greater than that of mild steel wire.

g. electrode angle

Since the angle between the electrode and the plate determines the point of application and direction of the arc force it has a profound effect on both penetration and undercut. The figures show the effect on horizontal/vertical fillet welds, and compare the effect obtained with a vertical arc with those obtained with leading and trailing arcs. The effect on undercutting can be particularly marked.



Effect of electrode angle: (a) H V fillet welds, (b) butt welds



h. flux depth

The flux burden or the depth of the flux is often ignored and the powder is simply heaped around the wire until the arc is completely covered. If optimum results are to be obtained the flux depth should be just sufficient to cover the arc, although at the point where the electrode enters the flux bed light reflected from the arc should just be visible. Too shallow a flux bed gives flash-through and can cause porosity because of inadequate metallurgical protection of the molten metal. Too deep a flux bed gives a worse bead appearance and can lead to spillage on circumferential welds. On deep preparations in thick plate it is particularly important to avoid excessive flux depth otherwise the weld bead shape and slag removal can be unsatisfactory.

Strip cladding

Although most applications of the submerged arc process make use of single - or multiwire systems using round wires, electrodes in the form a strip are often used for cladding purposes. Strips are usually 0.5mm thick, the commonest strip width being 60mm, but wider strips, e.g. 100mm can be used without any loss of quality. The big advantage of strip cladding is that penetration is low, particularly with DC electrode -ve polarity, and deposition rate is relatively high. Modern fluxes designed for strip cladding have greater current tolerance than earlier types and use of currents of up to 1200A with austenitic stainless steel strips gives deposition rates of up to 22mg/hr with DC electrode +ve polarity. Inconel can also be deposited and, provided the flux is low silica type and the Inconel strip used contains 2-3%Nb, good quality crack-free deposits can be obtained. Monel, aluminium bronze, nickel, and 13%Cr strips have also been successfully used as strip cladding electrodes. Good electrical contact between the strip and feed nozzle is essential.

QUESTIONS:

SUBMERGED ARC WELDING (SAW)

Q1 What are the welding parameters in SAW? - page 14.4.

(1) Current
(2) Electrod diameter
(3) Welding speed
(4) Arc voltage
(5) Electrode polarity
(6) Electrode angle
(7) Flux depth
(8) Electrode extension / stick out

Q2 State three (3) items which control weld metal composition in SAW.

(1) Wire
(2) Flux
(3) Heat input
(4) Arc Voltage.

Q3 State three (3) items of a flux which require inspection.

(1) Size.
(2) Type
(3) Condition - baking if required.

Q4 State two (2) types of a flux used in SAW and give brief details of recognition.

(1) Agglomerated - Granular in appearance (Basic).
(2) Fused - Flaky (Rutile).

Q5 Give an advantage and application for each of the following power types - see 14.4(5)

a) DCVe + - deep penetration → best surface appearance, → full penetration butt.
b) DCVe - - Shallow penetration ⇒ Surfacing.
c) AC - no arc blow ⇒ use in tandem wire. (two wire in parallel) ⇒ two pass in one go.

SECTION 15

CALIBRATION OF WELDING EQUIPMENT

Instrumentation fitted to arc welding equipment often becomes inaccurate through neglect, damage, wear, etc. The presence of errors in the readings may remain unknown and their extent unchecked. As a result, the values of the welding parameters indicated may lie well outside the working tolerances. Consequently problems may be experienced in achieving the desired weld quality. A significant level of rejects may be predicted with consequential costs of reworking, repair or even scrapping.

In high quality welding, regular checking of the parameters is therefore essential and should form a mandatory part of Inspection/Quality Assurance.

There are many different types of calibration equipment available, including Ammeters, Voltmeters or equipment specially designed to measure all the welding parameters.

Whatever the type of calibration piece used, they also must be calibrated for accurate measurement (usually to a National Standard).

CHECKLIST FOR CALIBRATING ARC WELDING EQUIPMENT

Welding Current:

Is the main parameter controlling heat input and penetration.
Check with Ammeters for inaccuracies.

Arc voltage:

Which is related to arc length and responsible for the weld bead profile.
Check with Voltmeter across the electrical circuit for inaccuracies.

Wire Feed Speed:

The most important parameter in MIG/MAG and submerged arc welding. It determines the welding current being drawn to a) melt the wire and b) fuse the workpiece.
Check with stopwatch of 15 - 30 secs or preferably with tachogenerator for inconsistency and inaccuracies.

Travel speed
(Mechanised):

Determines heat in-put penetration.
Pre-set travel speed and check meter against length of distance travelled in one minute.

(Manual)

Run out length

In recent years more attention has been given to Quality Assurance in arc-welding operations and in many cases it is of paramount importance to ensure that the correct welding parameters are being used in order to meet these requirements. Accurate calibration of the equipment therefore is necessary and "certificates of calibration" are required for all equipment,

i.e. **welding equipment**
measuring equipment
storage ovens, etc.

QUESTIONS

CALIBRATION OF WELDING EQUIPMENT

Q1 You have been asked to calibrate the output of a welding power source; indicate the tolerance that would be expected on amperage and voltage readings.

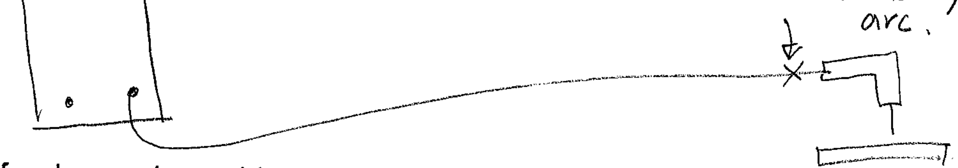
±5%

Q2 How is this tolerance achieved and what standard would you work to?

Measure
refer to Standard

Q3 When checking the welding parameters for MIG/MAG and MMA, from what position in the circuit would the most accurate readings be taken?

nearest possible to the rod holder / arc.



Q4 Is wire feed speed considered more accurate than amperage? Give reasons.

Yes, needles for Amp & Voltage always moving.

Q5 What is the British Standard for arc welding equipment?

BS 638.

SECTION 16

RESIDUAL STRESS AND DISTORTION

RESIDUAL STRESSES

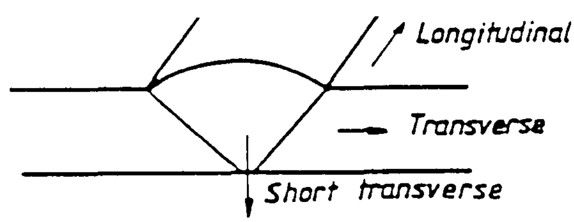
Q1 Metals contract during solidification and subsequent cooling, but if this contraction is prevented or inhibited, residual stresses will develop. Most metal products contain residual stresses, often up to the yield point. Pipe products for example are usually very highly stressed.

The tendency to develop residual stresses increases when the heating and cooling are localised. So welding with its very localised heating and the presence of liquid and solid metal in contact can be expected to induce very high levels of residual stresses.

Residual stresses can be difficult to measure with any real accuracy, but a rough guide is that when the weld metal exceeds $2in^3$ (14cm) then the total residual stress is about yield point in magnitude.

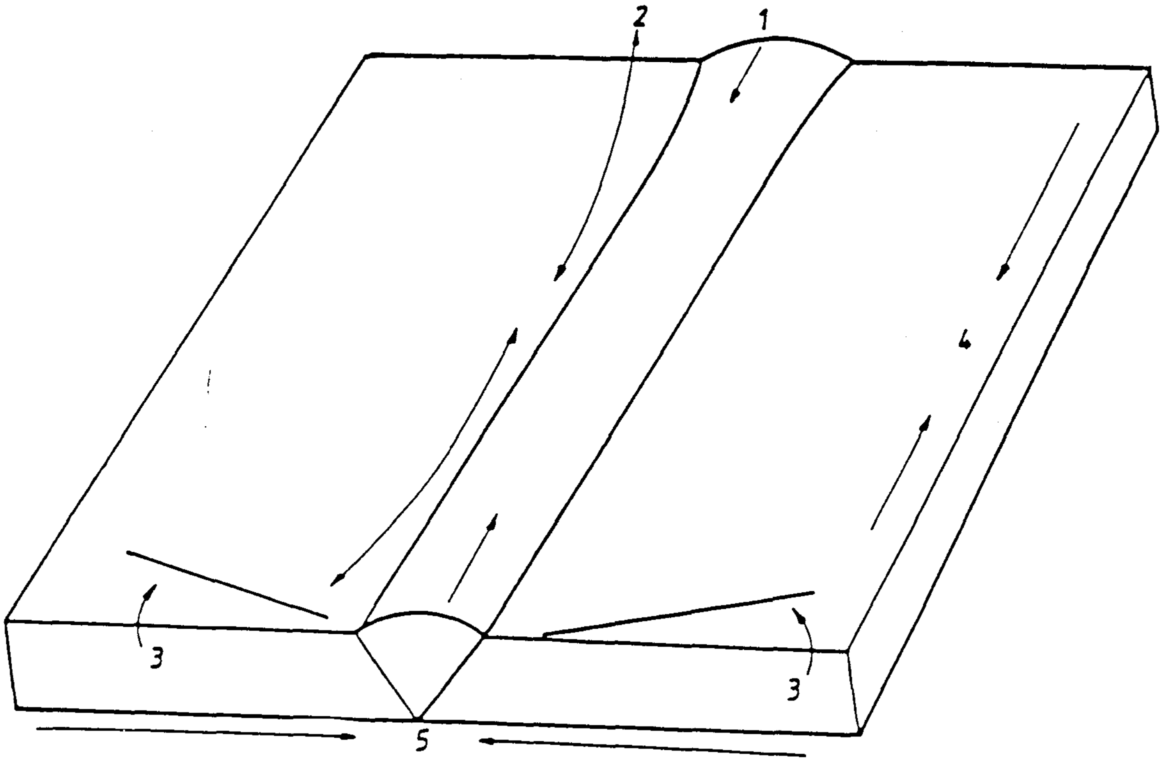
Normal welds develop residual stresses:

Q2
a) along the weld – longitudinal residual stresses
b) across the weld – transverse residual stresses
c) through the weld – short transverse residual stresses



DISTORTION

The action of the residual stresses in welded joints is to cause distortion. Consider a simple weld with a single V preparation.



The following movements can be detected:

1. Contraction in the weld metal and HAZ along the length.
2. Bowing - due to the greater volume of metal at the top of the weld.
3. Peaking due to the V angle.
4. Ripple (in sheet) away from the weld.
5. Contraction in the weld metal and HAZ transverse to the weld.

Control of distortion is achieved in one or more of three ways:

1. Presetting - so that the metal distorts into the required position.
2. Clamping - or restrain to prevent distortion, but this increases the level of residual stresses.
3. Welding sequence, i.e. balanced.
4. Joint design - single V to single U
5. Preheat

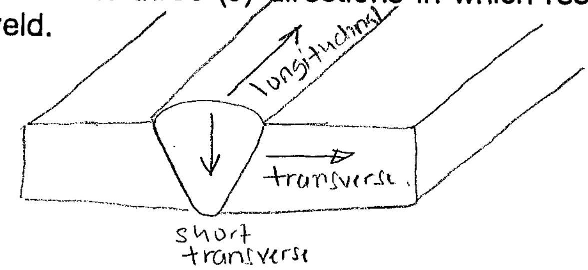
QUESTIONS

RESIDUAL STRESS AND DISTORTION

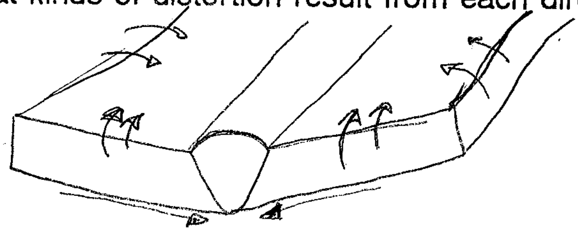
Q1 What causes residual stress in welds?

Metal contrant during cooling process, if the contraction is prevented/inhibited the residual stress introduced to the metal.

Q2 Name the three (3) directions in which residual stresses form in a weld.



Q3 What kinds of distortion result from each direction of residual stress?



① Contraction in the weld metal & HAZ along the length.
② Bowing - V shape of the weld
③ Peeking due to V angle.
④ Ripple away from the weld.

Q4 State two (2) methods of controlling distortion.

① Presetting
② Clamping
③ Joint Design → U shape from V shape
④ preheat.

Q5 How can residual stresses be reduced?

① Post weld heat treatment.

SECTION 17

WELDABILITY

Introduction

As a result of the heat input to which the steel is exposed in any form of welding the material undergoes certain changes, some of which are permanent. Amongst these changes are structural transformation during heating and cooling and changes in shape or size due to the thermal stresses. A steel which can be welded without any dangerous consequences resulting from these changes is said to possess **good weldability**. If, on the other hand, the changes due to a normal welding process are in serious danger of causing failure in a welded component, or if actual defects such as cracking occur during welding, the steel is said to possess **limited weldability** and can in most cases be welded, without risk, provided certain precautions are taken or certain pre- or post-welding treatments carried out. The term 'unweldable steels' is unrealistic. Any steel can be welded provided correct metallurgical conditions are chosen. Sometimes, however, these conditions may be impossible to realise in practical production work.

Weldability of steel

Weldability is a function of many inter-related factors but these may be summarised as :

1. Composition of parent plate
2. Joint design and size
3. Process and technique

Influence of process

Each process will give a characteristic intensity of power. Processes which offer the higher power intensity offer advantages in fusion welding because the essential melting can be obtained without excessive heat inputs with the consequent thermal expansion of the parent metal.

Successful welding often depends on feeding into the weld pool a filler wire which carries a deoxidant (or ferrite forming elements) hence processes which do not use filler wires are limited in application.

Influence of composition

The composition of the steel and its effect on weldability may be divided into two parts:

1. **Segregation effects, particularly that of sulphur**
   When a steel solidifies, there is a tendency for the iron to solidify fast and for the alloying elements to be accumulated in the centre of the ingot. This configuration is retained even after prolonged and severe rolling and results in high concentrations of sulphur in the central layers of the plate. These layers have little strength and are likely to crack if stressed.

2. **The tendency of the steel to harden**
   The hardening characteristics of steel will be mentioned in the heat treatment session. As the carbon or alloy content of the steel increases, the likelihood of low ductility, hardened microstructures forming also increases and should stresses exist cracking will result.

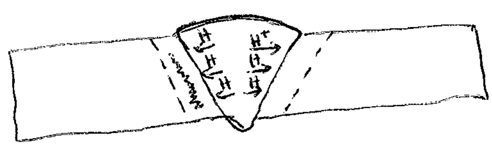
TYPICAL WELDABILITY DEFECTS

1. **SOLIDIFICATION CRACKING** also known as hot cracking

   Caused by sulphur from the parent material. During the solidification of the weld metal one is left with thin iron sulphide films between the solidifying grains which possess very little tensile strength – cracking results.

2. **HYDROGEN CRACKING (under bead cracking/hard zone cracking)**
   also known as delay cracking / HAZ cracking
   This phenomenon can occur during the welding of hardenable ferritic steels. Factors involved:

   1. **hardness**
   2. **stress**
   3. **temperature**
   4. **hydrogen level**



Duan
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3. LAMELLAR TEARING ✓

is a problem involving poor "through thickness" ductility and visually occurs in tee or corner joints in thick ferritic steels where high shrinkage strains act through the plate thickness in combination with parent metal inclusions. A "step-like" crack may occur.

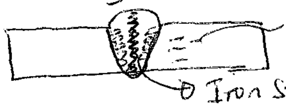
4. WELD DECAY IN AUSTENITIC STAINLESS STEELS ✓

Occurs in the HAZ due to the precipitation of chromium carbides at the grain boundaries resulting in a chromium deficiency in the grains themselves. Because of the loss of chromium, corrosion resistance is lost – "rusting" results.

More info:

Solidification cracking

- mainly happen in submerge arc welding process



- combination of sulfur impurities in parent metal & Iron in the weld pool.

Causes of solidification cracking ✓

① Excessively deep & wide weld bead ✓
② Sulfur ~~cont~~ impurities in parent metal ✓
③ Large root gap ✓
④ Too much restrain in weldment ✓

Prevention.

① Adjust parameters to obtain weld width between 1 and 1.2 of weld depth. ✓
② Clean off all traces of cutting oils ✓
③ Control joint fit up to reduce root gap ✓
④ Plan welding parametes to reduce thermally induced strain.
⑤ Use multipasses rather than one pass.
⑥ Use better quality plates.

Detection.

① Severe cracks detected visually or ~~by~~ surface NDT methods.
② RT for the solidification cracks that does not break to the surface.

Repair method

Locally gouge and grind

Hydrogen Cracking

also known as Delay cracking & HAZ cracking.

Causes.

① Damp electrode ✓ where hydrogen induced from the weld metal
② material too thick ✓ - especially in steel with high carbon content
③ Excessive root gap ✓, stress concentration.
④ Fast cooling ✓ which does not allow sufficient time for hydrogen to diffuse.
⑤ Quenching cause hard zone ✓

Prevention.

① Use hidrogen controlled welding rode dried and stored according to menufacturer recommendation
② Avoid welding in humid condition.
③ preheat the plate ✓ to minimize brittle zone.
④ Slow cooling rate ✓.

Dectection

① Very severe case can be detected visually.
② Medium severity cause could be found by UT & RT

Repair

① Remove by gouging & grinding.
② Crack in HAZ, require buttering to set the geometry.

QUESTIONS

WELDABILITY

Q1 List the four (4) general factors which must be assessed to determine the level of preheat.

① Carbon content (CE) - Type of material
② ~~plate~~ thickness
③ Atmospheric temperature
④ Joint Design
⑤ Process

Q2 List three (3) types of cracks found in weldments and their causes.

① Solidification Crack. — Sulfur contamination & poor weld shape.
② Hydrogen cracking — Hydrogen trap / Harden HAZ
③ Lamellar Tearing — Srinkage forces acting through the plate.

Q3 In which type (composition) of steel is weld decay experienced?

Austenitic Stainless Steel.

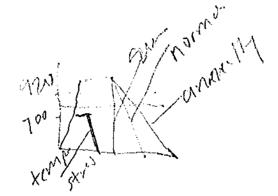
Q4 How can the level of hardness in the heat affected zone (H.A.Z.) be controlled.

Heat treatment (Preheat, post heat & insulating the weld)

Q5. Describe the full heat treatment requirement required for ensuring that basic electrodes are low in hydrogen.

① Baking ⇒ 350°C → 450°C → 1 hour.
② Holding ⇒ 80°C → 120°C ⇒ up to 8 hrs.
③ Quiver → 60°C → 80°C.

SECTION 18



HEAT TREATMENT

Many metals must be given heat treatment before and after welding. The inspector's function is to ensure that the treatment is given and given correctly, to the details supplied.

Below are the types of heat treatment available. The temperatures mentioned are for steels.

Process	Temperature	Cooling	Result
Annealing:	920°C	hold, furnace cool	improves ductility decreases toughness makes bending, etc easier lowers yield stress
Normalising:	920°C	hold, air cool	relieves internal stress improves mechanical properties increases toughness
Quench, harden:	920°C	hold, quench cool	hardens carbon steels prevents carbide precipitation in austenitic steels prevents temper brittleness when cooling after tempering prepares metal for tempering
Temper:	550–700°C	hold, air cool	increases toughness of quenched steels
Stress relief:	550–700°C	hold, air cool	relieves residual stresses improves stability during machining reduces hydrogen levels prevents stress corrosion cracking
Preheat for welding:	50–250°C	hold during welding, exceptionally higher	

N.B. This may be overall or local.

The inspector, in general, should ensure that:

a) Equipment is as specified
b) Equipment is in good condition, i.e. temperature control
c) Procedures as specified is being used

e.g. Method of application
Rate of heating and cooling
Maximum temperature
'Soak time'
Temperature measurement (and calibration)

DOCUMENTATION AND RECORDS.

QUESTIONS

HEAT TREATMENT OF WELDMENTS

Q1 Give the names of four (4) heat treatments which may be applied to steel weldments.

(1) Stress relieving.
(2) Tempering
(3) Preheating
(4) post heat treatment
(5) Hydrogen removal

Q2 State the maximum temperatures used when heat treating weldments.

650° - 700°C ⇒ below 723°C.

Q3 What temperature is used for tempering weldments?

550°C - 700°C

Q4 What is the objective of NORMALISING?

⇒(1) Improve toughness.
(2) Relieve internal stress
(3) improve mechanical properties

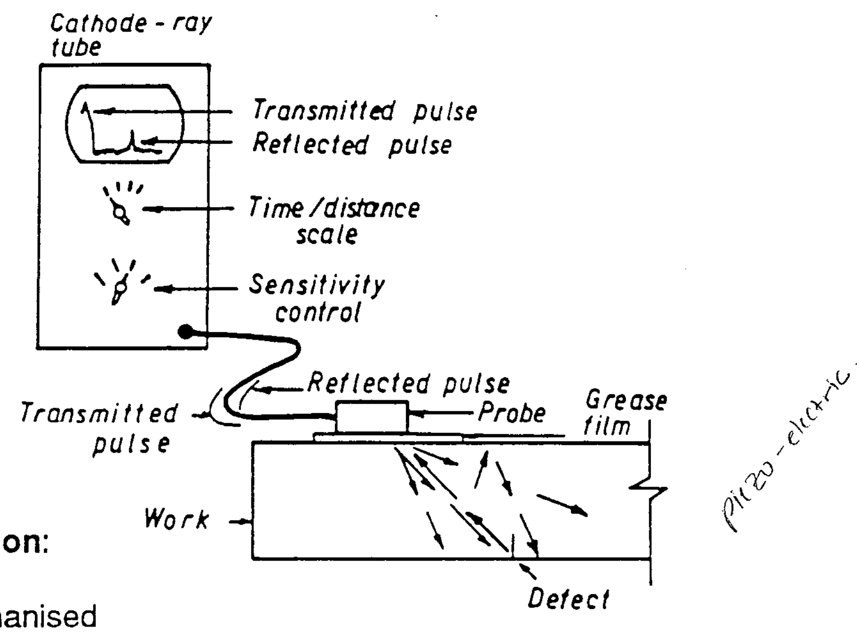
Q5 Which heat treatment is used when maximum toughness is required?

Quenching & Tempering

SECTION 19

NON DESTRUCTIVE TESTING

Ultrasonic inspection



Type of operation:

Manual or mechanised

Equipment:

Main unit containing pulse generator, display oscilloscope, probe (chosen to suit work).

Mode of operation:

A pulse of electrical energy is fed to the probe in which a piezo-electric crystal converts it to mechanical vibrations at an ultrasonic frequency. The vibrations are transmitted (via a layer of grease to exclude the air) through the work; if they encounter a defect some are reflected back to the probe, where they regenerate an electrical signal. A cathode ray tube trace is started when the original signal is sent, displays the reflected defect signal, and from it time, indicating distance from probe, and amplitude, indicating defect size, can be calculated.

Materials:

Most metal, except those with coarse or varying grain structure.

Overall advantages:

Immediate presentation of results ✓
No need to move personnel out (Harmless)
Can be battery powered
Depth locations of defects.

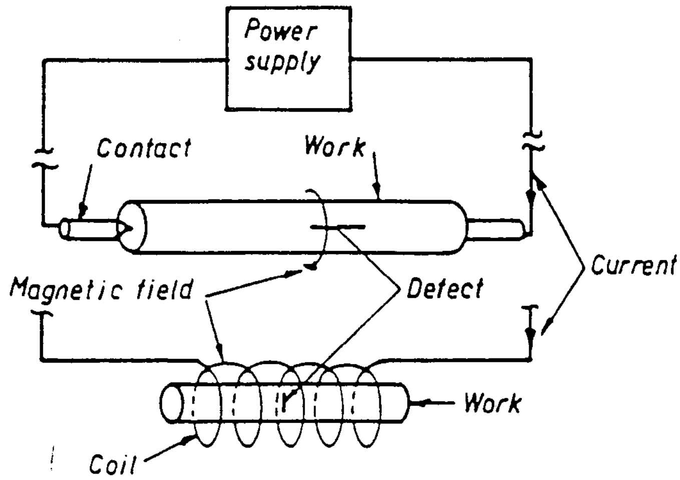
Overall limitations:

Trained and skilled operator required
No pictorial record

Safety

Moderate care needed as for other electronic equipment.

Magnetic particle inspection



Type of operation:

Manual or mechanised.

Equipment:

Power supply
Contacts or coil
Ultra-violet lamp (optional)
Portable or fixed installation.

Mode of operation:

The work is magnetised either by passing a current through it, or through a coil surrounding it. Defects on or near the surface disrupt the magnetic field (unless they are parallel to it). A magnetic particle fluid suspension is applied which concentrates around the defects. The work is viewed either directly or by ultra-violet lights using a dye which fluoresces; that is, emits visible light (this must be done where normal lighting is subdued). After testing, work may be demagnetised if required.

Materials:

Magnetic materials only
Ferritic steels
Some nickel alloys

Overall advantages:

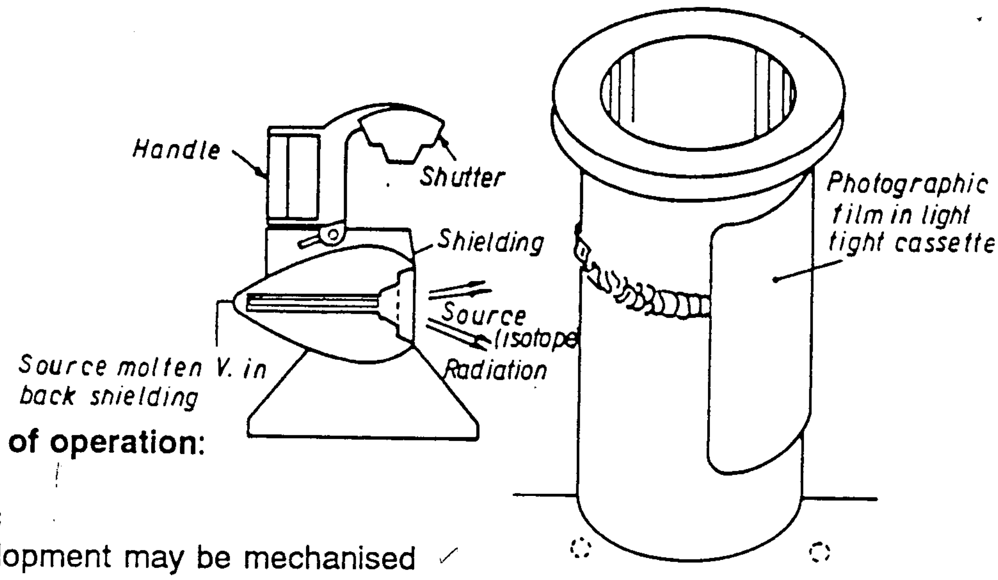
Direct indication of defect location
Initial inspection by unskilled labour (go or no-go)
Some indication of sub-surface defects but of low sensitivity
Not critically dependent on surface condition.

Overall limitations:

No use for non-magnetic materials
Defect detection critically dependent on alignment across magnetic field
Sub-surface flaws require special procedures.

Safety:
Moderate care needed in handling electric equipment and flammable fluids.

Gamma radiography



Type of operation:

Static
Development may be mechanised ✓

Equipment:

Radioactive isotope in storage container ✓
Remote handling gear ✓
Lightproof cassette ✓
Photographic development facilities ✓
Darkroom and illuminator for assessment ✓

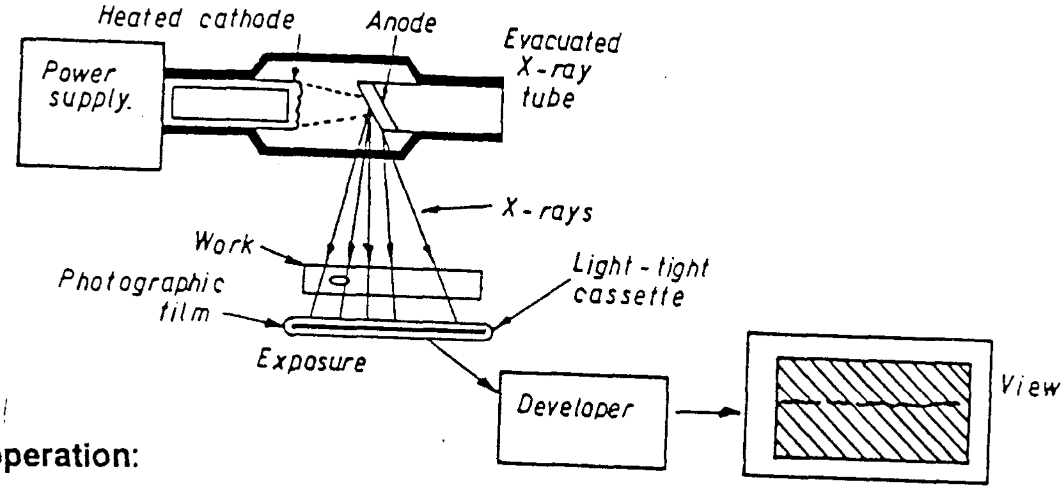
Mode of operation:

Gamma-rays, similar to X-rays, but of shorter wavelength are emitted continuously from the isotope: it cannot be 'switched off', so that when not in use it is kept in a heavy storage container which absorbs radiation. They pass through the work to be inspected. Parts of the work presenting less obstruction to gamma-rays, such as cavities or inclusions, allow increased exposure of the film. The film is developed to form a **radiograph** with cavities or inclusions indicated by darker images. Section thickness increases (such as weld) appear as less dense images.

Materials:

Most weldable metals may be inspected.

X-radiographs



Type of operation:

Static or transportable.

Equipment:

X-ray tube
Stand and control gear
Light-proof cassette
Photographic development facilities
Dark room and illumination for assessment.

Mode of operation:

X-rays are emitted from the tube and pass through the work to be inspected. Parts of the work presenting less obstruction to X-rays, such as cavities or inclusions, allow increased exposure of the film. The film is developed to form a **radiograph** with cavities or inclusions indicated by darker images. Section thickness increases (such as weld under-bead) appear as less dense images.

Materials:

Most weldable metals may be inspected.

Overall advantages:

Accurate pictorial presentation of results
Radiographs may be kept as a permanent record
Not confined to welds

Overall limitations:

Personnel must be clear of area during exposure - safety
Cracks parallel to film amy not show up
Film expensive.

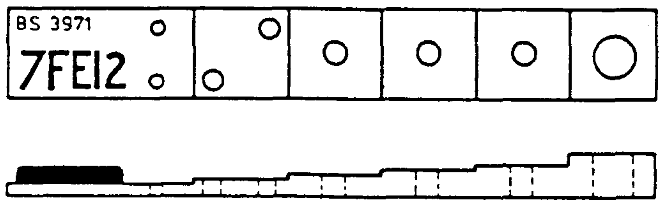
INTERNATIONAL
RADIATION WARNING SYMBOL

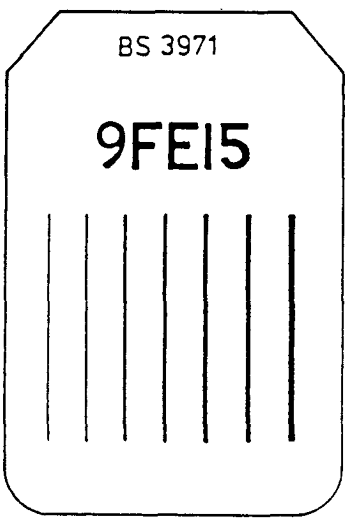
Safety:

Cumulative radiation risk to personnel requires stringent precautions.

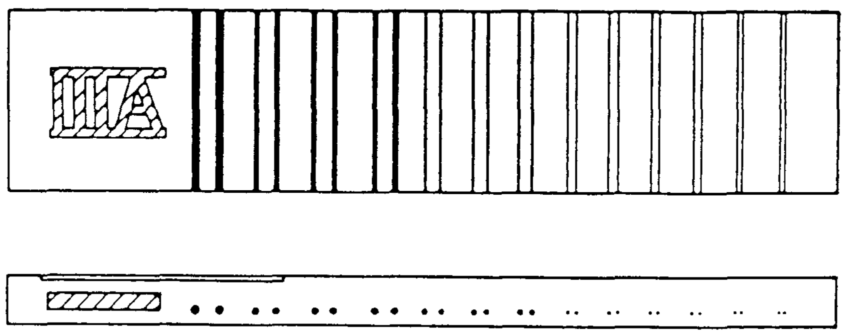
EXAMPLE OF IMAGE QUALITY INDICATORS

Step-hole type



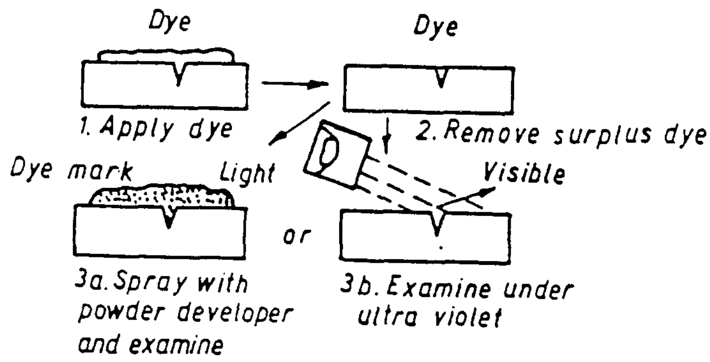


Wire type



Duplex type

Dye penetrant detection



Type of operation:

Manual or mechanised

Equipment:

Min:	Aerosols containing dye, developer etc.
Max:	Tanks – work handling gear (in some cases ultra-violet lamp).

Mode of operation:

A special dye is applied to the surface of the article to be tested. An interval of 1–10 min allows it to soak into any surface defects. The surface is then freed from surplus dye and the dye in the crack revealed by either:

(a) applying a white powder developer into which the dye is absorbed producing a colour contrast indication, or

(b) illuminating with ultra-violet light under which the dye fluoresces; that is, emits visible light. This must be done where normal lighting is subdued.

Materials:

Any

Overall advantages:

Low cost
Direct indication of defect location
Initial examination by unskilled labour (go or no go).

Overall limitations:

Surface defects only detected
Defects cannot readily be rewelded due to entrapped dye. Rough welds produce spurious indications.

Further reading:

Non-destructive testing
General Dynamics
Convair Div
San Diego
Calif
USA (1967)

Safety:

Low flash point dye and propellant gases.

QUESTIONS

NON-DESTRUCTIVE TESTING

Q1 Name four (4) NDT methods

(1) MPI
(2) UT
(3) RT
(4) PP

are full name

Q2 State the two types of rays used in radiography and a limitation of each.

i) Gamma ray - Not suitable for thin material
- Up to 65 mm thickness
- Source cannot be turned off.
- Not as clear as X-ray (lack of clearity)
- Strength of the isotop due to decay.

ii). X-ray - Bulky equipment. - not portable.
- Requires power source.

Q3 What process uses mechanical vibrations to detect defects?

Ultra Sonic Testing

Q4 Name a limitation of MPI.

(1) Able to detect on & near surface defect only
(2) Unable to use for non-magnetic material
(3) No permanent record

Q5 What is the main limitation of using the 'dye' method of inspection?

(1) Surface defect only otherwise cannot detect.

SECTION 20

REPAIR BY WELDING

INTRODUCTION

The repair of defects that occur during welding ranges from simple welding operations to improve weld profile to extensive metal removal and subsequent welding to rectify extensive cracking.

Repair of fabrication defects is generally easier than repair of service failures because the welding procedure used for fabrication may be followed during repair.

The repair of service failures may be difficult because access may be hazardous and the welding procedures used for the original fabrication may be impossible to apply.

This section considers the procedures and the underlying metallurgical principles for the repair of carbon and alloy steels, wrought and cast iron, and some non-ferrous alloys.

Types of defects

Defects requiring repair by welding can be divided into two categories, 1) fabrication defects and 2) service failures.

Fabrication defects

The commonest defects that can occur during the making of a weld include porosity, slag inclusions, undercut consisting of a groove in the parent metal at the edge of a weld, lack of fusion between the weld and the parent metal or between runs of weld metal, incomplete penetration, and solidification cracking.

Defects that can occur during welding but which may not occur until up to 48 hours after welding are hydrogen induced cracking of the weld metal or the heat affected zone of the parent metal and lamellar tearing of the parent metal.

Repair by welding involving removal of defective areas and replacement by sound material can cost up to 10 times as much as depositing similar quantities of weld metal correctly in the first place. Therefore it is important to avoid unacceptable defects and it can be a^N economic proposition in many cases to carry out fairly large scale procedure tests before fabricating critical components.

Having taken all possible precautions to meet acceptance standards, defects inevitably occur, especially when welding is carried out manually rather than by a mechanised method.

To judge whether compliance with the requirements of a code of practice have been met, it is necessary to be able to detect any defects by non-destructive testing and also to determine their dimensions and orientation. Codes recognise that flawless welds are almost always impossible to attain and various levels of acceptance are laid down in respect of allowable porosity and inclusions etc.

Planar defects such as cracks or lack of fusion may nearly always be prohibited and the normal procedure is to repair the welds followed by re-inspection.

The repair procedure may be very simple and merely require the deposition of additional weld metal to rectify undercut but the repair of deep seated defects such as lamellar tearing can entail extensive excavation and rewelding. The welding procedure for the repair weld can often be very similar to the original welding in respect to preheat, type of consumable, and welding conditions. However, if cracking is present the welding conditions may have to be changed to avoid this defect in the repair weld. There are cases in which fabrication defects are not discovered until final inspection and if a sub-section originally welded in the flat position is incorporated into a large structure it is possible that repairs may have to be carried out in less favourable welding positions such as vertically or overhead.

In critical components the repair procedure may have to be qualified by procedure tests particularly if fracture toughness requirements are specified.

In cases where extensive rectification would be required to meet code requirements experience at The Welding Institute has shown that considerable savings in both cost and time can be obtained if the significance of the defects present is assessed on a fitness for purpose basis. This involves calculation of the maximum growth of defects under fatigue loading and of the required toughness levels of weld metal, parent plate and HAZ to avoid brittle fracture during the peak loadings of a structure.

The application of fitness for purpose criteria has in some cases resulted in inspection authorities accepting defects that exceed the limits of code requirements.

Service failure

Service failure in the context of this paper consist of cracks caused mainly by fatigue, brittle fracture, stress corrosion or creep.

In some cases plant shut down may be necessary immediately a crack is discovered if, for example, it is found by leaking of a containment vessel, the crack having propagated from inside through the vessel wall.

In some rare cases a fatigue crack will relieve the stresses in a highly stressed area and will run out of steam and can be left without repair. In other cases fatigue crack growth can be monitored by periodical inspection until plant shut down for repair is convenient.

Brittle fracture is fortunately a relatively rare occurrence compared with fatigue, but when it occurs it can be fare more spectacular leading to disasters such as the breaking in half of ships, or the fragmentation of pressure vessels.

Whether repair is feasible depends on the proportion of the structure remaining intact, and repair can range from removal of the cracked area and welding to the pre-fabrication of new sub-sections which are welded into place. The latter expedient is considered to be rebuilding rather than repair.

The repair of service cracks may be difficult for one or all of the following reasons:

1. Access may be restricted, e.g. inside a mine winder.

2. Preheat and/or post weld heat treatments may be difficult or even impossible to apply, e.g. because of risk of damage to machined surfaces, plastic seals, electrical insulation etc. or presence of flammable materials.

3. The component cannot generally be rotated into the most convenient position for welding. Therefore potential welding may have to be used, e.g. circumferential seams of a pressure vessel may have to be repaired in the overhead position by manual welding whereas the vessel was originally fabricated by rotating it under a submerged arc welding machine. The change in welding process and position of welding could affect the fracture toughness. Therefore complex weld procedure tests may be required for the repair of critical items of plant.

4. The environment may be hazardous, e.g. heat, nuclear radiation, underground.

GENERAL TECHNIQUES FOR TYPICAL REPAIRS

Metal removal

The defect may be in a single run fillet weld requiring only a small amount of metal to be removed or it may be a large crack extending deep into parent metal.

For removing metal rapidly the most convenient method is air arc gouging in which the metal is melted by a carbon arc and is blown out of the cut by a stream of compressed air which passes through holes in a specially designed electrode holder.

Arc-air gouging can be used on both ferrous and non-ferrous metals but the surface finish is generally not as good as obtained by oxyacetylene gouging and the gouged surface finish allows the use of non-destructive testing by dye penetrant or magnetic particle inspection to check whether cracks or other defects have been completely removed.

Other thermal methods of metal removal, less commonly used, are oxygen-arc or oxyacetylene gouging. Mechanical methods include pneumatic chisels, high speed rotary tungsten carbide burrs and grinding wheels.

Groove shape

The minimum amount of metal should be removed by economic reasons but it is necessary to produce a groove wide enough for access and manipulation of the welding electrode or filler wire.

Widths may have to be increased if a repair involves welding in the overhead position or if the surface of the groove has to be buttered with a layer of weld metal of one composition before filing the groove with weld metal of a different composition to prevent weld metal cracking.

While it is more common to carry out a repair with weld metal or one composition only, it may still be advantageous to use the buttering technique particularly in large grooves to reduce the effect of shrinkage across the joint. Each layer of weld metal has a larger free surface than it would if the weld consisted of horizontal layers as in normal fabrication practice and this allows contraction to take place freely with minimum strain on the parent metal. This reduces the risk of cracking in the weld or the HAZ and also reduces the tendency for distortion of the component.

WELDING PROCESSES

The fusion welding processes commonly applied to repair welding are as follows :

1. Manual metal arc welding with flux coated electrodes.
2. Flux cored arc welding with coiled tubular electrodes, either gas shielded or self shielded.
3. MIG (metal inert gas) welding with coiled solid wire and inert shielding gas such as argon or helium.
4. MAG (metal active gas) welding with coiled solid wire and active shielding gas such as CO_2, argon–CO_2 or argon–oxygen shielding gases.
5. TIG (tungsten inert gas) welding with a non consumable tungsten electrode and a separately fed filler wire.
6. Oxyacetylene welding

Table 1 shows the general order of preference for repair welding processes for common materials.

For most ferrous alloys manual metal arc welding is the preferred repair method because of its adaptability to difficult situations where access may be restricted, the angle of inclination of the electrode to the workpiece not being as critical as that of a welding gun in the semi-automatic MIG or MAG processes.

Flux cored arc welding is used extensively in steel foundries for repair of castings which can be positioned so that welding can be carried out in the flat position in which maximum welding current and deposition rates can be used.

MIG welding is generally favoured for non-ferrous materials and is the first choice for welding aluminium alloys because of ease of MIG welding aluminium compared with manual metal arc welding and for high welding quality.

SUMMARY

Before a welding repair is carried out the need for repair must be carefully considered. If a component or structure contains defects of a known size, whether these are fabrication or service defects, a fitness for purpose evaluation may show them to be insignificant, thus saving the cost of repair.

When repair is shown to be necessary, the factors to be considered include the following:

1. The extent of repair and possible consequences such as distortion.
2. The access for welding and welding position
3. Requirements for preheat and/or post heat
4. Choice of welding consumables and welding procedure to avoid pre or post weld heat treatment.
5. The mechanical properties required in the weld metal and HAZ and the need for procedure tests.

Having suitable welding procedures and fulfilling the metallurgical requirements are the first two vital factors for a successful repair.

The third factor is a high level of welder and supervisory skill because the application of the first two factors under the difficult conditions under which some complex repairs are carried out depends on the expertise of these personnel.

QUESTIONS

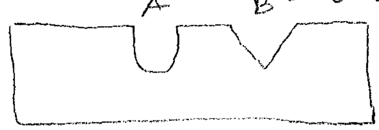
REPAIR WELDING

Q1 State six (6) points of importance of repair welding.

(1) NDT report ✓
(2) location of defect ✓
(3) Removal ✓
(4) NDT Groove ✓
(5) Repair procedure ✓
(6) Rewelding ✓
(7) NDT. ✓

Q2 Sketch a plan and side view of a typical repair excavation.

A B → Better shape for repair.



Q3 State two (2) non-destructive test methods that may be applied to a repair.

(1) MPI ⇒ demagnetise the groove.
(2) Dye Pent. (wait until weld is cooled)

Q4 At what stage would each NDT method generally be used.

(1) UT or RT.

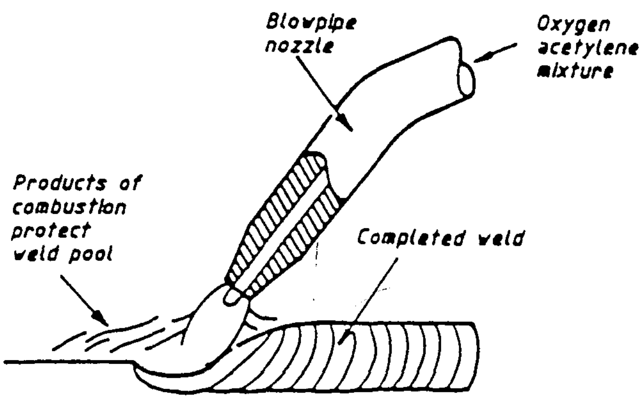
Q5 State three (3) documents which the inspector should refer to when carrying out repairs.

(1) NDT reports
(2) Repair procedure.
(3) Specification/code.

SECTION 21

OXY FUEL GAS WELDING, CUTTING AND GOUGING

GAS WELDING



Mode of Operation
A fuel gas (usually acetylene) and an oxidant gas (oxygen) are mixed and burnt.

The operator must manipulate the blowpipe to give the correct weld pool size, and also add filler metal as required.

The melting is slow compared with arc processes, limiting the speed of work. The weld pool is shielded from atmospheric contamination by the burnt gas mixture which can be made mildly oxidising or reducing.

Oxyacetylene (OA)

Typical defects associated with this process:

Unequal leg length fillet. ✓

- Too concave butt weld profile. ✓

Too convex butt weld profile. ✓

Undesirable weld profile (lap, fillet). ✓

Excessive penetration. ✓

Excessive fusion of root edges. ✓

Burnthrough. ✓

Undercut along vertical member of fillet welded T joint.

Root run too large with undercut in butt joint.

Undercut both sides of weld face in butt joint.

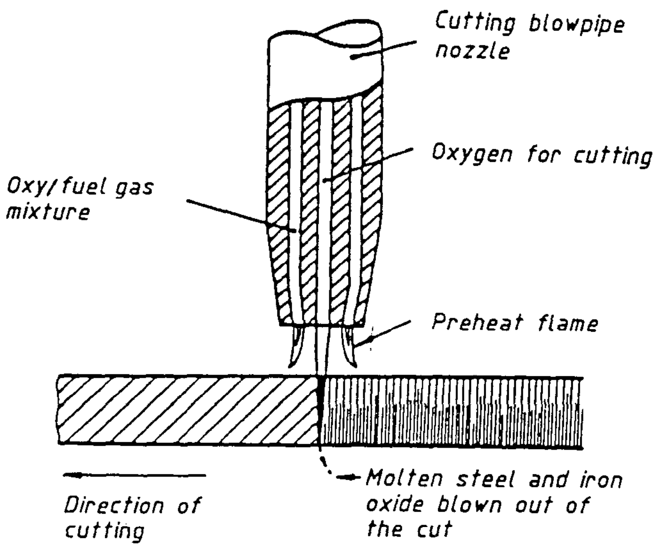
- Oxidised weld face.

- Overheated weld.

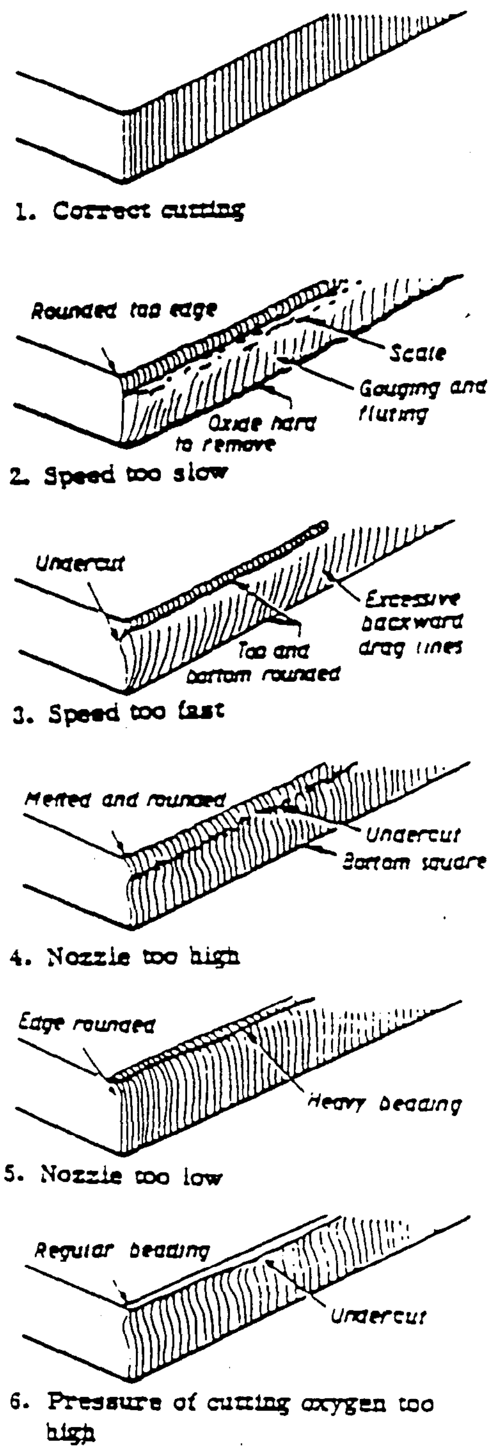
Incomplete root penetration in butt joints (single V or double V).

Incomplete root penetration in close square T joint.

THERMAL CUTTING
FLAME CUTTING
GAS CUTTING



Oxy/fuel gas cutting



Principles of cutting operation

There are two operations in gas cutting. A heating flame is directed on the metal to be cut and raises it to bright red heat; this is known as the ignition point. When this point is reached a stream high-pressure oxygen is directed on to the hot metal. This oxidizes the metal and forms a magnetic oxide of iron (Fe_3O_4). The melting point of this oxide is well below that of the iron, and it melts immediately and is blown away by an oxygen stream.

QUESTIONS

OXY FUEL GAS WELDING, CUTTING AND GOUGING

Q1 What is the principal limitation of oxy/acetylene welding?

Q2 Give three (3) flame types and their respective applications.

Q3 Give three (3) typical defects found with oxy/acetylene welding.

Q4 Give four typical defects found when cutting using the oxy/fuel process.

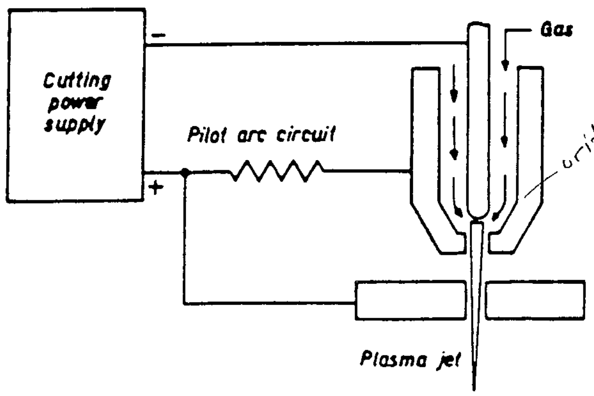
Q5 Give four (4) points of safety which require inspection when cutting.

SECTION 22

very hot gas column

ARC CUTTING SYSTEMS

PLASMA CUTTING



Type of operation: usually mechanised, but can be used manually

Equipment: power supply – similar to that needed for DC, TIG, but may have a higher output voltage
gas supply
plasma torch
guidance system for mechanised operation

Mode of operation

A TIG arc is constricted by positioning a small diameter orifice between the electrode and the work. The gas passing through the arc zone and the orifice is heated and would normally expand. The constriction prevents this and the gas is forced to accelerate through the orifice as a very hot gas column (plasma). The speed of the gas columns is near the speed of sound and will pierce (keyhole) metal. If there is relative motion between the torch and the work a cut will be produced. The plasma arc may be between the electrode and the work (transferred) or between the electrode and the nozzle (non-transferred).

Operating parameters

Current:	100-300A
Gas flow:	1.5-7m^3/hr
Thickness:	up to 200mm
Speed:	0.07-3m/min
Access:	good
Portability:	fair.

Consumables

Argon or argon-hydrogen mixtures in cylinders of 7m^3 orifice nozzles
Orifice nozzles
Tungsten electrodes.

Materials

Any metals except those of very high melting point
Some thin non-metals.

Typical applications

Cutting slabs in rolling mills
Fabrications in stainless steel and aluminium materials.

Overall advantages

Can cut materials to which it is difficult to apply other thermal processes, or mechanised cutting, such as aluminium, stainless steel and copper.

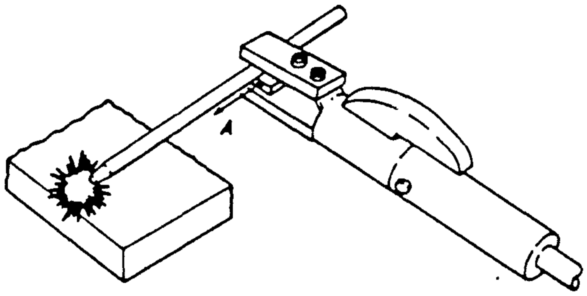
Overall limitations

High equipment cost
Cut edge not square
Noisy.

Safety

Arc emits visible and ultraviolet radiation
Hot debris blown out
Noise level may be high enough to require personnel to wear ear muffs.

AIR-ARC CUTTING



A = air jets which blow out metal from a molten pool

Type of operation: manual

Equipment: rectifier set or motor-generator (as for manual metal-arc welding) special electrode holder with compressed air jet air supply

Mode of operation

An arc is struck between the end of the electrode and the work. The molten metal is blown away by a compressed air jet attached to the electrode holder.

The process may be used for surface gouging or through cutting.

Operating parameters

Current:	80-1600A
Air supply:	up to 1MN/m^2 and 1m^3/min
Thickness:	up to 50mm
Access:	fair
Portability:	good

Consumables

Copper-coated carbon electrode 4.0-20mm diameter.

Materials

Wide range of metals.

Typical applications

Gouging out surplus weld metal or surface and internal defects
Preparation of J-edge for welding.

Overall advantages

Can use same equipment as manual metal-arc welding, with minimal addition.
Clean
Fast cutting.

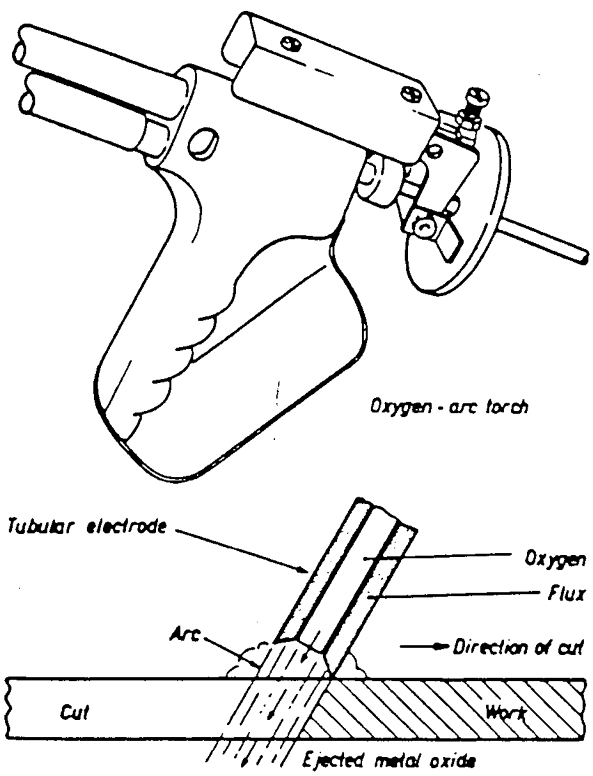
Overall limitations

Inaccurate cut
Wide cut
Difficult to mechanise.

Safety

Arc emits visible and ultraviolet radiation
Hot debris blown out of cut.

OXYGEN-ARC CUTTING



Type of operation: manual

Equipment: power supply as for manual metal-arc welding
special electrode holder with oxygen passage
oxygen regulator

Mode of operation

An arc is struck between the end of a hollow, consumable electrode and the work.

Oxygen is blown down the electrode and the metal of the work burns away, and is blown downwards to form the cut.

A coating on the electrode stabilises the arc and burns off so that a cup is formed. The cup maintains the correct arc length.

Operating parameters

Current:	100-150A
Oxygen:	0.3-0.5MN/m^2
Thickness:	6-50mm
Speed:	16-70m/hr
Access:	good
Portability:	good.

Consumables

Electrodes 5-8mm diameter
Oxygen in cylinders of 7m^3.

Materials

Wide range of metals.

Typical applications

Preparation for fabrication by manual metal-arc process
Salvage and scrapping.

Overall advantages

Simple equipment. Can also be used under water (with special electrodes).

Overall limitations

Manual operation only
Rough oxidised cut surface.

Safety

Arc emits visible and ultraviolet radiation.
Arcing on to oxygen cylinders must be avoided.
Debris from cut may cause fires and burns.
Risk of oxygen enrichment in enclosed spaces.

QUESTIONS

ARC CUTTING AND GOUGING

Q1 State three (3) safety precautions that must be observed when oxy/arc cutting.

Q2 State three (3) safety precautions that must be observed when air arc cutting.

Q3 Why must mechanical dressing follow arc air gouging operations.

Q4 What type of current is essential for arc cutting.

Q5 State two (2) methods of plasma arc cutting.

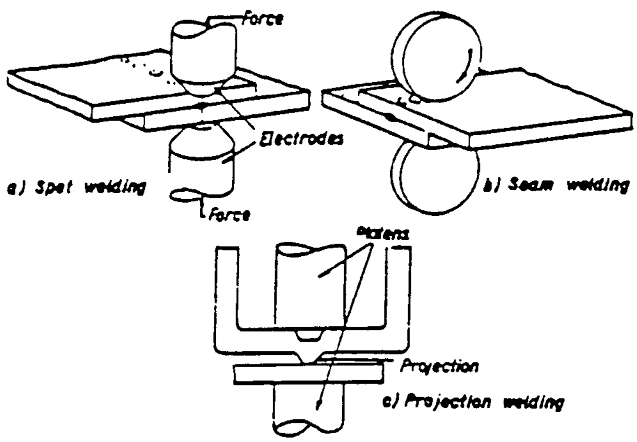
SECTION 23

OTHER WELDING SYSTEMS

Welding inspection also requires that inspection personnel have a reasonable understanding of other welding processes.

Overleaf are some of the other systems which you may come in contact with.

Welding by pressure
RESISTANCE WELDING
Electric resistant welding, erw.
Resistance, spot, seam or projection welding



Type of operation: manual or mechanical positioning of work, then automatic

Equipment: controller
timer
transformer and sometimes a rectifier
electrodes (copper alloy) with water cooling and force system

Resistance welding

Mode of operation

A high current at a low voltage (4-6), flows through the two components between the electrodes. The electrodes are of high conductivity material, so that most of the heat is generated at the high resistance interface between the faying surfaces of the two components, which melt and form the weld.

The force applied by the electrodes excludes atmospheric contamination and keeps the faying surfaces in contact.

Mechanical stepping (stitch welding) or roller electrodes (seam welding) may be used to make a series of spots, either independent or overlapping.

The area of the weld is usually defined by the area carrying current in turn fixed by the area of the electrode faces. In projection welding, on the other hand, current flow is limited by raised areas on the work.

Operating parameters

Current range:	100-500 000A; voltage 4-6
Cycle time:	0.1-3sec (per weld)
Range of thickness:	0.01-10mm

Electrode pressure:	7-70MN/m^2
Types of joint:	Spot weld on lap joint. Overlapping spots may be used to give a stitch or seam weld
Welding position:	any
Access:	fair
Portability:	portable equipment for light jobs, mains supply usually essential.

Consumables

Electrodes need replacement due to wear after about 1-10 000 welds, and may then be refaced. They are normally made from a copper alloy chosen to compromise between the conflicting requirements of high electrical conductivity and of reasonable wear resistance.

Materials

A wide range of metals, but copper is difficult.

Typical applications

Light fabrications from pressed sheet such as motor vehicle bodies domestic washing machine and refrigerator cabinets.

Overall advantages

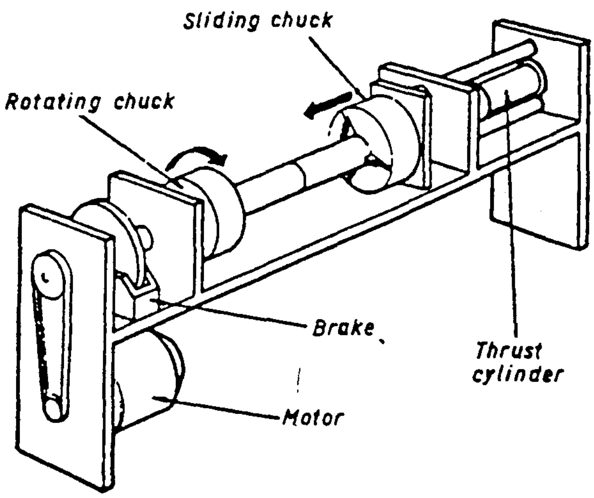
High production rate
No costly consumables
Unskilled operation.

Overall limitations

Thick material needs large expensive equipment. Joints are usually in the form of a lap, component size and access is limited by machine dimensions. NDT is difficult, quality control is by process control.

80 usss
150 m
1.5

Welding with pressure
FRICTION WELDING



Type of operation: mechanised

Equipment: motor to rotate one component
brake
axial force system, usually hydraulic
timer/control system
chucks for components

Mode of operation

The two parts to be joined are clamped in chucks and one part is rotated up to welding speed. The second part is brought into contact with the rotating part under axial load. Rubbing friction between the abutting faces produces a hot plastic zone, some of which is extruded radially from the joint taking with it any oxides formed at the joint face. After a preset time rotation is stopped still maintaining or increasing the axial load. The result is a forged butt weld having an excess metal oxide 'flash' which may be removed.

The force system is usually hydraulic or pneumatic; a hydraulic drive may be used for the rotating member.

Operating parameters

Rotational speed:	50rev/min — 80 000rev/min
Axial pressure:	15-400MN/m^2
Range of size:	1-150mm diameter
Cycle time:	5-500sec
Access:	one member must be rotated
Portability:	fair.

Consumables

Nil.

Materials

Almost all metals and thermoplastics. Good for joining dissimilar metals.

Typical applications

Internal combustion engine valves; head-to-stem joint of dissimilar metals
Stud welding
Rear axle casings, transmission and steering components for vehicles
Electrical connections.

Overall advantages

Produces welds consistently of high quality
Fast joining of large area
Suitable for wide range of materials
Equipment is mechanical, working on simple principle.

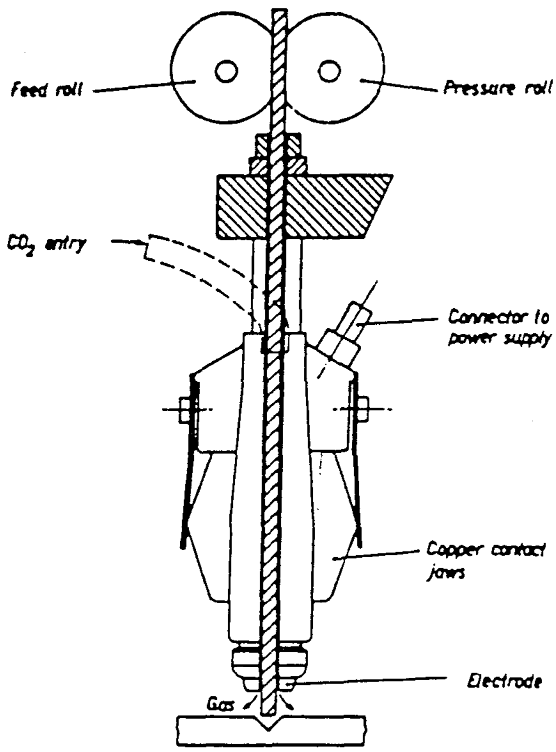
Overall limitations

One component must be rotated (orbital welding will eliminate this)
Angular alignment of completed weld not easily controlled.

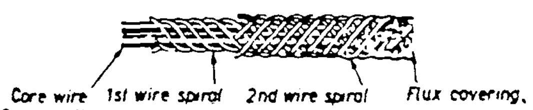
Safety

Usual precautions for moving machinery.

Fusion welding
AUTOMATIC METAL-ARC
(Fusarc Welding)



Automatic metal arc head with CO_2 shield.



Construction of electrode for automatic metal arc welding.

Type of operation:	mechanised or automatic
Equipment:	welding head, control panel electrode feed unit (may have additional CO_2 for shielding) Electrode reel. power source, transformer rectifier or generator — AC/DC up to 1000A work moving equipment and/or head moving equipment

Mode of operation

An arc is maintained between a fluxed electrode and the work. The arc length is controlled by a variable speed motor and feed roll system. The arc may have an additional CO_2 gas shield. The weld is protected and controlled by the flux coating as in MMA.

Operating parameters

Current range:	200–1000A
Deposition rate:	1-15kg/hr
Range of thickness:	6mm upwards
Types of joint:	butt and fillet
Welding positions:	butt joints flat, fillets, flat and HV
Access and portability:	good.

Consumables

Wire wound, flux-coated electrode 2.75-7.5mm on wire diameter. Supplied in coils of 13.5-22.5kg weight. The electrode composition can be selected to suit the parent metal. CO_2 gas in some cases.

Materials

Only carbon, low alloy high tensile and stainless steels.

Typical applications

Medium scale fabrication, pipework, shipbuilding, chemical plant.

Overall advantages

Good deposition rate, good quality weld metal. Tolerant to poor fitup and open air work.

Overall limitations

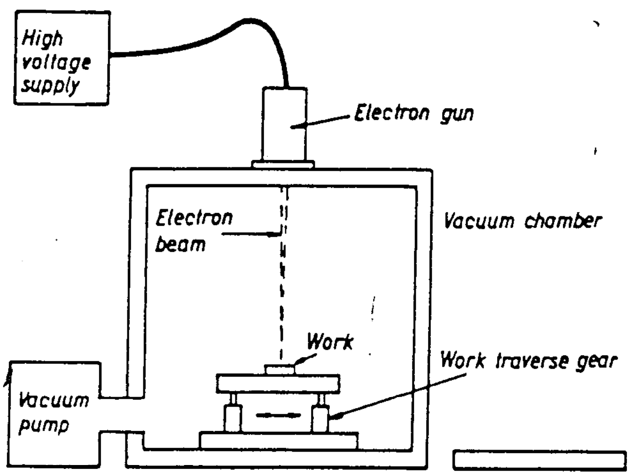
Open arc. Electrode needs careful handling. Limited penetration.

Safety

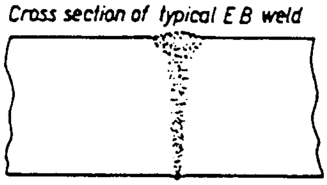
Intense arc. Copious fumes.

automatic mech. etc.

Fusion welding
ELECTRON BEAM



Cross section of typical E B weld



Type of operation: automatic or mechanised

Equipment: high voltage power supply
electron gun
vacuum chamber
vacuum pump
traversing unit, for work or gun

Mode of operation

The workpiece is heated by the bombardment of a beam of electrons produced by an electron gun.

Filler metal may be added if necessary.

Though the work is normally within a vacuum chamber, electron guns are currently under development which will allow a beam to travel a short distance through air.

Operating parameters:

Current range:	10-500mA
Voltage range:	10-150kV
Range of thickness:	0.2-100mm
Types of joint:	mostly butt
Welding positions:	limited by equipment
Access:	good but work must normally be lifted into and out of a fixed chamber
Portability:	poor.

Consumables

Filler wire may be added as necessary.

Materials

Any metal compatible with vacuum when molten.

Typical applications

Gear clusters/shaft joint
Turbine blade root joint
Full machined components (low distortion)
Difficult-to-weld materials.

Overall advantages

Excellent penetration. Low distortion
No weld metal contamination
High welding speeds
Ability to weld many normally unweldable materials.

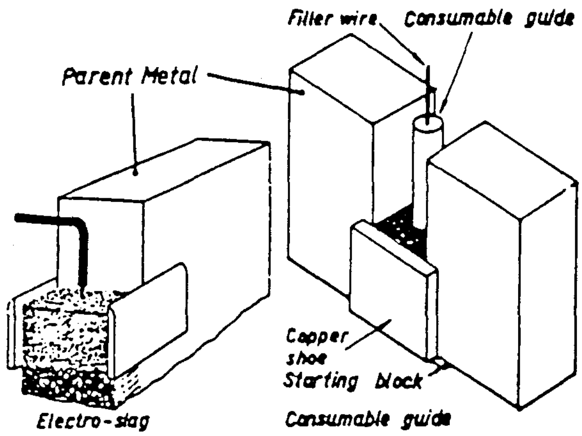
Overall limitations

High equipment cost
Vacuum necessary
Extreme accuracy needed in work preparation.

Safety

X-radiation emitted, but normally absorbed by chamber walls
High voltage
Operators can be trapped in large chambers.

Fusion welding
ELECTRO-SLAG
Consumable wire guide
Consumable nozzle



Type of operation: mechanised

Equipment: power source
wire feed unit
vertical traverse (for electro-slag only)
water-cooled copper shoes

Mode of operation

Welding is carried out vertically. The plates to be welded are set up with a 25-50mm gap (depending on thickness) between their edges (unprepared) and the electrode is introduced into the gap pointing vertically down. An arc is struck and granular flux added which is melted by the arc. The molten flux extinguishes the arc and the heat required for welding is then produced by the passage of current through the electrically resistive flux. Water-cooled copper 'shoes' are clamped against the plate surfaces, covering the gap on each side, to retain the molten flux and also the weld pool formed by the melting of the electrode and parent plate.

In electro-slag welding the electrode feed unit is moved up the joint as the gap is progressively filled with molten weld metal, and the retaining shoes are also moved up at the same speed.

The electrode in consumable guide welding is fed through a long tube which is positioned in the joint gap. As welding progresses the electrode wire and the guide are melted into the weld pool. The system is mechanically more simple since no vertical up movement of the wire feed unit is required.

Operating parameters

Current range:	450-1500A/per wire AC or DC
Welding speed:	0.3-3m/hr
Range of thickness:	20mm upwards
Welding position:	vertical
Types of joint:	butt and T-joints
Access:	poor
Portability:	fair

Consumables

Electrode wires are similar to those used for submerged-arc welding, and supplied on standard spools weighing 25-75kg. Consumable guides may be in the form of tubes or specially made hollow sections according to the particular application. The composition of both wires and guides must be chosen to suit the parent material and with reference to required weld metal properties. Fluxes are specially formulated and resemble submerged-arc welding fluxes.

Materials

Steels (European experience only). Other materials reported from U.S.S.R..

Typical applications

Thick pressure vessels
Thick civil engineering fabrication
Shipbuilding.

Overall advantages

Fast completion of joints in thick plate.

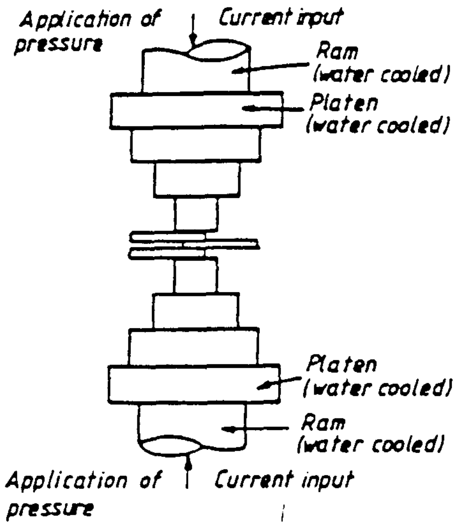
Overall limitations

Only for vertical or near-vertical joints. Welds have poor impact properties unless heat treated.

Safety

Molten metal spillage must be considered.

Welding with pressure
DIFFUSION BONDING



Type of operation: Mechanical

Equipment: Means of pressurising joints eg. press. Means of shielding joint eg. vacuum chamber. Means of heating typically resistance or HF induction. Control gear

Mode of operation

Stock is machined (typically 0.4mm CLA) cleaned and clamped in abutment. An interlayer of foil may or may not be used as a b[illegible]ding aid. The required level of shielding is e[illegible]ablished eg. the vacuum chamber is evacuated to say 10^{-3} Torr and heating is started. Bonding typically occurs at about 70% of the melting temperature of the stock and can be complete within 3 mins. (temperature dependent). The result is a diffusion bonded joint with excellent mechanical properties, little or no distortion and usually totally free from the normal type of weld defect.

Operating parameters

Bonding pressures:	5-15N/mm^2
Range of size:	5.0mm^2 to $10^6 mm^2$ at present state
Cycle time:	Determined by sample size and permissible heating rate usually 30mins or longer.

Access:	Poor, large bulky plant.
Portability:	Poor, probably non-existent.

Consumables

For some combinations of materials a shim of compatible material is employed.

Materials

Full range not yet established but most metals and inorganic non-metals can be diffusion bonded.

Typical applications

Heavy (Chunky) section constructions, hollow assemblies, complex multi-joint components, inaccessible joints, ultrasonic inspection test blocks.

Overall advantages

Low distortion single shot joining of large areas with very high joint quality.

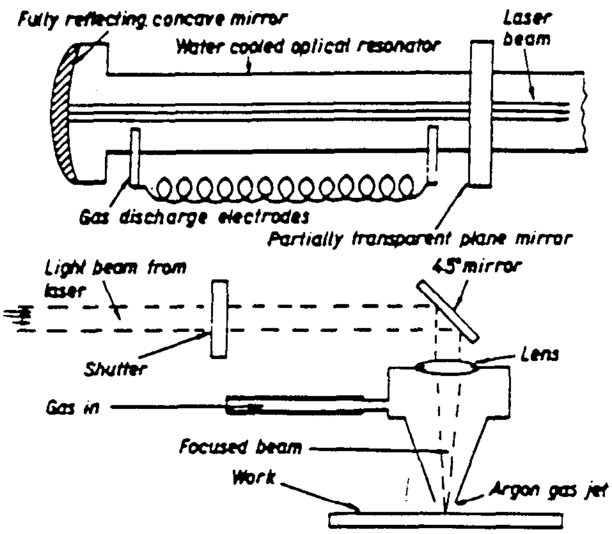
Overall limitations

Expensive and massive plant. Need for protection of joint area.

Safety

That for furnace and press operating.

Fusion welding
LASER WELDING



ype of operation: mechanised

quipment: laser
lens
work positioning system
gas shielding if required

ode of operation

he laser generates a powerful parallel beam light of one colour. The lens focuses this eam to a point at which the entire output ower (50W-2kW) of the laser is concentrated. a workpiece is placed at this point, it will sorb some of the light which will raise its mperature.

The laser may have a continuous or a ılsed output: the latter is limited in the thick-ess of material which can be welded as heating ust proceed at a slow enough rate to avoid ıpourising the surface.

The process applies no appreciable force to the components to be joined, but imposes tight limits on fitup and beam alignment.

Consumables

Gas filling in some continuous lasers.

Materials

Most metals can be joined in laboratory experiments, but those with high reflectivity at the operating wavelength present difficulties.

Typical applications

Continuous laser - development work only
Pulsed laser - reputed application to some small assemblies such as electronic components.

Overall advantages

Wide range of materials
No force on work.

Overall limitations

Equipment complex and expensive for size of joint and speed of working.

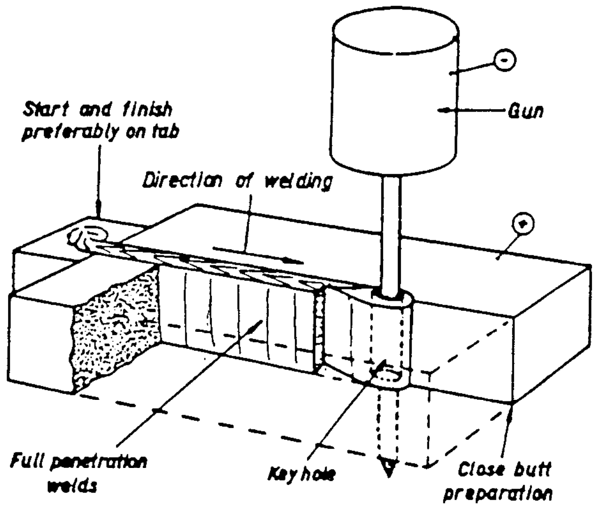
Safety

Laser radiation, either direct or reflected, can cause personal injury, particularly when it is focused on the retina of the eye by the eye lens, causing some degree of blindness.

Operating parameters (typical)

		Continuous	Pulsed
Laser:	power:	100W-1kW	50kW
	pulse duration/energy:	-	2msec/100J
	operating wavelength:	10.6 µm (medium infra-red)	0.6 or 1.06 µm (red or near infra-red)
	beam diameter:	15-30mm	12mm
	length:	5m	0.3m
Lens:	focal length:	150mm	100mm
Range of thickness:		up to 1.5mm	up to 1mm
Type of joint:		butt, lap, fillet	spot
Access:		good	good
Portability:		poor	fair.

Fusion welding
PLASMA ARC WELDING



Transferred arc mode

Type of operation: usually mechanised

Equipment: transformer rectifiers as for TIG but with an OCV of 60-140V
plasma torch
traversing system
wire feed device

Mode of operation

A TIG arc between an electrode and the workpiece is constricted by a small orifice. The shielding or plasma gas passing through the orifice is heated and can therefore expand only by accelerating through the nozzle at very high speed. The hot gas (plasma) is at approximately 16000°C and this, together with the jet effect, can produce complete penetration of the joint being welded (keyholing).

Operating parameters

Current:	100-300A
Gas flow:	0.3-3.0m/hr
Joint thickness:	3.0-15mm
Speed:	0.14-0.6m/min
Access:	good
Portability:	fair.

Consumables

Argon, argon-hydrogen, argon-helium mixtures in cylinders $7m^3$
Tungsten electrodes, nozzles.

Materials

Any metal which can be TIG-welded.

Typical applications

Butt welds in unprepared plate for chemical plant. High speed tube manufacture.

Overall advantages

Welding speeds up by about 40-100% compared with TIG.

Overall limitations

High equipment cost, accurate fitup essential. Difficult to use manually.

Safety

Powerful emitter of radiation
Noise hazard
Electrical hazard up to 400V
Ultraviolet light from arc.

QUESTIONS

OTHER WELDING SYSTEMS

Q1 How is contamination of the weld prevented in friction welding.

Q2 Explain the electro slag process "Mode of operation".

Q3 State two (2) processes that use the "keyholing" technique.

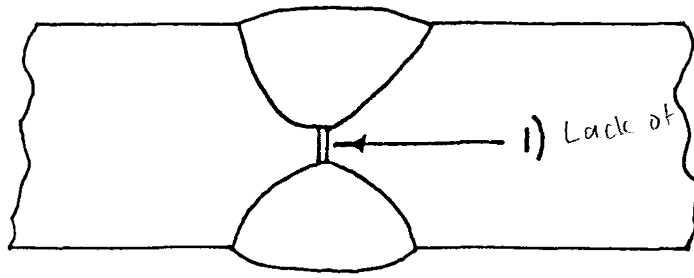
Q4 Why would PWHT be applied after electro slag welding?

Q5 State two (2) solid state processes.

SECTION 24

INTERNAL DEFECTS & THEIR INTERPRETATION

During interpretation it is necessary to identify associated defects, e.g. example 1.

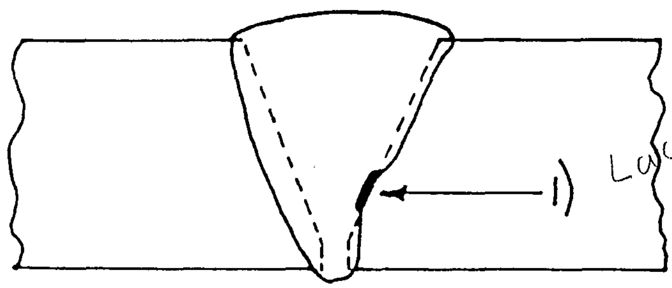


Report 1: Incomplete root penetration and root fusion

In the above sketch incomplete root penetration can be seen but, because of the loss of penetration, incomplete root fusion is also present.

Planar defects such as incomplete sidewall, incomplete inter-run and incomplete root fusion are very often associated with the presence of a non metallic inclusion, typically slag for MMA and SA and deoxidiser residue for MIG and TIG (ferritic steels).
e.g. example 2.

Process MAG

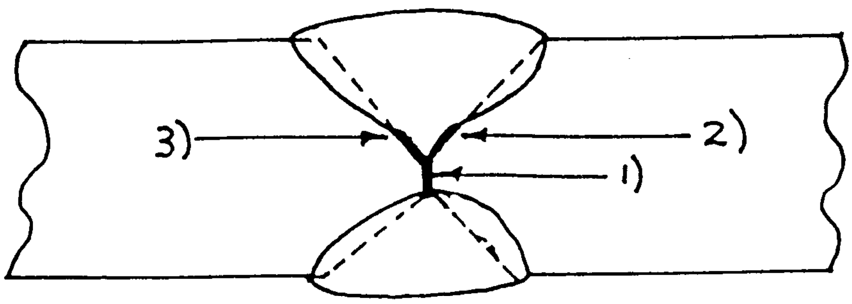


In this example incomplete sidewall fusion is present. Because the defect also has width it can largely be associated with a 'silica' inclusion.

Report 1: Incomplete sidewall fusion with associated silica dioxide inclusion (and dimension).

The sketch below shows a root penetration/fusion defect caused because of either insufficient root gap or no back gouging; on examination incomplete sidewall fusion has resulted because of poor access,
e.g. example 3.

Process MMA

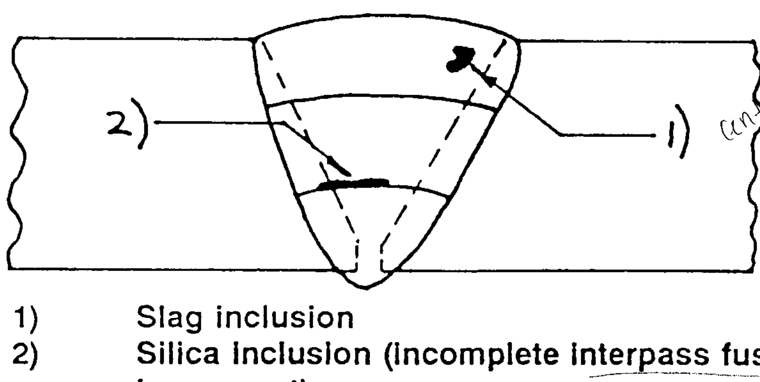


Report: 1) **Incomplete root penetration and root fusion**
2) **Incomplete sidewall fusion***
3) **Incomplete sidewall fusion***

*Your judgement will be necessary in order to determine any associated inclusion.

As previously mentioned, slag and silica inclusions are associated with specific processes. With regard to interpretation the inspector must confirm the welding process in order to make an accurate assessment. This may be by reference to the welding procedure or by assessment of the weld face. Slag inclusions will be clearly volumetric against silica inclusions which will have length and limited width,
e.g. example 4..

Slag inclusions or silica inclusions?



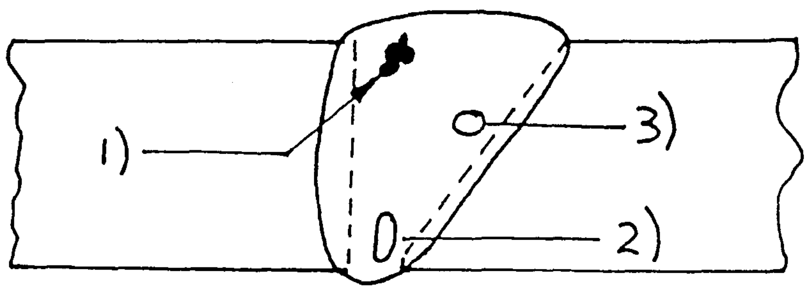
angular, dark color, irregular shape

Report: 1) Slag inclusion
2) **Silica inclusion (incomplete interpass fusion may also be present)**

In general terms, slag inclusions are non uniform in their shape, also very often the slag is still visible.

Gas inclusions, on the other hand, are generally uniform in their shape and are of a metallic appearance,
e.g. example 5.

Gas inclusions (pores), porosity or solid inclusions?

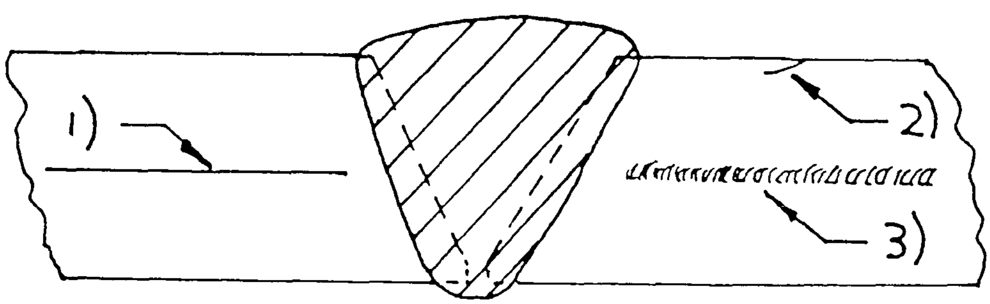


or worm hole, piping

Report: 1) **Slag inclusion** }
2) **Elongated gas cavity** } **dimensions required**
3) **Gas pore** ; sphere }

The inspector should report any parent metal defects (laps, laminations and segregation bands)
e.g. example 6.

Parent metal defects



Report: 1) **Laminations (straight and narrow)**
2) **Lap (near surface of material)**
3) **Segregation band (similar to lamination but lacks definite edges (hazy)).**

*Above are examples for reference, greater detail will be provided during the course.

APPENDIX

Certification Scheme for Welding and Inspection Personnel

Phase 6: Senior Welding Inspectors and Welding Inspectors

Codes, Standards and Specifications

The following is a list of Codes/Standards and Specifications to which candidates for the above examinations may use. They may be selected by the candidate or the candidate's employer.

The candidate is required to have a good working knowledge of his/her chosen Code/Standard or Specification. In addition, they should also be aware and in possession of any such specifications that may be cross referenced by their main application Code/Standard, relating to Materials, Consumables, Welding procedure/Welder qualifications, destructive and non destructive testing etc.

The candidate should ensure that the selected code, Standard/Specification is up to date, and wherever possible contains the latest amendments.

The use of any document not listed, may be permitted by contacting the Approvals Examiner responsible. In certain circumstances a copy for scrutinising may be requested before permission is given.

To be accepted for examination, candidates for Welding Inspector must have had **at least three years experience related to the duties required**, under qualified supervision.

Candidates need to be in satisfactory physical condition and the person completing the application form will be required to signify that the candidate's health and eyesight are adequate to enable him to carry out his duties.

British

BS 1113	Specification for design and manufacture of Water–tube steam Generating Plant (including superheaters, reheaters and steel tube economies).
BS 2633	Specification for Class 1 arc welding of ferritic steel pipework for carrying fluids.
BS 2654	Specification for manufacture of vertical steel welded storage tanks with butt–welded shells for the petroleum industry.
BS 2971	Specification for Class II arc welding of carbon steel pipework for carrying fluids.
BS 3351	Specification for piping systems for petroleum refineries and petro–chemical plants.
BS 4515	Specification for process of welding of steel pipelines on land and offshore.
BS 4677	Specification for arc welding of austenitic stainless steel pipe work for carrying fluids.
BS 5500	Specification for unfired fusion welded pressure vessel.
BS 6235	Code of practice for fixed offshore structures.

American

ANSI/ASME B31-3:	Chemical plant and petroleum refinery piping.
API 1104:	Standard for welding pipelines and related facilities (16th Edition).
ASME VIII division 1:	Boiler and Pressure vessel code.
ANSI/AWS DI.I:	Structural Welding Code (Steel)
ABS	Rules for Building and Classing Steel vessels (American Bureau of Shipping).

In addition the following are permissible:

AESS 6021: Parts 1 and 2	Fusion welded fabrication in Austenitic Stainless steel.
NF 0081/1&2:	NF Standard, Fabrication of stainless steel

British Engineering Standard BGC/PS/P2 1981. Specification for field welding of steel pipelines and installations.

MOD/NAVY	DGS - NAS 3	Acceptable standard for welds
	DGS - GS - 3003	General Welding Specification

Det Norske Veritas:	Rules for the design, construction and Inspection of offshore structures.

WELDING INSPECTION, STEELS - WIS 5

WORK INSTRUCTION FOR VISUAL INSPECTION PRACTICE

PLEASE READ CAREFULLY

YOU HAVE BEEN PROVIDED WITH THE APPROPRIATE SPECIMEN AND ARE REQUIRED TO COMPLETE THE FOLLOWING:

1. ENSURE THAT YOU RECORD THE SPECIMEN NUMBER ON YOUR REPORT SHEET

2. VISUALLY INSPECTION THE SPECIMEN AND REPORT:

   THE DEFECT TYPE
   THE DEFECT SIZE(S)
   THE DEFECTS CONDITION (e.g. SHARP or SMOOTH)

3. ON COMPLETION OF THE REPORTING OF THE DEFECTS, COMMENT ON ANY PHYSICAL FEATURES (CAP HEIGHT AND PROFILE, TOE BLEND, ETC.)

4. WITH THE APPROPRIATE ACCEPTANCE LEVELS, INDIVIDUALLY STATE THE 'STATUS' OF EACH DEFECT (e.g. ACCEPTANCE or REJECTABLE)

5. YOU ARE THEN REQUIRED TO SENTENCE THE SPECIMEN OVERALL (e.g. THE SPECIMEN IS .... TO THE REQUIREMENTS OF THE STANDARD ....19.........................)

6. WHEN YOU HAVE COMPLETED THE ABOVE, CHECK YOUR ANSWER!!

7. SPEAK WITH LECTURER FOR NEXT STAGE.

TRAINING SAMPLE ONLY

MACRO INSTRUCTION/REPORT SHEET [I.D: AM1030]

CHECK PHOTOGRAPH I.D MATCHES THIS REPORT I.D

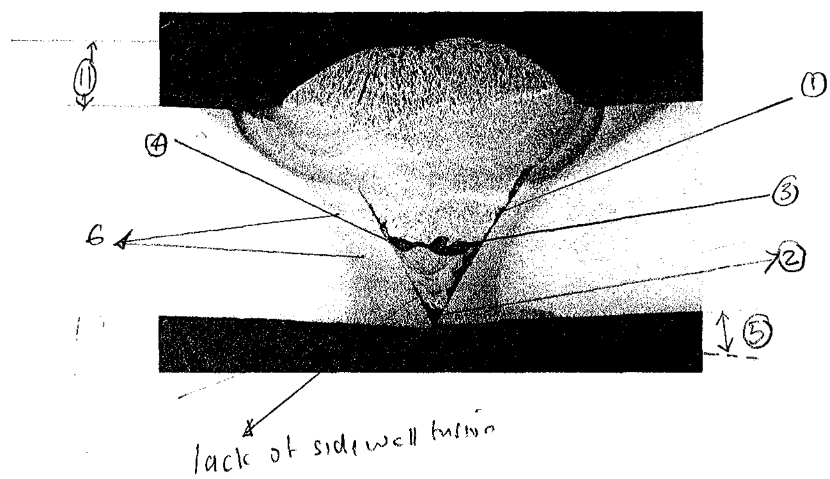
ALL DEFECTS TO BE REPORTED [AND SIZED IF REQUIRED]

THEN SENTENCED TO **ISO 5817 LEVEL B [STRINGENT]**

NOTE: PHOTOGRAPH IS AT X10 MAGNIFICATION

MATERIAL: **LOW CARBON STEEL**

WELDING PROCESS: **[MMA/SMAW]**



#	DEFECT	SIZE	ACCEPT/REJECT
1	lack of side wall fusion + slag		
2	lack of root penetration		
3	lack of interrun fusion + slag.		
4	lack of side wall fusion + slag.		
5	linear misalignment		
6	Spurious indication/inclusion		
7			
8			
9			
10			
11	**EXCESS WELD METAL**		
12	**EXCESS PENETRATION**		

COMMENTS:

SIGNATURE: AA	**DATE:** 29/05/01.

PRINT FULL NAME: MUHD RAMZA BIN ABD RAZAK

TRAINING SAMPLE ONLY

MACRO INSTRUCTION/REPORT SHEET [I.D: AM1031]

CHECK PHOTOGRAPH I.D MATCHES THIS REPORT I.D

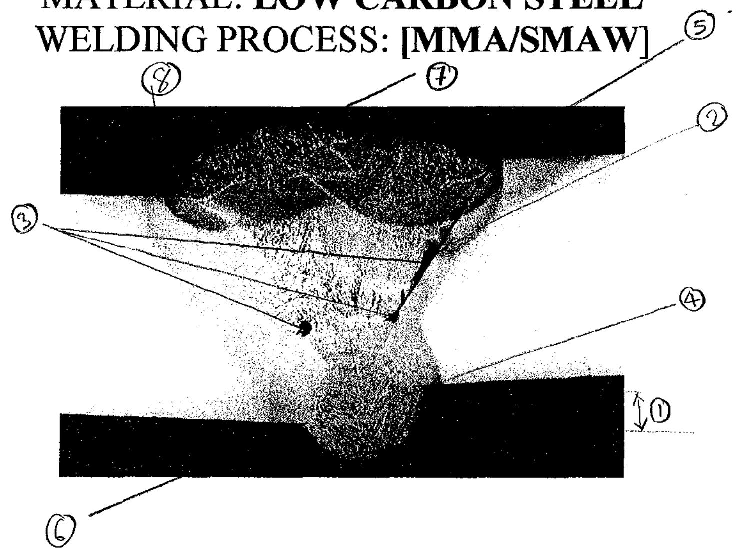
ALL DEFECTS TO BE REPORTED [AND SIZED IF REQUIRED]

THEN SENTENCED TO **ISO 5817 LEVEL B [STRINGENT]**

NOTE: PHOTOGRAPH IS AT X10 MAGNIFICATION

MATERIAL: **LOW CARBON STEEL**

WELDING PROCESS: **[MMA/SMAW]**



#	DEFECT	SIZE	ACCEPT/REJECT
1	misalignment	1.6mm	Reject
2	Lack of Side wall fusion	8.5mm	Reject
3	Slag inclusion	0.7mm, 1.6mm & 0.4mm	OK✓
4	Lack of Root Side Wall fusion	0.5mm	
5	Underfill	0.5mm	
6	Lack of Root Side wall fusion	0.3mm	
7	Excess weld metal	3mm	
8	overlap		
9			
10			
11	**EXCESS WELD METAL**		
12	**EXCESS PENETRATION**		

COMMENTS:

SIGNATURE:	**DATE:**

PRINT FULL NAME:

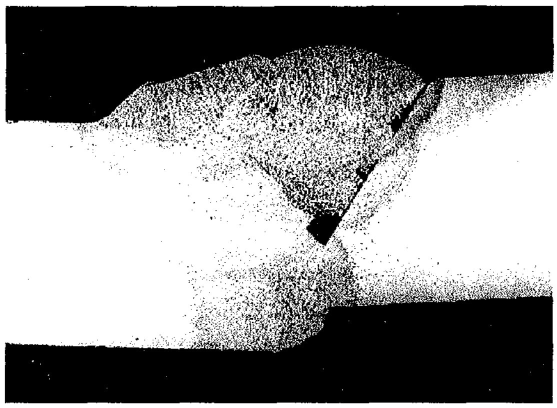
TRAINING SAMPLE ONLY

MACRO INSTRUCTION/REPORT SHEET [I.D: AM1032]

CHECK PHOTOGRAPH I.D MATCHES THIS REPORT I.D

ALL DEFECTS TO BE REPORTED [AND SIZED IF REQUIRED]
THEN SENTENCED TO **ISO 5817 LEVEL B [STRINGENT]**

NOTE: PHOTOGRAPH IS AT X10 MAGNIFICATION
MATERIAL: **LOW CARBON STEEL**
WELDING PROCESS: **[MMA/SMAW]**



#	DEFECT	SIZE	ACCEPT/REJECT
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11	EXCESS WELD METAL		
12	EXCESS PENETRATION		

COMMENTS:

SIGNATURE:	**DATE:**

PRINT FULL NAME:

TRAINING SAMPLE ONLY

MACRO INSTRUCTION/REPORT SHEET [I.D: AM1033]

CHECK PHOTOGRAPH I.D MATCHES THIS REPORT I.D

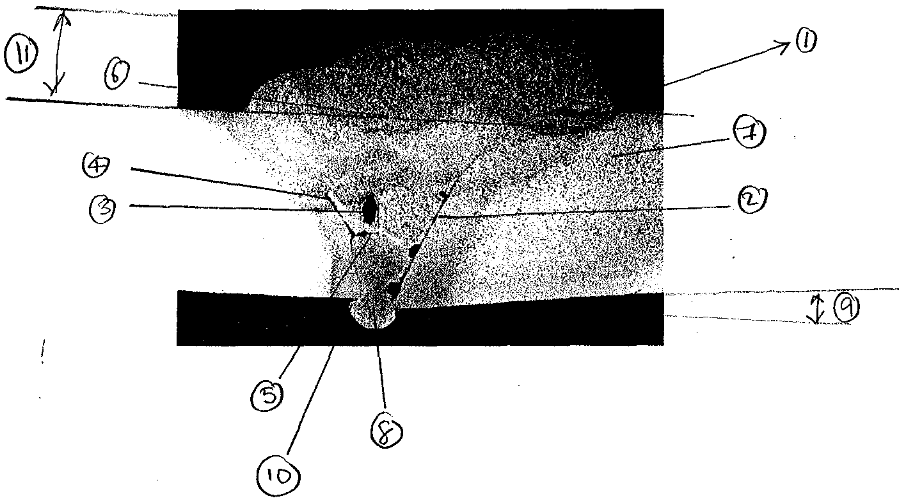
ALL DEFECTS TO BE REPORTED [AND SIZED IF REQUIRED]

THEN SENTENCED TO **ISO 5817 LEVEL B [STRINGENT]**

NOTE: PHOTOGRAPH IS AT X10 MAGNIFICATION

MATERIAL: **LOW CARBON STEEL**

WELDING PROCESS: **[MAG/GMAW]**



#	DEFECT	SIZE	ACCEPT/REJECT
1	Overlap	2.5mm	Reject.
2	lack of sidewall fusion + slag.	7.5mm	Reject.
3	Slag inclusion	l=0.8, H=1.4	Reject.
4	lack of side wall fusion	2.5mm	Reject.
5	lack of interrun fusion + slag	2mm	Reject.
6	Slag	0.5mm	Reject
7	lamination	0.5mm	not specified in ISO 5817
8	linear misalignment.	0.5mm	Accept.
9	angular misalignment		not specified in ISO 5817.
10	Overlap	0.5mm	
11	**EXCESS WELD METAL**	4.1mm	Reject
12	**EXCESS PENETRATION**	1.5mm	Reject.

COMMENTS:

SIGNATURE: [signature]	**DATE:** 31/05/01

PRINT FULL NAME: Muhd Ramiza

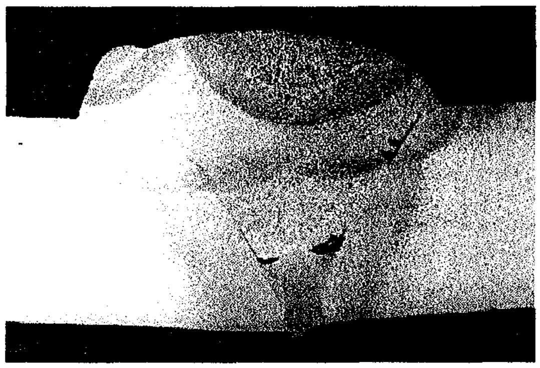
TRAINING SAMPLE ONLY

MACRO INSTRUCTION/REPORT SHEET [I.D: AM1034]

CHECK PHOTOGRAPH I.D MATCHES THIS REPORT I.D

ALL DEFECTS TO BE REPORTED [AND SIZED IF REQUIRED]
THEN SENTENCED TO **ISO 5817 LEVEL B [STRINGENT]**

NOTE: PHOTOGRAPH IS AT X10 MAGNIFICATION
MATERIAL: **LOW CARBON STEEL**
WELDING PROCESS: **[MMA/SMAW]**



#	DEFECT	SIZE	ACCEPT/REJECT
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11	EXCESS WELD METAL		
12	EXCESS PENETRATION		

COMMENTS:

SIGNATURE:	**DATE:**

PRINT FULL NAME:

QUALITY TRAINING SECTION - VISUAL INSPECTION REPORT

REFERENCE NO. OF WELDMENT: ____________________

PROCESS/PROCESSES: ____________________

TYPE OF BACKING: ____________________

PARENT MATERIAL: ____________________

JOINT CONFIGURATION: ____________________

APPLICATION STANDARD: ____________________

MATERIAL THICKNESS: ____________________

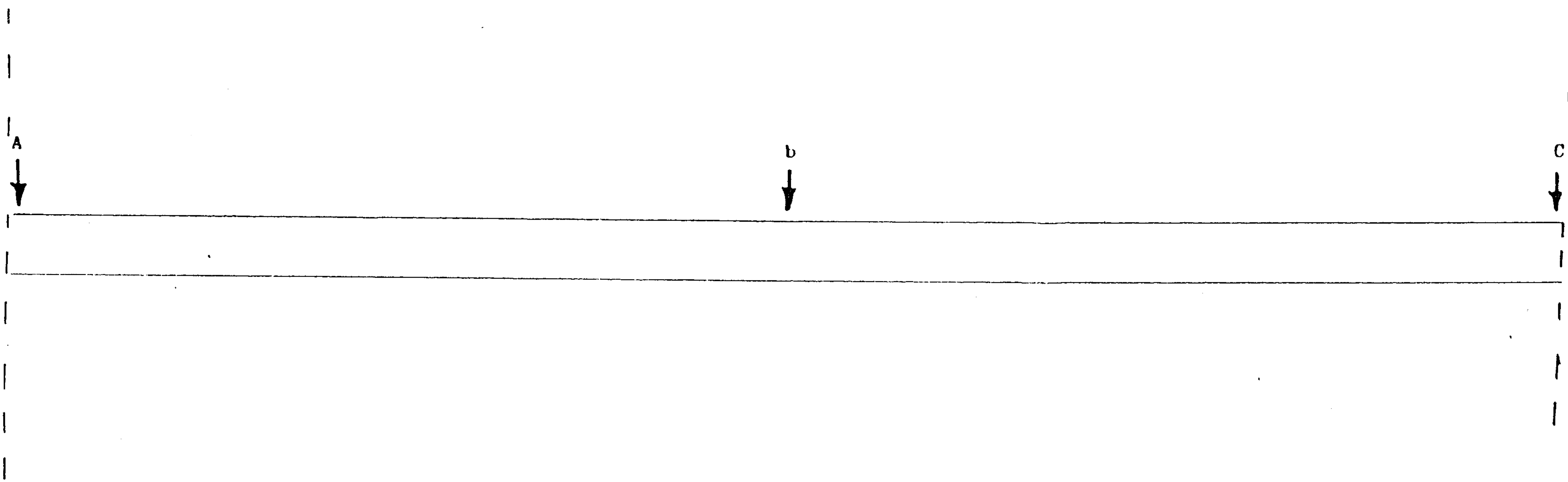
WELDING POSITION/S: ____________________

INSPECTORS SIGNATURE: ____________________

DATE INSPECTED: ____________________

COURSE REF. NO: ____________________

SKETCH STATING NATURE & LOCATION OF DEFECTS



QUALITY TRAINING SECTION - VISUAL INSPECTION REPORT

REFERENCE NO. OF WELDMENT: ____________

PROCESS/PROCESSES: ____________

TYPE OF BACKING: ____________

PARENT MATERIAL: ____________

JOINT CONFIGURATION: ____________

APPLICATION STANDARD: ____________

MATERIAL THICKNESS: ____________

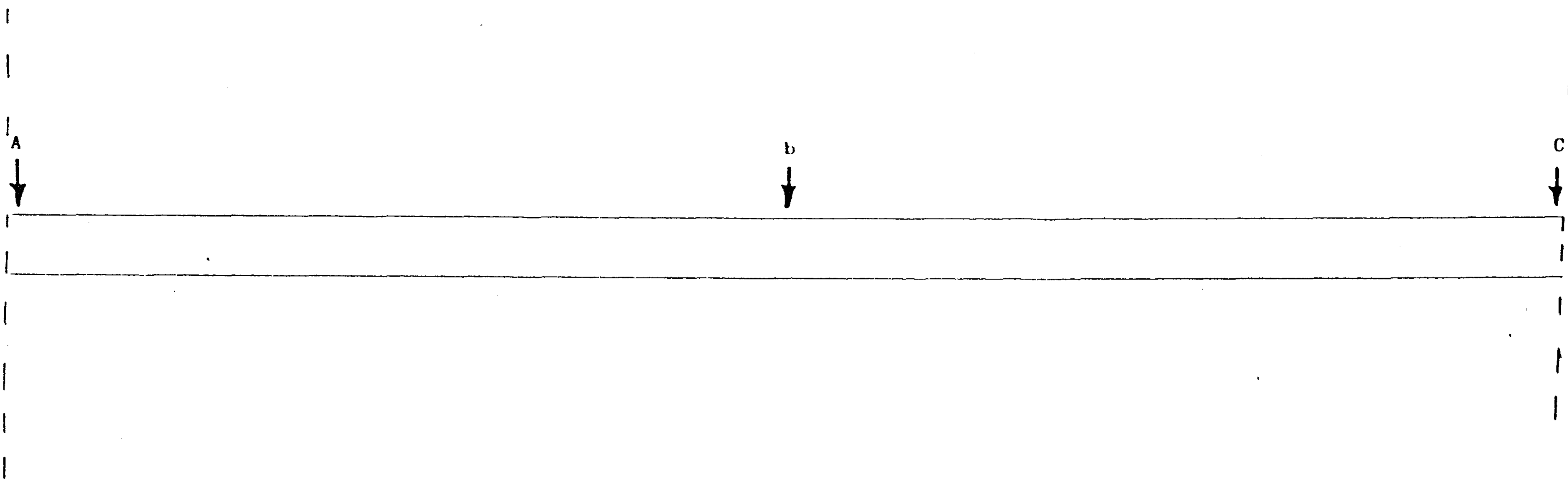
WELDING POSITION/S: ____________

INSPECTORS SIGNATURE: ____________

DATE INSPECTED: ____________

COURSE REF. NO: ____________

SKETCH STATING NATURE & LOCATION OF DEFECTS



QUALITY TRAINING SECTION - VISUAL INSPECTION REPORT

REFERENCE NO. OF WELDMENT: ______________________

PROCESS/PROCESSES: ______________________

TYPE OF BACKING: ______________________

PARENT MATERIAL: ______________________

JOINT CONFIGURATION: ______________________

APPLICATION STANDARD: ______________________

MATERIAL THICKNESS: ______________________

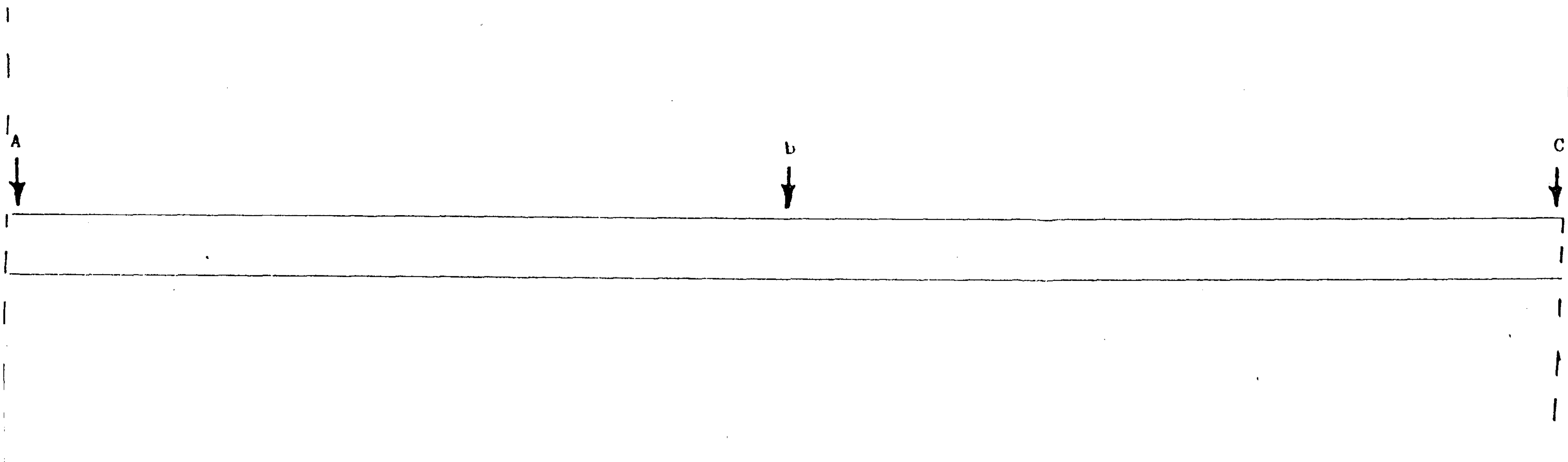
WELDING POSITION/S: ______________________

INSPECTORS SIGNATURE: ______________________

DATE INSPECTED: ______________________

COURSE REF. NO: ______________________

SKETCH STATING NATURE & LOCATION OF DEFECTS



QUALITY TRAINING SECTION - VISUAL INSPECTION REPORT

REFERENCE NO. OF WELDMENT: ______

PROCESS/PROCESSES: ______

TYPE OF BACKING: ______

PARENT MATERIAL: ______

JOINT CONFIGURATION: ______

APPLICATION STANDARD: ______

MATERIAL THICKNESS: ______

WELDING POSITION/S: ______

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DATE INSPECTED: ______

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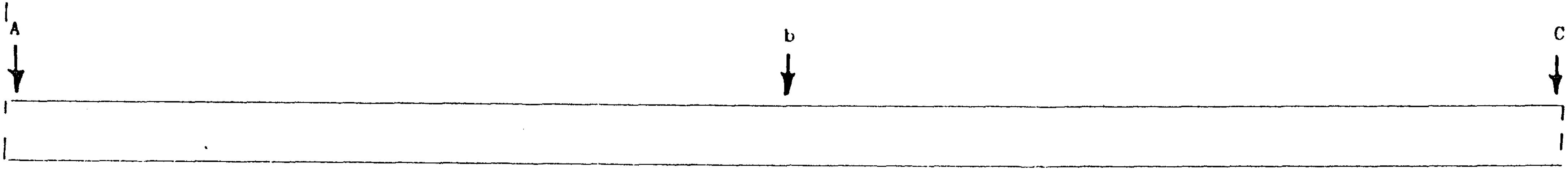

QUALITY TRAINING SECTION - VISUAL INSPECTION REPORT

REFERENCE NO. OF WELDMENT: ____________________

PROCESS/PROCESSES: ____________________

TYPE OF BACKING: ____________________

PARENT MATERIAL: ____________________

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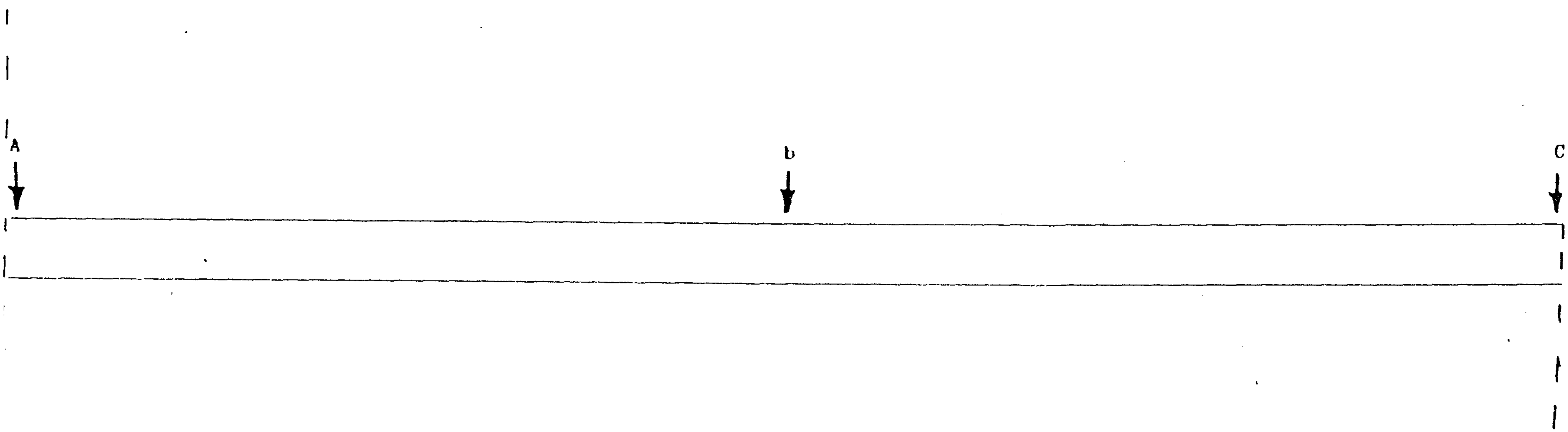

QUALITY TRAINING SECTION - VISUAL INSPECTION REPORT

REFERENCE NO. OF WELDMENT:

PROCESS/PROCESSES:

TYPE OF BACKING:

PARENT MATERIAL:

JOINT CONFIGURATION:

APPLICATION STANDARD:

MATERIAL THICKNESS:

WELDING POSITION/S:

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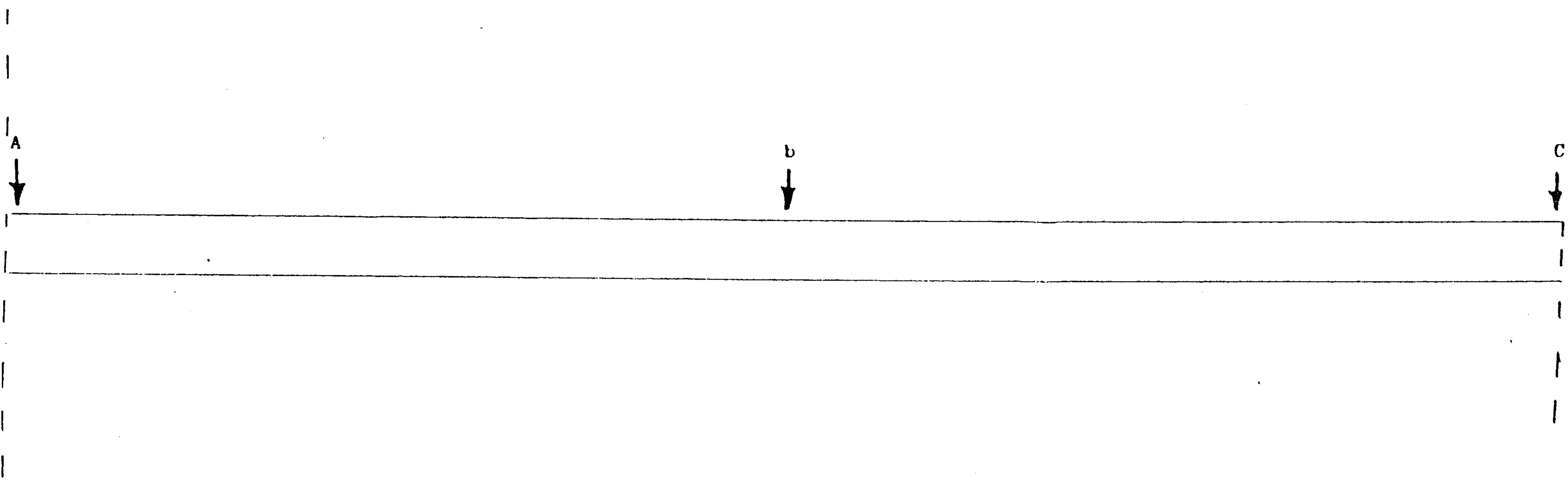

VISUAL INSPECTION REPORT

REF.NO. OF SPECIMEN :......................APPLICATION STND:..
MATERIAL THICKNESS: .... INSPECTORS'S NAME: ....
JOINT TYPE: .... INSPECTOR'S SIGNATURE ....
PIPE DIAMETER: .... DATE INSPECTED: ....

AREAS A–B & B–C WELD FACE/ROOT* *Delete as necessary

A B C

AREAS C–D & D–A

C D A

Overall Comments

ACCEPT/REJECT*
(Delete as necessary)

Signature:

VISUAL INSPECTION REPORT

REF.NO. OF SPECIMEN :......................APPLICATION STND:..
MATERIAL THICKNESS: .... INSPECTORS'S NAME: ....
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PIPE DIAMETER: .... DATE INSPECTED: ....

AREAS A–B & B–C WELD FACE/ROOT* *Delete as necessary

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PIPE DIAMETER: .... DATE INSPECTED: ....

AREAS A–B & B–C | WELD FACE/ROOT* | *Delete as necessary

A B C

AREAS C–D & D–A

C D A

Overall Comments

ACCEPT/REJECT*
(Delete as necessary)

Signature:

VISUAL INSPECTION REPORT

REF.NO. OF SPECIMEN :........................APPLICATION STND:..
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AREAS A–B & B–C WELD FACE/ROOT* *Delete as necessary

A B C

AREAS C–D & D–A

C D A

Overall Comments

ACCEPT/REJECT*
(Delete as necessary)

Signature:

TWI

SAMPLE NO:-
PROCESS:-

MATERIAL:-
JOINT TYPE:-

DEFECT	SECTION A-B etc	ACCUMULATIVE TOTAL	RELEVANT SECTION	AMOUNT ALLOWED	ACCEPT/ *REJECT
WELD FACE					
Excess Weld Metal					
Under Fill					
Undercut					
Cracks					
Porosity					
Slag Incl					
Misalignment					
Lack of Fusion					
Others					
Root					
Lack of Pen					
Incomplete Fusion					
Undercut					
Excess Pen					
Cracks					
Concavity					
Porosity					
Others					

Additional Comments:-

*Acceptable/Rejectable to Spec:-

Signature:-

Date:-

* Delete as Required

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PROCESS:-

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Additional Comments:-

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Signature:-

Date:-

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SAMPLE NO:-
PROCESS:-

MATERIAL:-
JOINT TYPE:-

DEFECT	SECTION A-B etc	ACCUMULATIVE TOTAL	RELEVANT SECTION	AMOUNT ALLOWED	ACCEPT/ REJECT
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Excess Weld Metal					
Under Fill					
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Cracks					
Porosity					
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Porosity					
Others					

Additional Comments:-

*Acceptable/Rejectable to Spec:-

Signature:-

Date:-

* Delete as Required

TWI

SAMPLE NO:-
PROCESS:-

MATERIAL:-
JOINT TYPE:-

DEFECT	SECTION A–B etc	ACCUMULATIVE TOTAL	RELEVANT SECTION	AMOUNT ALLOWED	ACCEPT/ REJECT
WELD FACE					
Excess Weld Metal			7.8.2 ✓	< 1/16 of parent metal thickness	
Under Fill			7.8.2	Not acceptable.	
Undercut			~~[illegible]~~ 9.7	[illegible] refer to table 4.	
Cracks ✓			9.3.10	not accepted except crater crack < 4mm.	
Porosity			9.3.9 ✓.	refer 9.3.9.2.	
Slag Incl			9.3.8	9.3.8.2.	(1) Individual length < 50mm. (2) aggregate < 75 mm within 300mm weld
Misalignment	/		~~9.3.9~~ 7.2	< 3mm	
Lack of Fusion			9.3.4 & 9.3.5		
Others arch burn.					
Root					
Lack of Pen			~~9.3.[illegible]~~ 9.3.1	a) Individual length < 25mm. b) In 300mm weld < 25mm accumulated c) > 8% in lengths weld < 300mm	
Incomplete Fusion			9.3.4		
Undercut			9.3.11 → 9.7		
Excess Pen			~~7.8.2~~ Not Stated	Seek advise.	
Cracks			9.3.10	Internal concavity does not exceed the thinner adjacent material.	
Concavity			9.3.6		
Porosity			9.3.9		
Others					

Additional Comments:-

*Acceptable/Rejectable to Spec:-

Signature:-

Date:-

* Delete as Required

Table 5. Acceptance levels

Abbreviations used:

t is the parent metal thickness. In the case of dissimilar thicknesses t applies to the thinner component;
w is the width of defect;
l is the length of defect;
h is the height of defect;
ϕ is the diameter of defect.

Defect type		Permitted maximum
Planar defects	(a) Cracks and lamellar tears	Not permitted
	(b) Lack of root fusion Lack of side fusion Lack of inter-run fusion	Not permitted
	(c) Lack of root penetration	Not permitted
Cavities	(a) Isolated pores (or individual pores in a group)	$\phi \leqslant t/4$ and ϕ 3.0 mm for t up to and including 50 mm ϕ 4.5 mm for t over 50 mm up to and including 75 mm ϕ 6.0 mm for t over 75 mm
	(b) Uniformly distributed or localized porosity	2 % by area * (as seen in a radiograph) for $t \leqslant$ 50 mm and pro rata for greater thicknesses
	(c) Linear porosity (spaced as for linear group of inclusions †)	Unless it can be shown that lack of fusion or lack of penetration is associated with this defect (which is not permitted) it should be treated as for individual pores in a group
	(d) Wormholes isolated	$l \leqslant$ 6 mm, $w \leqslant$ 1.5 mm
	(e) Wormholes aligned	As linear porosity
	(f) Crater pipes	As wormholes isolated
Solid inclusions	(a) Slag inclusions (1) Individual and parallel to weld axis	$t \leqslant$ 18 mm: $l \leqslant t/2 \leqslant$ 6 mm, $w \leqslant$ 1.5 mm $t >$ 18 mm $\leqslant$ 75 mm: $l \leqslant t/3$, $w \leqslant$ 1.5 mm $t >$ 75 mm: $l \leqslant$ 25 mm, $w \leqslant$ 1.5 mm
	(2) Linear group†	Aggregate length not to exceed 8 % of length of group, which in turn not to exceed 12 t in length
	(3) Individual and randomly orientated	As isolated pores
	(4) Non-linear group	As uniformly distributed or localized porosity
	(b) Tungsten inclusions (1) Isolated (2) Grouped	 As isolated pores As uniformly distributed or localized porosity
	(c) Copper inclusions	Not permitted
Profile defects	(a) Undercut	Slight intermittent undercut permitted, depth not to exceed approximately 0.5 mm
	(b) Shrinkage grooves and root concavity	As for undercut, but depth not to exceed 1.5 mm
	(c) Excess penetration	$h \leqslant$ 3 mm. Occasional local slight excess is allowable
	(d) Reinforcement shape	The reinforcement is to blend smoothly with the parent metal; dressing is not normally required provided the shape does not interfere with the specified non-destructive testing techniques
	(e) Overlap	Not permitted
	(f) Linear misalignment	$h \leqslant t/10$, 3 mm maximum

NOTE. The significant dimension of a defect in terms of its effect on service performance is the height or through thickness dimension. If ultrasonic examination is employed, it is probable that defect indications of very minor cross section will be obtained. In interpreting the requirements of this table, such indications having a dimension h of 1.5 mm or less should be disregarded unless otherwise agreed between the contracting parties.

* In assessing porosity the area of radiograph to be considered is the length of weld affected by the porosity times the maximum width of the weld.

† Individual inclusions within the group should not exceed the sizes for isolated pores (or individual pores in a group). A linear group is defined as a number of inclusions in line and parallel to the weld axis where the spacing between their adjacent ends does not exceed 6 times the length of the longest inclusion within the group. With parallel groups, all inclusions count towards the aggregate.