Welding Lecture - 13

Design of Weld joints

Design of Weld joints

(Refer class notes)

Q. 1. A plate 50 mm wide and 12.5 mm thick is to be welded to another plate by means of parallel fillet welds. The plates are subjected to a load of 50 kN. Find the length of the weld. Assume allowable shear strength to be 56 MPa.

Ans. In a parallel fillet welding two lines of welding are to be provided. Each line shares a load of $P = \frac{50}{2}\,\mathrm{kN} = 25\,\mathrm{kN}$. Maximum shear stress in the parallel fillet weld is $\frac{P}{lt}$, where t =throat length=$\frac{12.5}{\sqrt{2}}\,\mathrm{mm}$. Since $\frac{P}{lt} \le s_s = 56 \times 10^6$. Hence the minimum length of the weld is $\frac{25 \times 10^3 \times \sqrt{2}}{56 \times 12.5 \times 10^3}$ =50.5 mm. However some

extra length of the weld is to be provided as allowance for starting or stopping of the bead. An usual allowance of 12.5 mm is kept. (Note that the allowance has no connection with the plate thickness)

Q. 2. Two plates 200 mm wide and 10 mm thick are to be welded by means of transverse welds at the ends. If the plates are subjected to a load of 70 kN, find the size of the weld assuming the allowable tensile stress 70 MPa.

Ans. According to the design principle of fillet (transverse) joint the weld is designed assuming maximum shear stress occurs along the throat area. Since tensile strength is specified the shear strength may be calculated as half of tensile strength, i.e., $s_s = 35\,\text{MPa}$. Assuming there are two welds, each weld carries a load of 35 kN and the size of the weld is calculated from

$$35\times10^3 = l\times(\frac{10\times10^{-3}}{\sqrt{2}})\times35\times10^6$$

or $l = 141.42$ mm.

Adding an allowance of 12.5 mm for stopping and starting of the bead, the length of the weld should be 154 mm.

Example No: 3

Q. 3. A 50 mm diameter solid shaft is to be welded to a flat plate and is required to carry a torque of 1500 Nm. If fillet joint is used foe welding what will be the minimum size of the weld when working shear stress is 56 MPa.

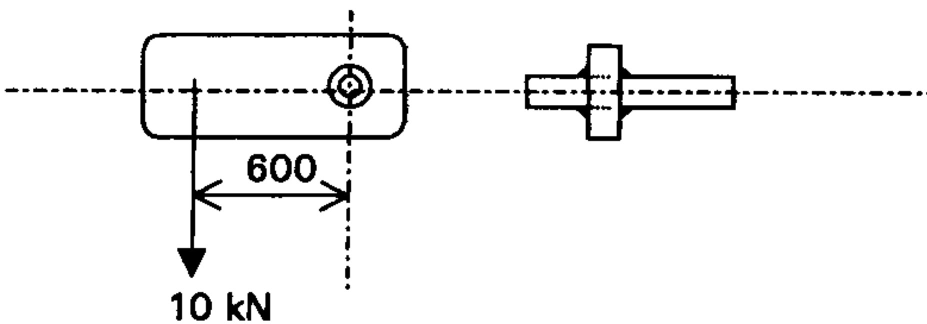
Ans. According to the procedure for calculating strength in the weld joint,

$$\frac{2T}{\pi t_{throat} d^2} = s_s \,,$$

where the symbols have usual significance. For given data, the throat thickness is 6.8 mm. Assuming equal base and height of the fillet the minimum size is 9.6 mm. Therefore a fillet weld of size 10 mm will have to be used.

Example No: 4

A 75 mm diameter tube through a 25 mm thick plate acting as a lever on a shaft. The tube is fillet welded to the plate on both sides.



What weld size is required if the throat stress is not to exceed 120 N/mm^2?

Welding Lecture – 14-15

Weld Defects

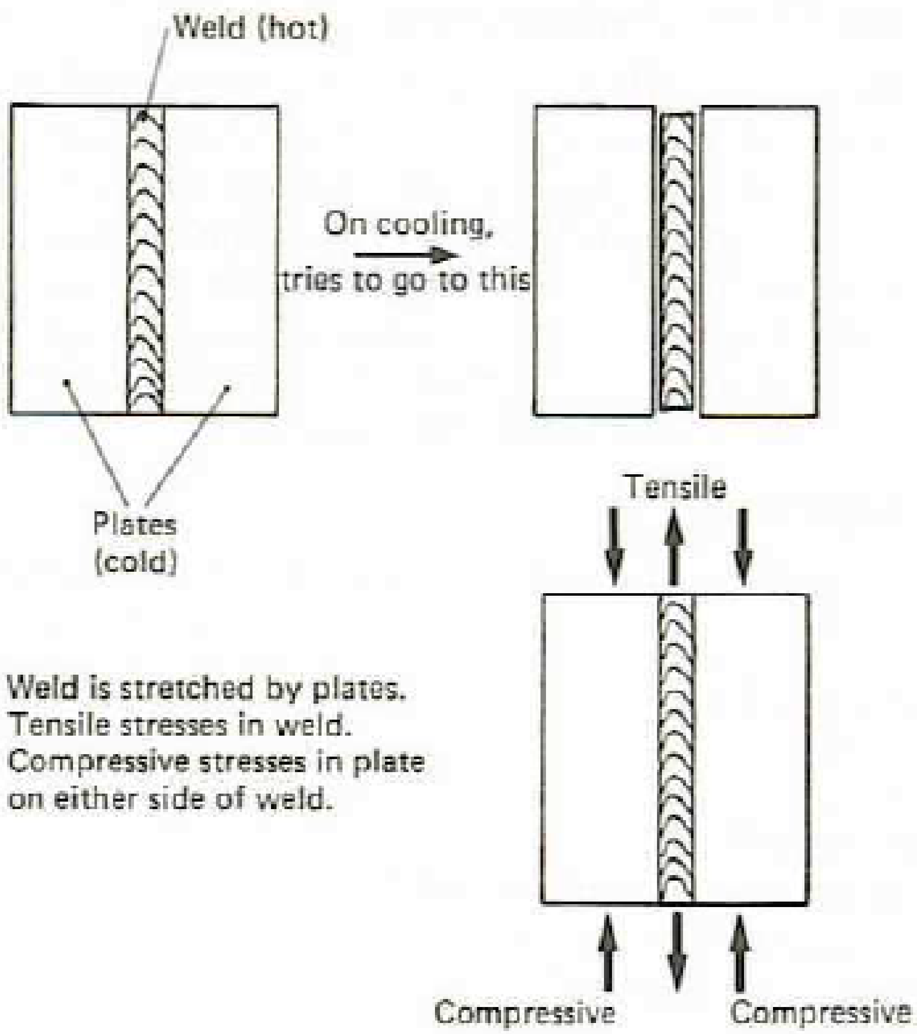
Weld Defects

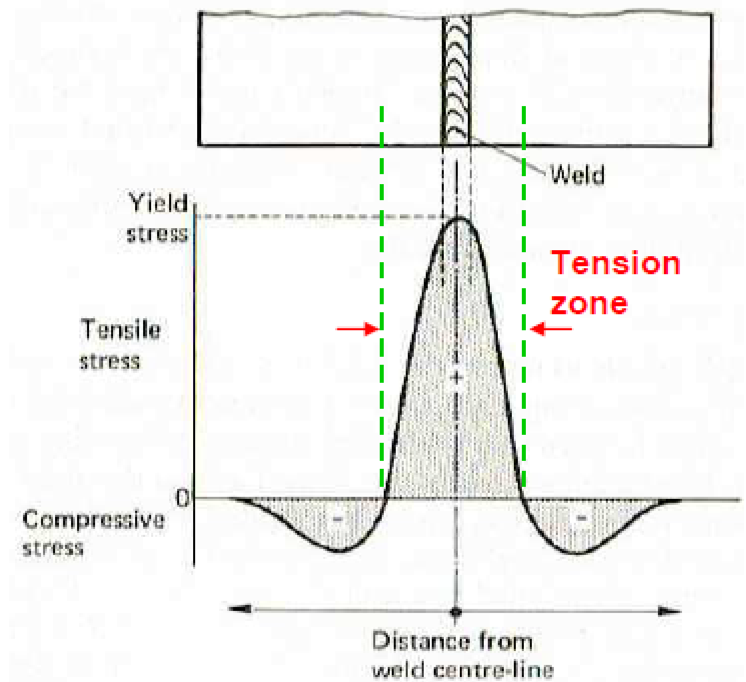
- Geometric defects
- Metallurgical defects

1. Residual stresses

- Residual stresses (internal stresses) are stresses that would exist in a body after removing all external loads
- Normally due to non uniform temperature change during welding
- Weld metal and adjacent base metal are restrained by the areas further away from the weld metal due to expansion and contraction

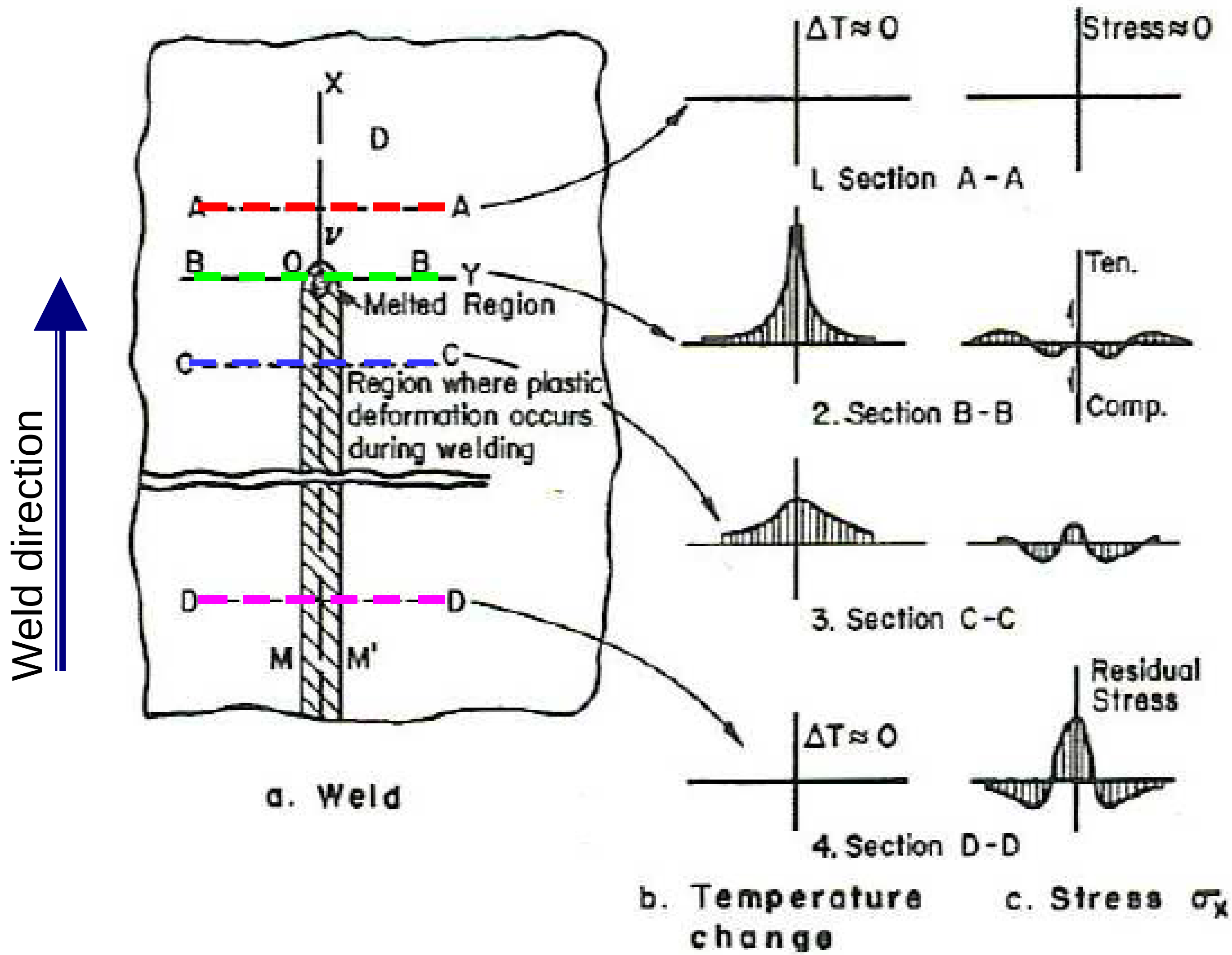
Residual stresses





Weld metal and adjacent base metal	Residual tensile stresses
Areas further away from weld metal	Residual compressive stresses

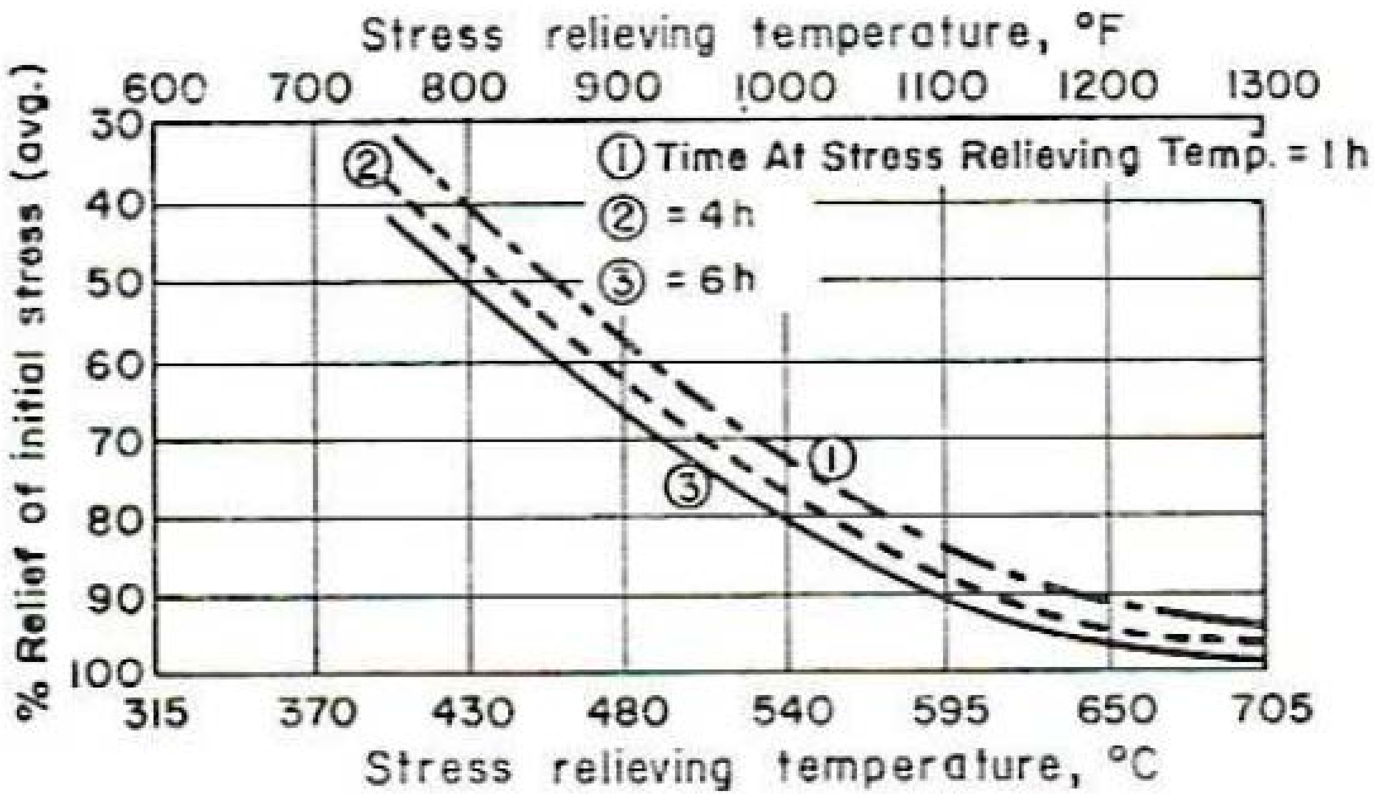
Changes in temperature and stresses during welding



Changes in temperature and stresses during welding

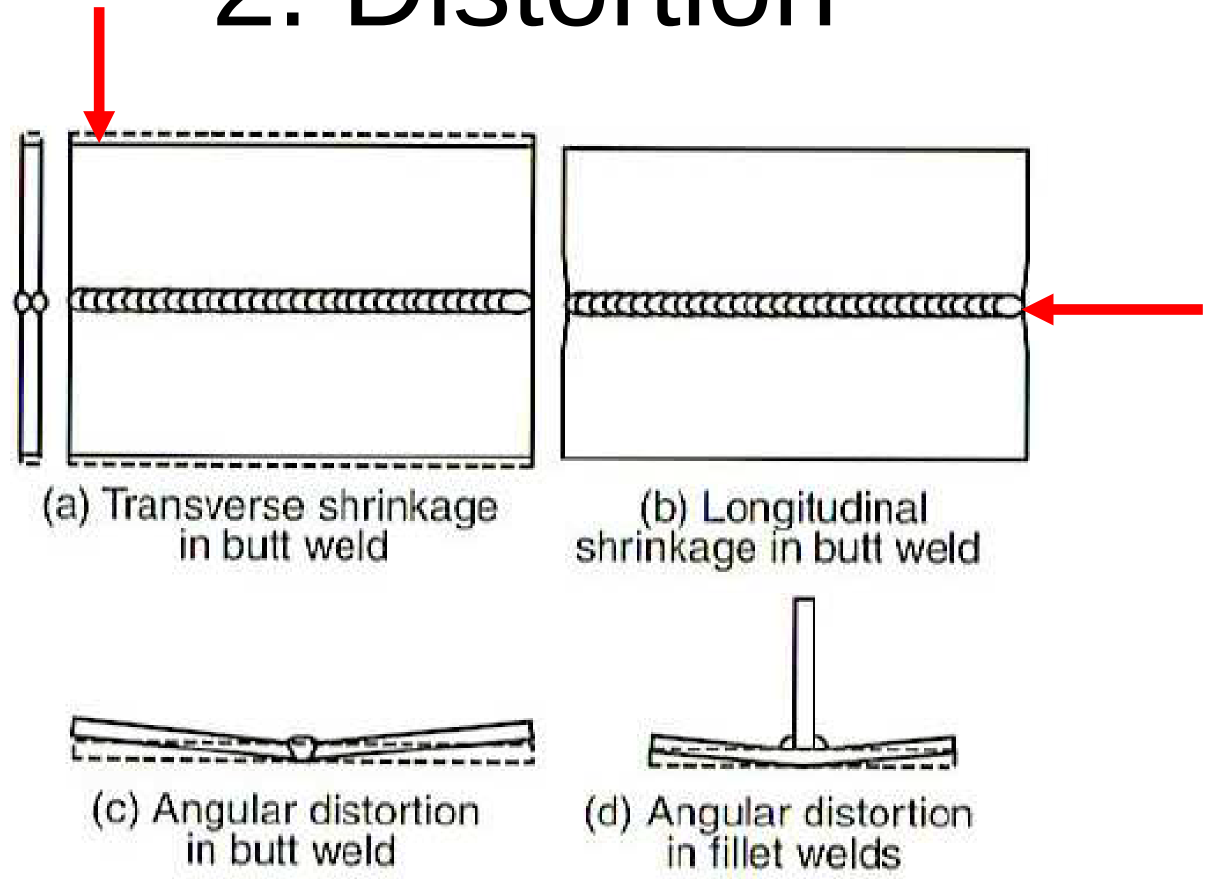
- A-A: Zero temperature and stress distribution
- B-B: Small compressive in the weld zone and small tensile in the base metal at B-B during melting of the weld metal.
- C-C: Developing of tensile stress in the weld centre and compressive in the area further away at C-C during cooling.
- D-D: Further contraction of the weld metal producing higher tensile stress in the weld centre and compressive in the base metal at D-D.

Effect of temperature and time on stress relief of steel welds



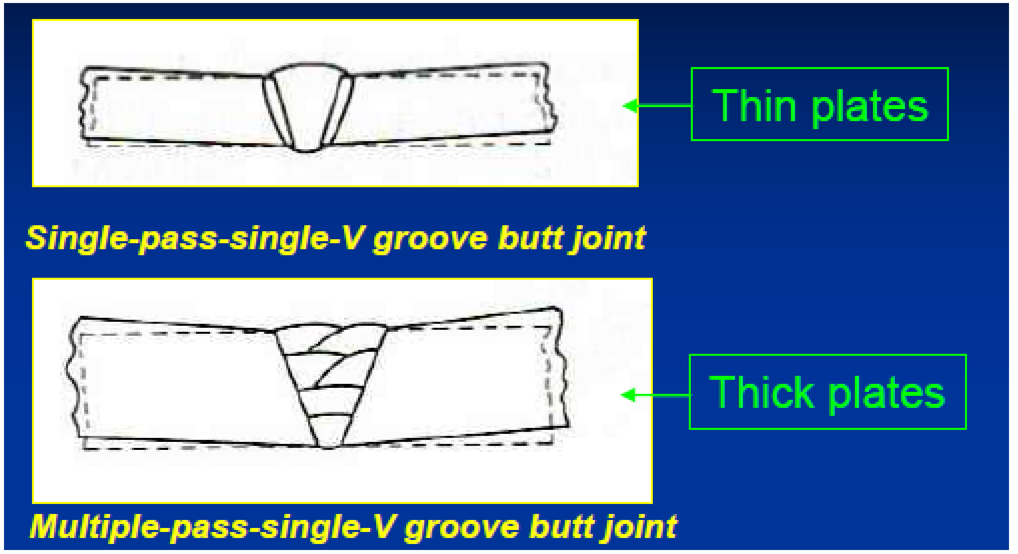
Stress relief temperature ↑ % Relief of initial stress ↑

2. Distortion



Weld distortion is due to solidification shrinkage and thermal contraction of the weld metal during welding

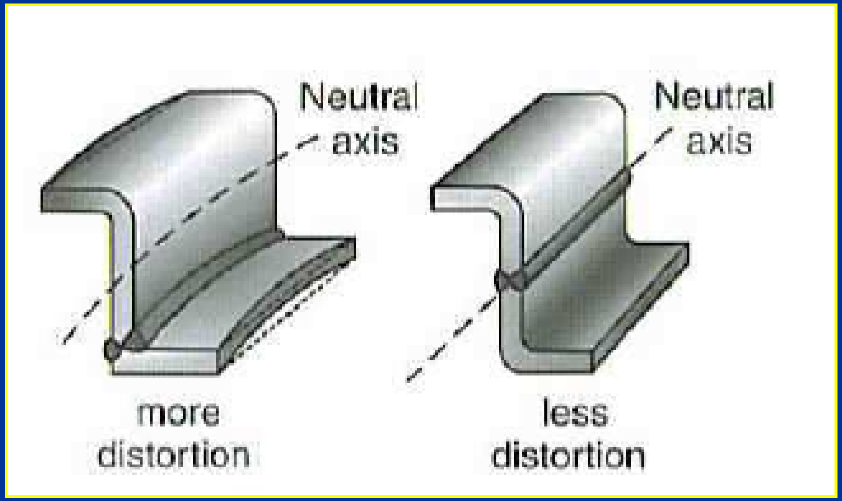
Angular distortion



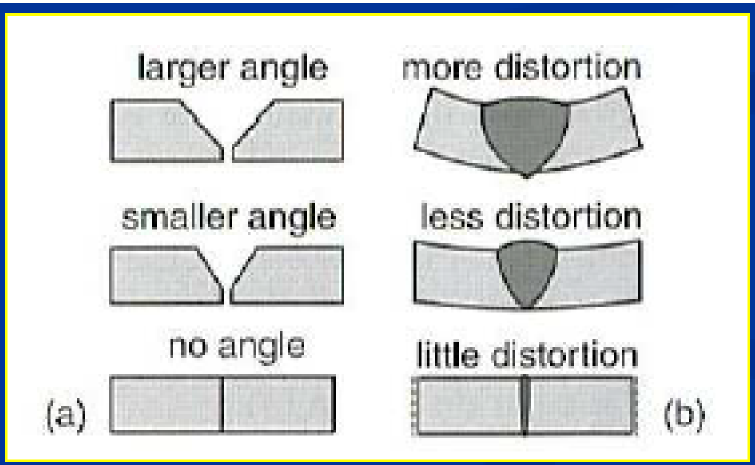
- Upward angular distortion usually occurs when the weld is made from the top of the workpiece alone.
- The weld tends to be wider at the top than the bottom, causing more solidification shrinkage and thermal contraction.

Remedies for angular distortion

- Reducing volume of weld metal
- Using double-V joint and alternate welding
- Placing welds around neutral axis
- Controlling weld distortion



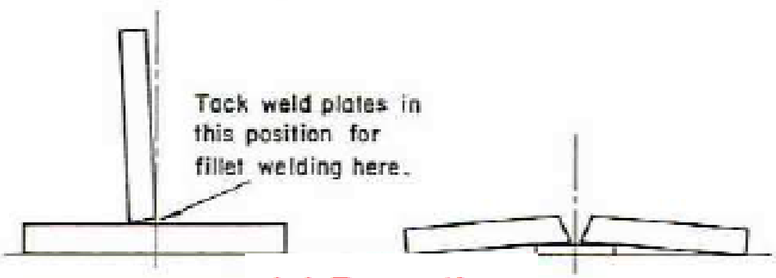
Placing weld around neutral axis



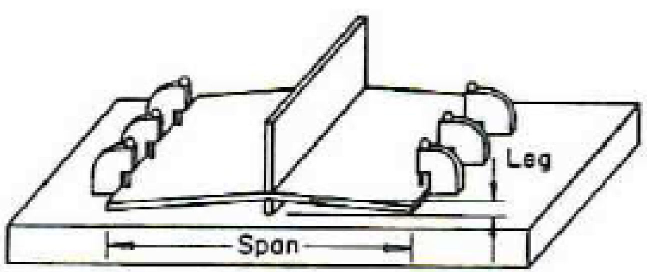
Reducing volume of weld metal and by using single-pass deep penetration welding.

Remedies for angular distortion

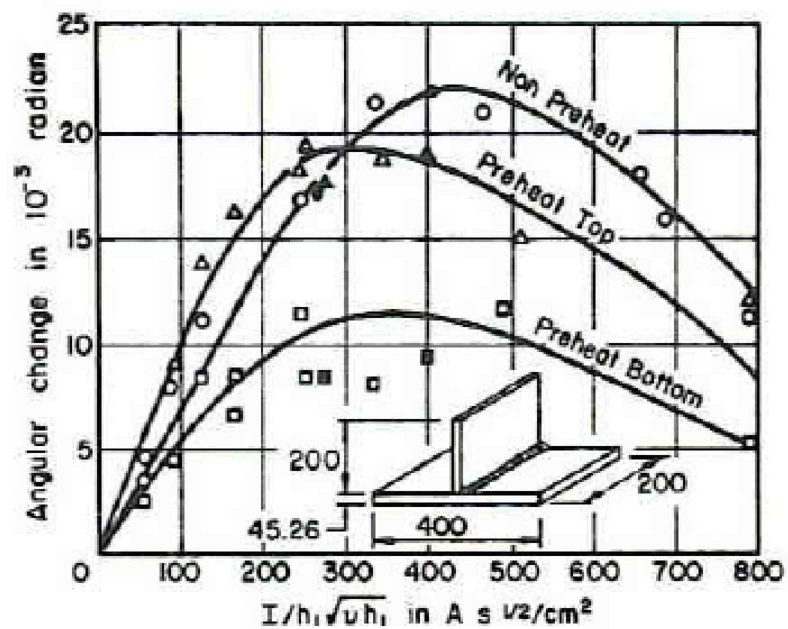
- Presetting: By compensating the amount of distortion to occur in welding.
- Elastic pre-springing can reduce angular changes after restraint is removed.
- Preheating and post weld treatment



(a) Preseting



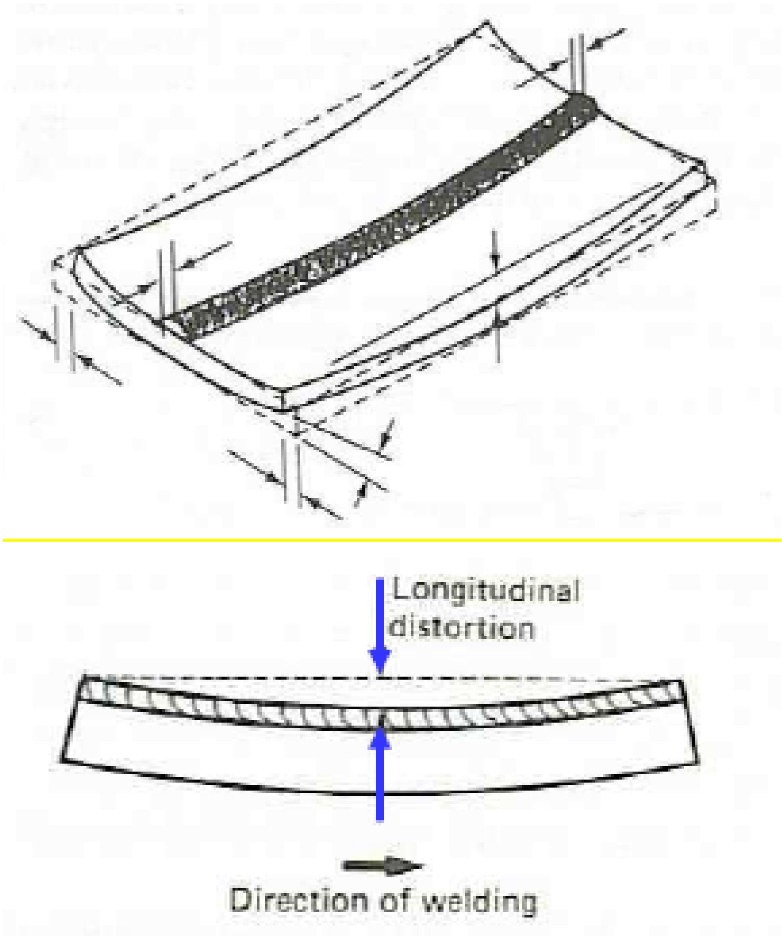
(b) Springing



(c) Perheating

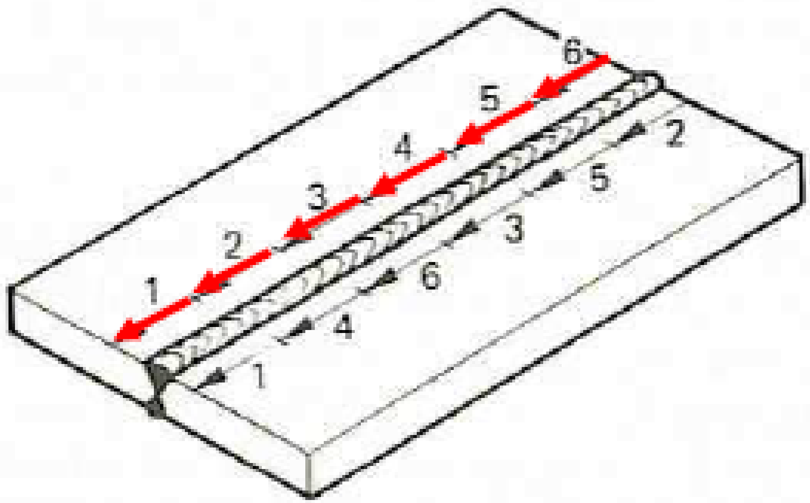
Longitudinal distortion

Heating and cooling cycles along the joint during welding build up a cumulative effect of **longitudinal bowing**



Remedies for Longitudinal distortion

- Welding short lengths on a planned or random distribution are used to controlled this problem
- Mechanical methods: straightening press, jacks, clamps
- Thermal methods : local heating to relieve stresses (using torches)



Sequences for welding short lengths of a joint to reduce longitudinal bowing

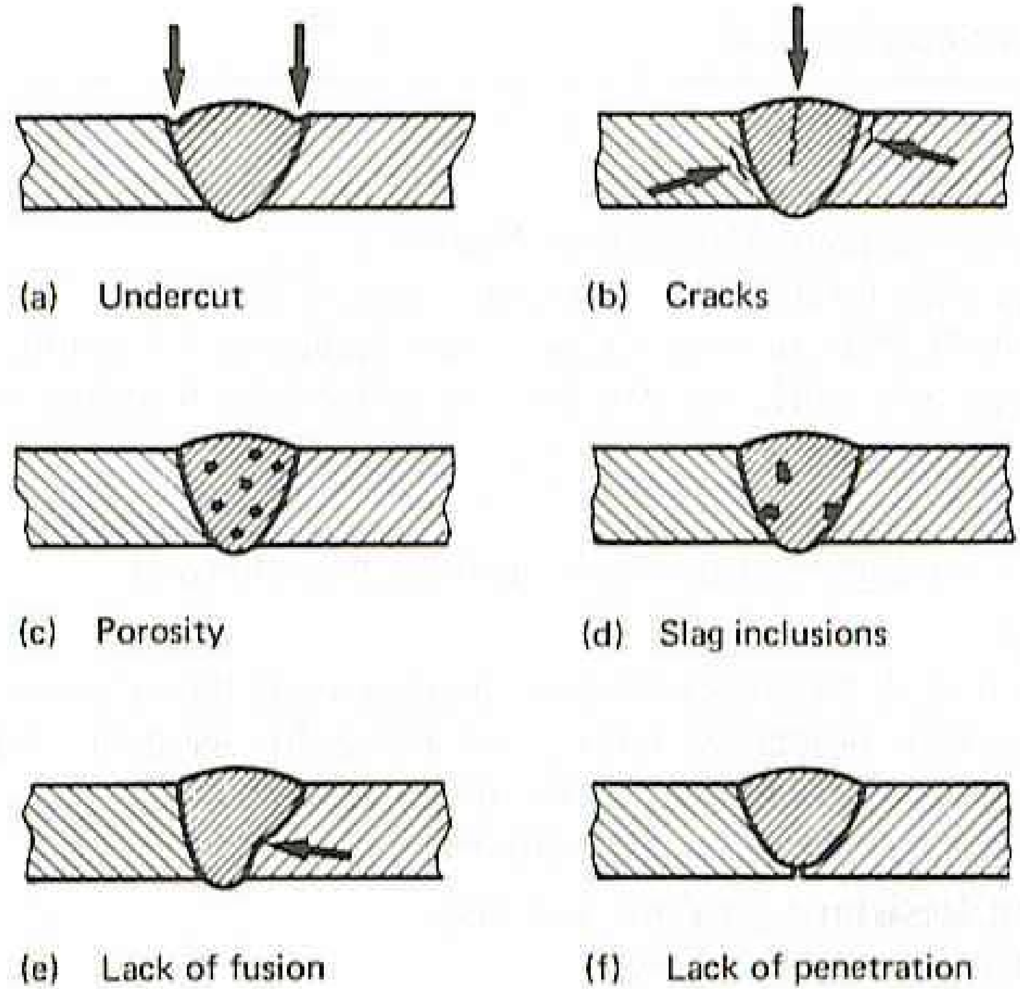
Defects & Discontinuity

- Defect: A flaw or flaws that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards
- Defect: The term designates rejectability
- Discontinuity: An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics.
- A discontinuity is not necessarily a defect

Weld Defects & Discontinuities

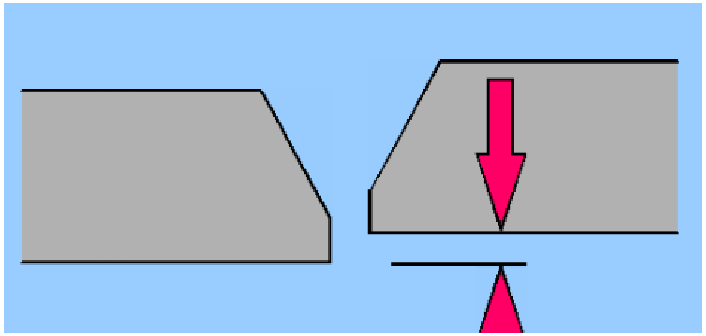
- **Misalignment** (hi-lo)
- **Undercut**
- **Underfill**
- **Concavity or Convexity**
- **Excessive reinforcement**
- **Improper reinforcement**
- **Overlap**
- **Burn-through**
- **Incomplete or Insufficient Penetration**
- **Incomplete Fusion**
- **Surface irregularity**
  - Overlap
- **Arc Strikes**
- **Inclusions**
  - Slag
  - Wagontracks
  - Tungsten
- **Spatter**
- **Arc Craters**
- **Cracks**
  - Longitudinal
  - Transverse
  - Crater
  - Throat
  - Toe
  - Root
  - Underbead and Heat-affected zone
  - Hot
  - Cold or delayed
- **Base Metal Discontinuities**
  - Lamellar tearing
  - Laminations and Delaminations
  - Laps and Seams
- **Porosity**
  - Uniformly Scattered
  - Cluster
  - Linear
  - Piping
- **Heat-affected zone microstructure alteration**
- **Base Plate laminations**
- **Size or dimensions**

Weld defects



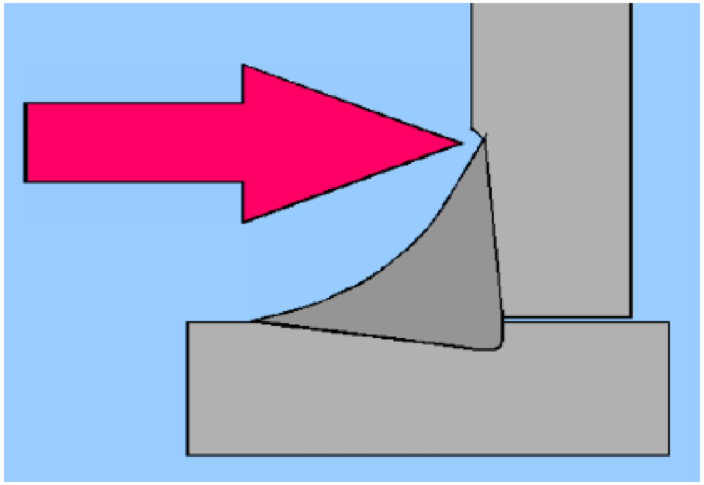
Mis-alignment

- Amount a joint is out of alignment at the root
- Cause: Transition thickness, carelessness
- Prevention-workmanship
- Repair- Grinding



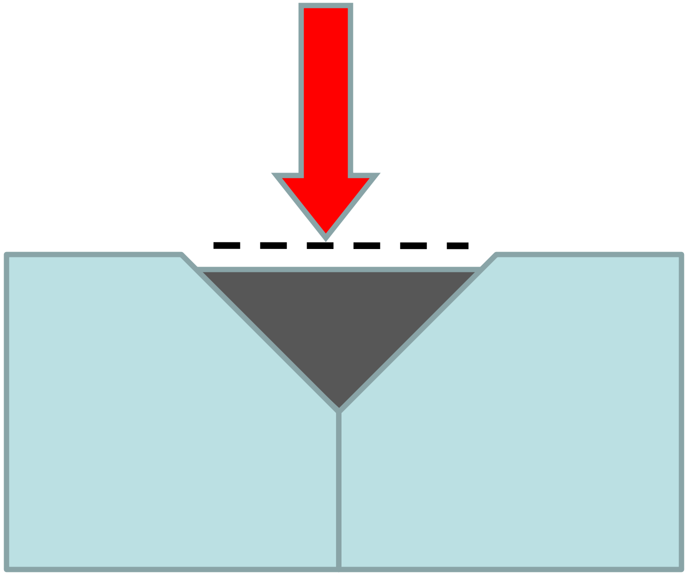
Undercut

- A groove cut at the toe of the weld and left unfilled
- Cause-Electrode angle, high amperage, long arc length, rust
- Prevention-set machine on scrap metal, clean metal before welding



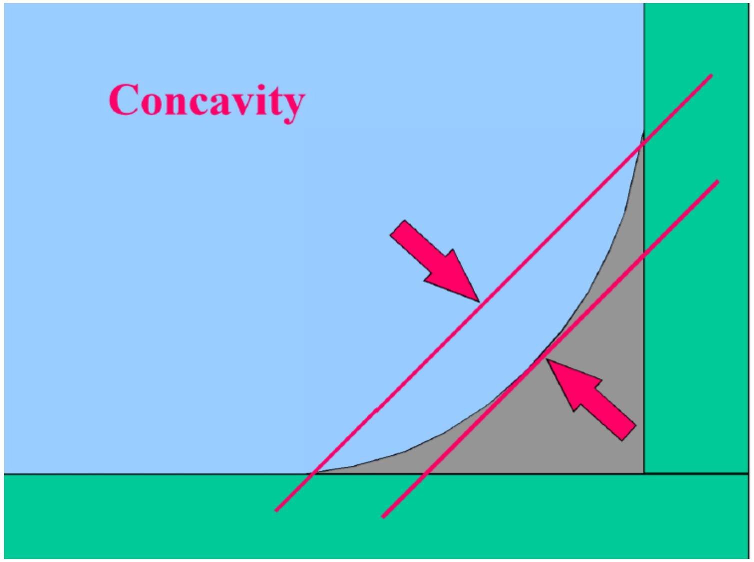
Insufficient fill

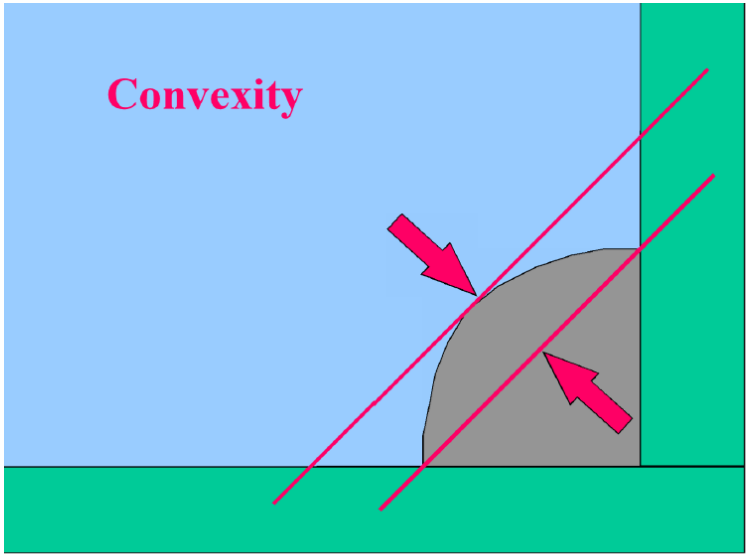
- The weld surface is below the adjacent surfaces of the base metal



Excessive Concavity & Convexity

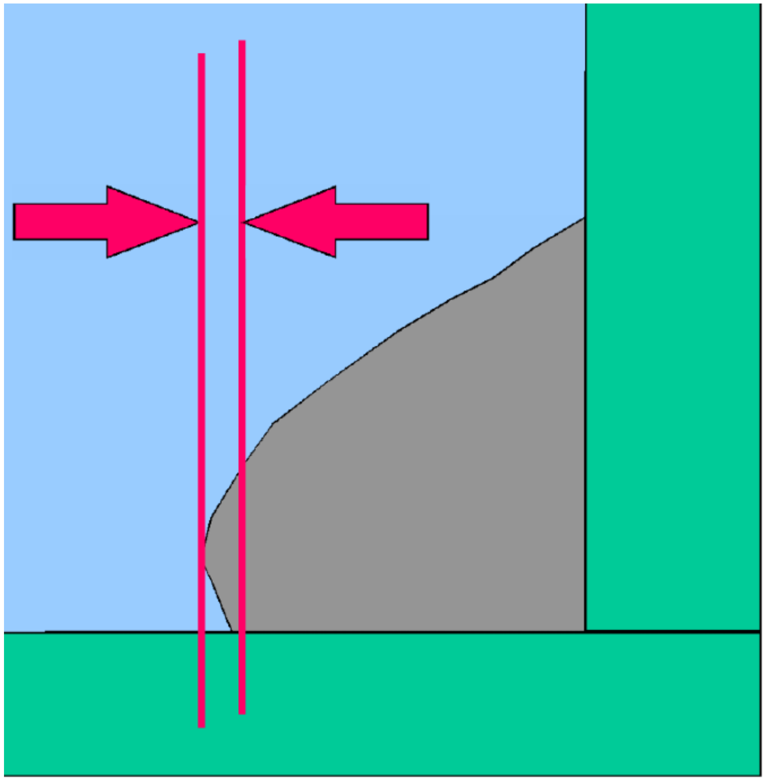
- Concavity or convexity of fillet weld which exceeds the allowable limit
- Cause: Amperage & travel speed
- Prevention- Proper parameters & techniques
- Repair- Grind



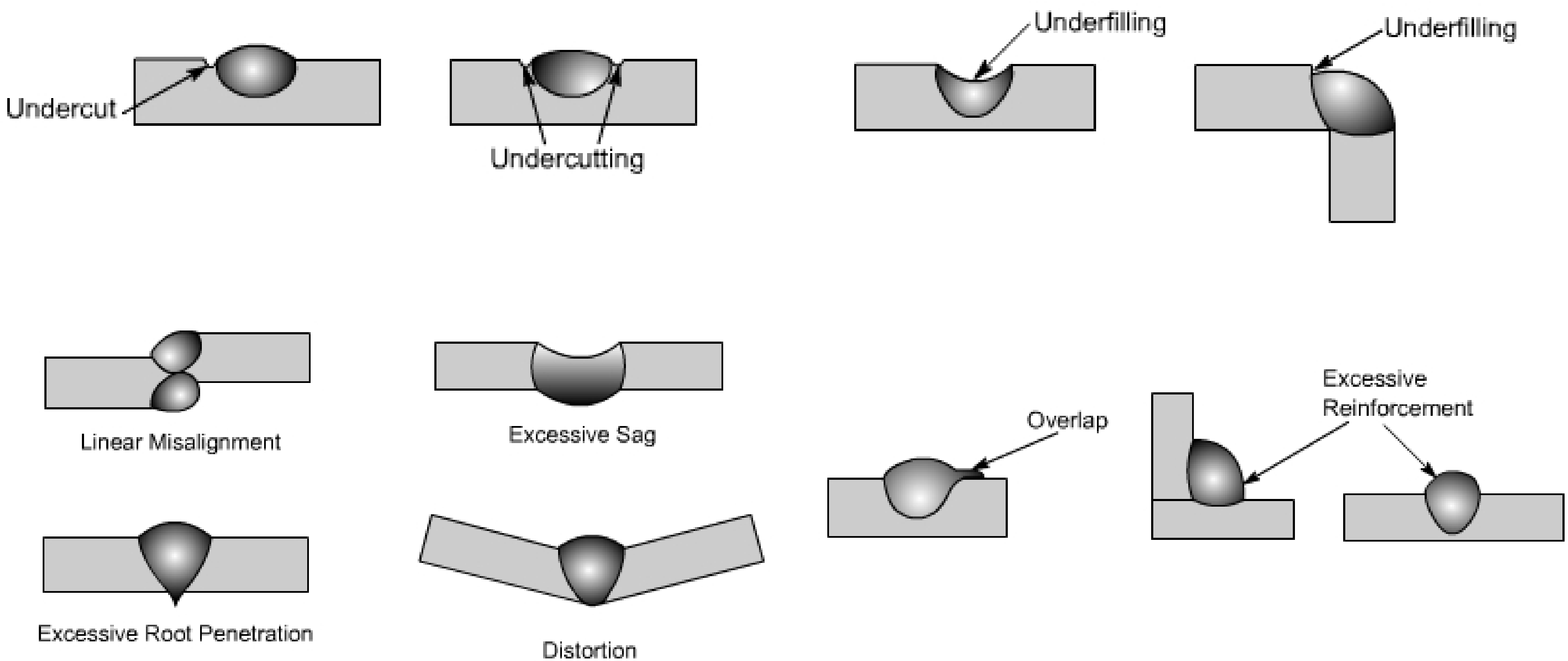


Overlap

- Face of the weld extends beyond the toe of the weld



Imperfect shapes

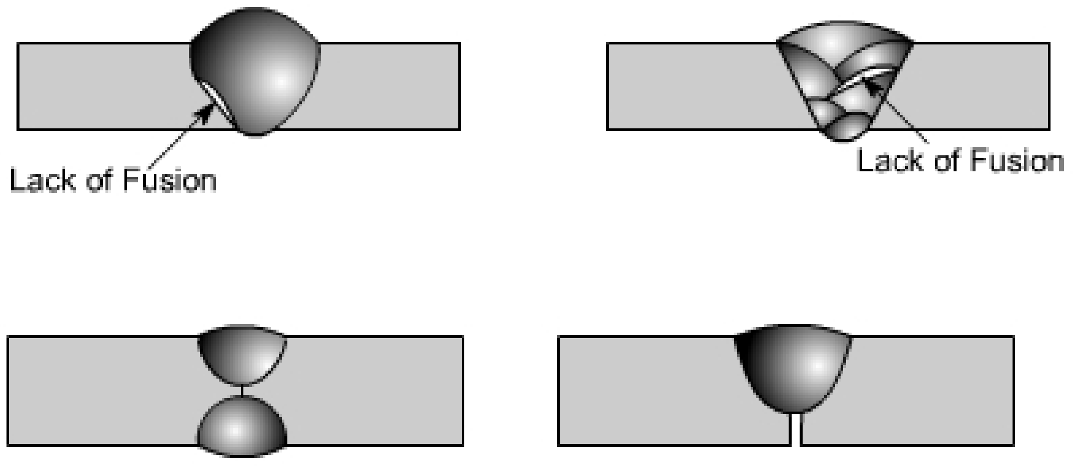


Burn through

- Undesirable open hole – completely melted through base metal
- May or maynot left open
- Cause- excessive heat input
- Prevention-reduce heat input by adjusting parameters
- Repair- Filling

Example of Burn through

Incomplete fusion



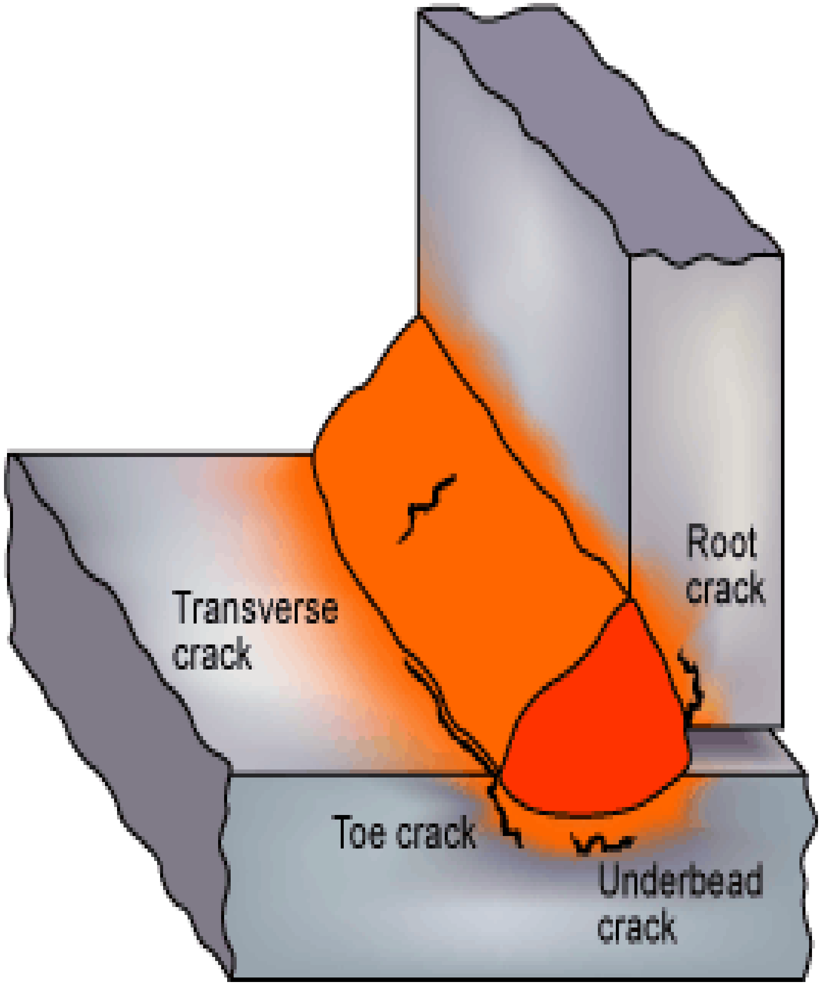
1. Lack of fusion between weld metal & base metal
2. Lack of fusion between multiple layers of weld metal

Incomplete fusion

- Weld metal does not form a cohesive bond with the base metal
- Cause- low amperage, steep electrode angles, fast ravel speed, lack of preheat etc.
- Prevention- eliminate potential causes
- Repair- remove & reweld

Cracks

- Longitudinal
- Transverse
- Throat
- Toe
- Root
- Underbead & HAZ



Metallurgical defects

Gas metal reactions

- Metals react with almost any gas except the noble or inert gases
- Gases, including N_2, O_2 & H_2, dissolve in liquids, including molten metals.
- Gas molecules (or atoms or ions) occupy the many rather large spaces between atoms of the metal in liquid form

Gas Dissolution and Solubllity In Molten Metal

- The amount of N_2, O_2 & H_2 that can dissolve in molten metal almost always increases with increasing temp. of the liquid
- Also a function of the partial pressure of the gas species above the liquid.
- This is expressed by Sievert's law:

Sievert's law

$$k = \frac{[\mathrm{gas}]}{P^{1/2}{}_{\mathrm{gas}_2}}$$

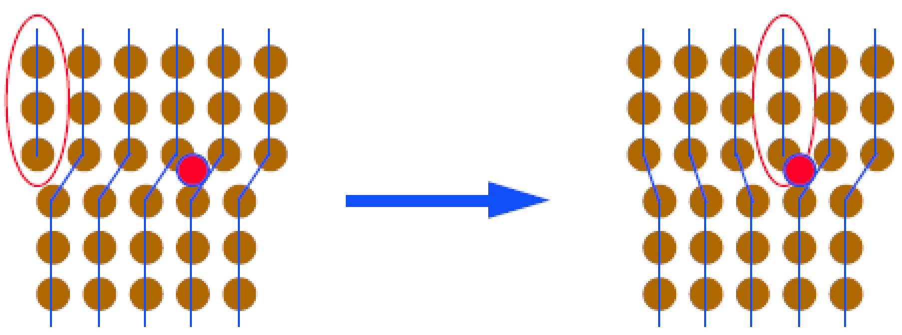
- k is the equilibrium constant,
- [gas] is the concentration as weight percent (wt%) of a particular gas in the molten metal, and
- P_{gas_2} is the partial pressure of the particular gas in diatomic molecular form.
- This relationship, known as Sievert's law, applies to all diatomic gases, including N_2, O_2 and H_2

Gas Dissolution and Solubllty In Molten Metal

- Once dissolved in molten metal, gases like N_2, O_2 and H_2 can lead to one or more of several things:
  - they can remain in solution to cause hardening;
  - they can remain in solution and stabilize a particular phase
  - they can be rejected from the melt upon solidification (presuming solubility decreases, as it often does) to produce porosity
  - they can lead to formation of brittle compounds

Gas Dissolution & Solid solution hardening

- Nitrogen and oxygen are potent solid solution strengtheners or hardeners to most metals, whether those metals are ferrous or nonferrous.
- Nitrogen and oxygen have this effect because they go into solution by occupying interstitial sites between atoms of the host or solvent.



Representation of a Dislocation Stopped by an Interstitial Atom

Solid Solution Hardening and Phase Stabillzatlon

- As small as the atoms of these gases are, they are still too large to fit into interstices without causing fairly substantial distortion of bonds and storing of energy.
- As a result, they increase strength by resisting the motion of dislocations by the repulsion between the strain field they produce and the strain field of dislocations trying to move in response to an applied stress.
- The effectiveness of nitrogen as a strengthening addition is comparable to carbon in iron.
- Unfortunately, increased strength and hardness comes at the expense of ductility and toughness

Porosity Formation

- Beyond some limit (the solubility limit), every molten metal oust as every liquid) will be unable to dissolve any more of a particular gas.
- Furthermore, that solubility limit in the molten metal usually decreases with decreasing temperature, until at the melting point, upon solidification, the solubility drops precipitously.

Porosity Formation

Solidification

Solubility decreases

Bubble formation

Buoyant bubbles attempt to move in the weld pool according to

1. the convection –
2. buoyancy (or gravity) force,
3. a surface tension gradient force,
4. an electromagnetic force, or an
5. impinging or plasma friction force

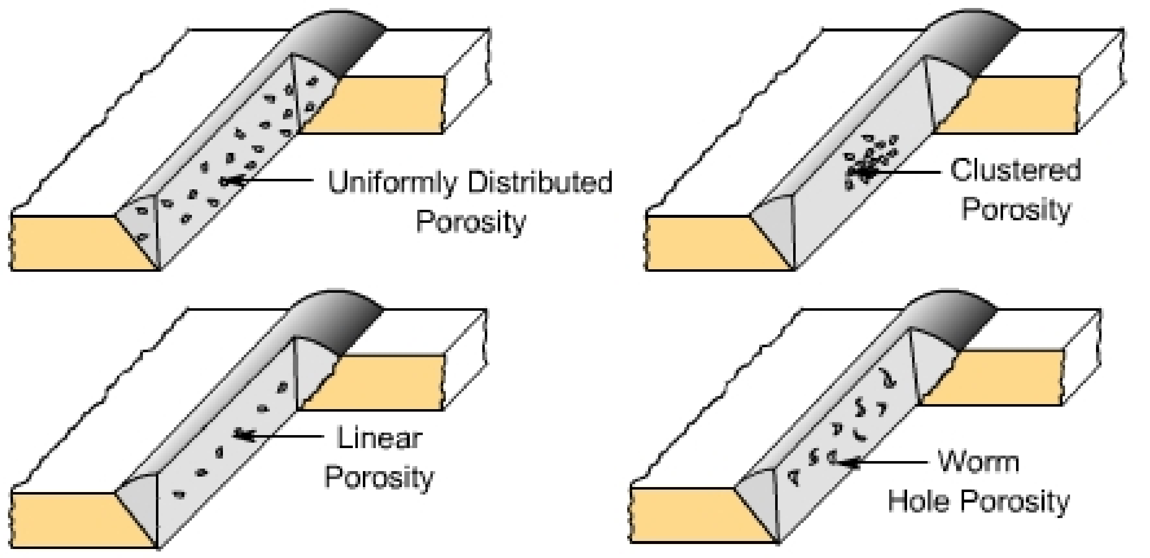
Bubbles may/not escape

Porosity → Problems

- First, it indicates that shielding was less than adequate, and that unwanted gas-metal reactions are occurring.
- Second, pores can easily act as stress risers, thereby promoting brittle (over ductile) fracture and aggravating susceptibility to cyclic loading (fatigue).
  - The fact that a pore can act to arrest a propagating crack by blunting it, and, thereby, reducing the stress at its tip, is not justification for accepting porosity. Unless every pore is intentionally introduced and controlled in size and location (which is absurd!),
- Third, Porosity indicates that the process is not under proper control

Porosity

- Single pore
- Uniformly scattered
- Cluster
- Linear
- Piping



Embrittlement Reactions

N_2, O_2, H_2

Nitrides

Examples

1. Fe_2N in Fe based alloys which reduce ductility and impact toughness.
2. AlN in Al containing steels → Hardness

Oxides

Examples

1. Fe_2O_3,
2. Al_2O_3,
3. SiO_2

Hydrides

Examples

1. TiH_2 causing embrittlement

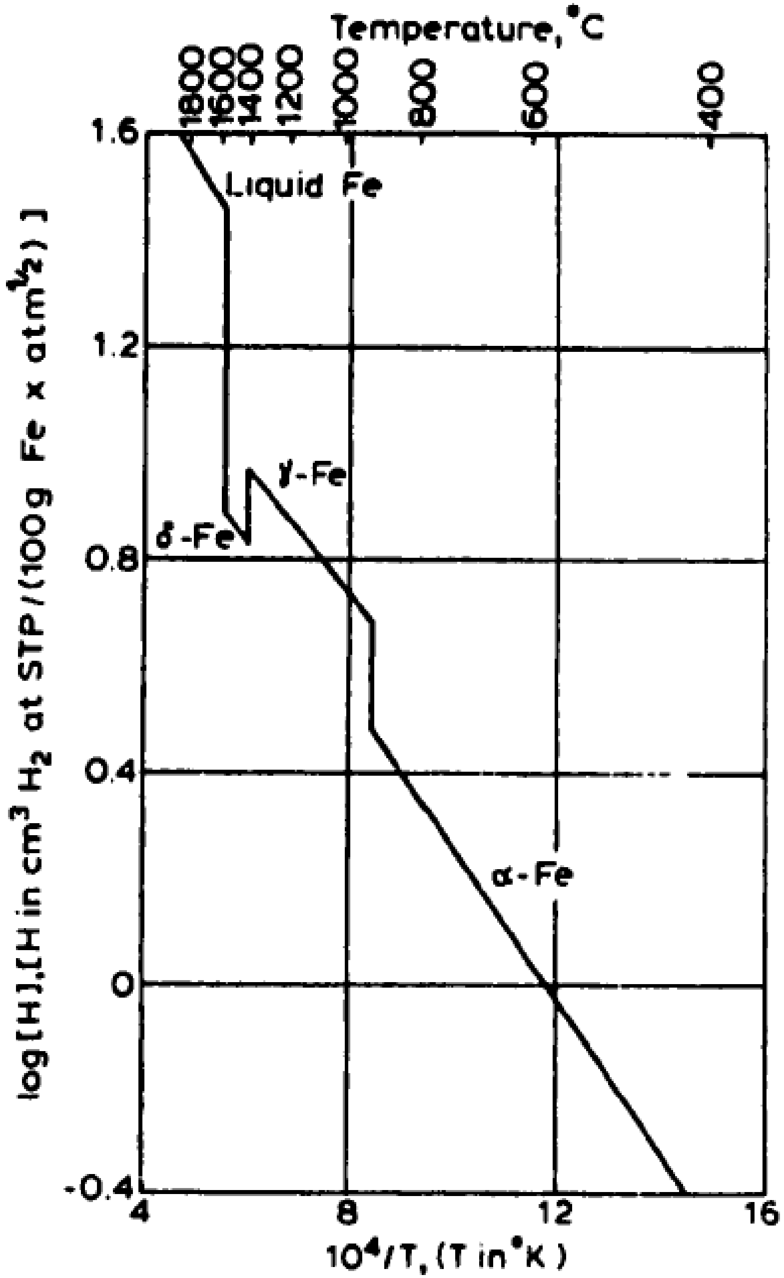
Embrittlement Reactions

- Dissolved gases can chemically react with molten metal to form compounds that are almost always (1) undesirable (since they are nonmetallic) and (2) inherently brittle.
- N_2 can form nitrides $\rightarrow$ Eg. In Fe based alloys to form acicular (needle-like) and crack-like Fe_2N, which reduce ductility and impact toughness.
- Nitrides also form in aluminum-containing steels to form extremely hard, but less brittle, aluminum nitride, which is the basis for nitriding steels (about 4 wt% of added Al) to improve their resistance to certain kinds of wear.
- O_2 can form oxides, as it does in Fe-based alloys, usually with silicon to form nonmetallic silicate inclusions, and in aluminum based alloys to form aluminum oxide inclusions.
- H_2 can form hydrides, and does in titanium to cause severe embrittlement.

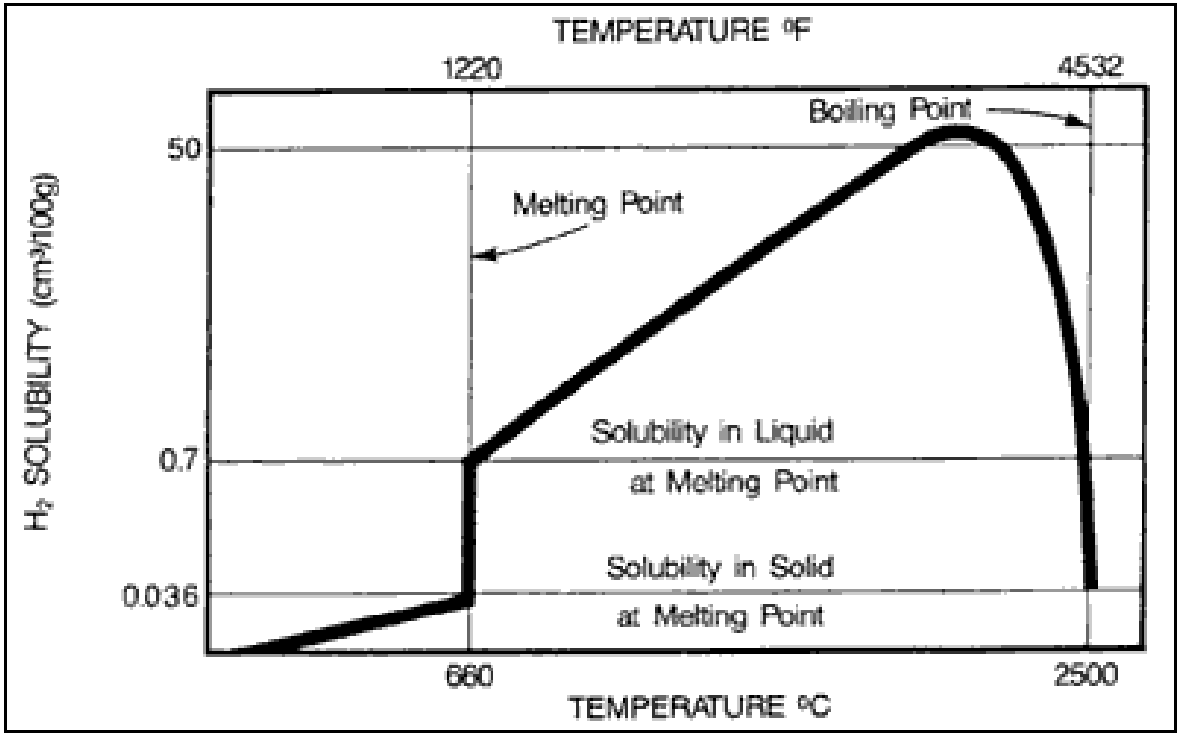
Hydrogen Effects

- Hydrogen is one of four or five elements (H, C, N, B, and, possibly, O) with a sufficiently small atomic diameter to dissolve interstitially in most metals.
- The introduction of hydrogen into construction steels has three major deleterious effects:
  - (1) Hydrogen embrittlement,
  - (2) Hydrogen porosity, and
  - (3) Hydrogen cracking

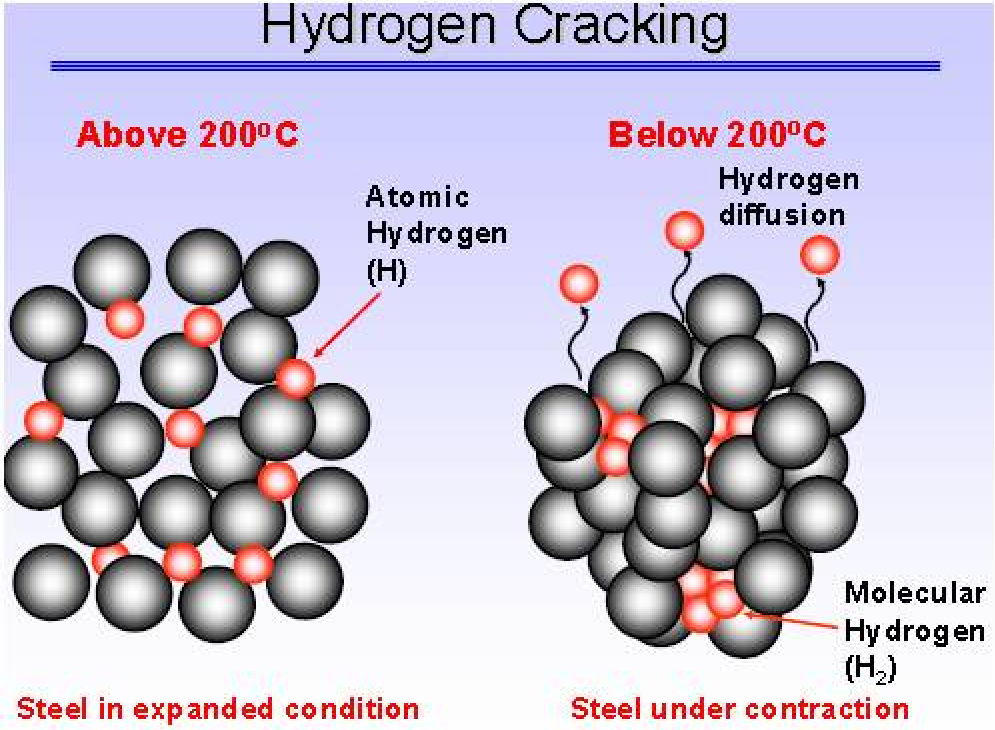
The solubility of hydrogen in iron as a function of temperature.



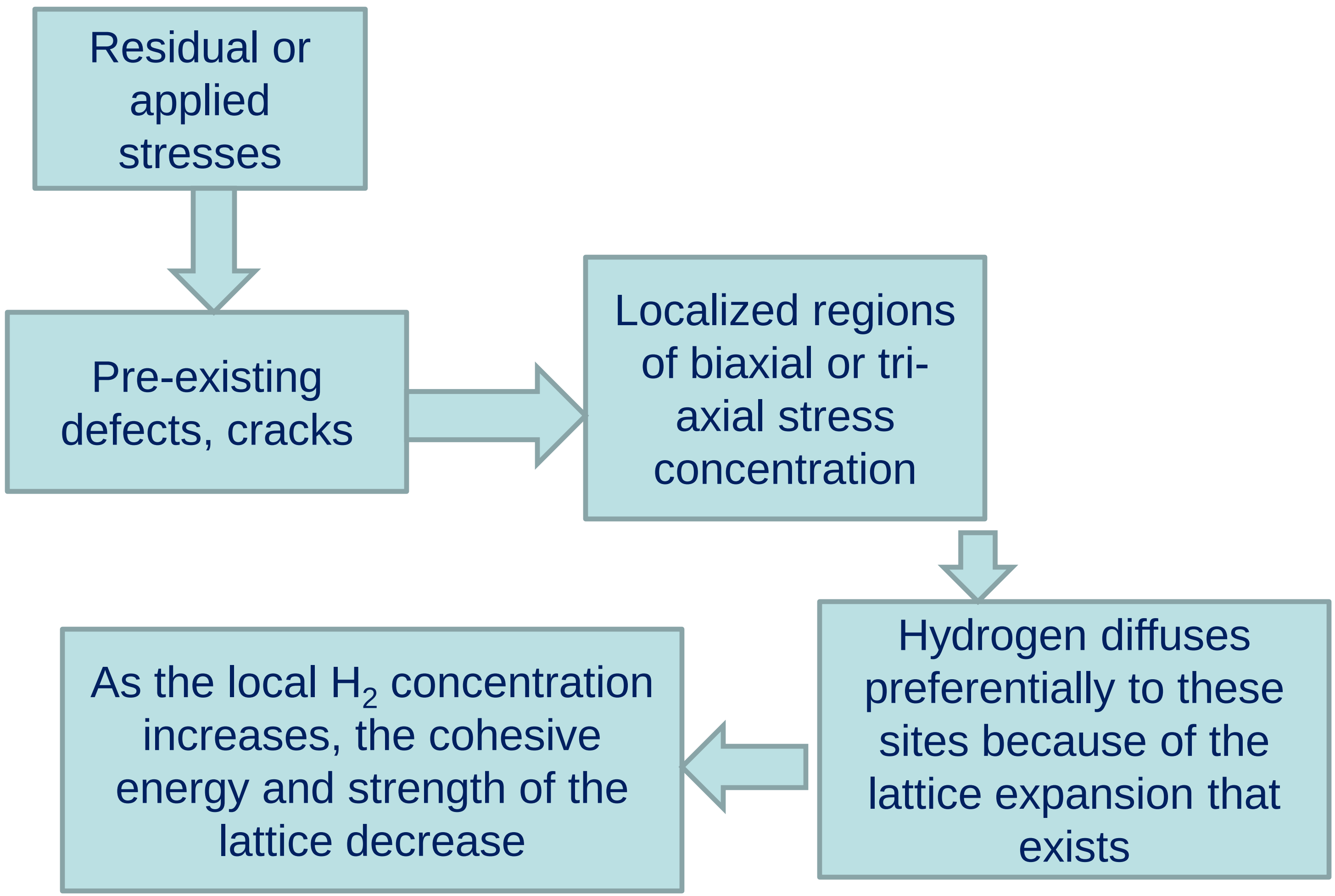
Solubility of H_2 in Aluminium



Hydrogen Cracking



Hydrogen Cracking



Hydrogen Cracking

- Preferred models involve the presence of pre-existing defect sites in the material, including small cracks or discontinuities caused by minor phase particles or inclusions.
- In the presence of residual or applied stresses, such sites may develop highly localized regions of biaxial or tri-axial stress concentration.
- Hydrogen diffuses preferentially to these sites because of the lattice expansion that exists.
- As the local hydrogen concentration increases, the cohesive energy and strength of the lattice decrease.
- When the cohesive strength falls below the local intensified stress level, spontaneous fracture occurs. Additional hydrogen then evolves in the crack volume, and the process is repeated.

Welding lecture -16

Weld Quality & Testing

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Weld Assessment

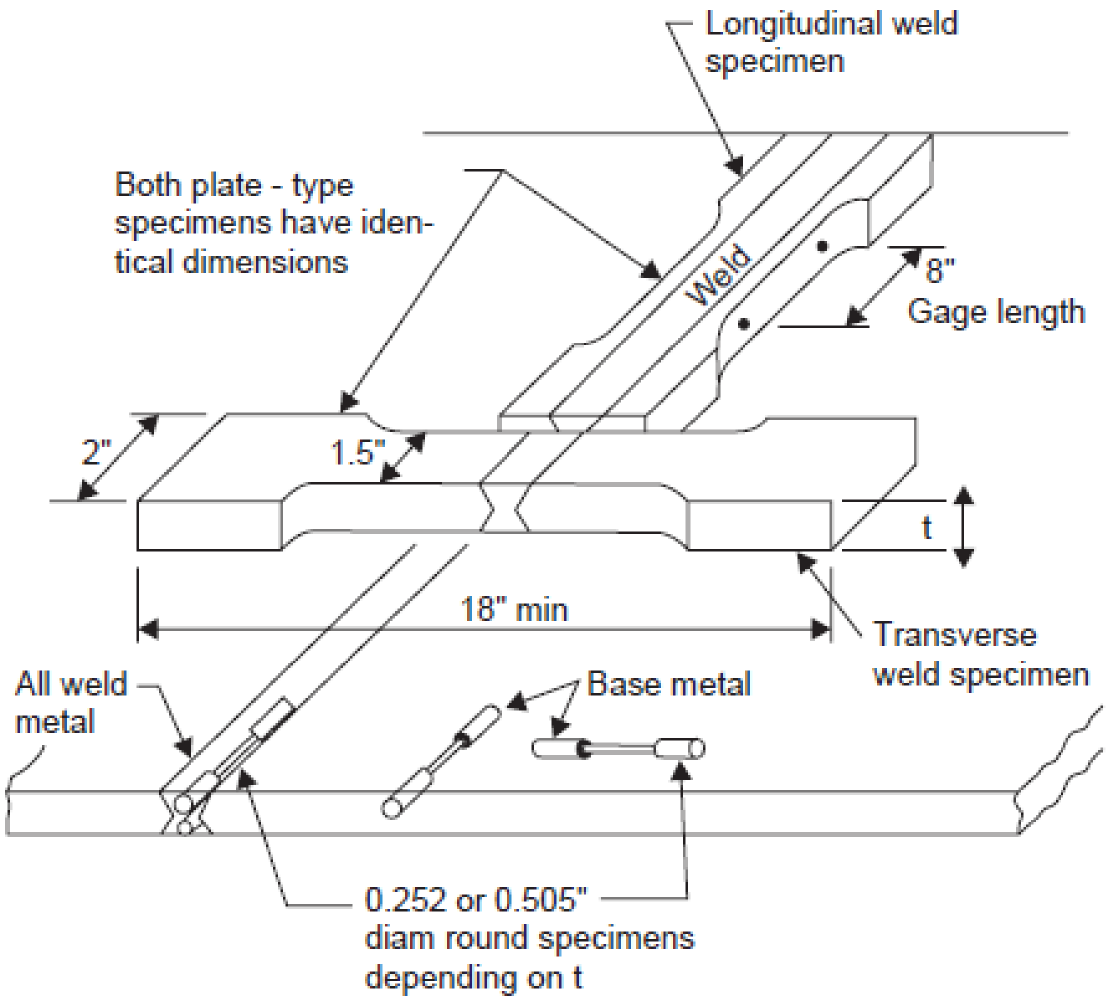
- ***Destructive testing***
  - Mechanical testing, i.e., tensile, fracture toughness, impact, fatigue tests.
  - Expensive, require specimen preparation under standard specifications.

- ***Non destructive testing***
  - Weldments are not destroyed.
  - Many NDT techniques are expensive and have their own limitations.
  - Inspection should be carefully planned to make sure the technique used is capable of detecting the concerned defects.

Destructive tests

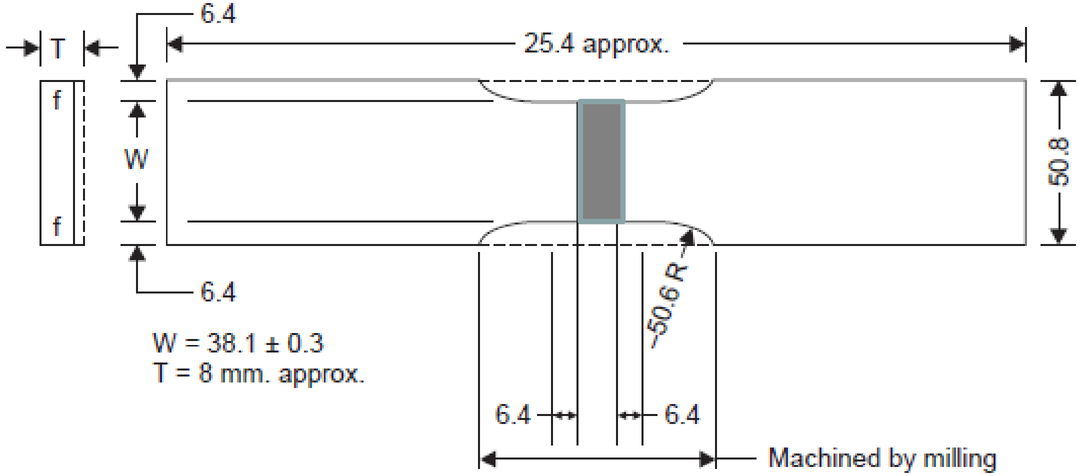
1. Tensile – ductility, elongation, tensile strength
2. Bending- ductility, elongation, tensile strength
3. Impact - Toughness
4. Hardness – Wear, abrasion
5. Fatigue
6. Cracking - Reeves test

Tension Tests: Specimen

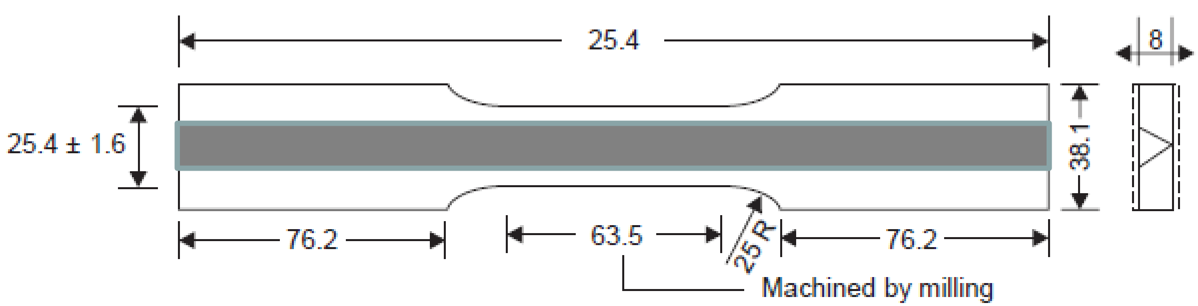


Tension Tests

- Transverse weld test specimen

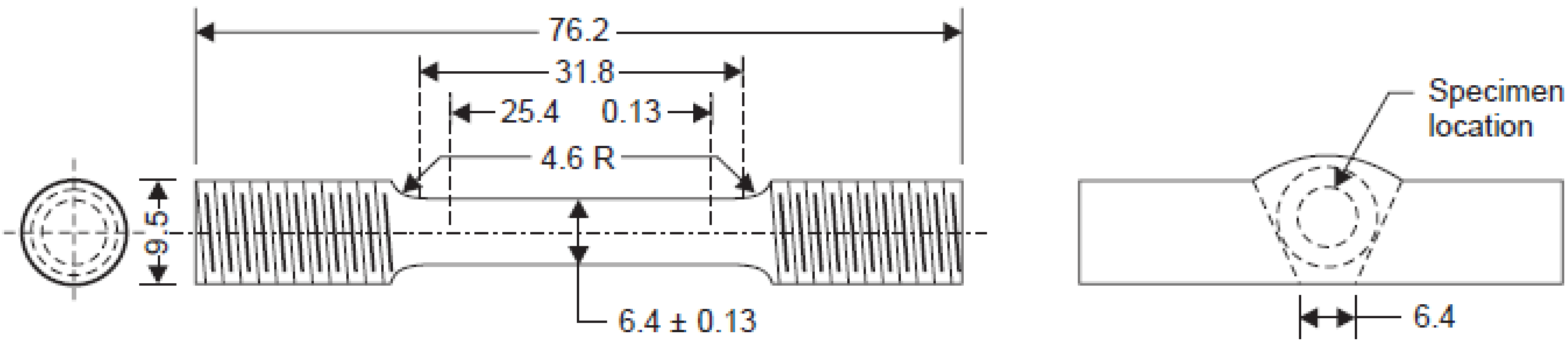


- Longitudinal weld test specimen

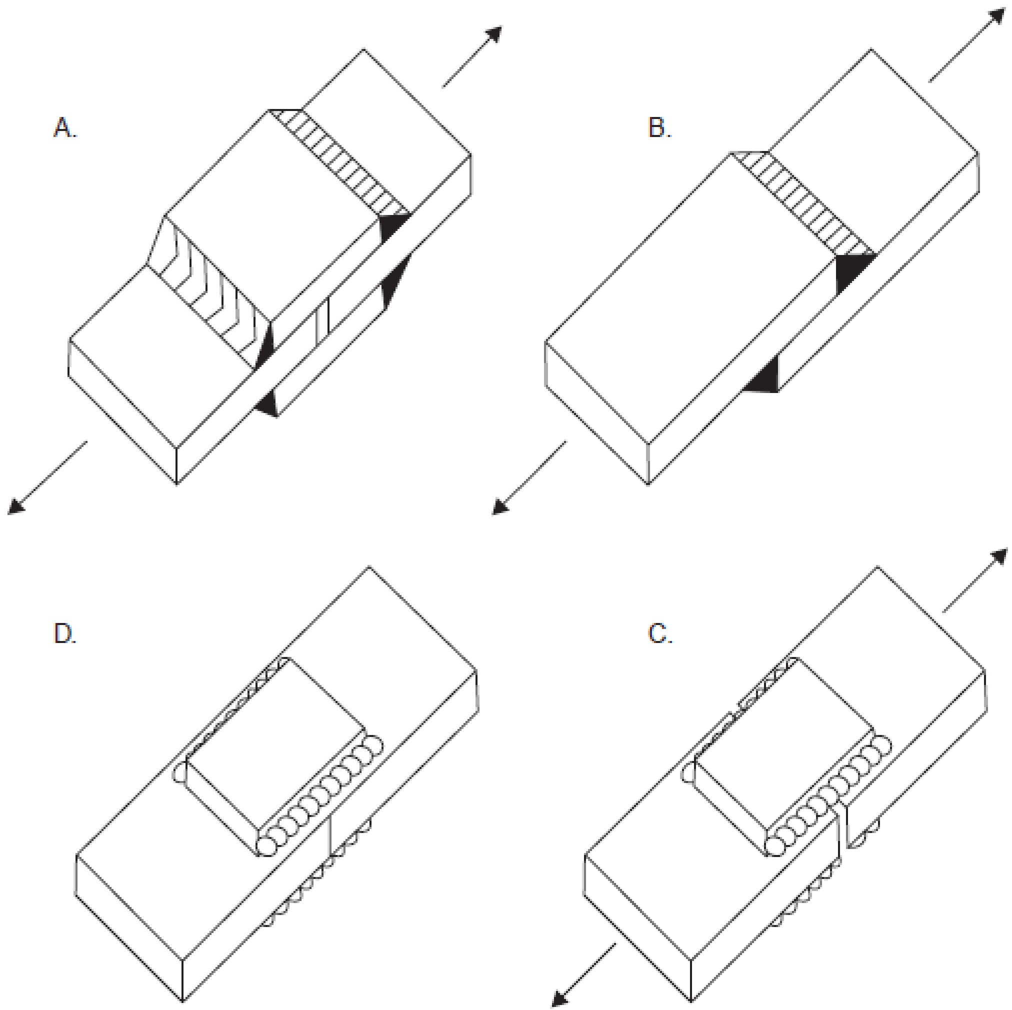


Tension Tests

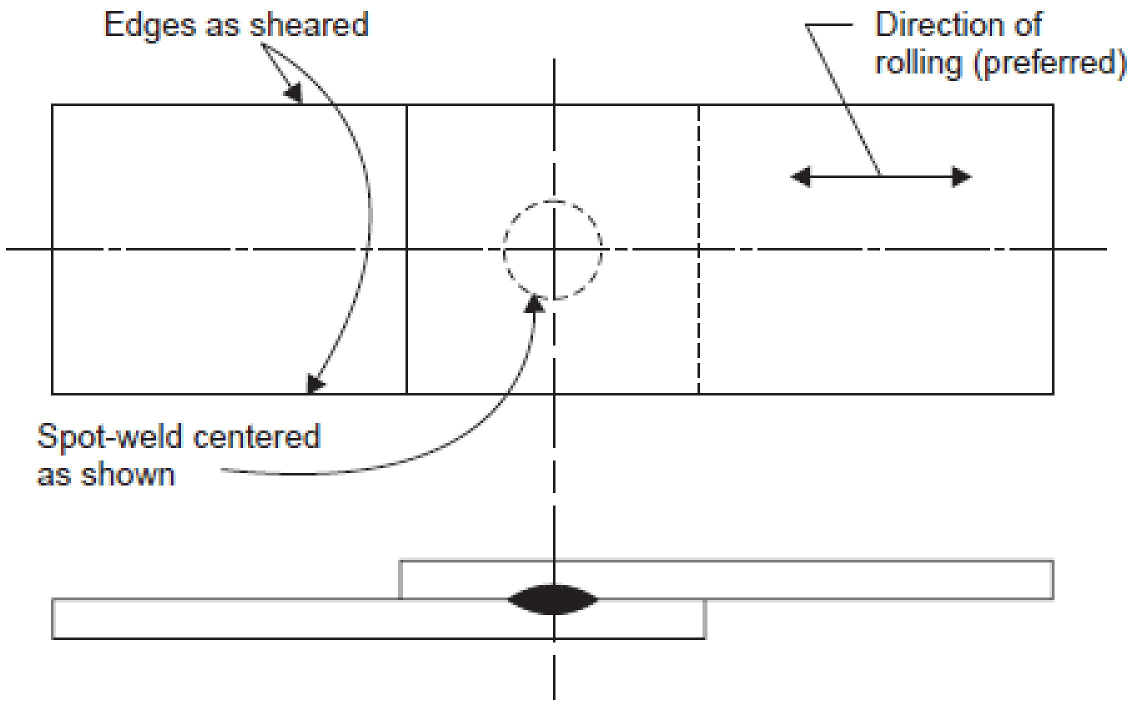
- All weld metal test specimen



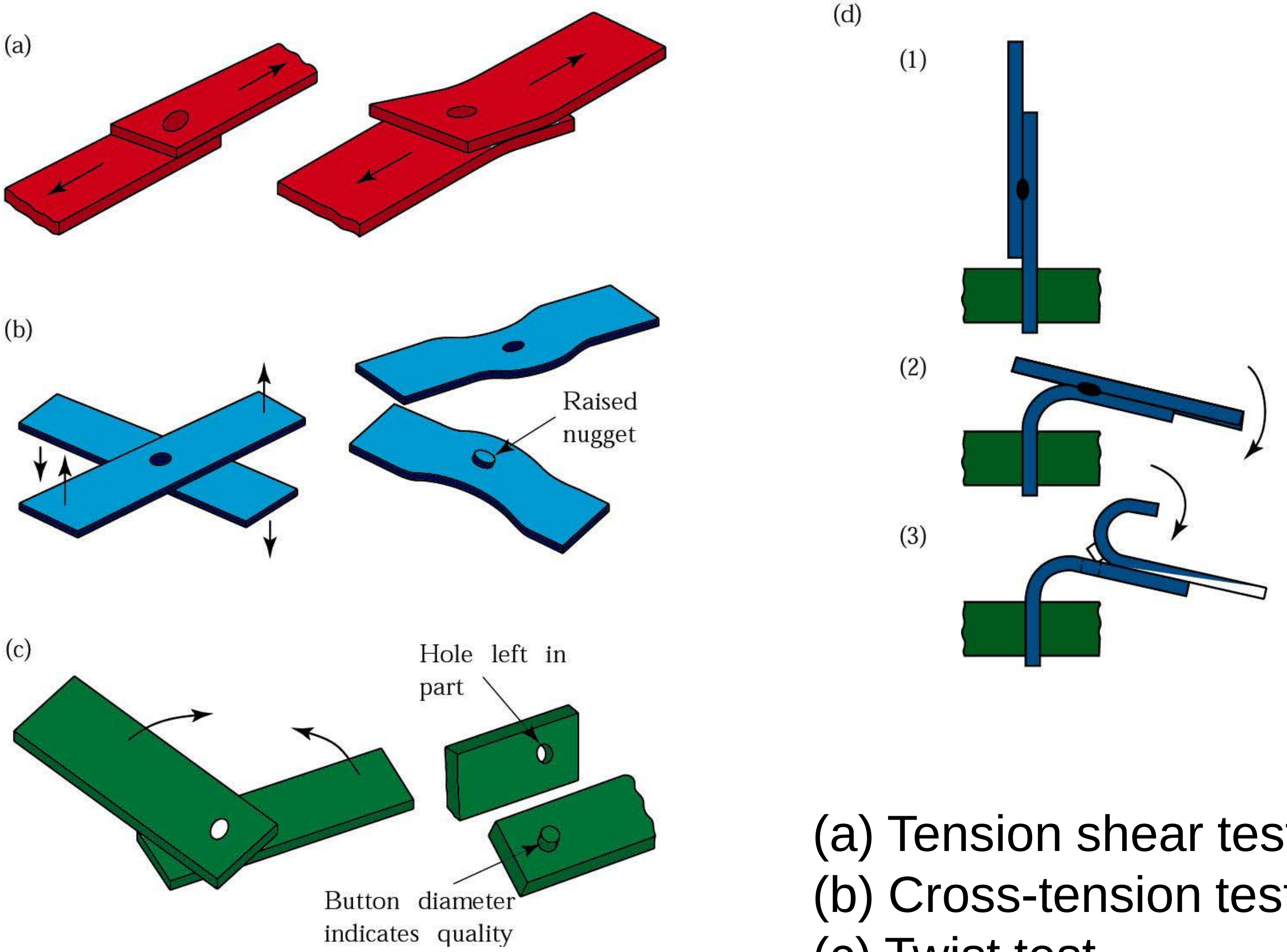
Fillet weld shear Tests



Tension shear Tests for resistance welds



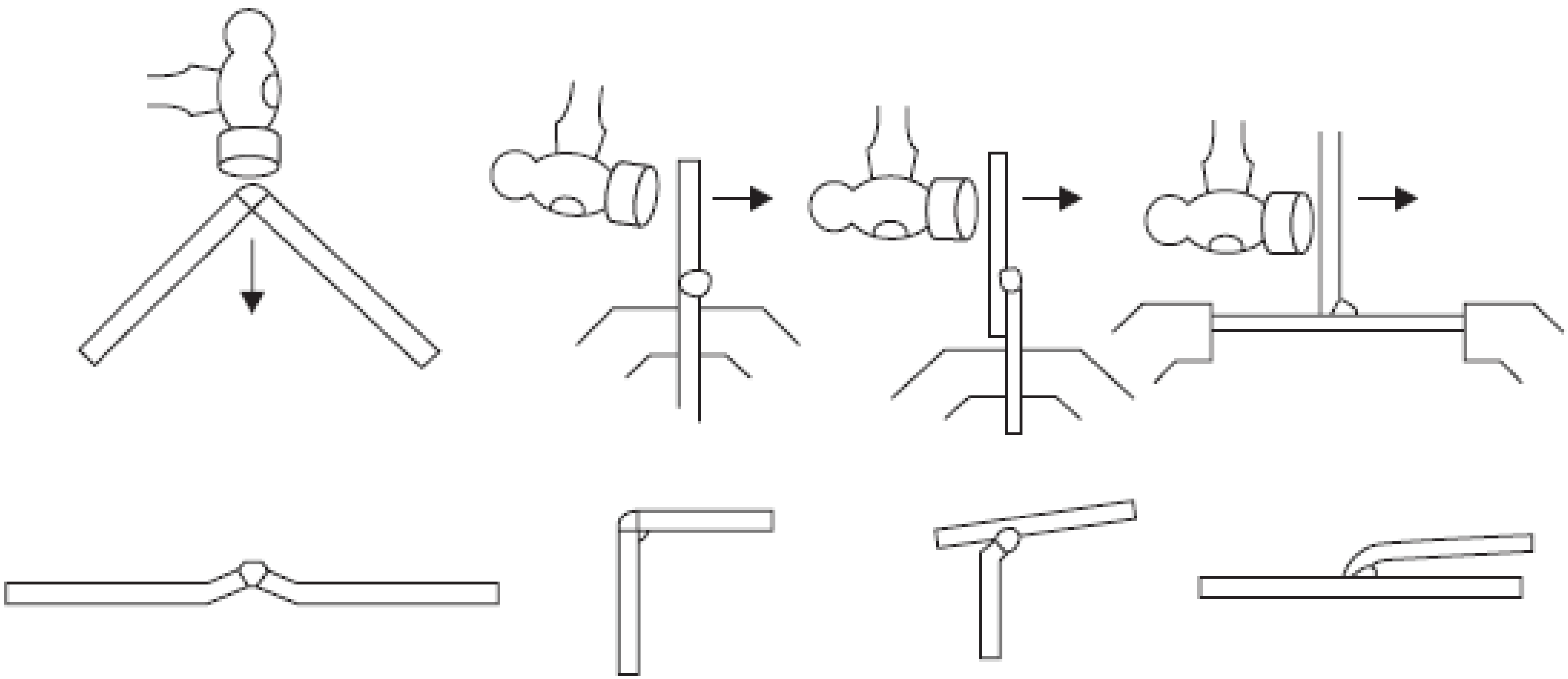
Testing of Spot Welds



(a) Tension shear test for spot welds.
(b) Cross-tension test
(c) Twist test.
(d) Peel test

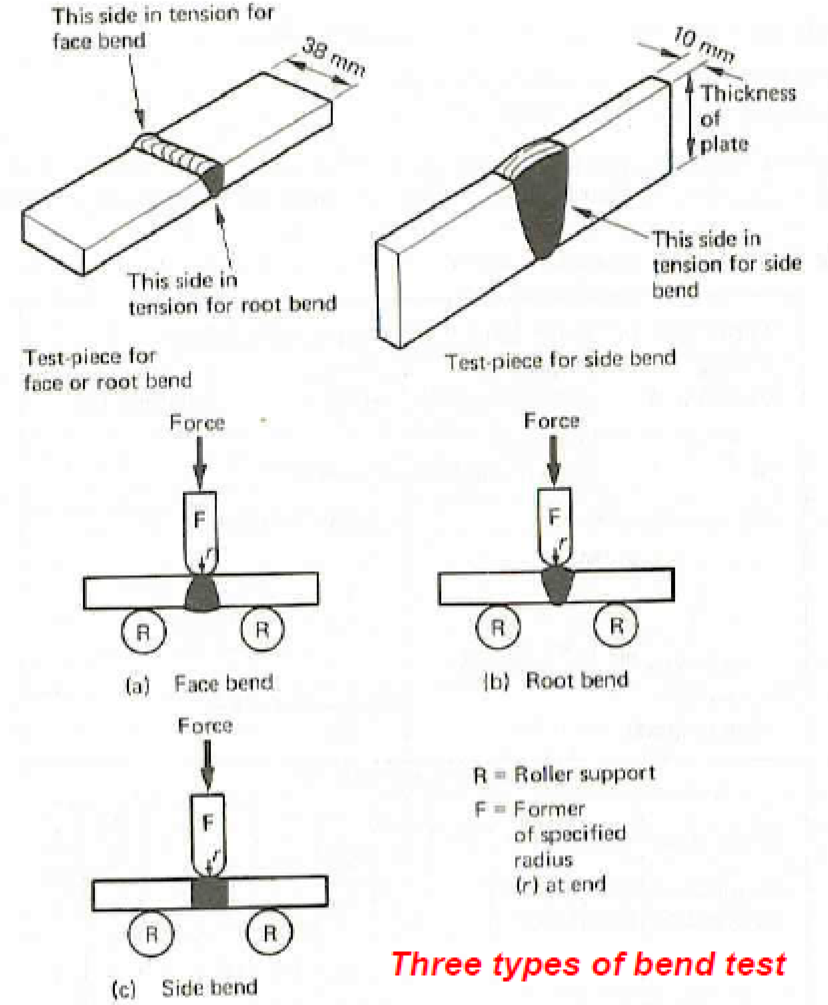
Bend Tests for corner, butt, lap, T-joints

Corner　　Butt　　Lap　　T-Joint



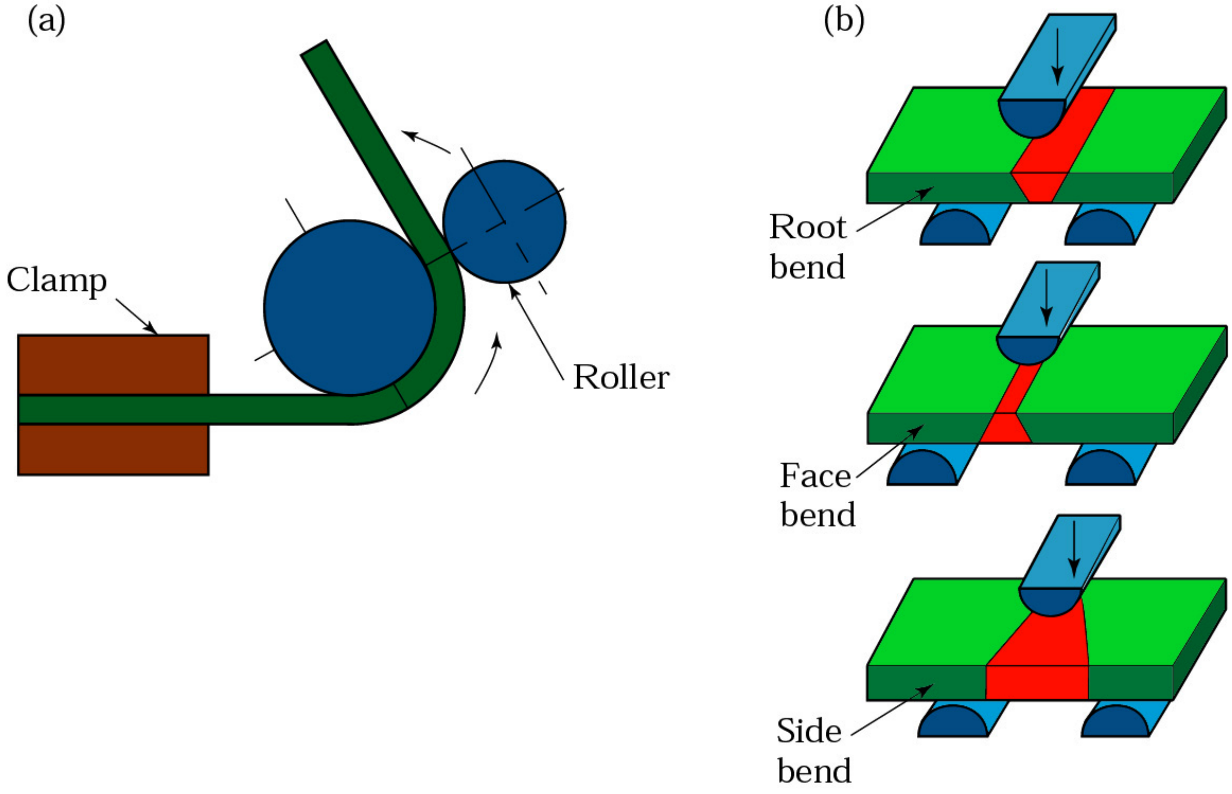
Bend Tests-Types

- Shows Physical condition of the weld
- Determine welds efficiency
  - Tensile strength
  - Ductility
  - Fusion and penetration



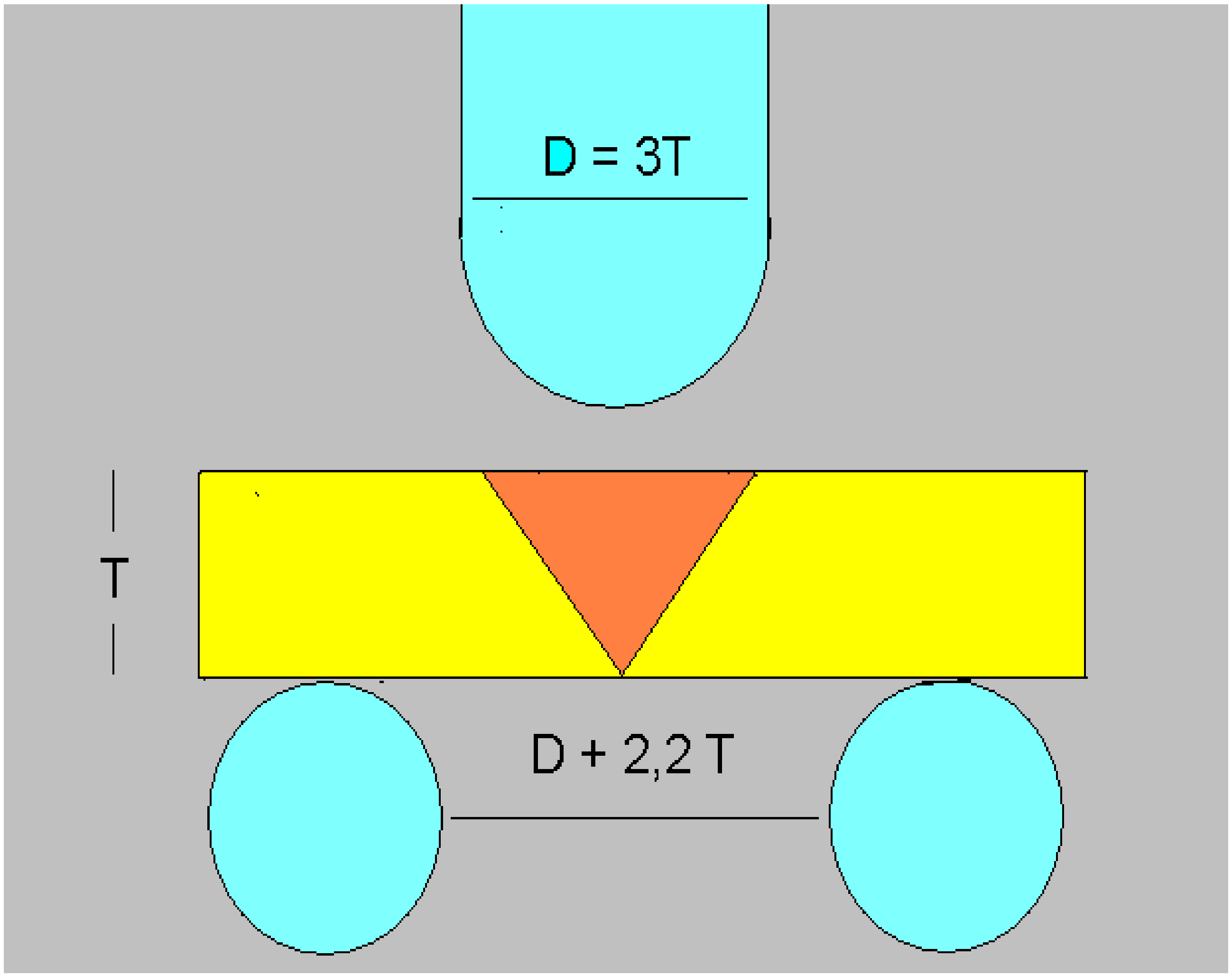
Three types of bend test

Bend test

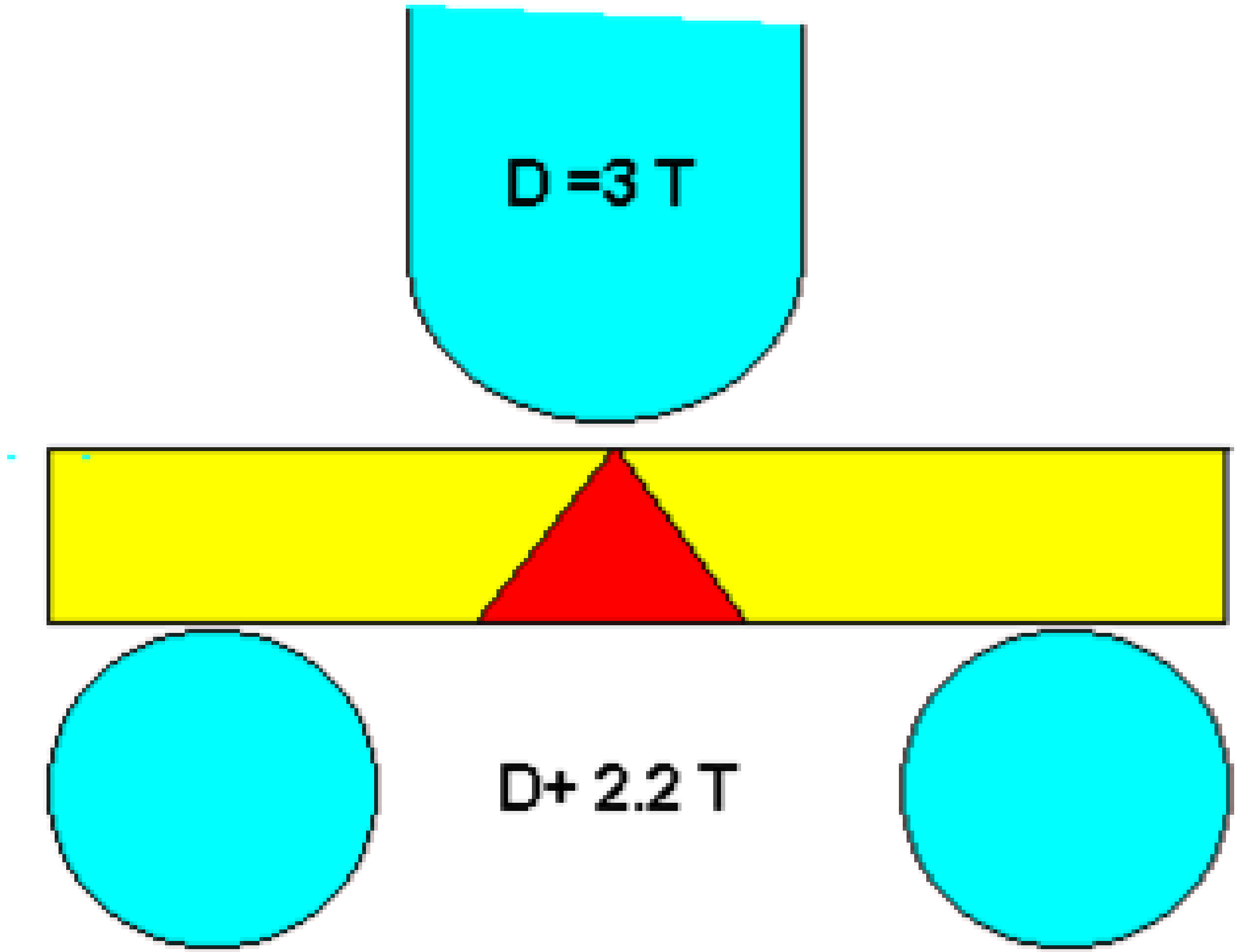


(a) Wrap-around bend test method for thin samples
(b) Three-point bending of welded specimens

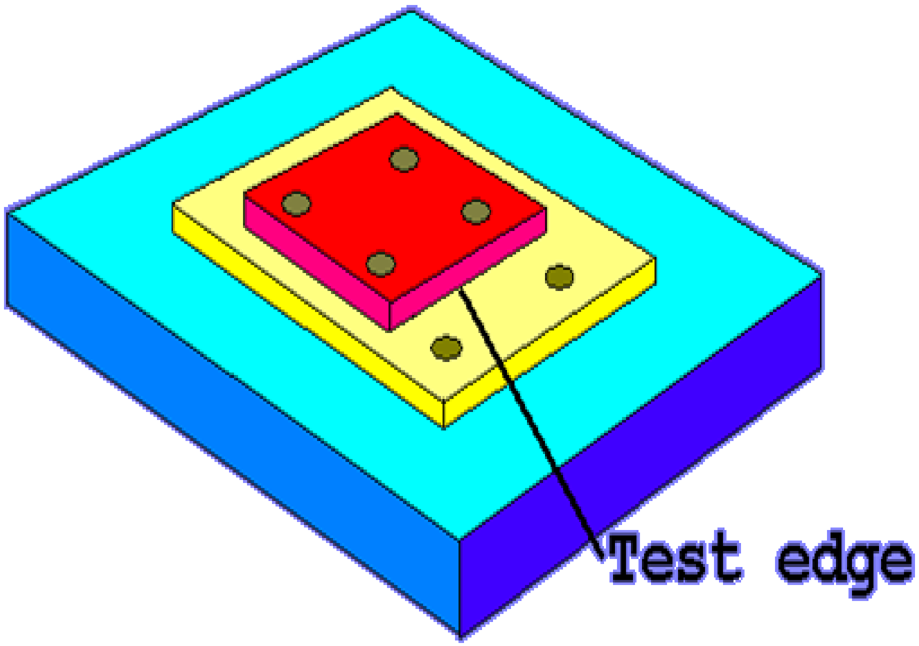
Bend Tests-Root bend test



Bend Tests-Face bend test



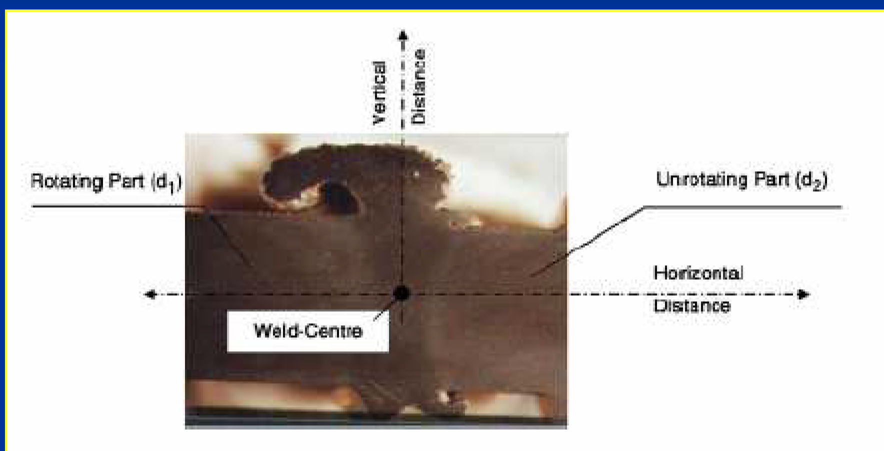
Cracking- Reeves test



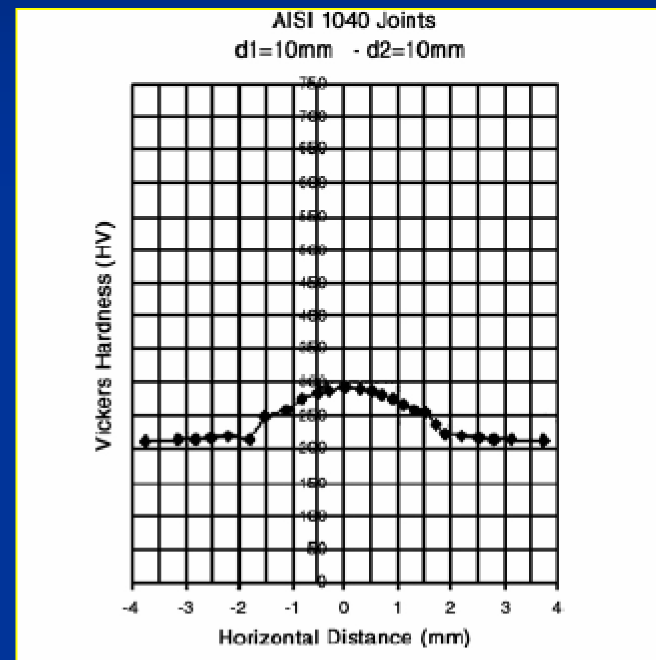
- Three Sides Are Welded With Known Compatible Electrodes.
- The front edge is welded with the test electrode.
- If incompatible it will crack.

Hardness test

Hardness profile



Hardness test orientation in the weld joint of AISI 1040 friction weld



Hardness profile

Non-destructive inspection of welds

- Visual Inspection (VT)
- Magnetic Particle Inspection (MT)
- Liquid (Dye) Penetrant Inspection (PT)
- X-Ray inspection (RT)
- Ultrasonic testing (UT)
- Air or water pressure testing (LT)

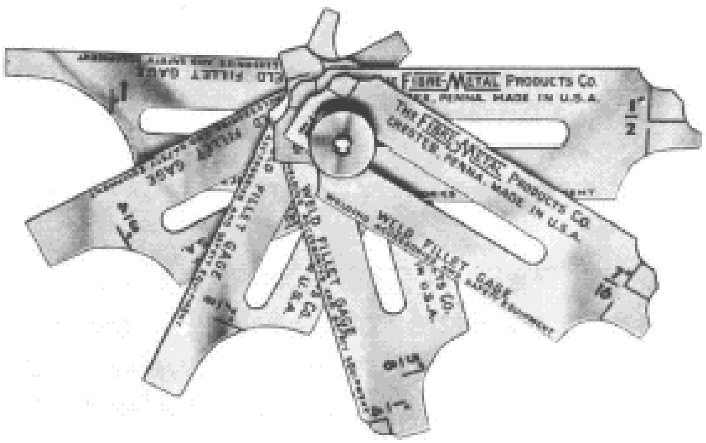
Visual Inspection (VT)

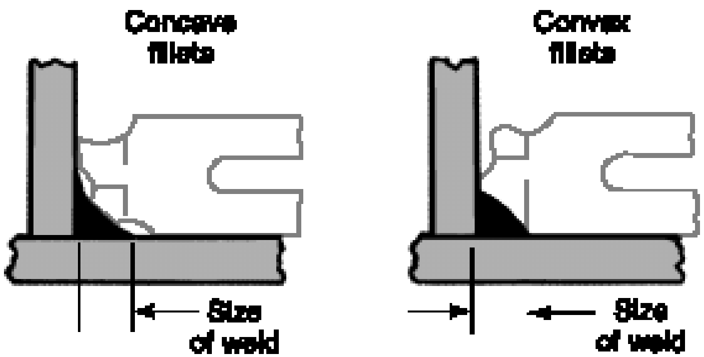
- Visual is the most common inspection method
- VT reveals spatter, excessive buildup, incomplete slag removal, cracks, heat distortion, undercutting, & poor penetration
- Typical tools for VT consist of Fillet gauges Magnifying glasses, Flashlights, & Tape measures or calipers.

Visual Inspection (VT)

- While welding
  - The rate the electrode melts
  - The way the weld metal flows
  - Sound of the arc
  - The light given of
- After welding
  - Under cut
  - Lack of root fusion
  - Any pin holes from gas or slag
  - Amount of spatter
  - Dimensions of weld

Visual Inspection (VT)





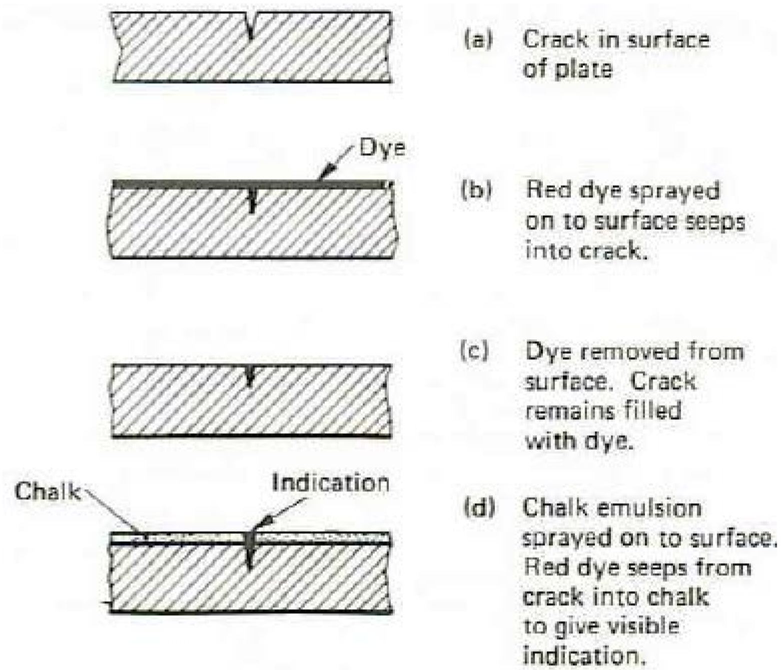
- Fillet gauges measure
  - The “Legs” of the weld
  - Convexity
    - (weld rounded outward)
  - Concavity
    - (weld rounded inward)
  - Flatness

Visual Inspection-Check list of defects

1. Surface cracks
2. Incomplete root penetration
3. Undercut
4. Underfill on face, groove, or fillet (concave)
5. Underfill of root (suck back)
6. Excessive face reinforcement, groove, or fillet (convex)
7. Excessive root reinforcement
8. Overlap
9. Misalignment
10. Arc strikes
11. Excessive spatter
12. Warpage (distortion)
13. Base metal defects

Liquid (Dye) Penetrant Inspection (PT)

1. The liquid penetrant (normally red) is applied on the surface containing cracks.
2. Waiting for the liquid penetrates into the cracks.
3. Clean off the excess liquid from the surface, but some liquid still remains in the cracks.
4. Developer (chalk emulsion) is applied to enhance the visible indication of cracks.



Liquid (Dye) Penetrant Inspection (PT)

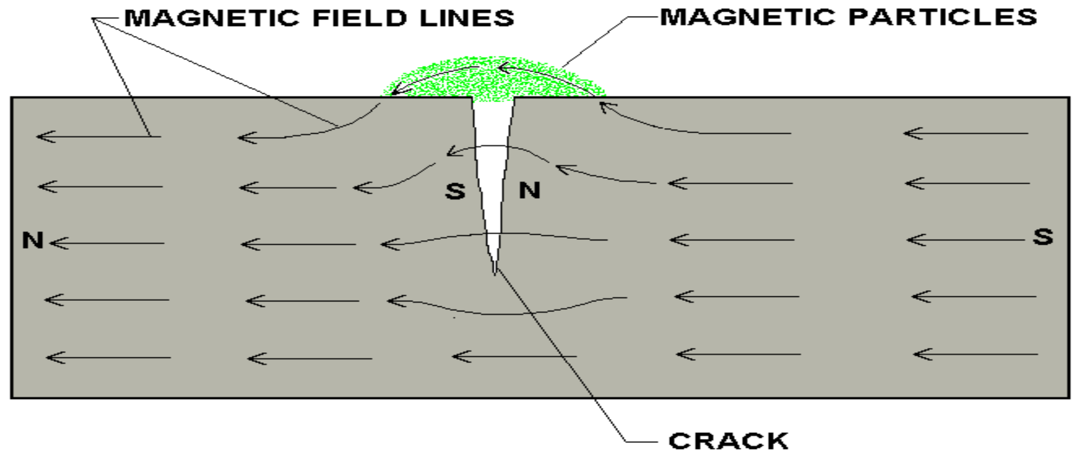
- Liquid penetrant inspection uses colored or fluorescent dye to check for surface flaws.
- Surface defects: PT will not show sub-surface flaws.
- Any material: PT can be used on both metallic and non metallic surfaces such as ceramic, glass, plastic, and metal.
- PT dose not require the part to be Magnetized

Magnetic Particle Inspection (MT)

- Magnetic Particle Inspection (commonly referred to as Magnaflux testing) is only effective at checking for flaws located at or near the surface.
- MT uses a metallic powder or liquid along with strong magnetic field probes to locate flaws. (Particles will align along voids)
- MT can only be used on materials that can be magnetized

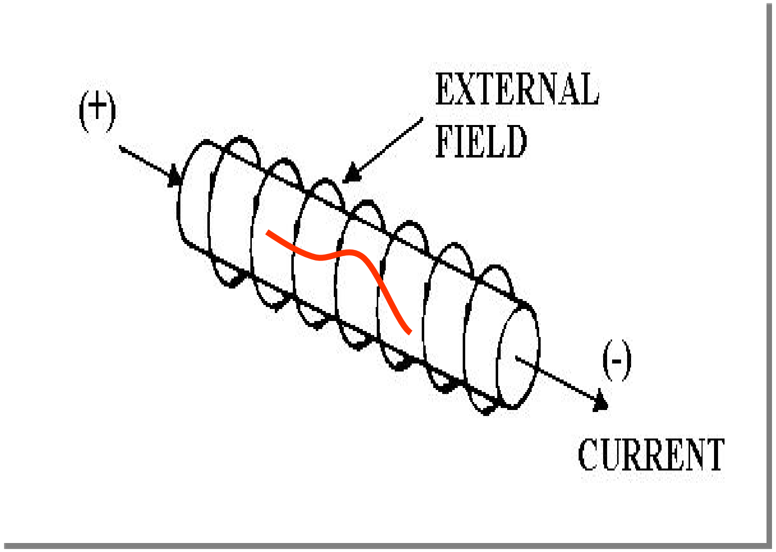
Magnetic Particle Inspection (MT)

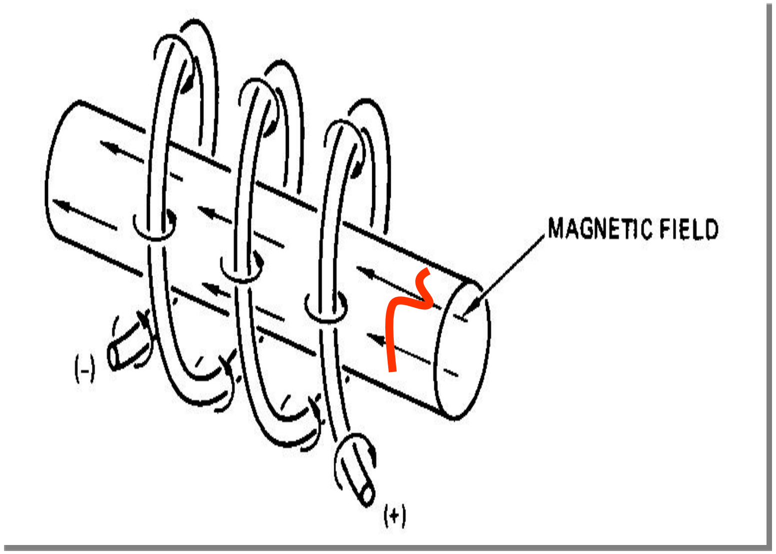
- Sensitivity is maximum if the magnetic field lines are perpendicular to the crack/ defect orientation



Magnetic particle inspection

Since defects may occur in various and unknown directions, each part is normally magnetized in <u>two directions at right angles</u> to each other.

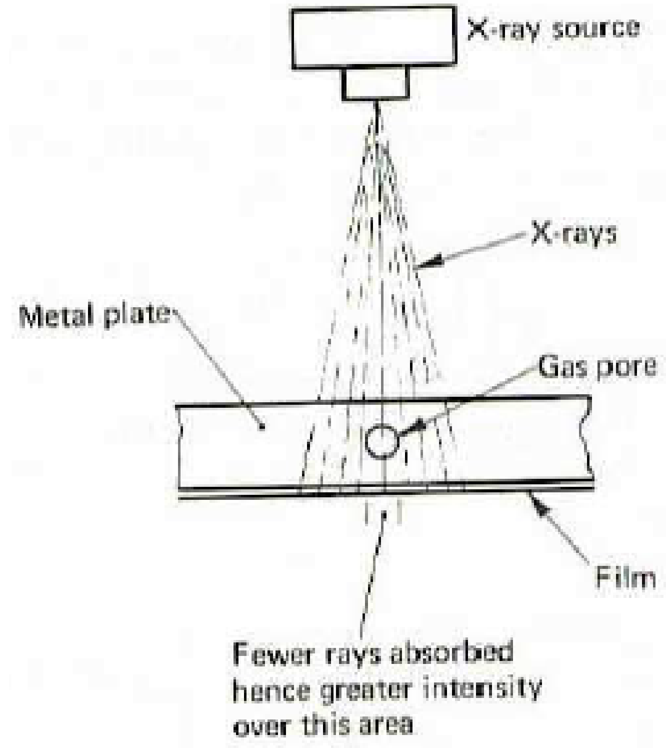




Magnetic Field Direction

Radiographic inspection (RT)

- Interior defects (porosity, cracks, voids) can be examined by using X-ray or gamma ray, which can penetrate through materials and its intensity depends on materials thickness and density.
- Provide a permanent film record which is easy to interpret.
- Slow and expensive, however this method is positive to determine defect size.
- RT inspections can reveal flaws deep within a component



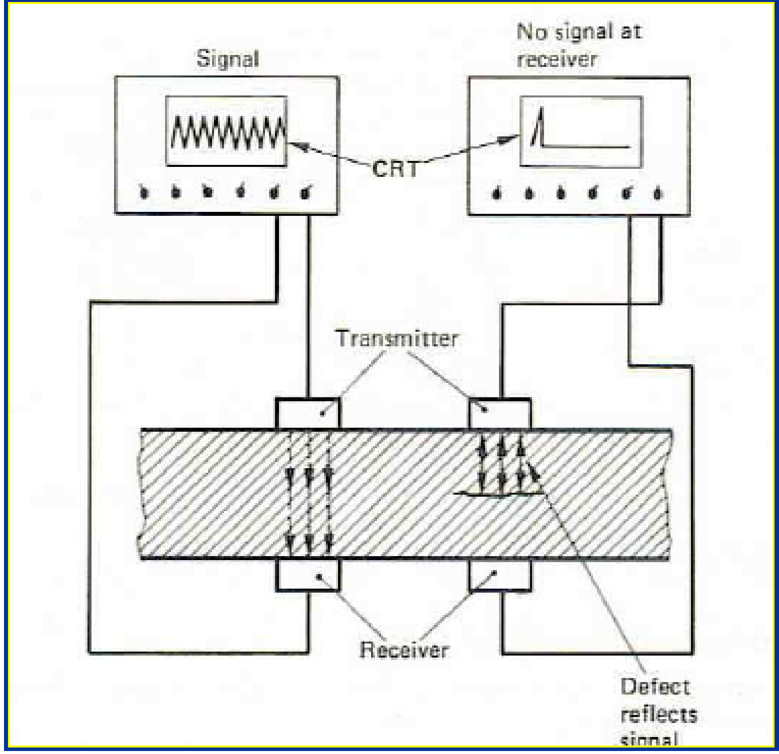
Ultrasonic testing (UT)

- Ultrasonic testing (UT) is a method of determining the size and location of discontinuities within a component using high frequency sound waves.
- Sound waves are sent through a *transducer* into the material and the shift in time require for their return or echo is plotted.
- Ultrasonic waves will not travel through air therefore flaws will alter the echo pattern

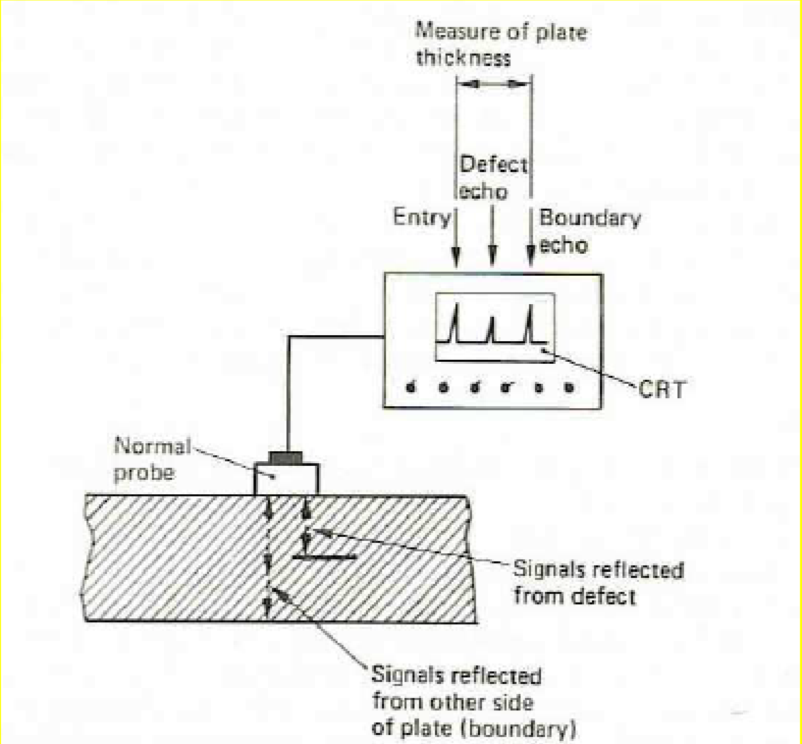
Ultrasonic testing (UT)

There are two ways of using ultrasonic waves for welded joint inspection

Transmission

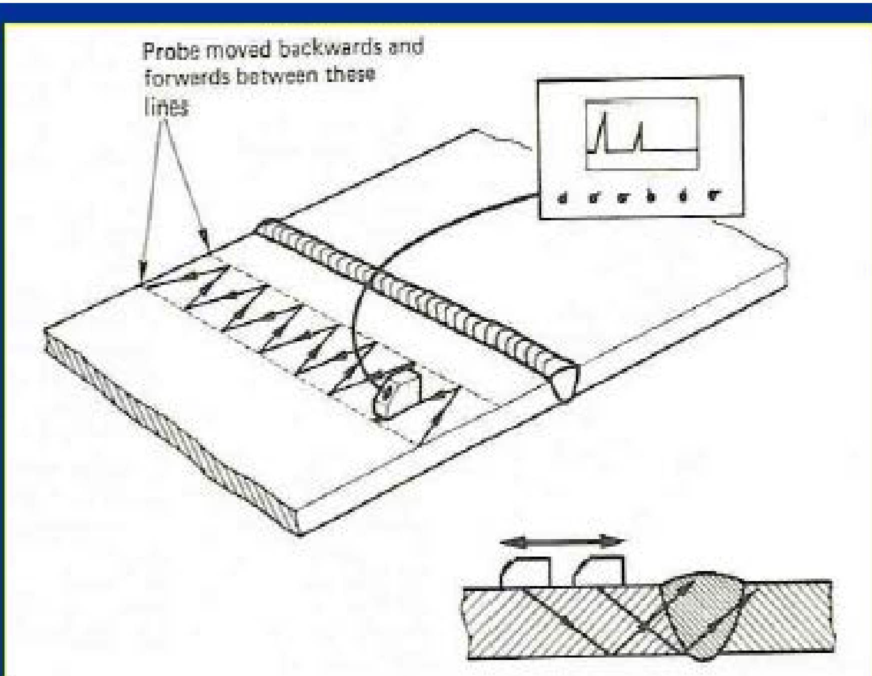


Reflection



Method and applications (UT)

- The location of the defect in the weld can be calculated
- Can be used to test all kinds of metals and materials, complex weldments → widely used.



Moving the probe to scan the thickness of the weld with an angle probe.

Ultrasonic inspection in pipeline

Air or water pressure testing (LT)

- Pressure testing or leak testing can be performed with either gasses or liquids.
- Voids that allow gasses or liquids to escape from the component can be classified as gross (large) or fine leaks.
- Extremely small gas leaks measured in PPM (parts per million) require a "Mass Spectrometer" to Sniff for tracer gases
- Used in spacecrafts, pipelines, ships etc.

Summary of NDT of welds

Method	Defects detected	Advantages	Disadvantages
Visual Inspection	•Inaccuracies in size, shape, • Surface cracks, porosity, •Undercuts, overlaps	•Easy to apply at any stage, •Low cost in capital & labour	•No permanent record •Only surface defects
Dye penetrant	• Surface cracks missed by VT	•Easy to apply • Low cost in capital & labour	• Only surface cracks
Magnetic particle	Surface & subsurface flaws	• Low cost, portable	• only magnetic materials • Interior cracks cannot be detected

Summary of NDT of welds

Method	Defects detected	Advantages	Disadvantages
Radiography	•Porosity •Slag •Cracks •Lack of fusion	• Reproducible, Permanent record • Deep flaws	• Expensive • Safety • Skill
Ultrasonics	• All subsurface defects	• Sensitive • Portable equipment	• Complex • Skill
Pressure testing	Fine through holes/pores	• high sensitivity, very fine holes can be detected	• Only for closed parts/vessels • Complex set up