Weldability and defects in weldments

Subjects of Interest

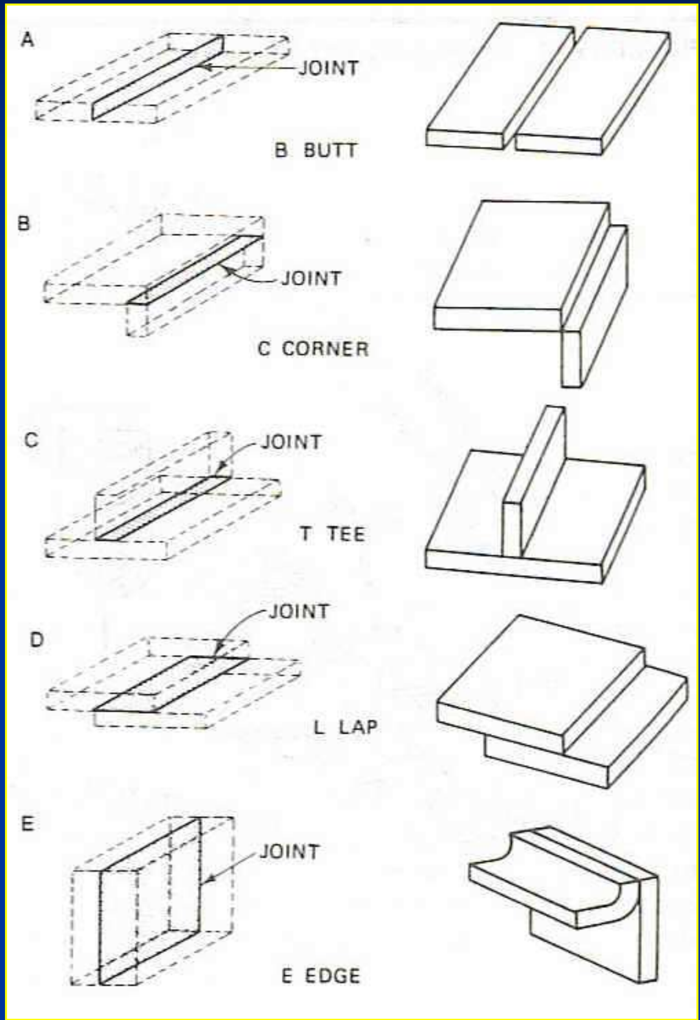
- Reviews of weld design and weldability
- Residual stresses and weld distortion
- Weld metal inhomogeneities
  - *micro/macro segregations*
  - *Banding*
  - *Inclusion*
  - *Gas porosity*
- Weld cracking
  - *Solidification cracking*
  - *Liquation cracking*
  - *Hydrogen cracking*

Objectives

This chapter aims to:

- Students are required to understand the causes of residual stresses, distortion and their remedies.
- Students are also required to differentiate weld defects that might occur during metal welding for example, solidification cracking, liquation cracking, distortion, weld embrittlement.
- Students can suggest possible remedies associated with individual weld defects.

Weld design – *joint type*



Welds are made at the junction of all the pieces that make up the ***weldment*** (assembled part).

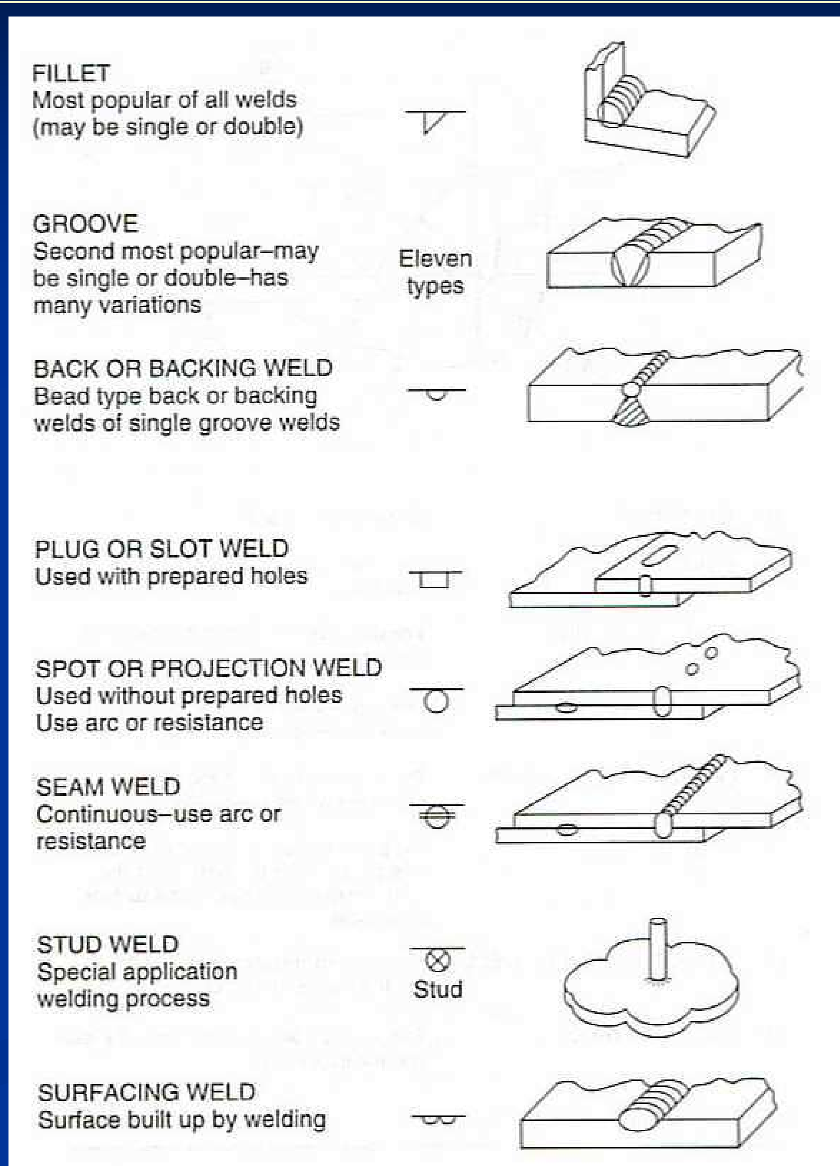
A: Butt joint	• A joint between two members aligned approximately in the same plane.
B: Corner joint	• A joint between two members located approximately at right angles to each other in the form of an L.
C: T-joint	• A joint between two members located approximately at right angles to each other in a form of a T.
D: Lap joint	• A joint between two overlapping members located in parallel.
D: Edge joint	•A joint between the edges of two or more parallel or nearly parallel members.

Five basic joint types

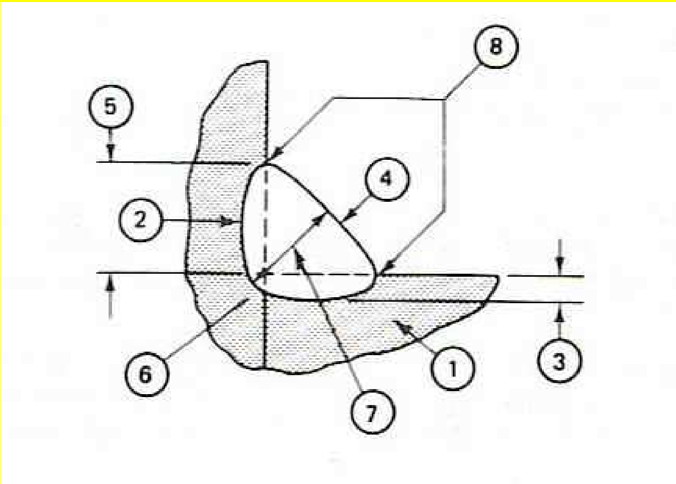
Weld design – ***weld type***

- *There are eight weld types:*

Fillet weld	**- On the joint**
Groove weld	**- In the joint**
Back weld	**- Made on the backside of the joint**
Slot weld	**- Used with prepared holes**
Spot weld	**- Weld at the interface of the members**
Seam weld	**- Without prepared holes**
Stud weld	**- Welding a metal stud**
Surface weld	**- Weld beads deposited on the base metal or broken surface**



Weld design – *Fillet weld*



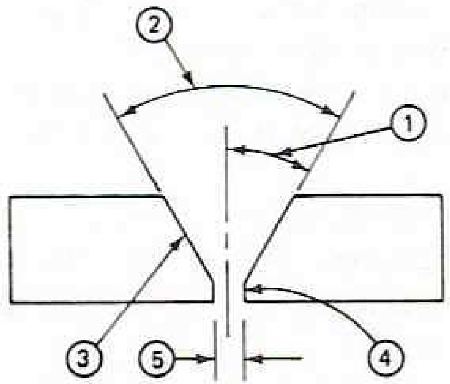
Fillet weld

Definitions of different parts in fillet weld

(1)	BASE METAL:	Metal to be welded.
(2)	BOND LINE:	The junction of the weld metal and the base metal.
(3)	DEPTH OF FUSION:	The distance that fusion extends into the base metal.
(4)	FACE OF WELD:	The exposed surface of a weld on the side from which the welding was done.
(5)	LEG OF A FILLET WELD:	The distance from the root of the joint to the toe of the fillet weld.
(6)	ROOT OF WELD:	The point or points, as shown in cross-section, at which the bottom of the weld intersects the base metal surface or surfaces.
(7)	THROAT OF FILLET WELD:	The shortest distance from the root of the fillet weld to its face.
(8)	TOE OF A WELD:	The junction between the face of a weld and the base metal.

Weld design – *Groove weld*

- There are ***seven basic groove welds***: square, V, bevel, U, J, flare V and flare bevel.



(1) BEVEL ANGLE: The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.

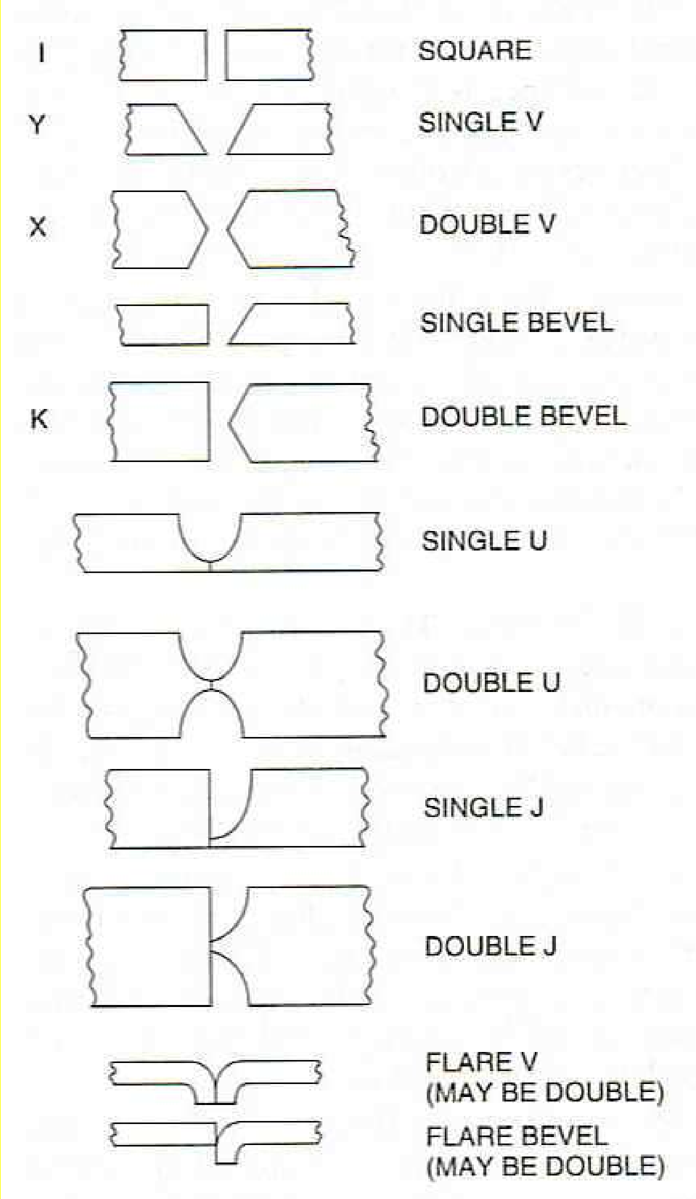
(2) GROOVE ANGLE: The total included angle of the groove between parts to be joined by a groove weld.

(3) GROOVE FACE: The surface of a member included in the groove.

(4) ROOT FACE: That portion of the groove face adjacent to the root of the joint.

(5) ROOT OPENING: The separation between the members to be joined at the root of the joint.

Groove weld



Types of groove welds

Weld approval

For quality control *→ Welding procedure sheet is approved and distributed to personnel concerned with its implementation.*

Details

- approval of welding process
- weld design
- Electrode used
- consumable used: filler, shielding gas, flux
- Inspection technique used

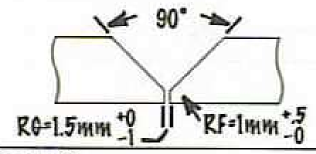
Typical Procedure Sheet for Manual Welding

Order No:	Drawing No:	Sheet No:	Joint Ref:
24021/AX/94	WS/24021/0824-04	WP1294	WP1294/1 to 3

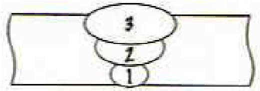
PROCESS: TIG

MATERIAL: Aluminium magnesium alloy 5083

JOINT PREPARATION:



WELDING SEQUENCE



CLEANING: Vapour degrease

GOUGING METHOD: N.A.

WELDING CONDITIONS

ELECTRODE	CONSUMABLES	Pass No.	Electrode Size (mm)	Filler diam. (mm)	A.C. or Polarity	Amps	Volts	Wire Feed speed m/min	Position
Specification: 1% Zirconiated	Filler Wire: BS2901: 5356	1	2.4	2.4	A.C.	90	-	-	F
		2	4.0	3.2	A.C.	210	-	-	F
Drying Method: N.A.	Shielding Gas: Argon	3	4.0	3.2	A.C.	210	-	-	F
	Flow Rate: 7 l/min								
	Flux: N.A.								

Preheat: None

Interpass Temperature: None

Post Heat: None

INSPECTION

Standard: Customer specification RT/56/1994

Inspecting Authority: Customer's representative

Method	
Visual	☑
Radiographic	☑
Ultrasonic	☐
Dye Penetrant	☑
Magnetic Particle	☐

Notes: Root run (pass 1) to be inspected by dye penetrant before depositing passes 2 and 3

Originator:	Checked:	Approved:	Date of Issue:	Returned to file:
GWT	P.J.	JF Smith	24/9/94	

Weldability

Definition

The capability of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

- Weldability depends on various factors such as, nature of metals, weld designs, welding techniques, skills, etc.
- It has been stated that ***all metals are weldable*** but some are more difficult than another.
- ***Steel*** is readily weldable (in many ways) than ***aluminium and copper.***
- ***Copper*** is not easily welded due to its high thermal conductivity which makes it difficult to raise the parent metal to its melting point. → require preheating ~300-400^{o}C.
- Some ***aluminium based die casting alloys*** give weld pool too large to control, and aluminium welds normally have oxide inclusions and porosity.

Weldability

Steels

- ***Weldability*** of steels is inversely proportional to its ***hardenability,*** due to ***martensite formation*** during heat treatment

Carbon content ↑ **Hardenability** ↑ **Weldability** ↓

- There is ***a trade-off*** between materials strength and weldability.

- ***Austenitic stainless steels*** tend to be the most weldable but suffer from distortion due to high thermal expansion. → Cracking and reduced corrosion resistance.

- ***Ferritic and martensitic stainless steels*** are not easily welded, often to be preheated and use special electrodes.

- ***Ferritic steels*** is susceptible to hot cracking if the ferrite amount is not controlled.

Weldability

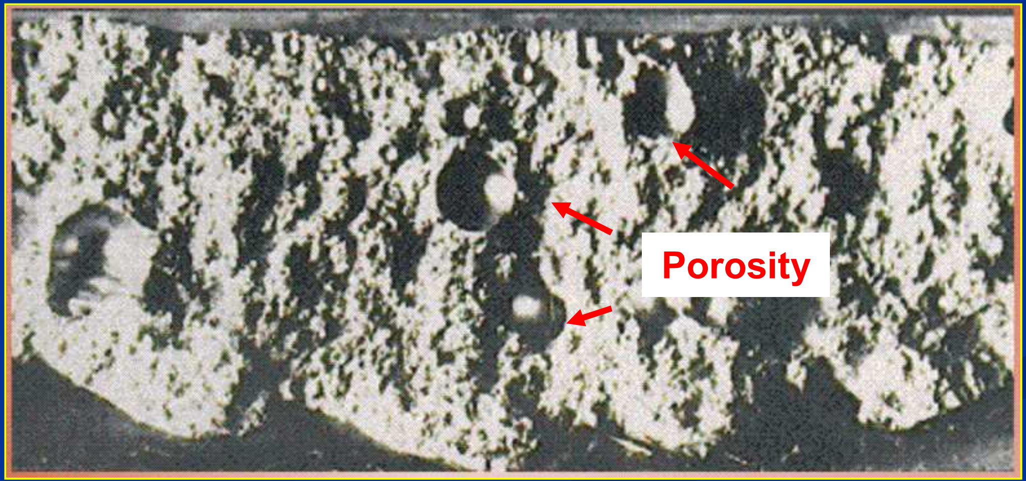
Aluminium and its alloys

• ***Weldability*** of aluminium depends on chemical composition of the alloy.

• ***Aluminium alloys*** are susceptible to hot cracking, oxide inclusions, dross, porosity (hydrogen).

• Most of wrought series, ***1xxx, 3xxx, 5xxx, 6xxx, and medium strength 7xxx*** can be fusion welded by TIG, MIG while ***2xxx and high strength 7xxx*** are not readily welded due to liquation and solidification cracking.

Cracks in aluminium welds



Porosity observed in aluminium welded specimen after fractured.

Weldability

Copper and copper alloys

- ***Weldability*** of copper depends on chemical composition of the alloy.

Copper

- High thermal conductivity → required preheating to counteract heat sink effect.
- Can be TIG or MIG welded.

Brasses

- Volatilization (toxic) of zinc is the main problem, reducing weldability.
- Low zinc content brass can be TIG or MIG welded.

Bronzes

- Most are weldable, except gun metal or phosphor bronzes.
- Require careful cleaning and deoxidization to avoid porosity.

- ***Silicon*** improves weldability due to its deoxidizing and fluxing actions.
- ***Oxygen*** causes porosity and reduce strength of welds.
- ***Tin*** increases hot-cracked susceptibility during welding.
- ***Precipitation hardened alloys*** should be welded in the annealed condition, and then precipitation hardening treatment.

Weldability

Titanium alloys

• ***Weldability*** of titanium depends on chemical composition of the alloy.

• Titanium alloys with low amounts of alloying elements are more readily welded. For example: CP titanium alloys, α, $\alpha+\beta$ titanium alloys.

• Highly stabilised beta titanium alloys are difficult to weld due to ***segregation***.

• Welding at above 500-550°C requires ***special precaution***.

• Fluxes are not normally used since they combine with titanium to cause brittleness.

• ***Welding processes***: TIG, MIG, PAW, LBW, EBW, FW, RW.

• ***Shielding gases***: ***Ar, He*** or the mixture of the two (avoid contact with oxygen).

• ***Filler metal*** grades should match the alloys being welded, normally with lower yield strength to retain ductility. (used unalloyed with lower β content to avoid martensite transformation and with minimised ***O, N, H*** contents).

• ***Thoriated tungsten electrodes*** (EWTh-1 or EWTh-2) are used for TIG welding.

Weldability

Magnesium alloys

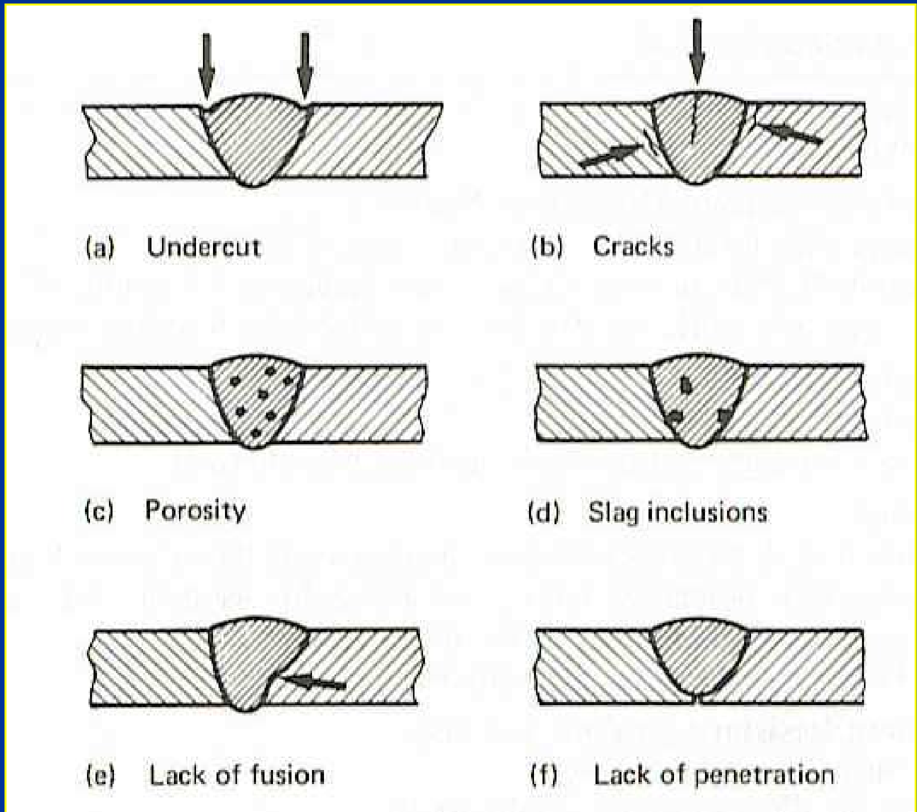
- ***Weldability*** of titanium depends on chemical composition of the alloy.

- ***Welding processes:*** Arc welding, RW as well as oxyacetylene welding, brazing. TIG and MIG are recommended.
- ***Strength of the weld joint*** is lowered in the base metal, in the work hardened condition, due to recrystallisation and grain growth in the HAZ.
- Similar to welding of aluminium, magnesium has low melting point, high thermal conductivity, thermal expansion, oxide surface coating.
- In ***Mg-Al-Zn*** alloys (AZxx), ***Al*** >10% improves weldability by refining grain structure, while ***Zn*** > 1% increases ***hot shortness***.
- Filler metals are selected by the composition of the base metals.

Defects in weldments

• It is ***unusual*** for the weldments to be ***completely sound***.

• They normally contain small defects such as porosity, slag, oxide inclusions, lack of fusion, undercut, crack, distortion, etc.



Cross sections of welds containing typical defects

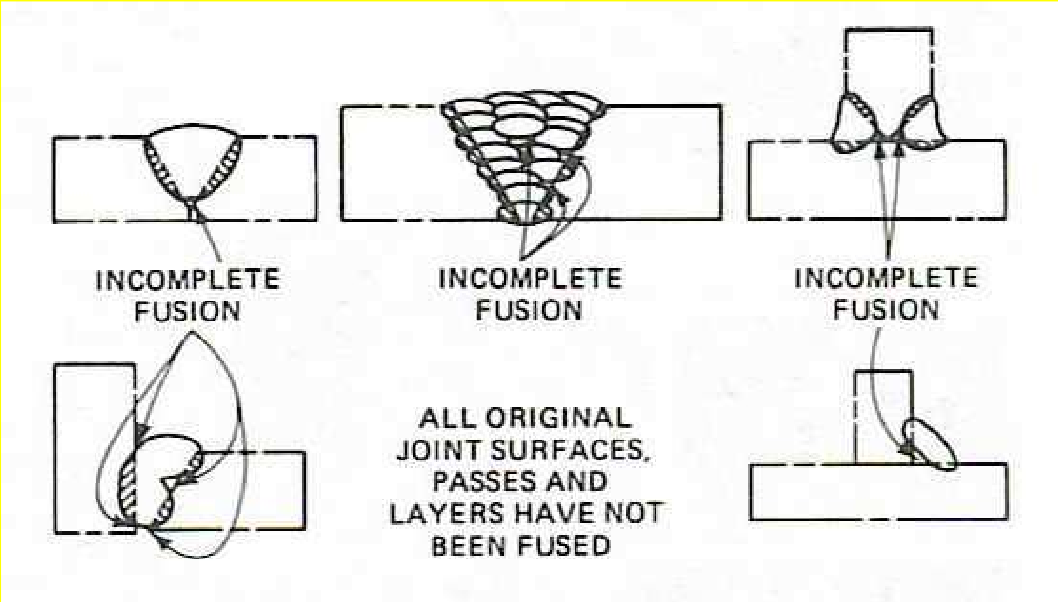
Understand the cause

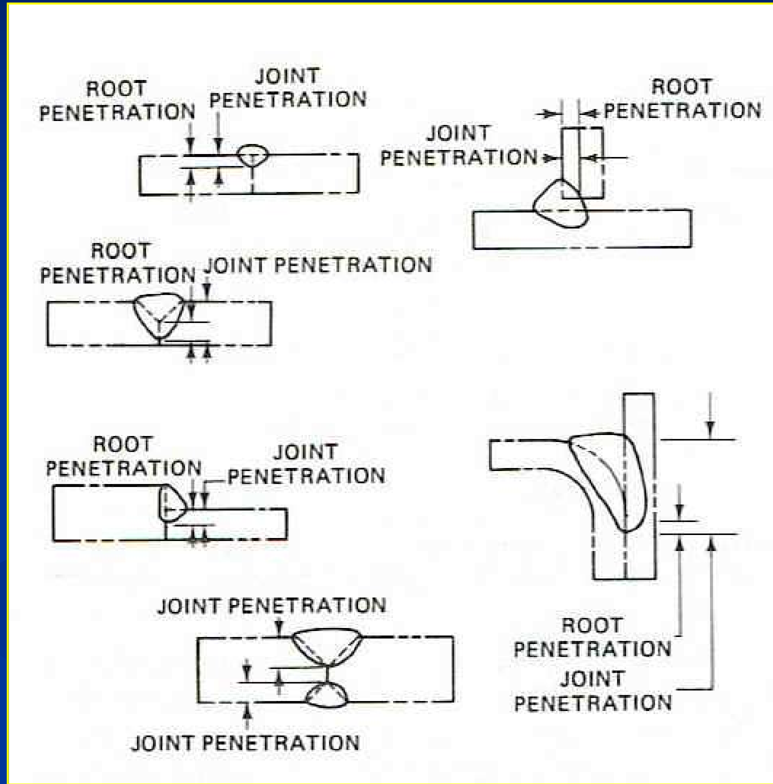
Solve/prevent the problem

• Furthermore, different metals have different weldability → so we need to understand the ***nature of the metal to be welded***.

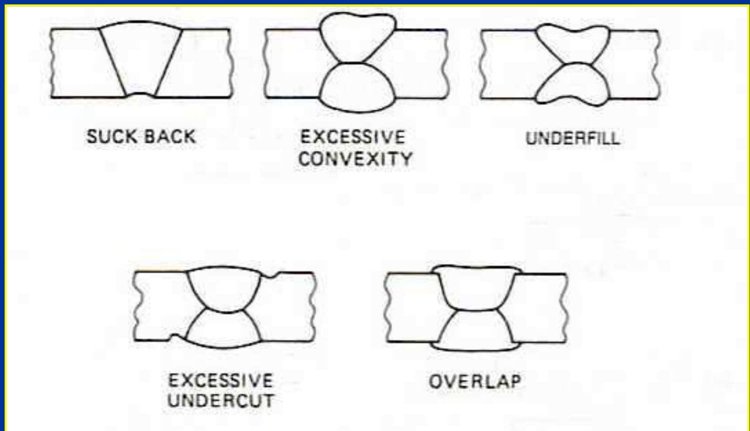
Defects in weldments

Incomplete fusion





Root and joint penetrations



Groove welds and various defects

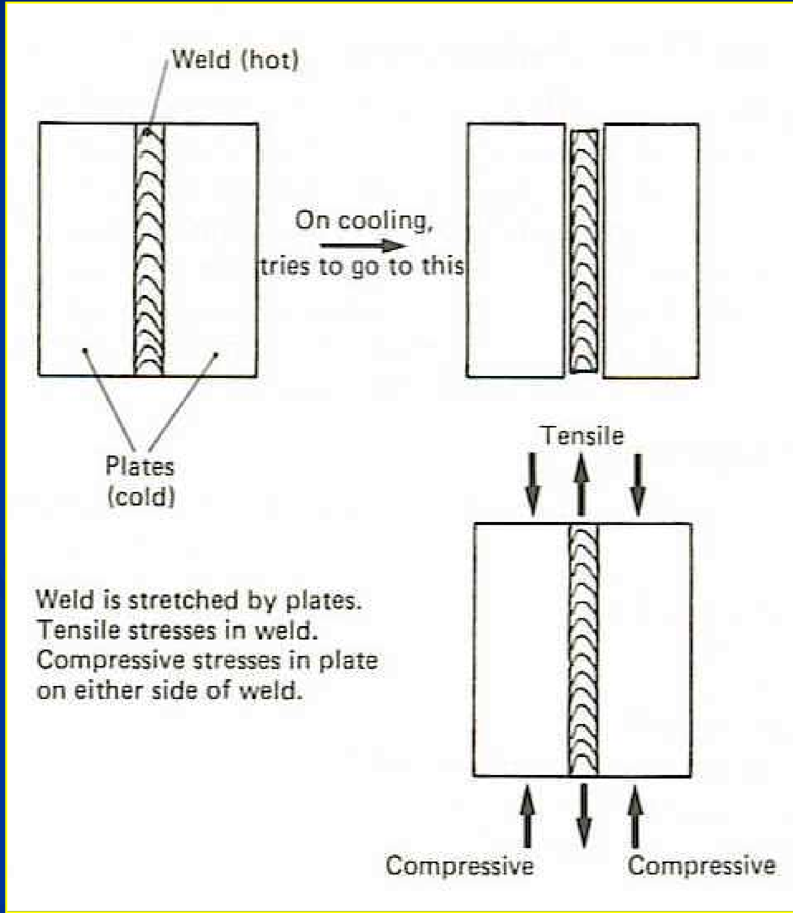
Residual stresses in weldment

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 in this case).*

- Weld metal and adjacent base metal are restrained by the areas further away from the weld metal due to ***expansion and contraction***.

Weld metal and adjacent base metal → **Residual tensile stresses**

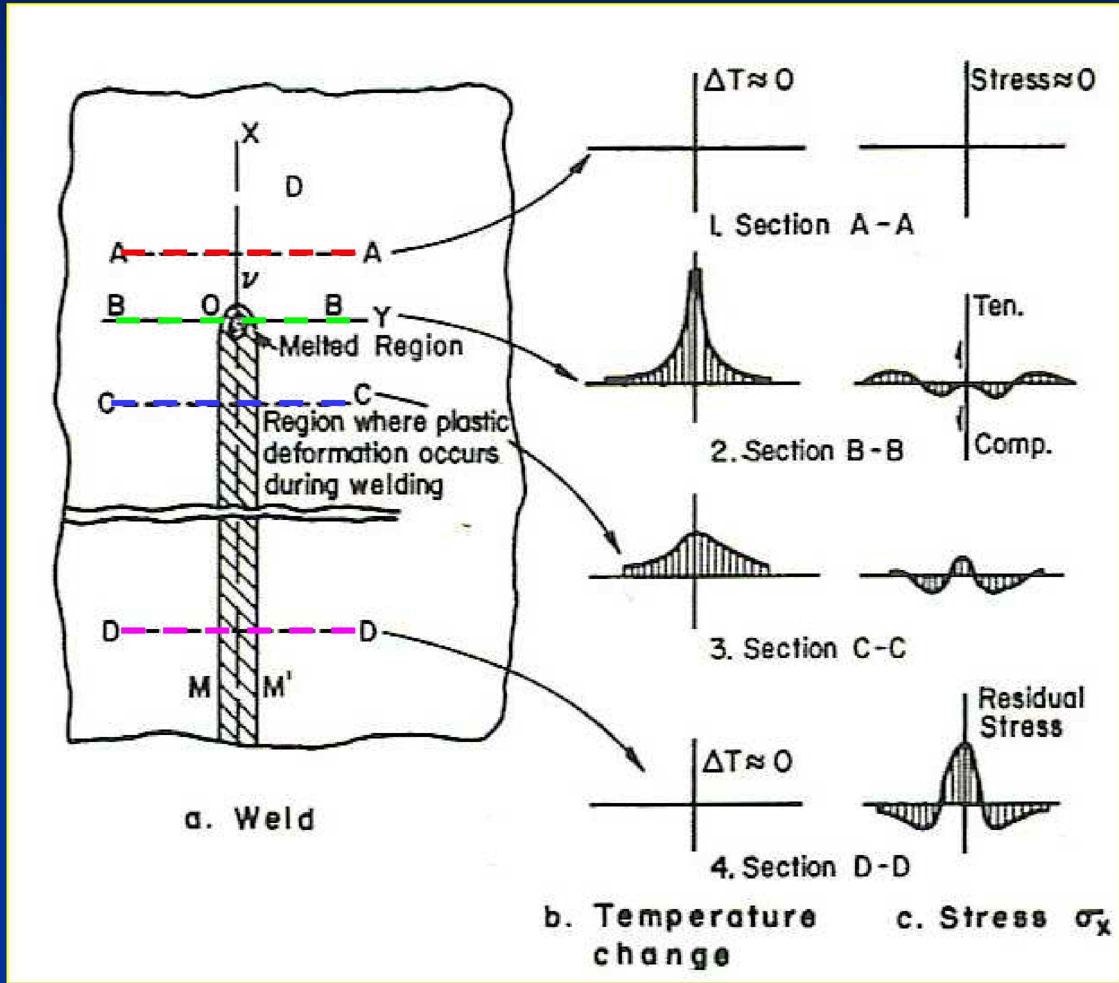
Areas further away from weld metal → **Residual compressive stresses**



Thermally induced residual stresses in weld.

Changes in temperature and stresses during welding

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



Changes in temperature and stresses during welding

Typical residual stress distribution in weldment (longitudinal)

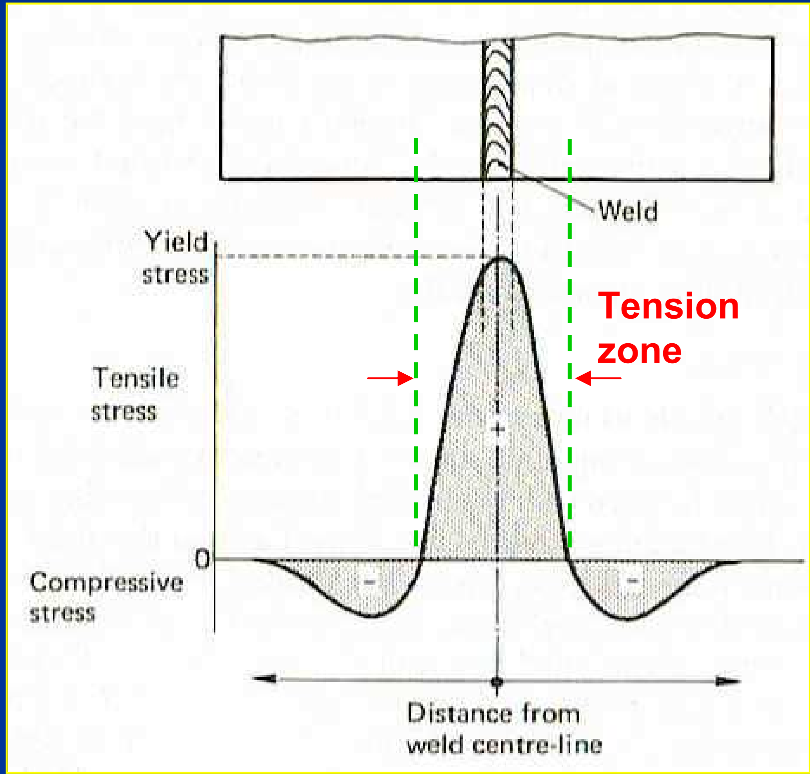
• ***Residual stress distribution*** across the weld shows ***tensile*** in the weld metal and the adjacent base metal and then goes ***compressive*** in the area further away from the weld metal.

• ***Residual tensile stresses*** are not desirable, which can cause problems such as ***hydrogen induced cracking*** and ***stress corrosion cracking.***

Remedies

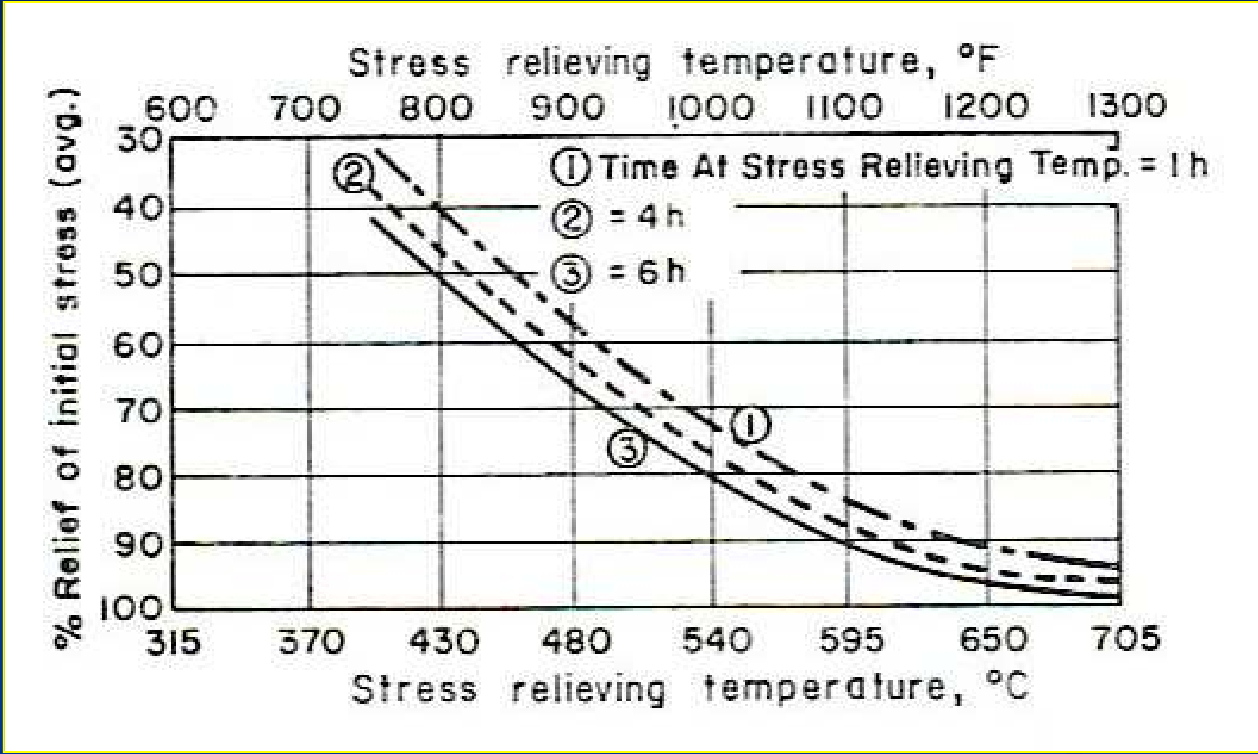
• ***Post weld heat treatment*** is often used to reduce residual stresses.

• Other techniques : preheating, peening, vibration have also been used for stress relief.



Typical residual stress (longitudinal) distribution in weldment

Effect of temperature and time on stress relief of steel welds



Stress relief temperature ↑

% Relief of initial stress ↑

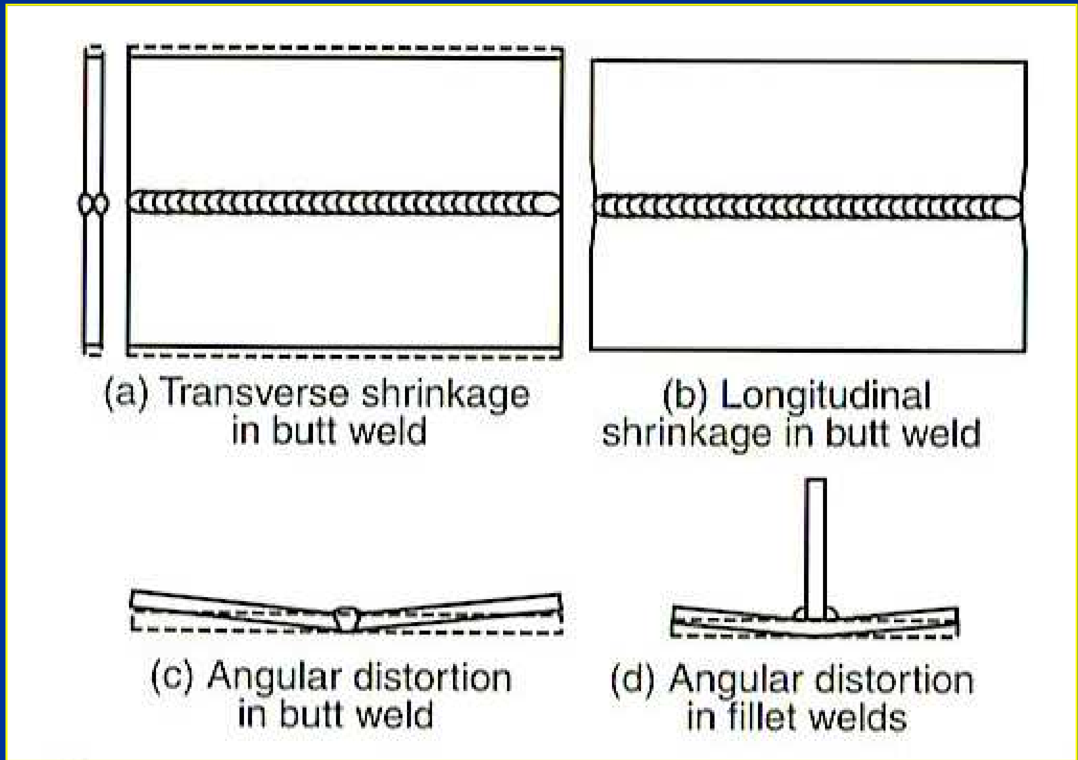
Typical thermal treatments for stress relieving weldments

Material	Soaking Temperature (°C)
Carbon steel	595–680
Carbon–½% Mo steel	595–720
½% Cr–½% Mo steel	595–720
1% Cr–½% Mo steel	620–730
1¼% Cr–½% Mo steel	705–760
2% Cr–½% Mo steel	705–760
2¼% Cr–1% Mo steel	705–770
5% Cr–½% Mo (Type 502) steel	705–770
7% Cr–½% Mo steel	705–760
9% Cr–1% Mo steel	705–760
12% Cr (Type 410) steel	760–815
16% Cr (Type 430) steel	760–815
1¼% Mn–½% Mo steel	605–680
Low-alloy Cr–Ni–Mo steels	595–680
2–5% Ni steels	595–650
9% Ni steels	550–585
Quenched and tempered steels	540–550

Source: Welding Handbook (2).

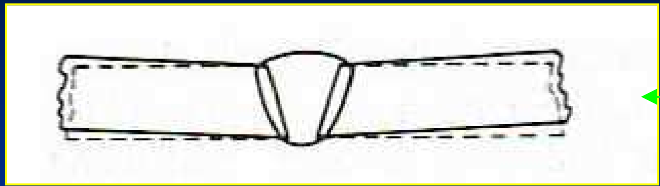
Distortion

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



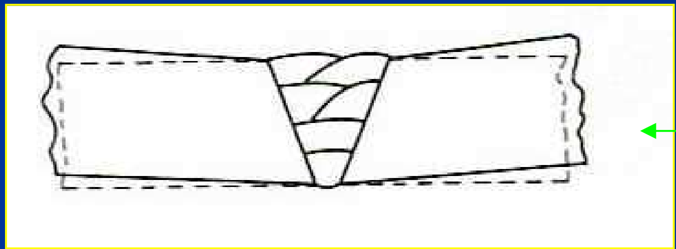
Distortion in welded structure

Angular distortion



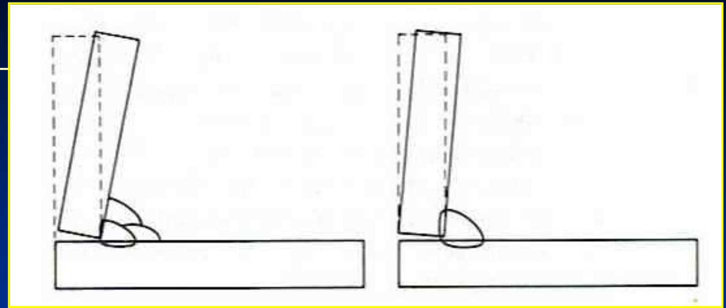
Thin plates

Single-pass-single-V groove butt joint

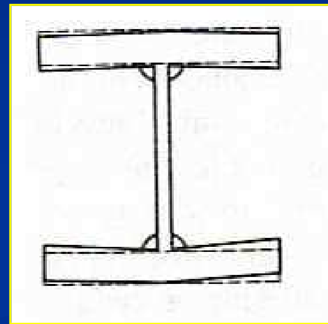


Thick plates

Multiple-pass-single-V groove butt joint



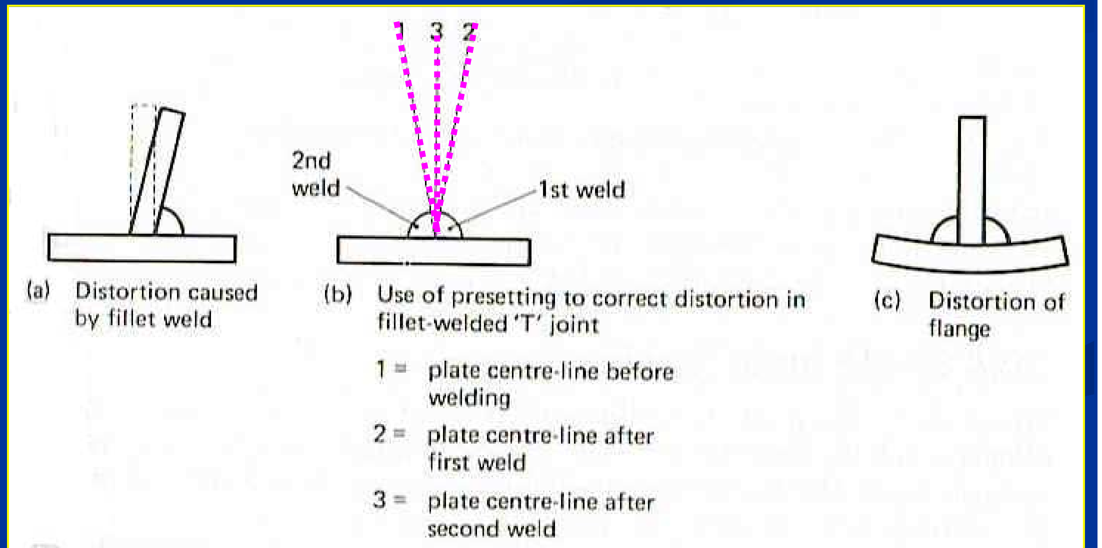
Inside fillet corner joint



Fabricated beam

- ***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***.

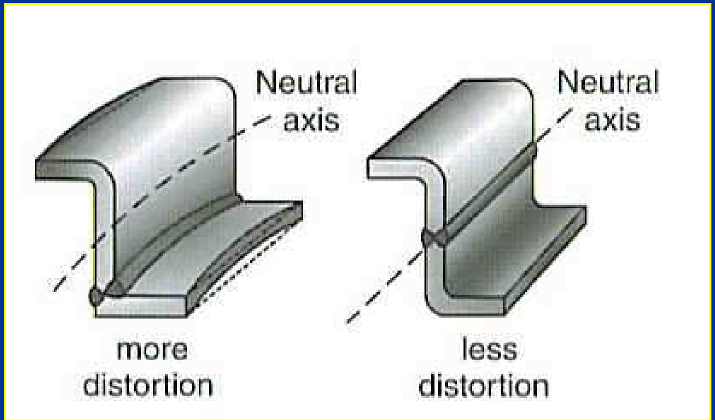


Distortion in fillet welding of T joint

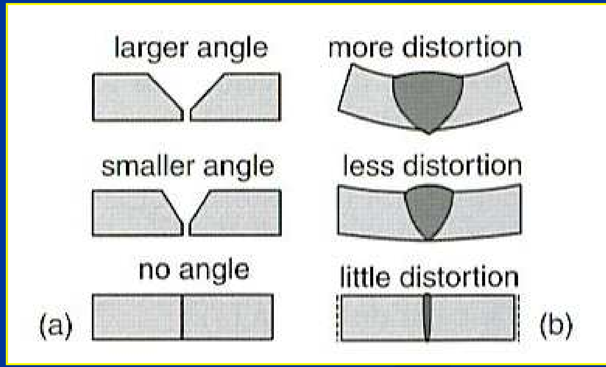
Remedies for angular distortion

There are several techniques used to reduce angular distortion.

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



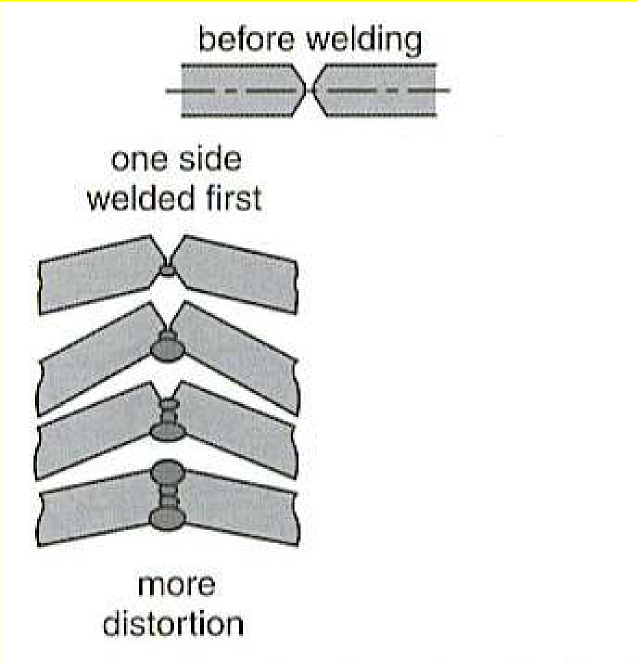
Placing weld around neutral axis



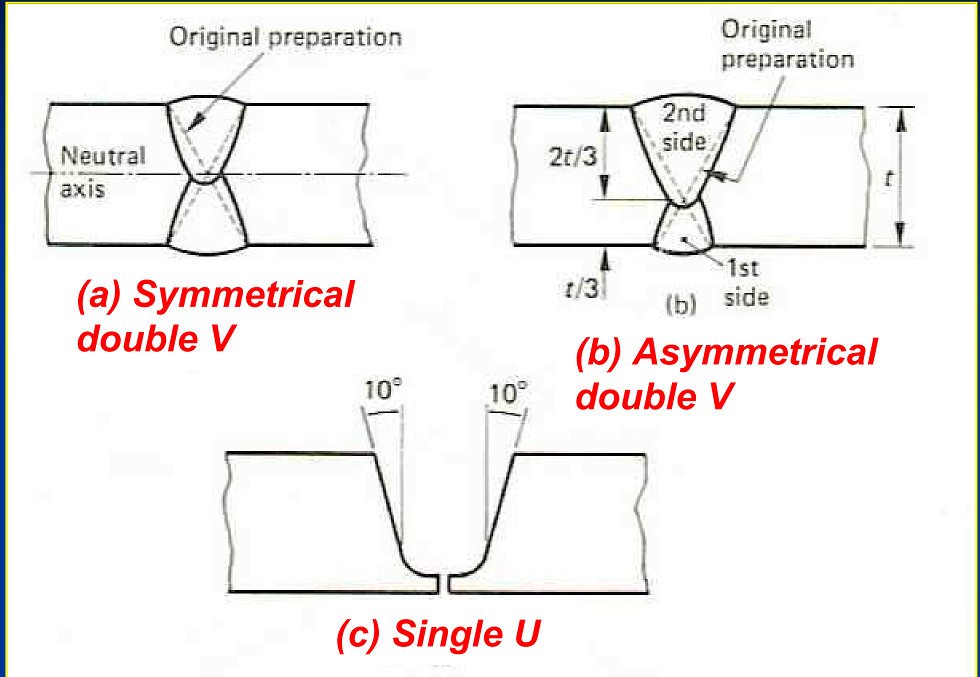
Reducing volume of weld metal and by using single-pass deep penetration welding.

Remedies for angular distortion

• Balancing the angular weld distortion on either side of the ***double V joint***.



Using double-V joint and weld alternately on either side of joint.



(a) Symmetrical double V

(b) Asymmetrical double V

(c) Single U

• ***Double V-joints*** balance the shrinkage → almost same amount of contraction on each side (a).

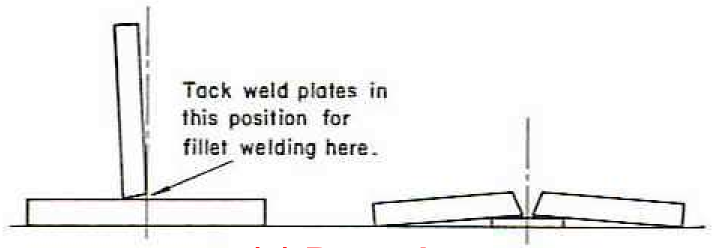
• ***Asymmetrical double V*** : The first weld always produces more angular distortion → the second side is larger too pull back the distortion when the first weld is made (b).

• A ***single U joint*** gives a uniform weld with through the section (c).

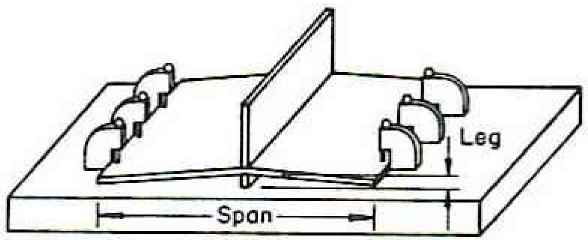
Remedies for angular distortion

Methods for controlling weld distortion:

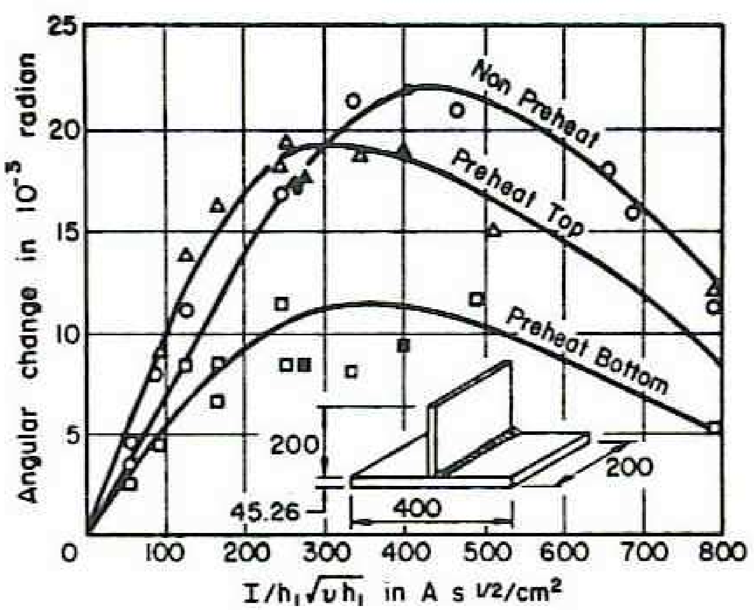
- **Presetting:** by compensating the amount of distortion to occur in welding.
- **Elastic prespringing** can reduce angular changes after restraint is removed.
- **Preheating and post weld treatment**



(a) Preseting



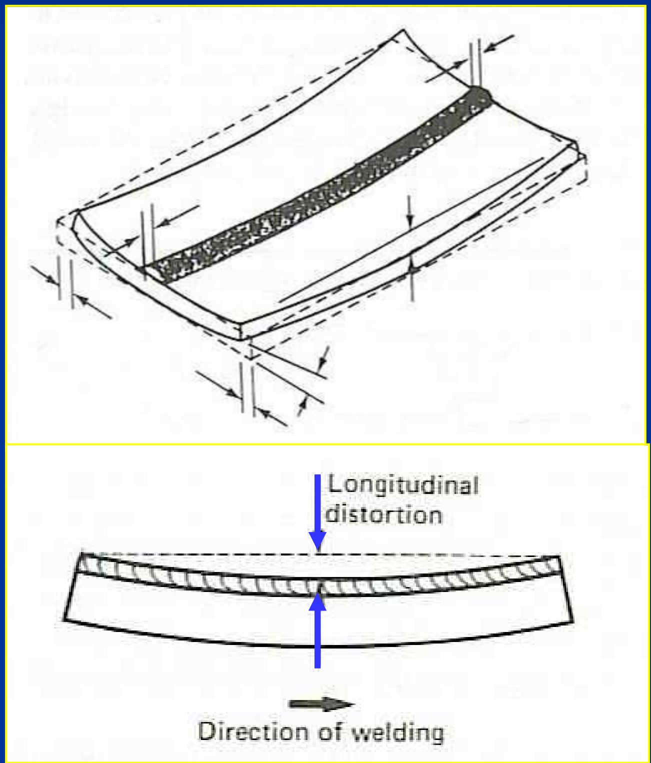
(b) Springing



(c) Perheating

Longitudinal distortion

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



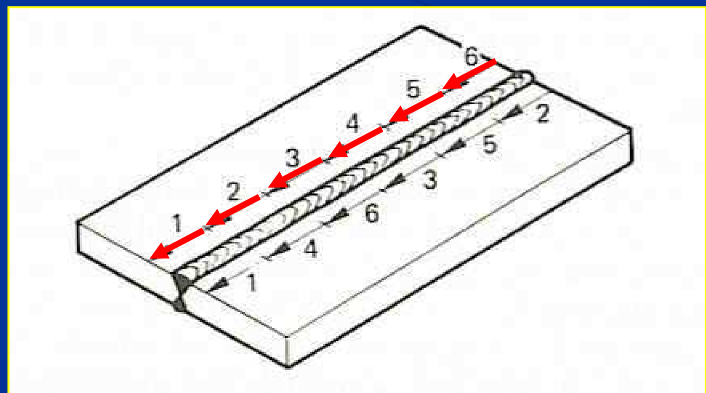
Longitudinal bowing of distortion in a butt joint

Remedies

• ***Welding short lengths*** on a planned or random distribution are used to controlled this problem.

• ***Mechanical methods*** : straightening press, jacks, clamps

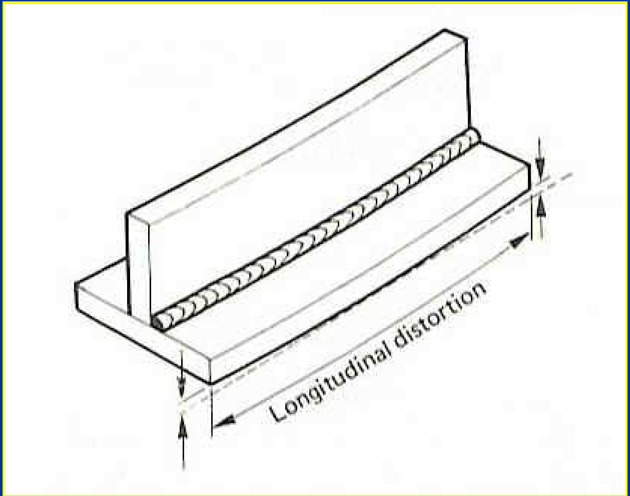
• ***Thermal methods*** : local heating to relieve stresses (using torches) → but cannot be used for highly conductive metal such as ***Al*** and ***Cu***.



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

Longitudinal distortion

• ***Angular distortion and longitudinal bowing*** can also be observed in joints made with ***fillet welds*** such as fillet-welded T joint.

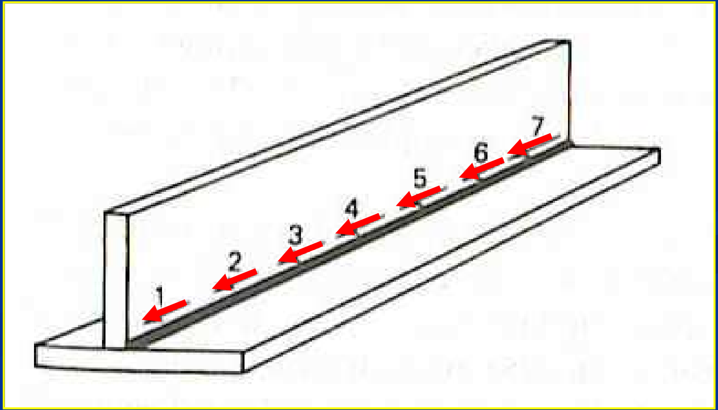


Longitudinal bowing in a fillet-welded T joint

Remedies

• ***Back-step technique*** is also used. Each small increment will have its own shrinkage pattern which then becomes insignificant to the whole pattern of weldment. (But time consuming)

• Using the ***smallest*** possible weld size.



Back step technique

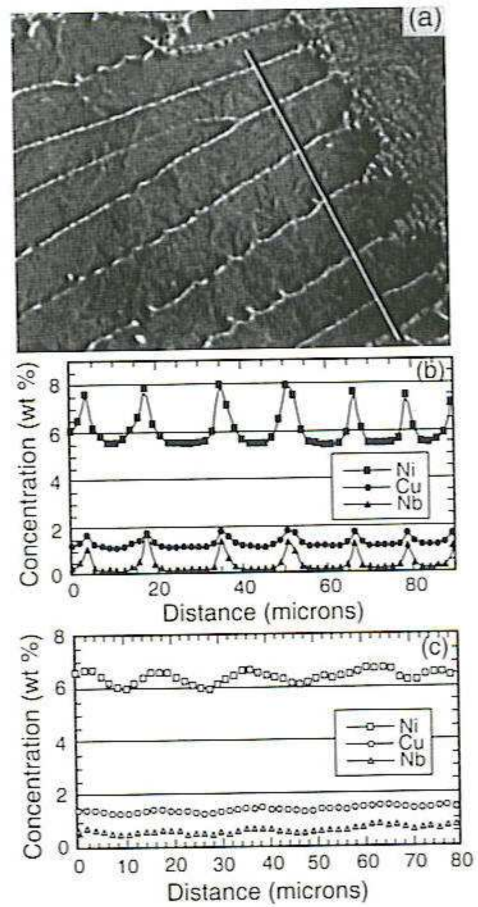
Weld metal chemical inhomogeneities

- *Micro segregation*
- *Macro segregation*
- *Banding*
- *Inclusions and gas porosity.*

Micro segregation

• Lack of solid state diffusion might cause micro segregation in weldments.

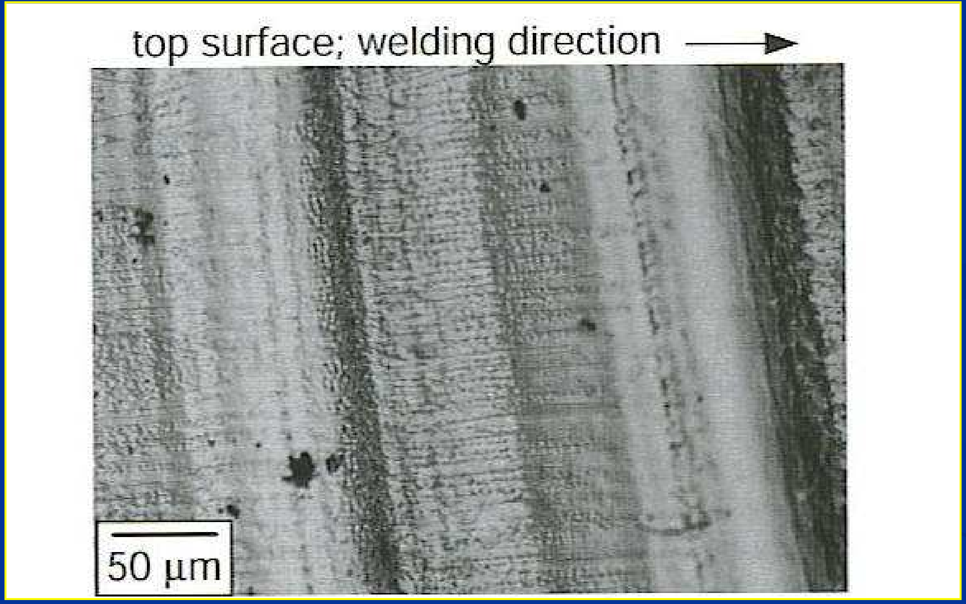
EX: *Solid state diffusion in a more closely packed FCC structure (austenite) is more difficult than a more open BCC structure (ferrite).*



Microsegregation across columnar dendrite near quenched weld pool in a martensitic stainless steel.

Banding

• Banding occurs due to fluctuations in welding speed and power input.

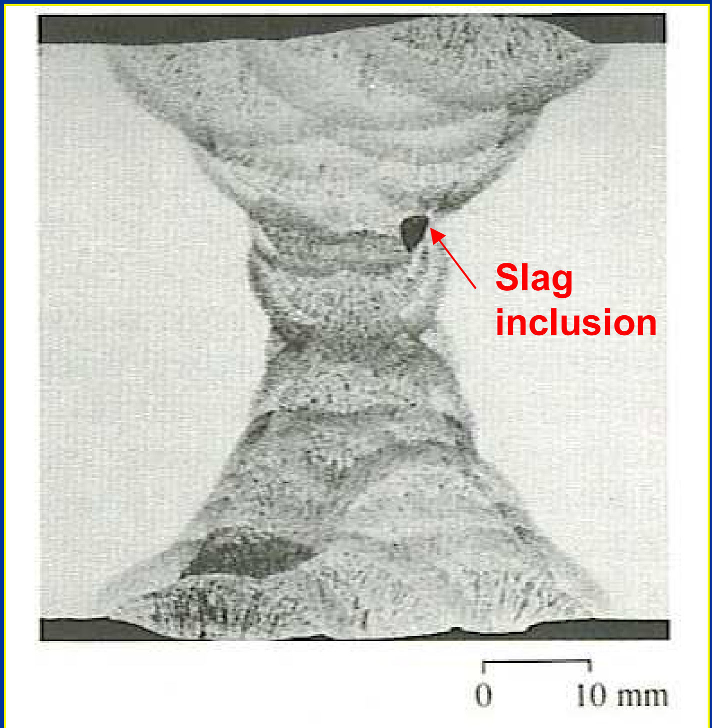


Banding and rippling near centreline of as-welded top surface of a 304 stainless steel YAG laser welded.

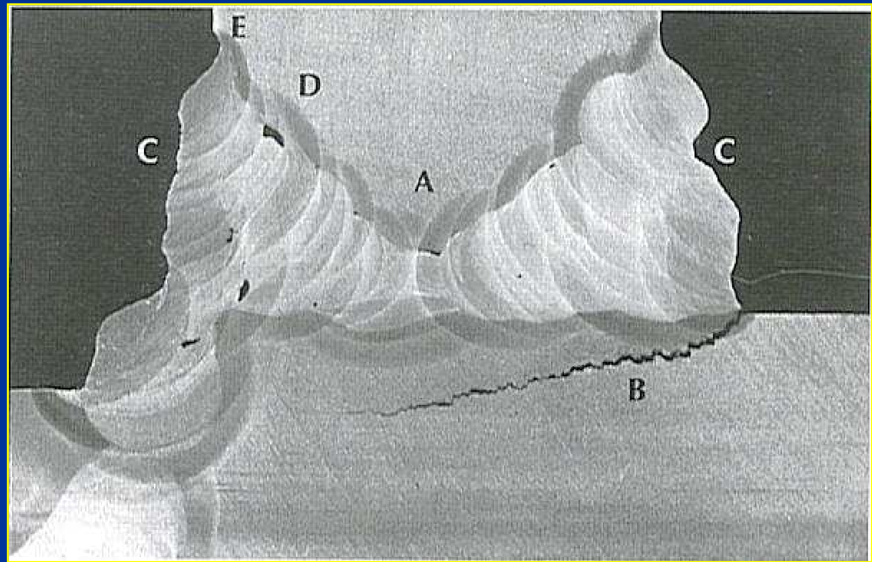
Inclusions and gas porosity

• ***Gas-metal and slag-metal reactions*** produce slag inclusion and gas porosity.

• ***Incomplete slag removal*** in multipass welding can cause slag inclusions trapped within the weld.



Radiograph of a weld showing a large slag inclusion.



Gas porosity and inclusions in multipass welding.

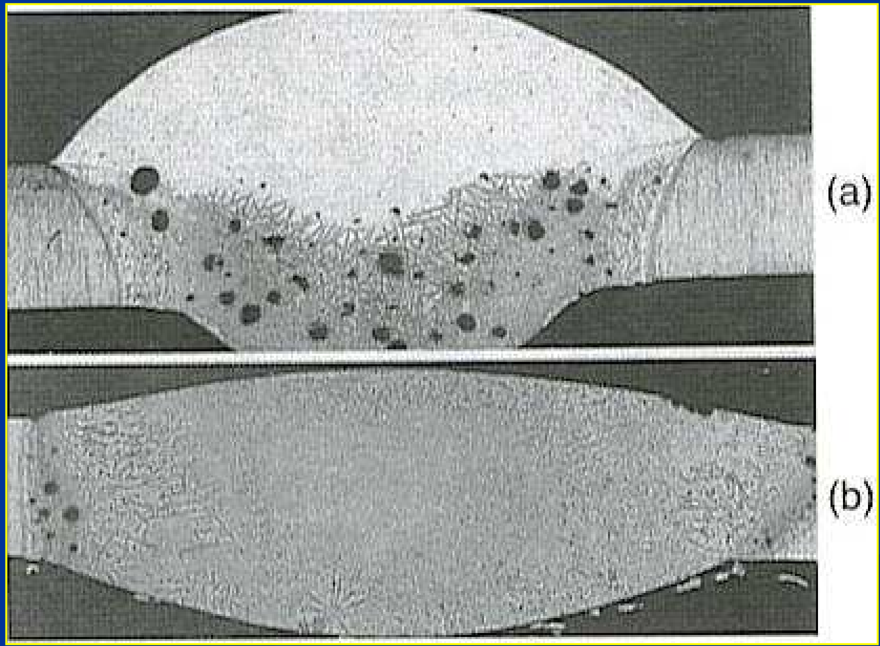
Macro segregation

• ***Weld pool macro segregation*** occur by ***lack of weld pool mixing*** (by convection) especially in welding of dissimilar metals, or some special types of rapidly solidified power metallurgy alloys.

• if the weld pool mixing is incomplete in single pass welding (greater extent) and even in multipass welding.

__Ex:__ macro segregation in some powder metallurgy alloys

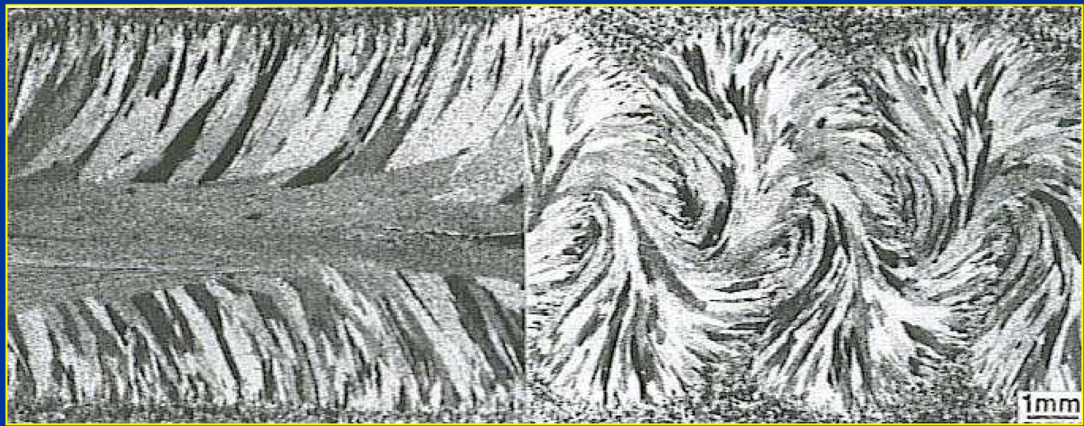
• Switching from AC to DCEN making the weld pool mixed better.



Powder metallurgy Al-10Fe-5Ce GTA welded with Al-5Si filler metal (a) AC, (b) DCEN

Remedies for macro segregation

- Applying ***magnetic weld pool stirring*** to give a better mixing in the weld pool.
- For ***GTAW***, using ***DCEN*** for a deeper weld penetration and mixing.
- Using proper filler metals.
- Give ***enough time*** for the weld pool to be melt. ***Ex:*** EBW with a high welding speed might not give enough time for weld pool mixing in welding of dissimilar metals.



Effect of weld pool stirring

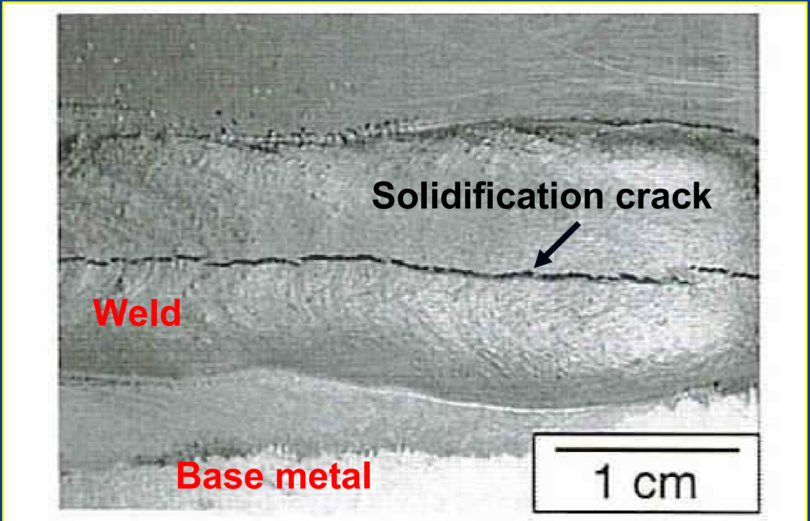
Weld cracking

There are various types of weld cracking

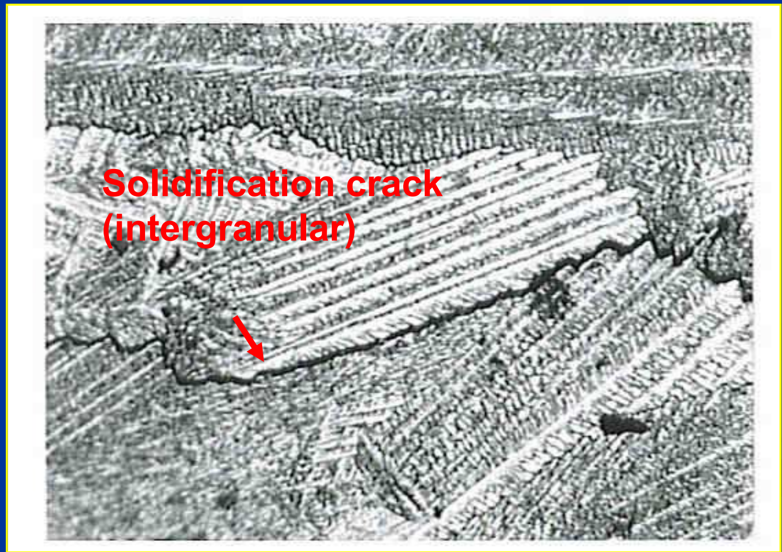
- ***Solidification cracking (hot cracking)***
- ***Hydrogen cracking (cold cracking)***
- ***Liquation cracking***
- ***Lamellar Tearing***

Solidification cracking

- Similar to casting, ***solidification cracking*** can also occur in welding.
- It happens at the terminal stage of solidification due to ***contraction of solidifying metal and thermal contraction***. (Intergranular crack)
- Solidification cracking is intensified if the base metal is attached on to non moving parts (building up tensile stresses).
- The less ductile the weld metal is, the more likely solidification cracking to occur.



Solidification cracking in a GMAW of 6061 aluminium

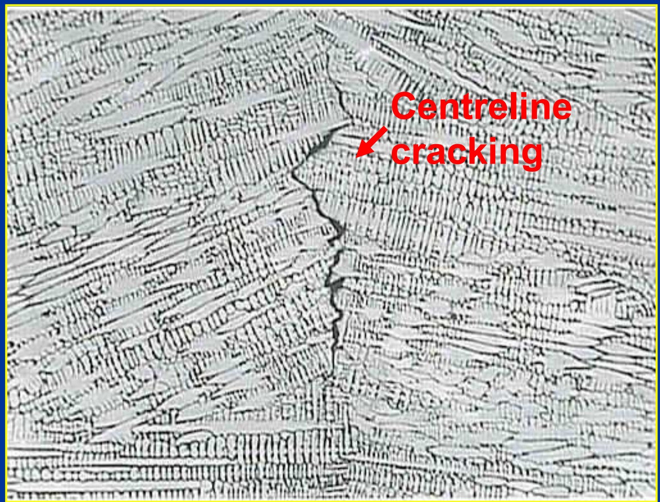


Solidification cracking in an autogenous weld of 7075 aluminium at high magnification.

Factors affecting solidification cracking

Grain structure

• ***Coarse columnar grains*** are more susceptible to solidification cracking than equiaxed grains.



Centreline cracking in a coarse-grained stainless steel weld

Contraction stresses

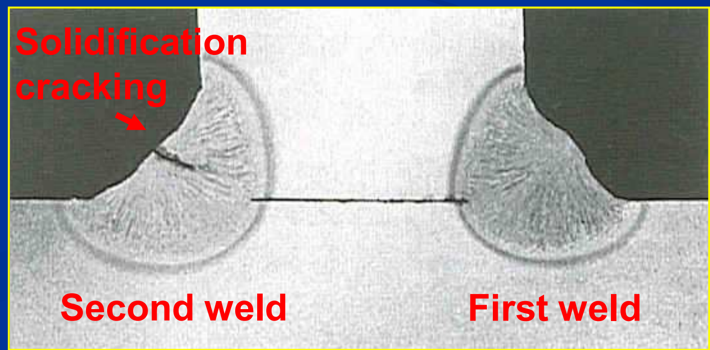
• Contraction stresses can be due to thermal contraction, solidification shrinkage.

Ex: Austenitic stainless steels (high thermal expansion) → susceptible to solidification cracking.

Restraining

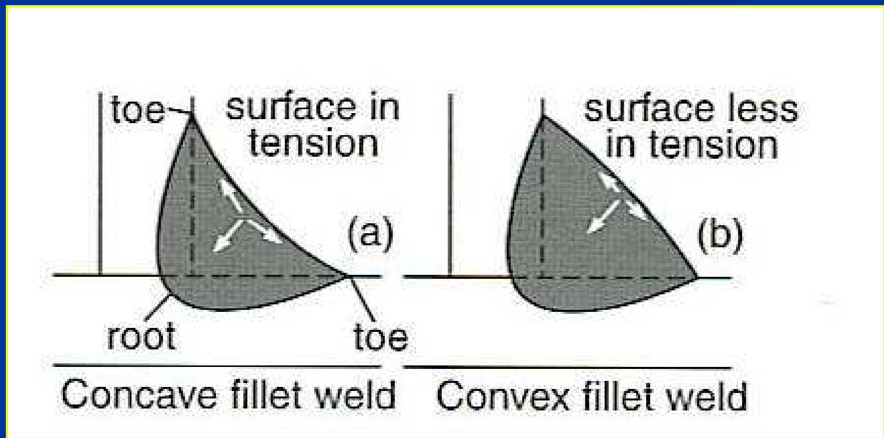
• The weldment is restrained after the first weld, causing solidification cracking in the second weld in T joints.

Solidification cracking in steel weld



Remedies for solidification cracking

- Controlling ***composition*** of the metal to be welded.
- Using ***filler metal*** with proper composition.
- Controlling ***Mn*** and ***S*** content in carbon and low alloy steels.
- Controlling ***solidification structure***: grain refining, arc oscillation, arc pulsation, etc.
- Controlling ***weld geometry***: concave fillet weld suffers higher tensile stress on the face than the convex fillet weld, deep weld is more susceptible to solidification cracking.



Hydrogen cracking (Cold cracking)

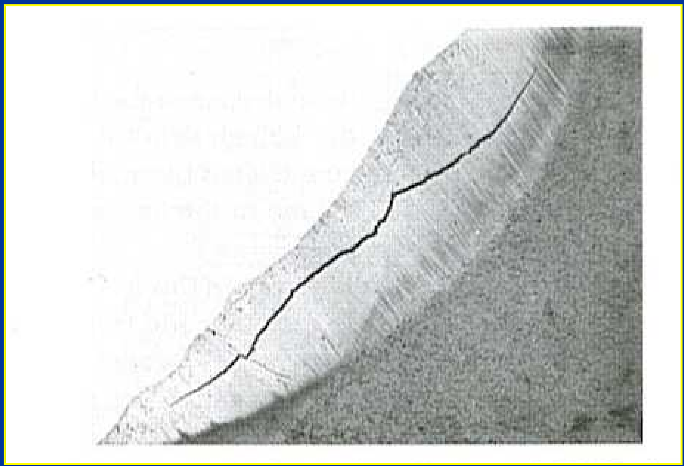
Hydrogen cracking occurs when

• ***Hydrogen*** in the weld metal → sources: moisture from metal surface, tools, atmosphere, flux,

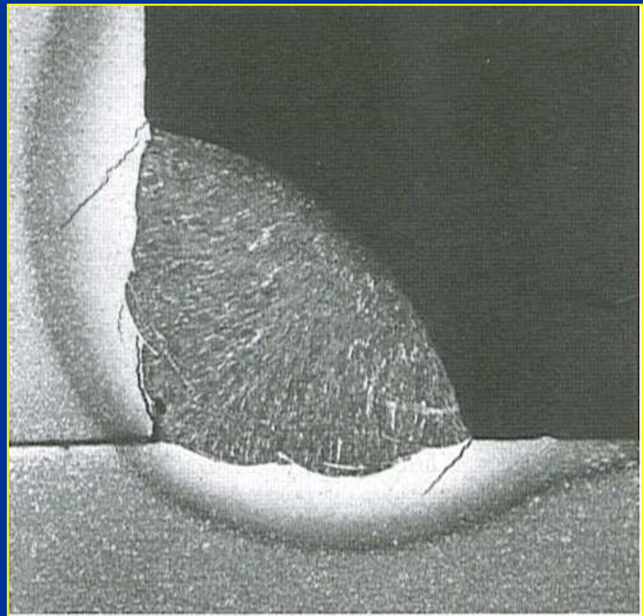
• ***High stresses***

• Susceptible microstructure : ***martensite*** (HAZ of carbon steels due to lower diffusion coefficient of hydrogen in austenite than in ferrite), combination of hydrogen + martensite promotes hydrogen cracking.

• Relatively ***low temperature***. (-100-200^{o}C) → cold cracking or delayed cracking.



Underbeaded crack in a low-alloy steel HAZ.

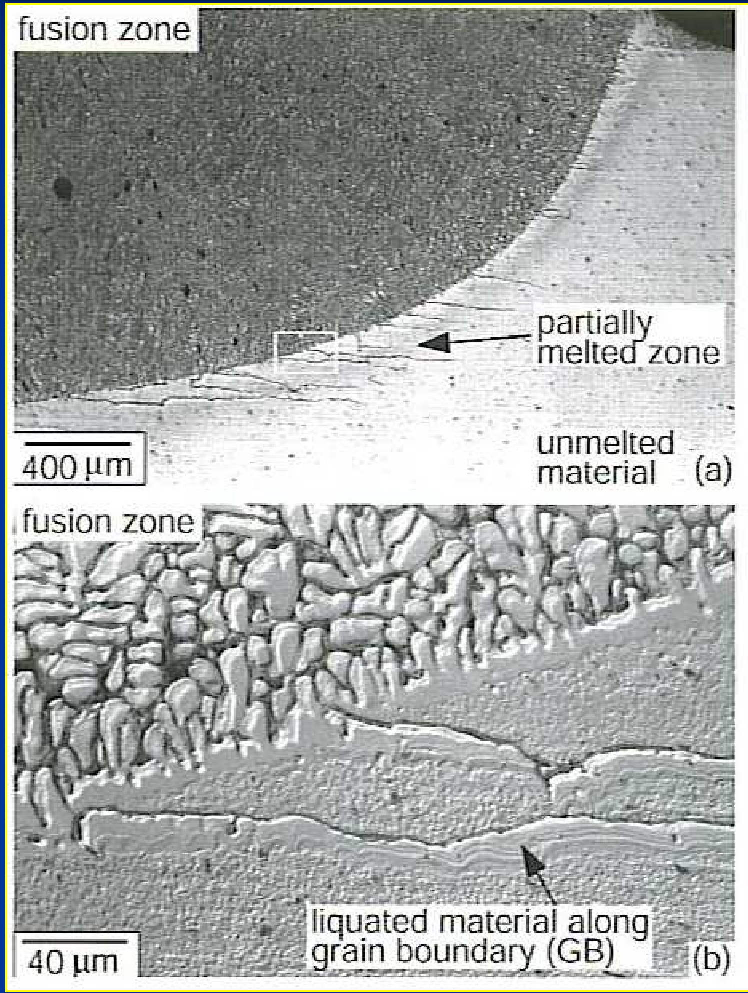


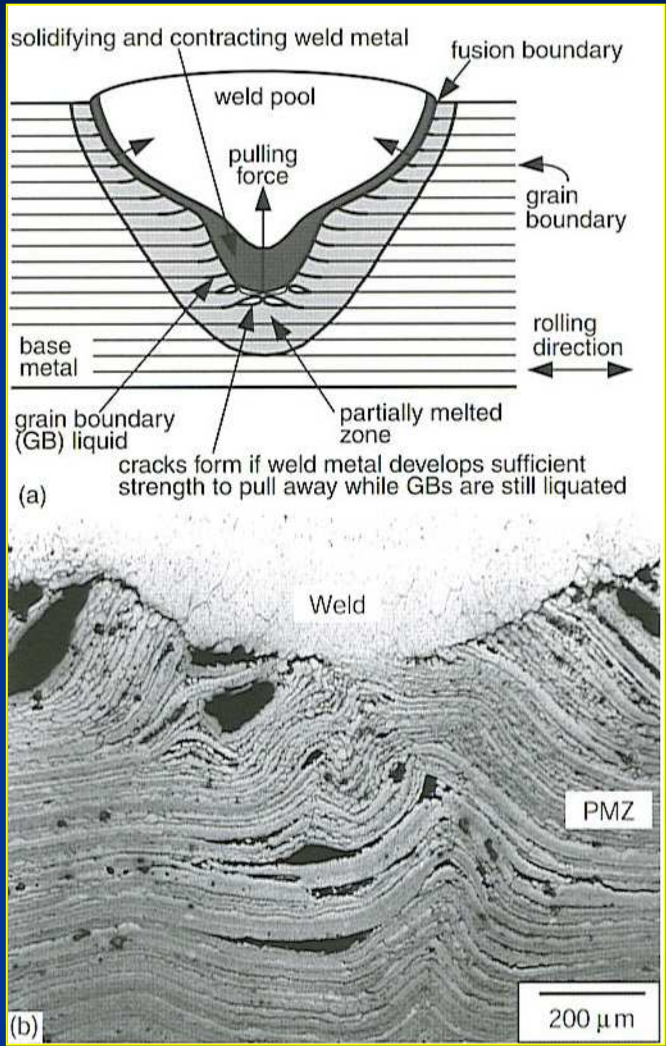
Hydrogen cracking in a fillet weld of 1040 steel.

Remedies for hydrogen cracking

- Controlling welding parameters: proper preheat and interpass temperature
- Postweld treatment: stress relief.
- Use proper welding processes and Materials (consumables), low strength filler metals.

Liquation cracking





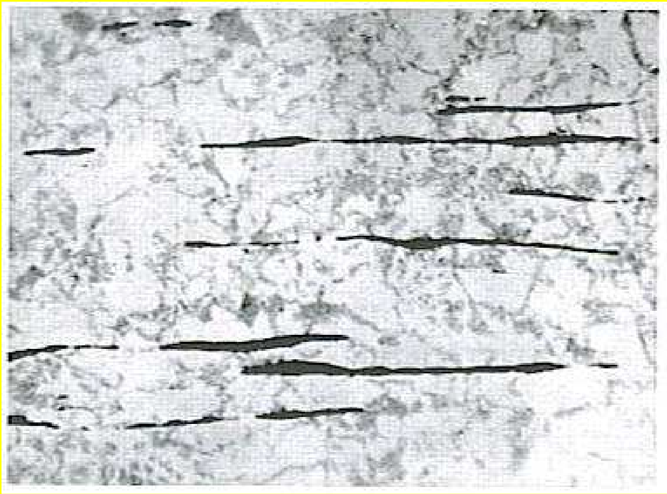
Segregation in PMZ → liquation cracking

Remedies for liquation cracking

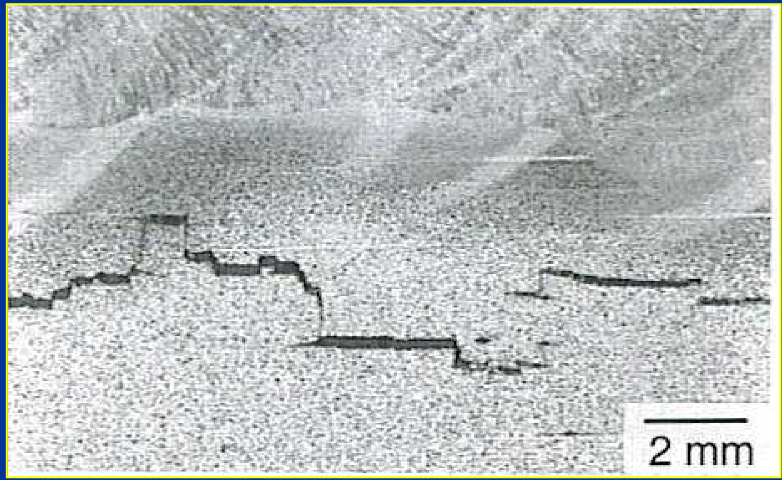
- Use proper filler metal.
- Reducing the heat input to lower the size of PMZ.
- Reducing the degree of restraint, lowering the level of tensile stresses.
- Controlling impurities, suppressing micro segregation at grain boundaries.
- Smaller grain size is better (less concentration of impurities on grain boundaries. Also control grain orientation.

Lamellar Tearing

• ***Lamellar tearing*** occurs when tensile stresses are acting on fibred structure (stringers of nonmetallic materials), causing decohesion of nonmetallic inclusions.



Lamellar tearing in steel



Lamellar tearing near a C-Mn steel weld

Remedies

• Avoid tensile stresses acting on transverse direction of the sample.

Weld defects

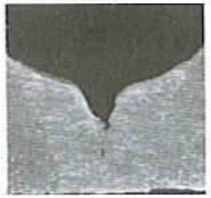
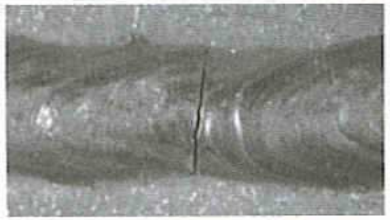
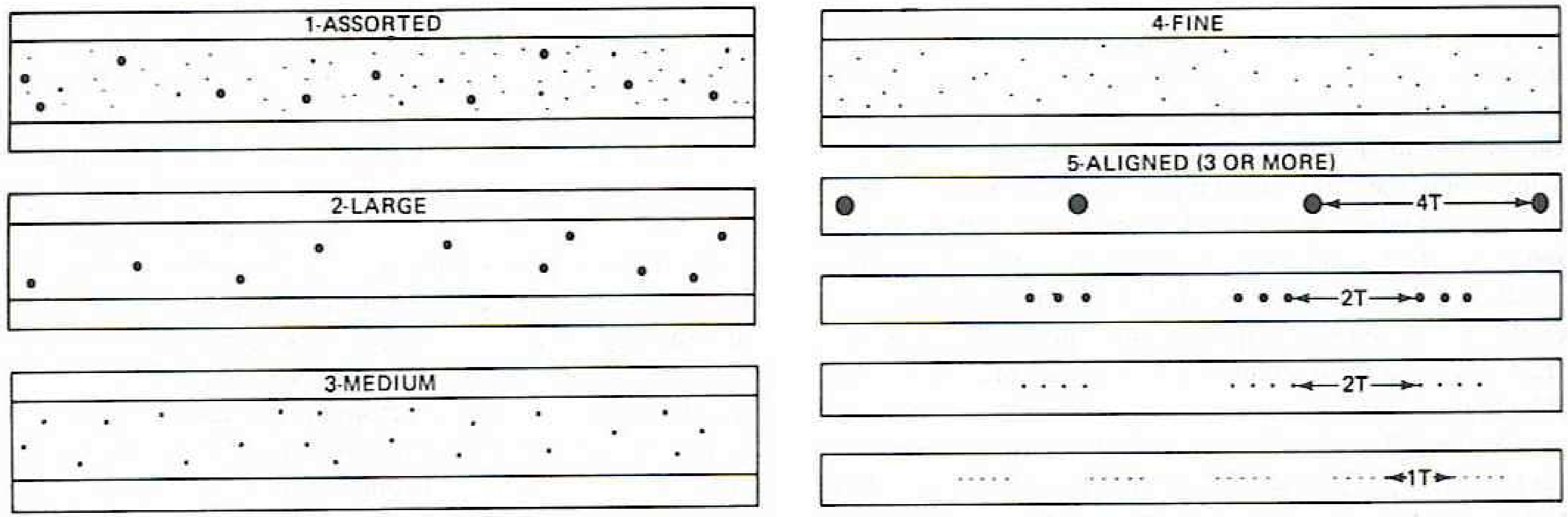
Weld Defect Class – Cracks Appearance or Cross Section or Radiograph Class No. 100	How Detected		Respon-sibility	Probable Cause	Corrective Action
 Longitudinal Crack A	VT MT PT RT UT	X X X X X	design X welder X shop	General 1. Incorrect electrode. 2. High restraint of joint. 3. Rapid cooling of weld.	1. Use proper or matched electrode. 2. Reduce rigidity of weldment or change welding sequence. Use higher ductility welding filler metal. 3. Use preheat and/or inner pass heat to reduce cooling rate.
 Longitudinal Crack B	VT MT PT RT UT	 X X X	design X welder X shop	4. Improper joint preparation. 5. Fillet weld longitudinal crack.	4. Use proper joint for welding process. 5. Change center line of weld to avoid interface between parts.
 Crater Crack C	VT MT PT RT UT	X X X X X	design welder X shop	Crater Crack 1. Unfilled crater. 2. Crater crack in submerged arc welding.	1. Filler crater with proper technique. 2. Utilize run-out-tab.
 Transverse Crack D	VT MT PT RT UT	X X X X X	design welder X shop X	Transverse Crack 1. Incorrect electrode. 2. Rapid cooling. 3. Welds too small for size of parts joined.	1. Use proper electrode. 2. Use larger electrode, higher welding current or preheat. 3. Use larger weld possibly larger welding electrode.

FIGURE 21-35 Collection of weld defects: cracks.

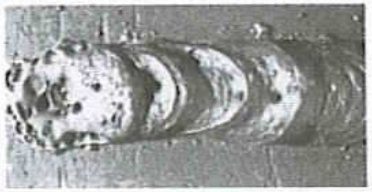
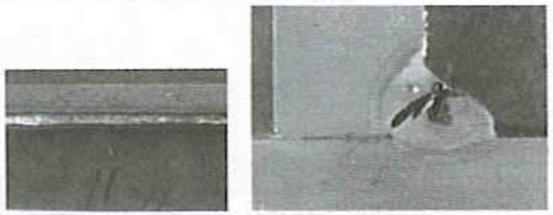
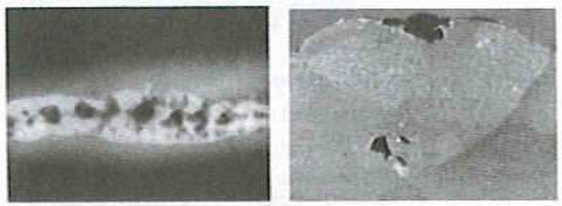
Weld defects

FIGURE 21-36 Porosity chart for pipe welds.



Weld defects

FIGURE 21-38 Collection of weld defects: cavities.

Weld Defect Class - Cavities Appearance or Cross Section or Radiograph Class No. 200	How Detected	Responsibility	Probable Cause	Corrective Action
 A	VT X MT PT RT UT	design welder X shop X	Surface Porosity General 1. Welding over foreign material on surface such as rust, oil, moisture, paint, etc. 2. Damp electrodes. 3. Improper base metals such as free machining or high sulphur. 4. Welding current too low.	1. Clean weld bevels and area adjacent to weld and keep clean. 2. Use fresh dry electrodes or rebake electrodes that have been exposed to dampness. 3. Utilize correct base metal possibility to use low hydrogen type electrodes. 4. Increase welding current.
 B	VT X MT PT RT UT	design welder X shop X	Gas Shielded Welding Processes 1. Incorrect shielding gas type. 2. Incomplete gas coverage due to breeze, defective gas system, clogged nozzle, etc.	1. Use specified shielding gas. 2. Provide windshields, check efficiency of gas system such as broken hoses, gas valves, empty tanks, clean nozzle.
 C	VT X MT X PT X RT X UT X	design welder X shop X	3. Moisture in the shielding system. 4. Poor gas coverage. 5. Welding over tack weld made with shielded metal arc process.	3. Check to make sure gas is dry or welding grade. Check for water leaks in water cooled systems. 4. Use proper nozzle to work distance. Check gas flow rate, may be too high or too low. 5. Utilize gas metal arc for tack welding.
 D	VT X MT PT RT X UT X	design welder X shop X	Submerged Arc Welding 1. Damp submerged arc flux. 2. Contaminated surface of electrode wire, dirt and/or moisture. 3. Too many fines in flux.	1. Utilize fresh dry flux or dry damp flux. 2. Clean surface of electrode wire. 3. Use fresh flux and discard fines.

Weld defects

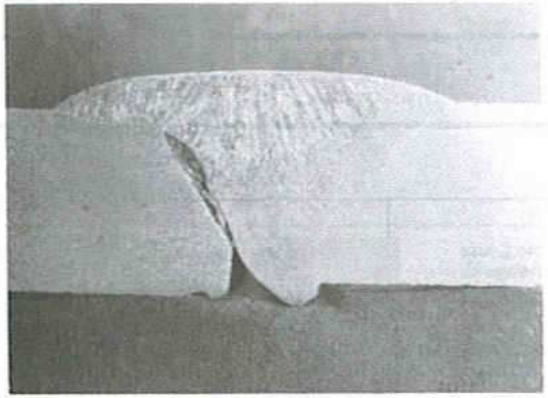
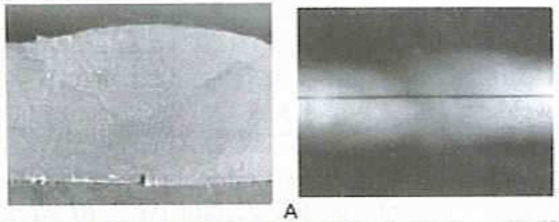
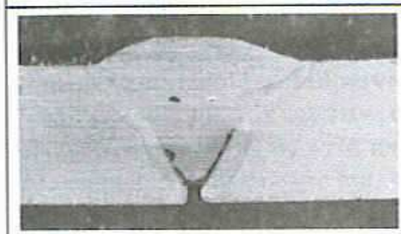
Weld Defect Class — Solid Inclusions Appearance or Cross Section or Radiograph Class No. 300	How Detected		Responsibility		Probable Cause	Corrective Action
 A	VT		design		General 1. Slag inclusion between passes. 2. Intermittent slag inclusion at edge of bead (wagon tracks). 3. Irregular surface of bevels. 4. Incorrect welding technique or wrong current or voltage. 5. Submerged arc welding —flux inclusion.	1. Remove solidified slag after each pass. 2. Remove slag at bead edge. Utilize proper technique to avoid high crowned bead contour. 3. Provide for smooth bevel surface, grind if necessary. 4. Utilize correct welding technique for electrode type and joint design. 5. Improper direction of electrode wire. Welding current too low. Electrode wire misdirected possible correction use wire straightener. Improper joint detail.
	MT					
	PT		welder	X		
	RT	X	shop			
	UT	X				
 B	VT		design			
	MT					
	PT		welder	X		
	RT	X	shop			
	UT	X				
 C	VT		design			
	MT					
	PT		welder	X		
	RT	X	shop	X		
	UT	X				

FIGURE 21-39 Collection of weld defects: solid inclusions.

Weld defects

FIGURE 21-42 Collection of weld defects: incomplete fusion.

Weld Defect Class — Incomplete Fusion Appearance or Cross Section or Radiograph Class No. 400	How Defected	Respon-sibility	Probable Cause	Corrective Action
 A	VT X MT PT X RT X UT X	design X welder X shop	General 1. Welding speed too fast. 2. Electrode too large for joint detail. 3. Welding current too low. 4. Improper joint design such as excessive root face or minimum root opening..	1. Reduce welding speed. 2. Utilize correct size electrode. 3. Increase welding current for more penetration. 4. Utilize correct joint detail.
 B	VT X MT X PT RT X UT X	design X welder X shop	5. Improper joint fit-up such as root opening too small. Shielded Metal Arc Welding 1. Irregular travel speed. 2. Irregular arc length	5. Make setup correct to agree with joint design detail. 1. High speed will reduce complete fusion, lower speed will cause com-plete fusion. 2. Maintain proper arc length.
 C	VT X MT X PT RT X UT	design X welder X shop X	Gas Metal Arc Welding 1. Incomplete fusion— (cold shut)	1. Direct arc at leading edge of puddle. Current too low, voltage too low, adjust for proper pro-cedure. Pause too short at dwell when weaving. Increase pause to allow melting of base metal.
 D	VT X MT PT RT X UT X	design welder X shop	Submerged Arc Welding—Semiautomatic 1. Incomplete root fusion.	1. Failure to direct welding electrode to root of weld joint.

Weld defects

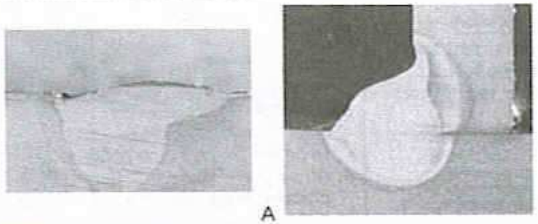
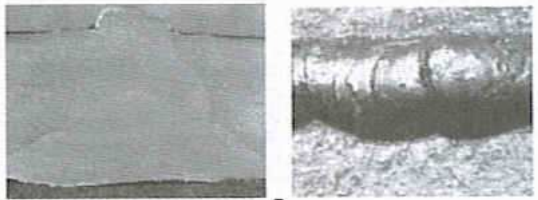
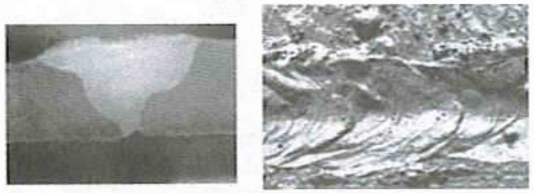
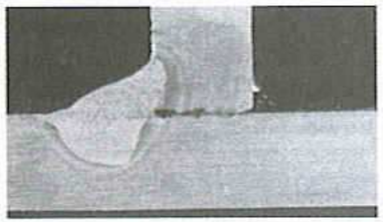
Weld Defect Class — Imperfect Shape Appearance or Cross Section or Radiograph Class No. 500	How Defected	Respon-sibility	Probable Cause	Corrective Action
 A	VT X MT X PT X RT X UT X	design welder X shop	Undercutting 1. Faulty electrode manipulation. 2. Welding current too high. 3. Incorrect electrode size (usually too large). 4. Incorrect electrode for welding position. 5. Incorrect electrode angle.	1. Use uniform weave in groove welding pause at edges. 2. Use prescribed welding current for electrode size. 3. Use correct electrode size for size weld being made. 4. Use correct electrode with position capabilities. 5. Adjust electrode angle to fill undercut area.
 B	VT MT X PT RT X UT X	design welder X shop		
 C	VT X MT X PT X RT X UT X	design welder X shop	Incorrect Profile 1. Excessive root penetration. 2. Travel speed too slow. 3. Excessive crown or reinforcement. 4. Incomplete root or negative root reinforcement or "suck back" (internal concavity). 5. Improper fillet contour usually wide on horizontal and not sufficient on vertical leg. 6. Incorrect electrode type.	1. Root opening too wide. 2. Welding current too high. 3. a. Welding speed too slow. b. Welding voltage too high arc length too long, correct arc length. 4. a. Voltage too high. b. Travel speed too fast. c. Root opening too wide. 5. Improper welding technique. Welding current too high. Reduce welding current. Use smaller electrode. 6. Use proper electrode type.
 D	VT X MT X PT X RT X UT X	design welder X shop		

FIGURE 21-46 Collection of weld defects: incorrect shape.

Weld defects

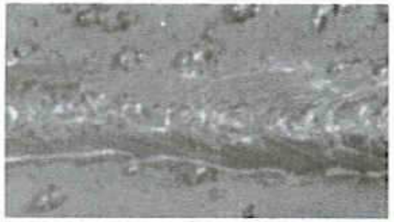
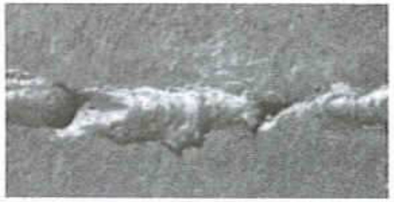
Weld Defect Class — Miscellaneous Defects Appearance or Cross Section or Radiograph Class No. 600	How Detected	Respon-sibility	Probable Cause	Corrective Action
	VT X MT PT RT X UT	design welder X shop	Poor Appearance 1. Welding current too high or too low. 2. Improper technique. 3. Faulty electrode. 4. Irregular travel speed.	1. Use prescribed procedure. 2. Provide additional welding training. 3. Use fresh electrode or determine correct type to be used. 4. Allow for additional practice and experience.
	VT X MT PT RT UT	design welder X shop	Excessive Weld Spatter 1. Arc blow—see welding current. 2. Excessive welding current for type and size electrode. 3. Excessive long arc—high voltage. 4. Improper electrode type.	1. Reduce arc blow—use alternating current. 2. Adjust for proper welding current for size electrode used. 3. Hold proper arc length and use correct arc voltage. 4. Utilize proper electrode type for location.
	VT X MT PT RT X UT	design welder X shop	Poor Tie-In 1. Incorrect electrode angle. 2. Improper technique for restriking arc.	1. Use correct electrode angle. Imrpove training. 2. Provide additional training and experience.
	VT X MT PT RT X UT	design welder X shop X	Whiskers 1. Root opening too wide.	1. Use correct root opening. Use weaving motion and direct arc on weld puddle.

FIGURE 21-47 Collection of weld defects: miscellaneous.

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