Marine Construction & Welding

NA21003

Autumn 2019

P6

Residual Stress & Distortion

Residual Stress & Distortion

Welding process leads to nonuniform thermal cycles of heating and cooling causing shrinkage forces to develop.

This occurs in the shipbuilding industry for panels, subassemblies and assemblies where welding is done.

The shrinkage forces cause different types and degrees of distortion depending on the pattern of forces developed.

Buckling of side shell panels of a ship

Distortion effects

Weight restrictions result in increased use of thin plates leading to higher distortion levels.

This increases man-hour requirement for fitting, flame straightening, and rework.

Therefore, in-process control of welding distortion is more desirable than post welding rectification from the point of manufacturing efficiency.

Distortion effects:

- Affect the hydrodynamic performance of a vessel
- Deck and bulkhead undulations cause problems with equipment installation

Distortion types

Thermal stresses during welding may cause distortions and produce high levels of residual stresses. These may make the structure vulnerable to fracture, buckling, fatigue and also increased corrosion.

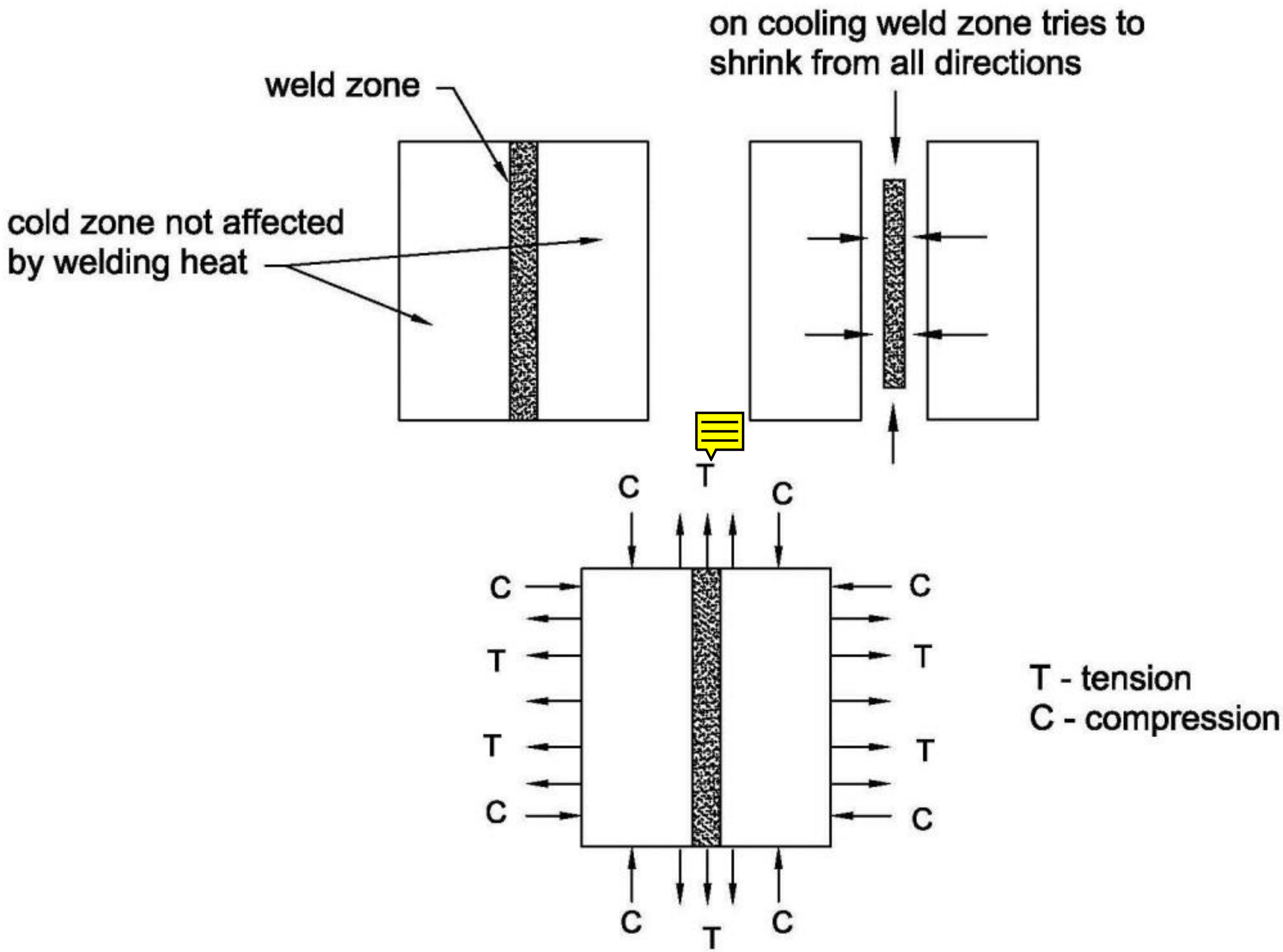
Transverse shrinkage: Dimensional reduction in a direction perpendicular to the welding line.

Longitudinal shrinkage: Dimensional reduction in a direction parallel to the welding line. Generally smaller than the transverse shrinkage (about 1/1000 of the weld length)

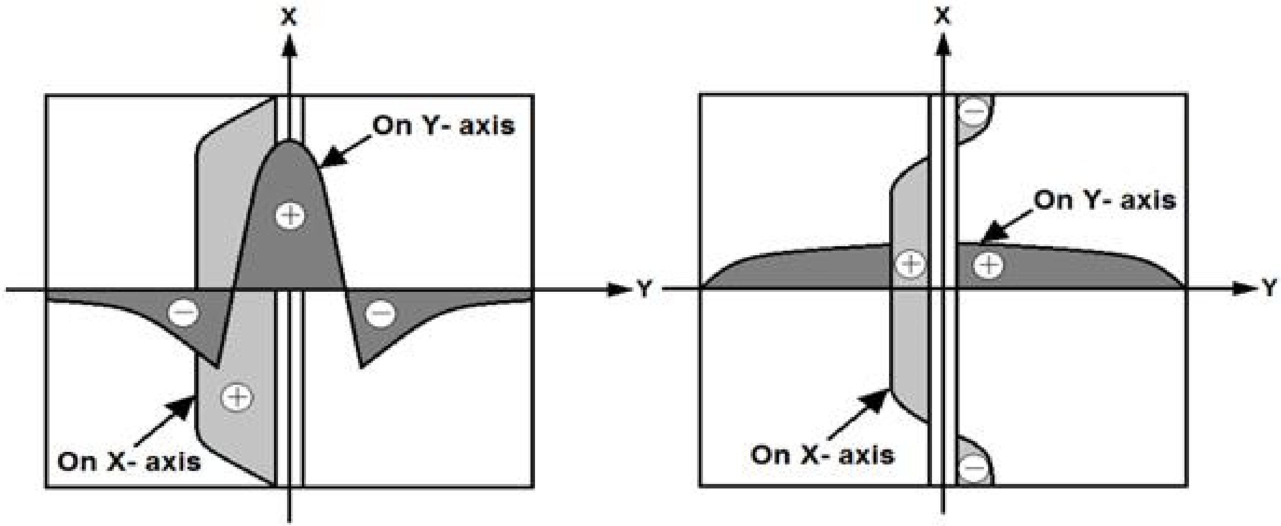
Angular distortion: Angular change that occurs due to a non-uniform thermal contraction through the thickness of the plate due to uneven heating.

Buckling: Produced by compressive stresses developed due to the welding of stiffeners, especially in case of thin stiffened panels.

Residual Stress development



Residual Stress distribution



a) Longitudinal stresses

b) Transverse stresses

Typical welding residual stress distribution in a butt-welded joint

Tensile and compressive residual stresses are denoted by +ve & -ve signs respectively.

As the transverse (along Y axis) thermal gradient is larger than the longitudinal thermal gradient, the transverse plastic strain and shrinkage are much larger.

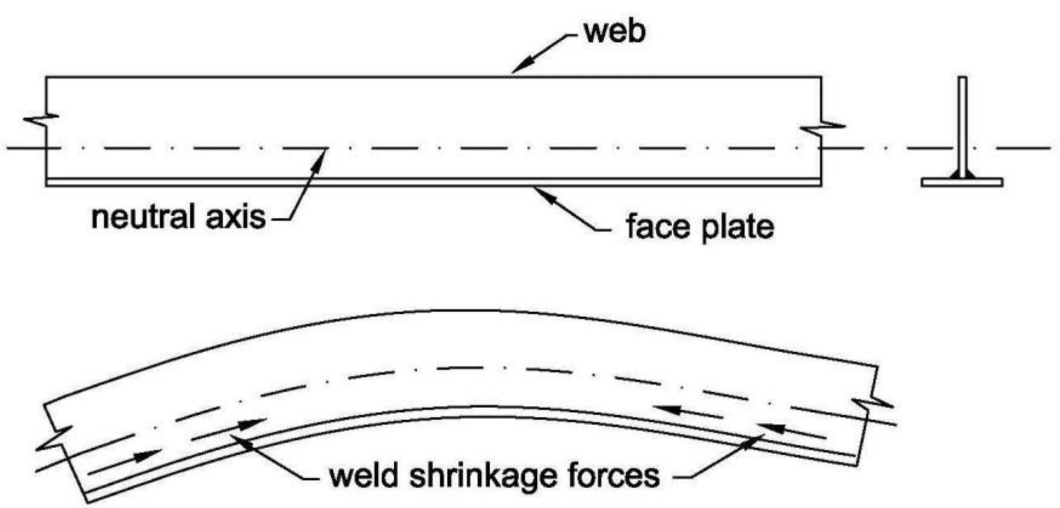
Hence, the magnitude of transverse residual stress is much smaller than the longitudinal residual stress.

Longitudinal Bending Distortion

In fabrication of built-up girders, it is often observed that bending occurs along the length of the beam.

This happens due to the shrinkage of the weld deposit joining the web to the face plate. If the joint is below the neutral axis of girder, bending takes place.

As the fillet deposit shrinks longitudinally, a bending moment is developed about the neutral axis of the tee section causing a "bowing effect".



Distortion Control

Distortion Control

Weld-induced distortion is a major concern in the shipbuilding industry. Some degrees of in-plane and out-of-plane distortions are inevitable.

Following methods are used for distortion control and mitigation.

- **Distortion control through design:**

The effect of frame spacing and plate thickness on the buckling strength of the stiffened panels can be checked in the design stage.

By increasing plate thickness and/or reducing stiffener spacing, the critical buckling stress of a panel can be increased.
Thus out-of-plane distortion due to buckling caused by weld induced stresses can be avoided.
However, these parameters should be so chosen that the increase in weight is minimized.

Distortion Control

- **Distortion control through fabrication technique:**

Appropriate fabrication procedures should be followed for controlling weld induced distortion.

Mismatch of joints should be avoided during welding.

Restraining structures against possible distortions leads to accumulation of stress which results in more distortion when the restraining fixtures are released.

A certain amount of shrinkage allowance can be provided which would allow the structure to shrink freely without any restraint.

Distortion Control

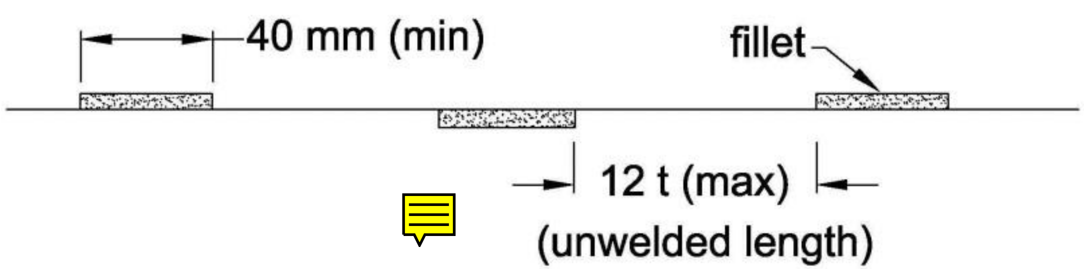
- **Heat input:**

Weld-induced distortions can be reduced by reducing the heat input.

The fillet weld size should be reduced with decreasing plate thickness.

Increasing the welding speed reduces heat flow in the welded components leading to reduced deformations.

Intermittent welding can be done to reduce the overall weld metal deposition, reducing the total heat input. Hence for controlling weld-induced distortions wherever possible, staggered welds should be used.

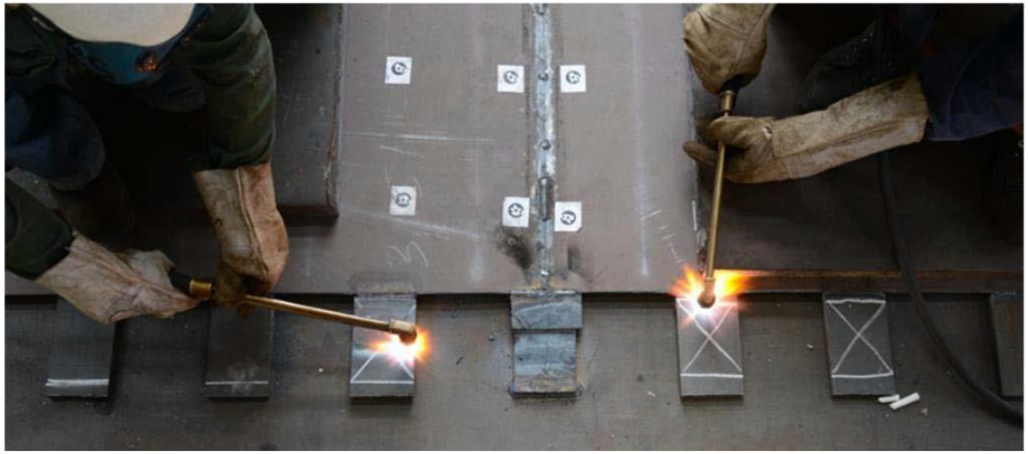


Distortion Control

- **Thermo-Mechanical Tensioning:**

In TMT method, tensioning and restraining lugs are placed along the stiffener location both for longitudinal and transverse stiffeners.
As the lugs cool down, they shrink and exert tensile forces on the plate panel.

Once stiffener welding is completed, these TMT lugs are then released. The plate will then shrink back because of release of the elastic tensioning force, causing compressive stress to generate. This compressive stress will partly/fully nullify the tensile stress that developed due to welding of the stiffeners.



Distortion Control

- **Heat Sinking:**

Heat from the welded region is removed such that it does not spread in the plates away from the weld zone.

By keeping the base metal cool, the modulus of elasticity and yield strength of the base metal is not lowered. This reduces residual stresses and distortion. Allowable cooling rates must be checked when designing a heat sink.

- **Weld Sequencing**

Keeping all other welding parameters intact, the welding sequence has much impact on the distortion patterns of stiffened panels.

Proper welding sequencing is required to avoid excessive shrinkage and buckling distortion.

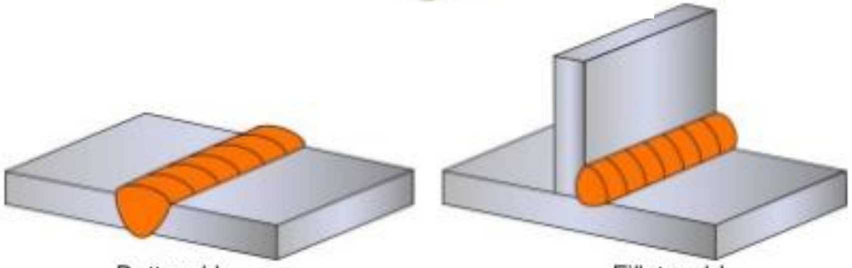
Welding Defects

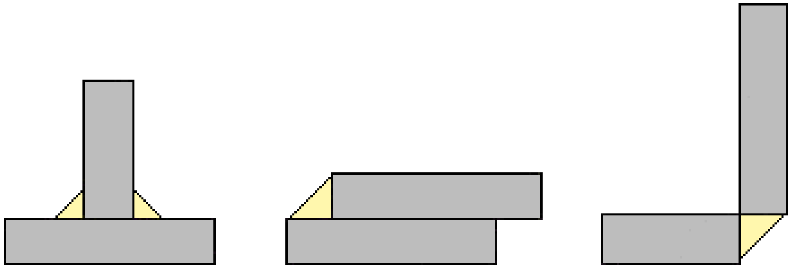
Welding Defects

During welding, certain flaws or imperfections can be present in the welded joint.

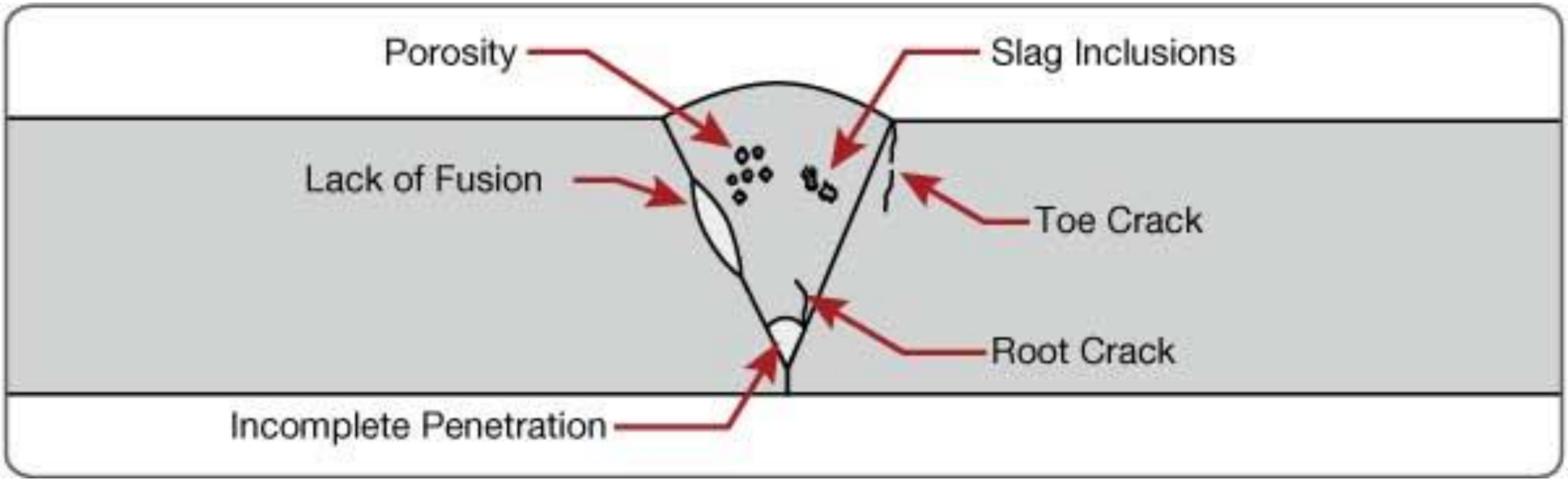
Depending on their, size, location and type, the flaws may considered as defects.

The defects need to be rectified. Remedial measures are to be implemented to remove these defects, as because a structure cannot be put to service with defects.





Welding Defects: Types

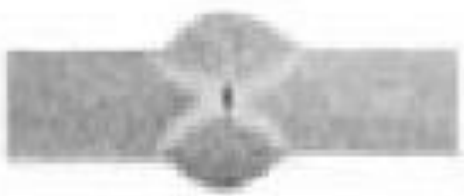


Welding Defects: Types

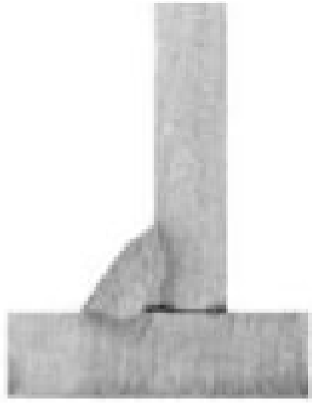
❑ **Lack of penetration**

a) Weld bead does not penetrate entire thickness of plate (no root penetration)

b) Two opposing weld bead do not interpenetrate



c) Weld bead does not penetrate toe of the fillet weld

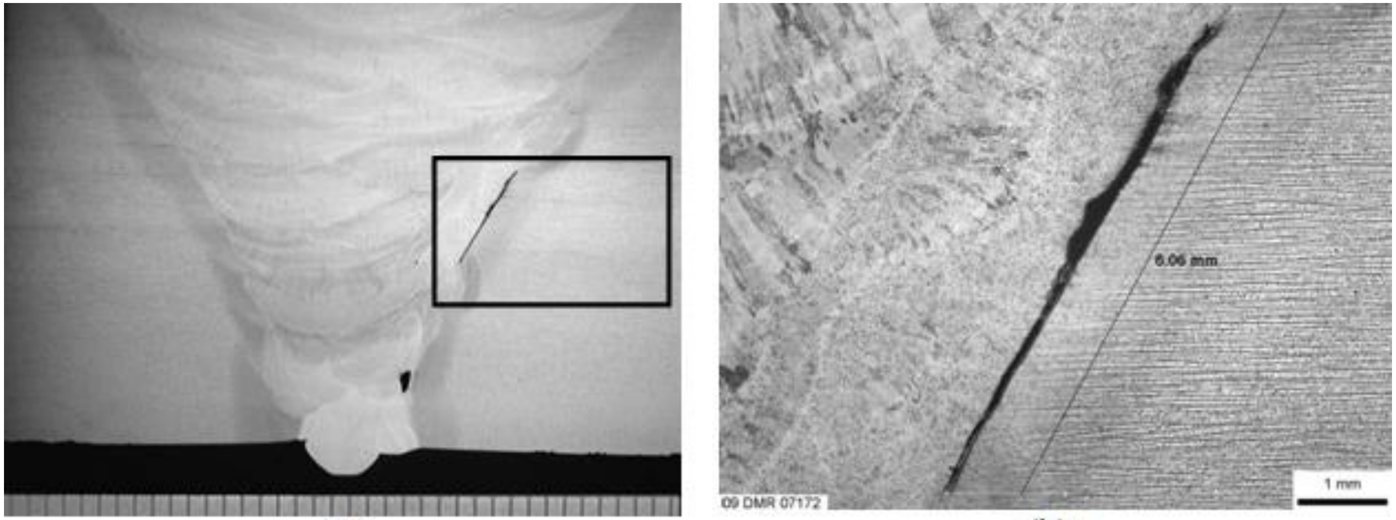


Welding Defects: Types

❑ **Lack of fusion**

Lack of fusion occurs when there is no fusion between the weld metal and the surfaces of the plate being welded.

Poor welding technique is the main cause. Either the weld pool is too large because of too slow welding speed or because of a very wide weld joint.



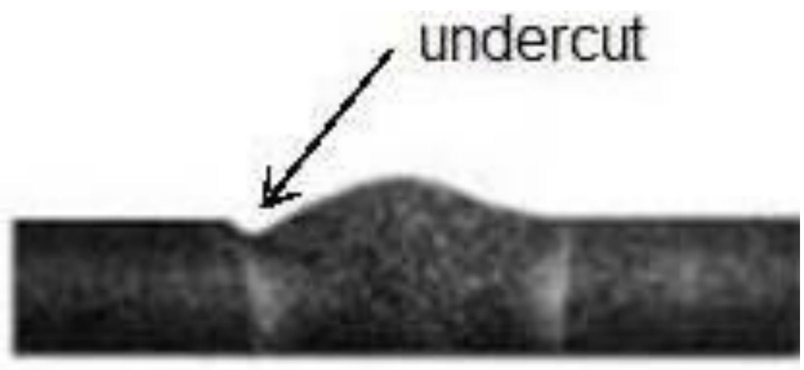
(a) (b)

Welding Defects: Types

- **Undercut**

A groove is formed in the parent metal running along the edges of the weld bead

It is mainly encountered in butt welds. It is caused by improper welding parameters, particularly the travel speed and arc voltage.

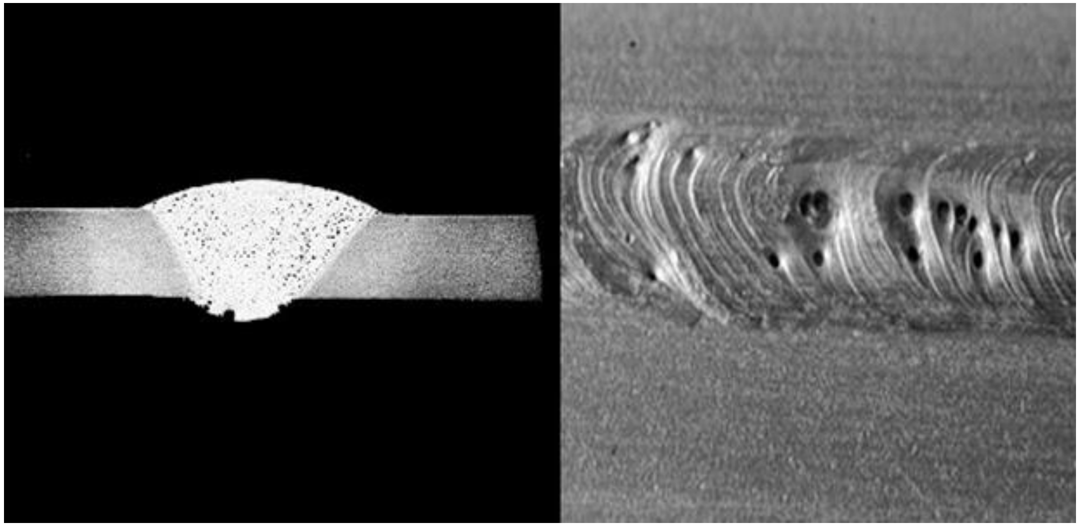


Welding Defects: Types

- **Porosity**

Porosity generally occurs as a cluster of gas pores in the solidified weld bead, either within it or at the surface.

This is generally caused from atmospheric contamination. For porosity in steel weld nitrogen and excessive oxygen are the main reasons. Electrode or metal contamination, inadequate gas shielding, etc. are other reasons.



Welding Defects: Types

- **Slag inclusion**

Here, slag gets entrapped in between weld deposits.

It is associated with welding processes which use flux for shielding of the arc and molten metal pool, like SMAW, SAW, and FCAW.

Depending on the size of a slag particle, some slag inclusions are tolerated, i.e. no rectifying measures are taken.

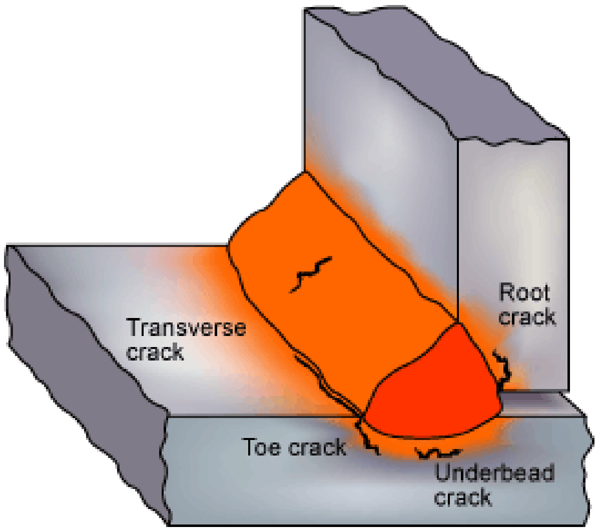
However, larger slag particles or slag entrapment constitute a weld defect and it has to be removed either by arc gouging or by deep grinding.

Welding Defects: Types

❑ Weld cracks

Cracks in welds develop mainly due to the shrinkage strains that occur with the cooling of the weld metal. Hydrogen concentrations in HAZ also cause cracking.

For welding of higher tensile strength materials extra care should be taken in terms of welding sequence, preheating and temperatures to avoid cracking tendencies.



Non-destructive testing

Non-destructive testing

Nondestructive testing (NDT) involves examination of the surface and subsurface of the welded joint to verify compliance with industrial standards.

The NDT methods that are commonly used to examine finished welds in shipbuilding are: **visual inspection, dye penetrant, magnetic particle, radiographic and ultrasonic testing.**

Visual Inspection

Visual inspection is extensively used to evaluate the quality of a weld or component.

It is easily carried out, inexpensive and usually does not require special equipment.

Visual inspection can be enhanced by various methods ranging from low power magnifying glasses to computer aided imaging systems.

Dye penetrant testing

One of the the oldest and most widely used of all the NDT methods. It can be used on any non-porous material.

Its use is confined to the detection of surface cracks.

Dye penetrant testing is used to reveal surface flaws in the form of cracks by bleed out of the colored or fluorescent dye from the flaw.

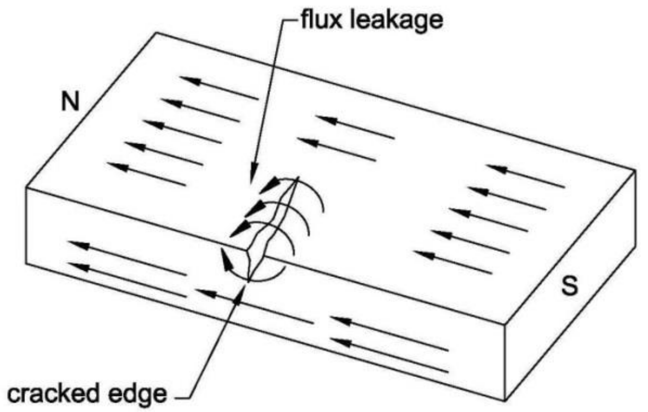
Magnetic particle testing

Used for detection of surface and near-surface flaws in ferromagnetic materials.

A magnetic field is applied to the specimen using a permanent magnet, electromagnet, or equivalent hand-held devices.

If a flaw is present, the magnetic flux 'leaks' from the surface of the specimen in the region of the flaw. Fine magnetic particles, applied to the surface of the specimen, are attracted to the area of flux leakage, creating a visible indication of the flaw.

This method can only detect surface discontinuity and that of sub-surface up to a limited depth of about 6 mm depending on the magnet strength.



Radiographic testing

This technique involves the use of penetrating gamma or X-radiation to examine parts and products for imperfections.

Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal soundness of the part.
Possible imperfections are indicated as density changes in the film.

Ultrasonic testing

Here, beams of high-frequency sound waves are introduced into materials for the detection of subsurface flaws in the material.

The sound waves travel through the material with some loss of energy (attenuation) and are reflected at interfaces (cracks or flaws). Any discontinuity in the medium acts as an interface because of sharp change of material density.

Ultrasonic testing advantages

- It can detect both surface and subsurface discontinuities
- Higher penetrating power for flaw detection compared to other NDT methods
- High accuracy level in detecting the location, size, and shape of the flaw
- Preparation time for carrying out testing is minimum
- No need for post processing, instantaneous results are obtained
- Computer aided systems can produce detail images of the flaws
- No health hazard
- Equipment is portable and can be easily handled

Under Water Welding

Introduction

With increasing age of offshore structures,

- ➢ Experience fatigue and corrosion damage
  - ➢ Under water repair methods becomes important

Critical aspects of underwater welding

- Influence of pressure,
- Hydrogen enriched environment,
- Rapid cooling rates

❖These unique variables affect the chemistry and mechanical properties of under water weldments

Underwater arc welding is performed either in,

- ✓ Wet environment, or
- ✓ A protective habitat.

- Both environments experience increased pressure with depth.

- Wet environment significantly increases the cooling rate during welding.

- Welding in a dry and high pressure environment requires the construction of a chamber around the weld zone to create the dry habitat.
- The cost of hyperbaric welding is therefore much higher than that of wet welding.
- The setting up and tearing down of equipment can be very expensive in a deep-sea environment.
- Each fabrication situation requires a customized setup.

Underwater Welding Methods

Dry Chamber Welding

Welding is done at ambient water pressure in a simple open-bottom dry chamber.

Accommodates the head and shoulders of the welder/diver in full diving gear.

Dry Spot Welding

Welding is done at ambient water pressure within a small transparent, gas filled enclosure with only the welder/diver’s arms in the enclosure.

Dry Welding at Atmospheric Pressure

Welding is done in a pressure vessel, pressure is maintained at approximately one atmosphere regardless of outside ambient water pressure.

Dry Welding in a Habitat (hyperbaric welding)

- Welding is carried out in a chamber sealed around the structure at ambient water pressure.
- The chamber is filled with a gas (commonly helium) at the prevailing pressure.
- Produces high-quality weld joints that meet X-ray and code requirements.
- GTAW is employed for this process.

Wet Welding

- At ambient water pressure with the welder/diver in water without any physical barrier between water and the welding arc.

- The arc and the molten weld metal are shielded by a gaseous bubble composed of gases produced from decomposition of the flux of the welding electrode plus oxygen and hydrogen disassociated from the water.

Wet Welding Variables

Factors that adversely affect wet weldments

- Hyperbaric pressure accentuates arc instability.
- Increased pressure affects chemical composition of the deposited weld metal.
- Disassociation of the water promotes hydrogen pick-up in the weldment.
- Infinite heat-sink causes high cooling rate.
- Formation of gaseous bubble that displaces the water from the weld pool area.

Effect of Pressure

Hyperbaric pressure may adversely affect,

- Arc stability and metal transfer,
- As-deposited weld metal composition.

Arc Instability

Under hyperbaric conditions,

- Compression of gases takes place causing increase in its thermal conductivity.
  - ➢ Leads to constriction of the welding arc
  - ➢ Elevation of the potential drop across the arc column.

❖ This increases energy density causing substantial changes in anode and cathode behaviour causing arc instability.

Effect of changes in changes in composition of deposited weld metal

- High weld metal oxygen content has been related to the decrease in weld metal toughness.
- Manganese and carbon variations in the deposited weld metal can cause significant change in hardenability of weld metal.

Cooling Rate

- Enormous heat sink causing extremely high cooling rate.

Effect of pressure on boiling temperature of water

- The boiling temperature of water increases with increase in hydrostatic pressure.

Depth (m)	Boiling Temp. ($0\ ^0C$)
0	100
10	121
50	160
100	188
305	238

❖ If that superheated water is physically confined to the weld area, it helps in maintaining high Temperature.

The protective Bubble

- Volume and density of the gases vary substantially with depth and pressure.
- Transient in nature.
  - Volume constantly fluctuates
  - Forms, grows to the largest volume depending on its surface tension, deflates, regenerates, and so on.

- This cyclic fluctuation of bubble volume becomes very rapid in shallow water,

Wet welding processes

- Shielded Metal Arc Welding is still the most preferred welding method for underwater wet welding.

- Current, welding speed, and electrode angle depend on position of weldment.

Dry welding processes

- In underwater dry welding processes, GTAW, SMAW and FCAW welding methods are most commonly used.

- GTAW is generally least sensitive to depth and pressure.

- The independent control over heat source and rate of wire feeding makes the process ideal for filling varying root openings.