WELDING DEFECTS
OBJECTIVES

To:

• Understand the definition & cause of weld defects
• Solve the problem
• Suggest possible remedies associated with individual weld defects.
INTRODUCTION

• Performance & longevity of welded structure in service depends on:
  – the presence or absence of defects in weld joints.
• Not possible for the welds to be completely sound
• Improper welding parameters & wrong welding procedures introduce defects in the weld metal and HAZ
• Defects impair the strength of weld joints
• A defective weldment fails under service conditions & causes damage to property & loss of human lives
DEFINITION OF WELDING

Definition:
“Process of joining two similar or dissimilar metals by heat or by pressure or by both using a filler metal to achieve a defect less joint having the physical properties similar to that of parent metal”.

Dissimilar metal means:

• Those that are chemically different (steel, Cu, Al, etc).
• Those that are metallurgically different (MS, SS, etc).

* Dissimilar metal imparts galvanic cell corrosion

Commonly welded base metals:

– Ferrous-[WI, CI, C-steel (low, med, high), alloy steel, SS]
– Non-ferrous-(Al, Cu, Mg, Ni, Zn & their alloys)
Arc welding: (the most popular process)
- SMAW or MMAW
- FCAW
- TIG welding or GTAW
- MIG welding or GMAW
- MAG welding or CO$_2$ welding
- SAW
- Plasma arc welding
- ESW
- EGW

Gas welding:
- Oxy-acetylene welding
- Oxy hydrogen welding
- Air acetylene welding

Resistance welding:
- Spot welding
- Seam welding
- Resistance butt welding
- Flash butt welding

Solid state welding
- Diffusion welding
- Forge welding
- Friction welding
- Ultrasonic welding

Thermo chemical welding
- Thermit welding
- Atomic hydrogen welding

Radiant energy welding
- Plasma welding
- Laser beam welding
- Electron beam welding

Allied process
- Soldering
- Brazing
- Adhesive welding
WELDING PROCESSES MAINLY USED ON IR

- MMAW
- SAWMIG/MAG
- Gas welding
- Thermit welding
- Flash butt welding
- Gas pressure welding
- Brazing
# WELDING PROCESSES USED ON IR

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>USES ON IR</th>
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</table>
| MMAW    | 1. For repair of Rly comp like coaches, wagons, Bridge girders, Bogies of diesel & electric locos  
          2. For fabrication of above Rly components, the process was replaced by MIG/MAG & SAW  
          3. For reclamation & reconditioning of worn out Rly components like Rly points & crossings, hangers, eq beam of trimount bogies, gas inlet casing of diesel locos, etc |
| SAW     | 1. Used for fabrications of Rly components like bridge girders, diesel engine block, wagons, fabricated bogies  
          2. For reclamation of worn out wheel flanges of C & W (both cast & rolled forged) |
| MIG/MAG | 1. Used for fabrications of Rly components like bridge girders, C& W, fabricated bogies  
          2. For reclamation of worn out Rly components like Rly points & crossings, equiliser beam of trimount bogies, etc |
# WELDING PROCESSES USED ON IR

<table>
<thead>
<tr>
<th>PROCESS</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Gas welding</td>
<td>Presently limited on IR. However, used for repair of small defects for general purposes. Also used for joining of some non-ferrous comp</td>
</tr>
<tr>
<td>Brazing</td>
<td>Mainly used for joining of electrical comp of E &amp; D locos. Also used for joining of Al &amp; Cu tubes of AC coaches</td>
</tr>
<tr>
<td>Thermit welding</td>
<td>Most widely used for joining of rails of IR (70% of rails joining)</td>
</tr>
<tr>
<td>FBW</td>
<td>Used for joining rails</td>
</tr>
<tr>
<td>GPW</td>
<td>Limited for joining of rails</td>
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</tbody>
</table>
NOMENCLATURE OF A FILLET WELD

*concave fillet weld has higher tensile stress on the face than the convex fillet weld
NOMENCLATURE OF A FILLET WELD

- Penetration
- Root
- Convex
- Flat
- Toe
- Concave
WELDING DEFECTS
WHAT IS A WELDING DEFECT?

The defects in the weld can be defined as irregularities in the weld metal produced due to incorrect welding parameters or wrong welding procedures or wrong combination of filler metal and parent metal. It can simply be defined as: “Defects introduced during welding beyond the acceptance limit that can cause a weld to fail”. A defect does not allow the finished joint to withstand the required strength (load).
FAILURE DUE TO WELDING DEFECT ON %AGE BASIS

According to the American Society of Mechanical Engineers (ASME) welding defect causes are broken down into the following % age:-

- 41% poor process conditions
- 32% operator error
- 12% wrong technique
- 10% incorrect consumables and
- 5% bad weld grooves.
PRESENCE OF WELDING DEFECTS: ACTION

What should be done when Welding-defects are detected?

One should **reject** the items and put them temporarily on hold.

One should determine the cause and try to implement a **corrective action** to avoid future reoccurrence.

Then an authorized professional should determine, if the defects are **repairable** or not. If yes, by which procedure. Standard procedures may be approved for routine application.
All discontinuities are not defects. Discontinuities are rejectable only if they exceed specification requirements.

Radiographic standards used for evaluation of weld defects:

- IIW standards
- ASTM standards

*Acceptance standards vary with service requirements
Five IIW standards:

- Black
- Blue
- Green
- Brown
- Red
IIW STANDARDS

Black

- A homogeneous weld or a weld with a few small scattered gas cavities

Blue

- Very slight variation from homogeneity in the form of one or more of the following defects:
  - Cavity
  - Shrinkage cavity
  - Slag inclusion
  - Undercut

Green

- Slight variation from homogeneity in the form of one or more of the following defects:
  - Gas cavity
  - Shrinkage cavity
  - Slag inclusion
  - Undercut
  - Incomplete penetration
IIW STANDARDS

Brown

• Marked deviation from homogeneity in the form of one or more of the following defects:
  – Gas cavity
  – Shrinkage cavity
  – Slag inclusion
  – Undercut
  – Incomplete penetration
  – Lack of fusion

Red

• Gross deviation from homogeneity in the form of one or more of the following defects:
  – Gas cavity
  – Shrinkage cavity
  – Slag inclusion
  – Undercut
  – Incomplete penetration
  – Cracks
Specified welding defects level as per ASTM E-390 Vol-II

• **Defects not allowed:**
  – Shrinkage /Crack
  – Lack of Fusion
  – Burn through
  – Elongated Porosity

• **Defects allowed:**
  – Incomplete Penetration up to level-II
  – Slag Inclusion up to Level-III
  – Undercut up to level-IV
  – Porosity:
    • Coarse scattered Porosity up to level-II
    • Cluster Porosity up to Level-III
    • Fine scattered Porosity up to Level-IV
CLASSIFICATION OF WELDING DEFECTS

• One of the IIW documents classifies all welding defects into six groups according to their appearance.
  ➢ **Crack**- includes all types of cracks such as crater cracks, hot cracks, cold cracks, etc
  ➢ **Cavity**- includes blow holes, porosities, shrinkage, pipes, etc
  ➢ **Incomplete fusion & penetration**- includes lack of fusion, lack of penetration, etc
CLASSIFICATION OF WELDING DEFECTS

- **Solid inclusion** - includes slag, metal oxides, tungsten, wagon track, etc
- **Imperfect shape** - under cut, under fill, over lap, excessive penetration, improper bead shape, etc
- **Miscellaneous defects** – includes arc strike, excessive spatter, rough surface, uneven ripples, etc
CLASSIFICATION OF WELDING DEFECTS

All these defects fall under two categories-

- **Visual defect /Surface weld defect/External defect**
  - surface cracks
  - over laps
  - under cuts
  - under fills
  - excessive penetration
  - surface porosity
  - excessive spatter
  - Arc strike, etc.

- **Hidden defect/sub surface weld defect/Internal defect**
  - lack of fusion
  - lack of penetration
  - sub surface blow holes/ porosity
  - shrinkage cavity
  - slag inclusion
  - tungsten inclusion, etc.
CRACKS

• A hair line separation in the BM/BM-WM-bdy / WM/HAZ

• May appear:
  – at the root or
  – middle or
  – In the crater
  – surface or
  – subsurface

• Most dangerous of all defects

• Occurs in the WM when localized stresses exceed the UTS of material.

• May be of microscopic or macroscopic sizes.
CRACKS

Long crack in HAZ parallel to weld bead

Long crack in weld metal running through centre of the weld
CRACKS

Cause:-
• Poor ductility of base metal
• High C & S- content of BM/WM
• High contraction stresses
• Electrode with high hydrogen content

Remedy:-
• Pre- heating
• Mn/S ratio: 18 min.
• Use low H₂ electrode
• Avoid rapid cooling

Classification:-
Cracks may be grouped mainly into two categories-
  – Hot crack
  – Cold crack
HOT CRACKS

• Crack in the weld that occurs just after the welds are completed and sometimes while the welds are being made.
  – Develops at high temperatures
  – Propagates between the grains of the material (intercrystalline)
  – Occurs in the weld metal & sometimes in HAZ.
• “solidification crack” (weld metal)
• “liqueation crack” (HAZ)
HOT CRACKS

Cause:

• High residual stresses in weld metal
• Low weld ductility
• Too high welding current
• High thickness of work piece (thicker the work piece, faster the cooling rate)
• high ratio of S &P with low Mn content, high C & Ni content (high harden ability
HOT CRACKS

Prevention:
• Controlling composition of the metal (S<0.007%) to be welded
• Using filler metal with proper composition & low tensile strength
• Pre-heat
  • reduces rate of cooling
  • not essential for Aus.SS (martensite does not occur).

Repair:
• Remove and re-weld
COLD CRACK

- Occurs after the metal has completely solidified (at temp -100°C to 200°C)
- Can occur several days after weld
- Occurs in C-steel, low & high alloy steel
  - propagates both between grains and through grains.
  - often associated with non-metallic inclusion (elongated MnS).
  - occurs in both weld metal and HAZ but generally in HAZ
COLD CRACK

Adjacent plate is transformed to austenite when heated by welding; hydrogen is soluble in this region.

This region remains as ferrite which has no solubility for hydrogen.

Difficult for hydrogen to diffuse any farther.

movement of H₂ during arc welding
COLD CRACK

Cause-

- Hydrogen pick up during welding
  - Source of hydrogen:
    - Moisture in base metal & welding electrodes
    - Surface contaminated with organic substances
    - Surrounding atmospheres
  - Phase changes (e.g. formation of martensite) during cooling

Prevention:

- Controlling welding parameters:
  - proper pre-heating:
    - reduces diffusion of H₂
    - ensures no moisture
  - Post-welding treatment:
    - stress relief.
COLD CRACK

• Clean joint from rust

• Use proper welding processes and consumables:
  – Low strength filler metals.
  – Use low hydrogen type baked electrode

Repair:
  – Remove and reweld.
CRATER CRACK/STAR CRACK

“A depression left in weld metal where the arc was broken or the flame was removed or electrode was changed”.

• They are hot cracks
• Occurs at the crater of the weld
  – usually star shaped, but may have other shapes.
  – most frequently found in austenitic SS (high thermal coeff).

![Diagram of weld metal with star-shaped cracks]
CRATER CRACK/STAR CRACK

Cause:
• The center of weld pool becomes solid before the outside, pulling the center apart during cooling.
• High current (deep crater)

Prevention:
• can be minimised by filling craters to a slightly convex shape prior to breaking the welding arc.
• may be avoided through improved welding skill

Repair:
– remove and reweld using appropriate procedure.
POROSITIES/BLOW HOLES

“Porosity is a group of small voids, where as blow holes are comparatively bigger hole or cavity caused by entrapment of gases [gases: \( H_2, CO, CO_2, N_2 \& O_2 \) from coating ingredients in the electrode or moisture, oil, grease, rust, etc on BM] within the solidified weld”.

- Porosity can occur on or just below the surface of a weld.
- Porosity in the weld and HAZ may lead to cracking.
Gas porosity or blow holes

cluster porosity
BLOW HOLES / POROSITIES

**Cause:**

- Work piece or electrode contains/contaminated with:
  - High sulphur & carbon
  - Excessive moisture, rust or scale, oil, grease, etc
- Atmospheric gases \([\text{N}_2, \text{excessive } \text{O}_2 (\text{Al-welding})]\)
- Anodising coating on Al (contains moisture)
- Long arc
- Fast solidification rate

**Prevention:**

- Preheat
- Maintain proper arc length
- Use low hydrogen electrode
- Use recommended procedure for baking & storing electrodes
- Clean joint surfaces & adjacent surfaces
UNDER CUT

“A defect that appears as a groove formed in the BM adjacent to the toe of a weld along the edge of the weld & left unfilled by the weld metal”.

• Generally located parallel to the junction of weld metal & base metal at the toe or root of the weld
• Reduces the cross-sectional thickness of the base metal
• Acts as stress raiser in fatigue loading
UNDER CUT

Cause:
• High welding current & arc voltage
• Too large electrode dia
• Incorrect electrode angle
• Longer arc length

Prevention:
• Use prescribed welding current for electrode size.
• Adjust electrode angle to fill undercut area.
• Correct travel speed, arc length, etc.

Repair:
• Gouge & weld with low hydrogen electrode
OVER LAPS

“An imperfection at the toe of weld caused by over flow of weld metal on the surface of parent metal without fusion” (protruded weld metal beyond the toe)

• Tends to produce mechanical notch
• Starts a crack at the sharp point where the weld metal and base metal come together at the over-lapped surface
OVERLAPS

Cause:-
– current too low
– Too large deposition in a single run
– Longer arc
– slow arc travel speed.

Prevention:
– Proper welding technique
– Use proper size of electrode

Repair:
– Overlap must be removed to blend smoothly into the base metal.
LACK OF PENETRATION

“Improper penetration of weld metal through the thickness of joint or weld metal not extending to the required depth into the joint root”

• Acts as stress riser from which a crack may propagate
LACK OF PENETRATION

Cause –
• Root gap too small
• High welding speed
• Low heat input
• Too large electrode dia

Prevention:
• Proper joint preparation
• Proper heat input & welding speed
• Use suitable size of electrode

Repair:
• Back gouge and back weld or remove and reweld.
LACK OF FUSION

“Lack of complete melting/fusion of some portion of the weld metal in a joint”

- May be at the root, sides or between two runs.
- Reduces the strength of welds & makes welded structures unreliable
LACK OF FUSION

lack of fusion between passes
LACK OF FUSION

Cause:
• Low welding current
• Excess welding speed
• Unfavourable heat input

Prevention:
• Maintain proper current & welding speed
• Proper cleaning of each bead

Repair:
• Chipping back & re-welding
EXCESSIVE PENETRATION/ICICLES

“Weld metal lying outside the plane joining the toes”

• Makes notches that create stress concentration.
• An economic waste

Cause :-

• Too wide a root gap
• Too high welding current
• Slow travel speeds
• Large size electrodes
EXCESSIVE PENETRATION/ICICLES

Prevention:
– Correct the root opening and root face
– Reduce the wire-feed speed

Repair:
– Remove and re-weld
SPATTER

“Small globular metal drops / particles thrown out during welding & stick to the BM surfaces along its length”.

• Metal lost
• Do not form a part of the weld.
• Excessive spatters unacceptable.
SPATTER

Cause –

– Excessive arc current
– Excessive long arc
– Improper shielding gas
– Electrodes coated with improper flux ingredients
– Damp electrodes

Prevention:

– Correct welding current for type & size electrode used.
– Correct proper arc length & use correct arc voltage
– Spatter cure SC-07 (Non-toxic, non-pollutant, water-based inorganic anti–spatter flux)
– can easily be removed either by hair brush or by washing.

Repair:

– Remove by grinding or sanding.
INCLUSION

“Metallic or nonmetallic solid material entrapped within the WM, between weld passes or between WM & BM”.

• May be in the form of slag or any other foreign material, which does not get a chance to float on the surface of the solidifying WM
• H$_2$: the most undesirable inclusion (causing: cold crack)
• Lowers the strength of joint & make it weaker
• Non- metallic inclusion:-
  – Most dangerous
  – May be sulphide, oxide, silicate or aluminate type
  – Acts as stress raiser
• Slag inclusions are elongated or globular pockets of metallic oxides and other solid compounds.
INCLUSION

Slag inclusion

Sand inclusions

Slag inclusion

Oxide inclusions
INCLUSION

Possible causes for slag inclusion:
- Inadequate cleaning of weld metal between passes
- Rapid rate of welding
- Too large electrode
- Improper current
- Long arcs

Prevention:
- Maintain proper current & heat input
- Proper cleaning of weld

Repair:
- Chip back & re-weld
METALLIC INCLUSION

Entrapped droplets of tungsten in welds in TIG welding.
– extremely brittle & can fracture easily under stress.

Cause –
• Dipping of tungsten electrode into molten weld pool
• Use of heavy current
• Over heating & melting of W-electrode
• Use of oxygen contaminated shielding gas

Prevention:
• Avoid contact between the electrode & the work
• Use larger electrode

Repair: Grind out and re-weld
METALLIC INCLUSION

W-inclusion

TIG WELDING
ARC STRIKE

“Localised HAZ”

When a welder accidentally strikes the electrode or the electrode holder against the work, usually adjacent to the weld, causing an unwanted arc. Such spots are referred to as “arc strikes” which can initiate failure in bending or cyclic loading

- Must be avoided
- The repair of such damage may be difficult & costly, involving chipping & pre heating before re welding
- If this is not an option then the arc spot can be post heated
“Linear slag inclusions along the axis of weld”

Cause:

– Improper technique

Prevention:

– remove slag from previous passes.
BURN-THROUGH

“The holes burned through the parent metal in a single pass weld or the root run in multi run welds”

• seldom occurs

Cause:-

• Excessive welding current with low welding speed
• Insufficient root face
• Excessive root gap

Repair:

• Remove and re-weld
• PWHT

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SHRINKAGE CAVITY or CONTRACTION CAVITY

“A cavity formed by shrinkage of weld metal during its solidification”.

– Seldom occurs