KEMPPI Welding Technology Course

Weld defects, their Causes & Remedies

R.Banerjee
Two Major Aspects of Fusion Welding

- Effects of welding
- Defects of welding
Effects of welding are those which will always happen when we weld –

- Residual stresses
- Distortion
- Formation of HAZ with metallurgical changes
Defects of Welding

- Defects are those which can be theoretically eliminated, such as –
- Cracks, Lack of Fusion, slag inclusions, porosity and undercuts
- Only when we understand the nature of these defects and why they occur, can we eliminate them
Discontinuities & Defects

**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 but all defects are discontinuities.

**Defect**
- A defect is a rejectable discontinuity, which occurs in an amount great enough to render a particular object or structure unsuitable for its intended service based on criteria in the applicable code.
Classification of Defects

- **Planar defects / Two dimensional defects** -- E.g. cracks, lack of fusion, lack of penetration, are critical in nature and are not tolerated to any extent.

- **Volumnar defects / Three dimensional defects** -- E.g. slag inclusion, cavities, porosities, etc are tolerated to a certain extent depending on the product class and applicable code.

- **Geometric defects** -- E.g. excess reinforcement, underfill, root suckback, distortion are also permitted to a certain extent.
Types of Defects

- External defects
- Internal defects
- Dimensional defects
External defects

- Undercut
- External Cracks
- External Blowhole and porosity
- Slag sticking
- Edge of the plate melted off
- Excessive convexity/oversized weld/ Excessive Reinforcement
- Excessive Concavity/Insufficient Throat thickness/ Insufficient fill
External Defects contd.

- Incomplete Root penetration /Lack of penetration
- Excessive Root penetration
- Overlap
- Mismatch
- Uneven/Irregular bead appearance
- Spatters
- Suck back
Internal defects

- Cracks
- Blowhole and porosity
- Slag Inclusions
- Lack of fusion
- Lack of Root penetration
- Tunsten inclusion
- Laminations
Dimensional defects

- Distortion
- Incorrect Joint Penetration
- Incorrect Weld Size
- Incorrect Weld Profile
- Misalignment
Failure of Pressure Vessel during Hydro-test
External Defects
A groove melted into the base metal adjacent to the WELD TOE OR WELD ROOT AND LEFT UNFILLED by weld metal
Typical Appearance of Undercut
Undercut Adjacent to Fillet Weld
Undercut
Overlap

The projection of weld metal beyond the weld toe or weld root
Overlap Examples
Overlap
Undercut & Overlap

- Undercut
- Overlap
Lack Of Penetration

Lack Of Penetration - shallow fusion between weld metal and base metal.

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improper joint preparation.</td>
<td>Material too thick. Joint preparation and design must provide access to bottom of groove.</td>
</tr>
<tr>
<td>Improper weld technique.</td>
<td>Keep arc on leading edge of weld puddle.</td>
</tr>
<tr>
<td></td>
<td>Reduce travel speed.</td>
</tr>
<tr>
<td>Insufficient heat input.</td>
<td>Increase amperage. Select larger electrode and increase amperage.</td>
</tr>
</tbody>
</table>
Lack Of Penetration

Inadequate or Lack of Penetration
Examples Of Lack Of Penetration
Excessive Penetration

Weld metal melting through Base Metal and hanging below weld
Excessive Penetration
Burn-through

Definition: When an undesirable open hole has been completely melted through the base metal. The hole may or may not be left open.

Cause: Excessive heat input.

Prevention: Reduce heat input by increasing travel speed, use of a heat sink, or by reducing welding parameters.

Repair: Will be defined by standards. Filling may suffice. Otherwise, removal and re-welding may be required.
Burn-through
Excessive Reinforcement

**Definition:** Specifically defined by the standard. Typically, Reinforcement should be flush to 1/16” (pipe) or flush to 1/8” (plate or structural shapes).

**Cause:** Travel speed too slow, amperage too low

**Prevention:** Set amperage and travel speed on scrap plate.

**Repair:** Remove excessive reinforcement and feather the weld toes to a smooth transition to the base plate.
Excessive weld reinforcement
Excessive reinforcement
**Insufficient Reinforcement**

**Definition:** Specifically defined by the standard. Typically, Underfill may be up to 5% of metal thickness, not to exceed 1/32” as long as the thickness is made up in the opposite reinforcement. Not applied to fillet welds.

**Cause:** On root reinforcement - Too little filler metal will cause thinning of the filler metal. In OH position, too hot or too wide will cause drooping of the open root puddle.

**Prevention:** Use proper welding technique. Use backing or consumable inserts. Use back weld or backing.

**Repair:** Possibly simply increase the face reinforcement. If back welding is not possible, must remove and reweld.
Insufficient reinforcement
Insufficient Fill on the Root Side (Suck back)

**Definition:** The weld surface is below the adjacent surfaces of the base metal at the weld root.

**Cause:** Typically improper joint preparation or excessive weld pool heat.

**Repair:** Back weld to fill. May require removal of weld section by grinding for access to the joint root.
Suck back
Spatter

**Definition:** Small particles of weld metal expelled from the welding operation which adhere to the base metal surface.

**Cause:** Incorrect welding parameters, high amperages, long arc length, damp electrodes

**Prevention:** Correct the cause.

**Repair:** Remove by chipping, grinding or sanding.
Spatter and Slag Inclusion
Scattered Surface Porosity
Dimensional Defects
**Misalignment (hi-lo)**

**Definition:** Amount a joint is out of alignment at the root

**Cause:** Carelessness. Also due to joining different thicknesses (transition thickness)

**Prevention:** Good Workmanship.

**Repair:** Grinding. Careful on surface finish and direction of grind marks.
Convexity
Excessive Concavity or Convexity

**Definition:** Concavity or convexity of a fillet weld which exceeds the specified allowable limits

**Cause:** Amperage and travel speed

**Prevention:** Observe proper parameters and techniques.

**Repair:** Grind off or weld on. Must blend smoothly into the base metal.
Internal Defects
Crack

- A fracture type discontinuity
- Characterised by a sharp tip and high ratio of length to width (depth)
Cracks

- Longitudinal
- Transverse
- Crater
- Throat
- Toe
- Root
- Under bead and Heat-affected zone
- Hot
- Cold or delayed
Longitudinal Crack
Transverse Crack
Toe Crack
Cracks
Underbead Cracks
Hot cracking in welds

- Hot cracking or solidification cracking is caused due to low melting eutectics formed at the grain boundary.
- As the weld solidifies, in combination with shrinkage stresses, leads to cracks in fully austenitic welds.
- Promoted by S, P, Nb, Ti, N etc.
- Also prevented by reducing heat input and controlling design stress.
Cold cracking generally occurs in the HAZ of the base material next to the weld.

Also called Hydrogen induced cold Cracking (H ICC), delayed cracking or HAZ cracking.

Most significant weldability problem in carbon – manganese and low alloy steels.
# Base metal cracking

<table>
<thead>
<tr>
<th>Possible Causes</th>
<th>Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2 in atmosphere</td>
<td>Use low H2 welding process; Post heating or post weld heat treat immediately</td>
</tr>
<tr>
<td>Hot cracking</td>
<td>Use low heat input; deposit thin layers;</td>
</tr>
<tr>
<td>Low ductility</td>
<td>Use preheat; anneal the base metal</td>
</tr>
<tr>
<td>High residual stresses</td>
<td>Redesign the weldment; change welding sequence; apply intermediate stress relief heat treatment</td>
</tr>
<tr>
<td>High hardenability</td>
<td>Preheat; increase heat input; heat treat without cooling to room temperature</td>
</tr>
</tbody>
</table>
Incomplete Fusion

• Definition: Where weld metal does not form a cohesive bond with the base metal.

• Cause: Low amperage, steep electrode angles, fast travel speed, short arc gap, lack of preheat, electrode too small, unclean base metal.

• Prevention: Eliminate the potential causes.

• Repair: remove and reweld, being careful to completely remove the defective area. This is sometimes extremely difficult to find.
Incomplete Fusion
Incomplete Fusion
Incomplete Fusion

Incomplete Fusion – failure of weld metal to fuse completely with base metal or a preceding weld bead.

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<th>Possible Causes</th>
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<tbody>
<tr>
<td>Insufficient heat input.</td>
<td>Increase amperage. Select larger electrode and increase amperage.</td>
</tr>
<tr>
<td>Improper welding technique.</td>
<td>Place stringer bead in proper location(s) at joint during welding.</td>
</tr>
<tr>
<td></td>
<td>Adjust work angle or widen groove to access bottom during welding.</td>
</tr>
<tr>
<td></td>
<td>Momentarily hold arc on groove side walls when using weaving technique.</td>
</tr>
<tr>
<td></td>
<td>Keep arc on leading edge of weld puddle.</td>
</tr>
<tr>
<td>Workpiece dirty.</td>
<td>Remove all grease, oil, moisture, rust, paint, coatings, slag, and dirt from work surface before welding.</td>
</tr>
</tbody>
</table>
Lack of Fusion
Sequence of runs – Good Practices

- Difficult to clean
- Easy to clean
Lack of Fusion
Porosity - Types

Porosities are gas pores found in the solidified weld bead.

- Single Pore
- Uniformly Scattered
- Cluster
- Linear
Porosity
Clustered Porosity
Slag Inclusion

**Definition:** Slag entrapped within the weld

**Cause:** Low amperage, improper technique, Trying to weld in an area that is too tight. Improper wire brushing / cleaning between passes.

**Prevention:** Increase amperage or preheat, grind out tight areas to gain access to bottom of joint.

**Repair:** Remove by grinding. Reweld.
Slag inclusion
**Tungsten Inclusion**

**Definition:** A tungsten particle embedded in a weld. (Typically GTAW only)

**Cause:** Tungsten electrode too small, amperage too high, electrode dipped into the weld pool or touched with the fill rod.

**Prevention:** Thoriated or Zirconiated tungsten electrodes are used in place of pure tungsten electrodes.

**Repair:** Grind out and reweld
Tungsten inclusion
Laminations

- Base Metal Discontinuity
- May require repair prior to welding
- Formed during the milling process
Lamellar Tearing

- Is generally associated with welding of fairly large highly restrained structures
- Occurs predominantly in plate material
- Due to presence of non-metallic inclusions
- Difficult to detect by NDT techniques. Maybe assessed by STRA of tensile test in short transverse direction
- Cracks can occur in parent plate / HAZ and generally run parallel to the plate surface
# Identification and Characterisation of Defects

- **Destructive Tests**
  - Tensile Test
  - Macro Test
  - Charpy Test
  - Fracture Test
  - Bend Test

- **Non-destructive Testing**
  - Ultrasonic Test (UT)
  - Magnetic Particle Test (MPT)
  - Liquid Penetrant Test (LPT)
  - Radiography Test (RT)
  - Visual Test (VT)
Acceptance levels of Defects
Defects and their Limits as per ISO 5817 -2003

<table>
<thead>
<tr>
<th>No.</th>
<th>Reference to ISO 6520-1:1998</th>
<th>Imperfection designation</th>
<th>Remarks</th>
<th>( r ) mm</th>
<th>Limits for imperfections for quality levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>1.1</td>
<td>100</td>
<td>Crack</td>
<td>—</td>
<td>( \geq 0.5 )</td>
<td>Not permitted</td>
</tr>
<tr>
<td>1.2</td>
<td>104</td>
<td>Crater crack</td>
<td>—</td>
<td>( \geq 0.5 )</td>
<td>Not permitted</td>
</tr>
<tr>
<td>1.3</td>
<td>2017</td>
<td>Surface pore</td>
<td>Maximum dimension of a single pore for — butt welds</td>
<td>0.5 to 3</td>
<td>( d \leq 0.3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>— fillet welds</td>
<td></td>
<td>( d \leq 0.3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maximum dimension of a single pore for — butt welds</td>
<td></td>
<td>( d \leq 0.3 ), but max. 3 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>— fillet welds</td>
<td></td>
<td>( d \leq 0.2 ), but max. 2 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( &gt; 3 )</td>
<td></td>
<td>( d \leq 0.2 ), but max. 2 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( h \leq 0.1 ), but max. 1 mm</td>
</tr>
<tr>
<td>1.4</td>
<td>2025</td>
<td>End crater pipe</td>
<td>( h \leq 0.2 \ ( r ) )</td>
<td>0.5 to 3</td>
<td>Not permitted</td>
</tr>
<tr>
<td>1.5</td>
<td>401</td>
<td>Lack of fusion (incomplete fusion)</td>
<td>—</td>
<td>( \geq 0.5 )</td>
<td>Not permitted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micro lack of fusion</td>
<td>Only detectable by micro examination</td>
<td></td>
<td>Permitted</td>
</tr>
<tr>
<td>1.6</td>
<td>4021</td>
<td>Incomplete root penetration</td>
<td>Only for single side butt welds</td>
<td>( \geq 0.5 )</td>
<td>Short imperfections: ( h \leq 0.2 \ ( r ) ), but max. 2 mm</td>
</tr>
</tbody>
</table>
### Table 1 (continued)

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<tr>
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<th>Remarks</th>
<th>( t ) mm</th>
<th>Limits for imperfections for quality levels</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>1.7</td>
<td>5011</td>
<td>Continuous undercut</td>
<td>Smooth transition is required. This is not regarded as a systematic imperfection.</td>
<td>0.5 to 3</td>
<td>Short imperfections: ( h \leq 0.2 t )</td>
</tr>
<tr>
<td></td>
<td>5012</td>
<td>Intermittent undercut</td>
<td></td>
<td></td>
<td>( h \leq 0.2 t, \text{ but max. } 1 \text{ mm} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( h \leq 0.05 r, \text{ but max. } 0.5 \text{ mm} )</td>
</tr>
<tr>
<td>1.8</td>
<td>5013</td>
<td>Shrinkage groove</td>
<td>Smooth transition is required.</td>
<td>0.5 to 3</td>
<td>( h \leq 0.2 \text{ mm} + 0.1 r )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( h \leq 0.05 r, \text{ but max. } 0.5 \text{ mm} )</td>
</tr>
<tr>
<td>1.9</td>
<td>502</td>
<td>Excess weld metal (butt weld)</td>
<td>Smooth transition is required.</td>
<td>( \leq 0.5 )</td>
<td>( h \leq 1 \text{ mm} + 0.25 h, \text{ but max. } 10 \text{ mm} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( h \leq 1 \text{ mm} + 0.1 h, \text{ but max. } 5 \text{ mm} )</td>
</tr>
</tbody>
</table>
Guidance on Quality Levels for Imperfections – ISO 5817 - 2003

<table>
<thead>
<tr>
<th>Level Symbol</th>
<th>Quality Levels for weld imperfections</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Moderate</td>
</tr>
<tr>
<td>C</td>
<td>Intermediate</td>
</tr>
<tr>
<td>B</td>
<td>Stringent</td>
</tr>
<tr>
<td>Discontinuity Category &amp; Inspection Criteria</td>
<td>Static Loaded (Nontubular)</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Underrun - In fillet weld upto 1.6 mm subject to it does not exceed 10% of the weld length. No underun is permitted for web-to-flange welds of girder</td>
<td>Applicable</td>
</tr>
<tr>
<td>Undercut - Upto 1 in. not to exceed 1mm. For an accumulated length of 2 inch in any 12 inch for material above 1 in. Undercut above 1.6 mm not allowed.</td>
<td>Applicable</td>
</tr>
<tr>
<td>Porosity - No porosity in the butt weld traverse to tensile strength. In other butt welds and for fillet weld the size of 1 mm in linear inch of weld and shall not exceed 19 mm in 12 in length of weld</td>
<td>Applicable</td>
</tr>
<tr>
<td>Porosity - In fillet weld the frequency of porosity shall not exceed one in 100 mm of weld length and the maximum diameter shall not to exceed 2 mm.</td>
<td>Not-Applicable</td>
</tr>
</tbody>
</table>
# Visual Inspection Acceptance Criteria

<table>
<thead>
<tr>
<th>Discontinuity Category &amp; Inspection Criteria</th>
<th>Static Loaded (Nontubular)</th>
<th>Dynamic Loaded (Nontubular)</th>
<th>All Loads (Tubular)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crack - The weld shall have no crack</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Weld/Base-Metal Fusion - Through fusion shall exist between weld metal to weld metal and base metal</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Crater - All crater shall be filled up to the full cross section except for the ends of the intermittent fillet welds outside the effective length</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Weld Profiles - Weld profiles shall be in conformance to 5.24</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Time of Inspection - Immediately after the completed weld reaches the ambient temp. For ASTM A514, A517, A709 not less than 48 Hrs.</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
</tbody>
</table>
Thank You