Defects and Discontinuities

Tim Turner
Elizabethtown Technical College
Defect

- A flaw or flaws that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. The term designates rejectability.
Discontinuity

• An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.
# Weld Joint Discontinuities

- **Misalignment** (hi-lo)
- **Undercut**
- **Underfill**
- **Concavity or Convexity**
- **Excessive reinforcement**
- **Improper reinforcement**
- **Overlap**
- **Burn-through**
- **Incomplete or Insufficient Penetration**
- **Incomplete Fusion**
- **Surface irregularity**
  - Overlap
- **Arc Strikes**

- **Inclusions**
  - Slag
  - Wagontracks
  - Tungsten

- **Spatter**

- **Arc Craters**

- **Cracks**
  - Longitudinal
  - Transverse
  - Crater
  - Throat
  - Toe
  - Root
  - Underbead and Heat-affected zone
  - Hot
  - Cold or delayed

- **Base Metal Discontinuities**
  - Lamellar tearing
  - Laminations and Delaminations
  - Laps and Seams

- **Porosity**
  - Uniformly Scattered
  - Cluster
  - Linear
  - Piping

- **Heat-affected zone microstructure alteration**

- **Base Plate laminations**

- **Size or dimensions**
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:** Workmanship. Transition angles not to exceed 2.5 to 1.

- **Repair:** Grinding. Careful on surface finish and direction of grind marks. Inside of Pipe /Tube difficult.
Undercut

- **Definition:** A groove cut at the toe of the weld and left unfilled.

- **Cause:** High amperage, electrode angle, long arc length, rust

- **Prevention:** Set machine on scrap metal. Clean metal before welding.

- **Repair:** Weld with smaller electrode, sometimes must be low hydrogen with preheat. Sometimes must gouge first.
Undercut

(cont......)

Undercut typically has an allowable limit. Different codes and standards vary greatly in the allowable amount.

Plate - the lesser of 1/32” or 5% (typ.)
Insufficient Fill

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

- Cause: Improper welding techniques

- Prevention: Apply proper welding techniques for the weld type and position. Use stripper beads before the cover pass.

- Repair: Simply weld to fill. May require preparation by grinding.
Insufficient Fill on the Root Side (suckback)

- 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.
- Prevention: Correct cause. (see next slide)
- Repair: Backweld to fill. May require removal of weld section by grinding for access to the joint root.
Cause for Insufficient Fill at the Root

Some liquids, like water or molten steel, try to cover as much surface area of whatever they are in contact with as possible.

Welding a root pass too wide can also cause the bead to sag (overhead position).
Removing a root pass by grinding

1. Recreate the groove geometry as closely as possible.

2. Use a saw or die grinder and 1/16 - 1/8” cut off wheel to recreate root opening. Remember repairs are sometimes required to be made with a smaller electrode.

3. Open the groove angle. Be careful to leave the proper root face dimension.

4. Feather the start and stop to blend smoothly into and out of the existing weld.
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.
Convexity
Reinforcement
The amount of a groove weld which extends beyond the surface of the plate

- Excessive
- Insufficient
- Improper contour

Face Reinforcement
Root Reinforcement
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.
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 backwelding is not possible, must remove and reweld.
Improper Weld Contour

- **Definition:** When the weld exhibits less than a $135^0$ transition angle at the weld toe.

- **Cause:** Poor welding technique.

- **Prevention:** Use proper techniques. A weave or whip motion can often eliminate the problem.

- **Repair:** The weld face must be feathered into the base plate.
Overlap

• Definition: When the face of the weld extends beyond the toe of the weld

• Cause: Improper welding technique. Typically, electrode angles and travel speed.

• Prevention: Overlap is a contour problem. Proper welding technique will prevent this problem.

• Repair: Overlap must be removed to blend smoothly into the base metal. Be careful of deep grind marks that run transverse to the load. Also be careful of fusion discontinuities hidden by grinding. Use NDT to be sure.
Overlap

Overlap is measured with a square edge such as a 6” rule. No amount of overlap is typically allowed.
Burn-through (non-standard)

• 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 rewelding may be required. Some standards may require special filler metal and/or PWHT.
Incomplete or Insufficient Penetration

• Definition: When the weld metal does not extend to the required depth into the joint root

• Cause: Low amperage, low preheat, tight root opening, fast travel speed, short arc length.

• Prevention: Correct the contributing factor(s).

• Repair: Back gouge and back weld or remove and reweld.
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, arc off seam.

• Prevention: Eliminate the potential causes.

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

- Definition: A localized coalescence outside the weld zone.

- Cause: Carelessness

- Prevention: In difficult areas, adjacent areas can be protected using fire blankets.

- Repair: Where applicable, arc strikes must be sanded smooth and tested for cracks. If found, they must be remove and repaired using a qualified repair procedure and inspected as any other weld.
Inclusions

• Slag
• Wagontracks
• Tungsten
Slag Inclusion

• Definition: Slag entrapped within the weld

• Cause: Low amperage, improper technique, Trying to weld in an area that is too tight. Slow travel in Vertical Down

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

• Repair: Remove by grinding. Reweld.
Wagon Tracks (non-standard)

- Definition: Slang term for a groove left at the toe of a root pass which becomes filled with slag and is trapped in the weld.
- Cause: The contour of the root pass is too high, or the weld toe is not bonded to the base metal
- Prevention: Use proper technique to deposit the weld root.
- Repair: Best repaired before applying the hot pass. Carefully grind the root pass face flat. Be careful not to gouge other areas on the weldment.
Tungsten Inclusion

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

- Cause: Tungsten electrode too small, amperage too high, AC balance on +, Upslope too high, electrode tip not snipped, electrode dipped into the weld pool or touched with the fill rod, electrode split.

- Prevention: Eliminate the cause

- Repair: Grind out and reweld
Inclusions

• fix when you see it. otherwise grind out & fix
Whiskers

• Unsightly
• Inhibits material flow in piping
• Are inclusions
• Can break off in pipes and damage equipment downline
Spatter

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

• Cause: Long arc length, severe electrode angles, high amperages.

• Prevention: Correct the cause. Base metal can be protected with coverings or hi-temp paints.

• Repair: Remove by grinding or sanding. Sometimes must be tested as if it were a weld.
Arc Craters

• Definition: A depression left at the termination of the weld where the weld pool is left unfilled.

• Cause: Improper weld termination techniques

• Prevention:

• Repair: If no cracks exist, simply fill in the crater. Generally welding from beyond the crater back into the crater.
Cracks

- Longitudinal
- Transverse
- Crater
- Throat
- Toe
- Root
- Underbead and Heat-affected zone
- Hot
- Cold or delayed
Longitudinal Crack

• Definition: A crack running in the direction of the weld axis. May be found in the weld or base metal.

• Cause: Preheat or fast cooling problem. Also caused by shrinkage stresses in high constraint areas.

• Prevention: Weld toward areas of less constraint. Also preheat to even out the cooling rates.

• Repair: Remove and reweld
Transverse Crack

• Definition: A crack running into or inside a weld, transverse to the weld axis direction.

• Cause: Weld metal hardness problem

• Prevention:

• Repair:
Crater Crack

- Definition: A crack, generally in the shape of an “X” which is found in a crater. Crater cracks are hot cracks.
- Cause: The center of the weld pool becomes solid before the outside of the weld pool, pulling the center apart during cooling
- Prevention: Use crater fill, fill the crater at weld termination and/or preheat to even out the cooling of the puddle
- Repair:
Throat Crack

• Definition: A longitudinal crack located in the weld throat area.

• Cause: Transverse Stresses, probably from shrinkage. Indicates inadequate filler metal selection or welding procedure. May be due to crater crack propagation.

• Prevention: Correct initial cause. Increasing preheat may prevent it. Be sure not to leave a crater. Use a more ductile filler material.

• Repair: Remove and reweld using appropriate procedure. Be sure to correct initial problem first.
Toe Crack

• Definition: A crack in the base metal beginning at the toe of the weld

• Cause: Transverse shrinkage stresses. Indicates a HAZ brittleness problem.

• Prevention: Increase preheat if possible, or use a more ductile filler material.

• Repair:
Root Crack

• Definition: A crack in the weld at the weld root.

• Cause: Transverse shrinkage stresses. Same as a throat crack.

• Prevention: Same as a throat crack

• Repair:
Underbead Crack

- Definition: A crack in the unmelted parent metal of the HAZ.
- Cause: Hydrogen embrittlement
- Prevention: Use Lo/Hi electrodes and/or preheat
- Repair: (only found using NDT). Remove and reweld.
Hot Crack

- **Definition:** A crack in the weld that occurs during solidification.

- **Cause:** Micro stresses from weld metal shrinkage pulling apart weld metal as it cools from liquid to solid temp.

- **Prevention:** Preheat or use a low tensil filler material.

- **Repair:**
Cold Crack

- **Definition:** A crack that occurs after the metal has completely solidified

- **Cause:** Shrinkage, Highly restrained welds, Discontinuities

- **Prevention:** Preheat, weld toward areas of less constraint, use a more ductile weld metal

- **Repair:** Remove and reweld, correct problem first, preheat may be necessary.
Repairs to Cracks

• Determine the cause
• Correct the problem
• Take precautions to prevent reoccurrence
• Generally required to repair using a smaller electrode
Base Metal Discontinuities

- Lamellar tearing
- Laminations and Delaminations
- Laps and Seams
Laminations

- Base Metal Discontinuity
- May require repair prior to welding
- Formed during the milling process
Lamination effects can be reduced by joint design:
Delaminations
Laps and Seams

A mill-induced discontinuity in which results from a lump of metal being squeezed over into the surface of the material.

If beyond acceptable limits, must be removed and repaired or discarded.
Porosity

- Single Pore
- Uniformly Scattered
- Cluster
- Linear
- Piping
Single Pore

• Separated by at least their own diameter along the axis of the weld
Uniformly Scattered Porosity

• Typically judged by diameter and proximity to a start or stop
• Often caused by low amperage or short arc gap or an unshielded weld start
Cluster Porosity

- Typically viewed as a single large discontinuity
Linear Porosity

- being linear greatly affects the severity of this discontinuity
Piping Porosity

• Generally has special allowable limits
Porosity

- preheat will help eliminate
- may need an electrode with more deoxidizers
- Use run-on/run-off taps
- restart on top of previous weld and grind off lump
Heat-affected zone microstructure alteration

• add drawing of HAZ of groove weld with leaders to:
  – grain refinement
  – grain growth
  – hardened areas
  – softened areas
  – precipitate susceptible areas.
Size or dimension

• If it renders the part unusable, it is a defect.
• If it is outside the allowable limit, it renders the part unusable.
• Things don’t have to be perfect, just within the acceptable tolerance. Working to perfection is too time consuming and costly
Hammer marks

- Stress risers
- Unsightly
- Unnecessary
REPAIR TECHNIQUES

• May involve:
  – different process
  – different procedure
  – different preheat/PWHT
  – different electrode
  – smaller electrode
Only repair defects. Discontinuities are, by definition, acceptable. Repair is therefore unnecessary and not cost effective.
Inspection Tools
Fillet Weld Size - For equal leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.
Fillet size is difficult to measure without gages.

Convex fillet  Concave fillet  Flat fillet

Fibre Metal Fillet Gage
There Are 2 Types of Gages

1. To measure
   Concave fillets
   - Gages against throat to measure useful leg size
   - 5/16"

2. To measure
   Convex fillets
   - Measures actual useful leg size
   - 5/16"

Fibre Metal Fillet Gage
Measuring Convex Fillets

RIGHT
Measure the smaller of two legs for a true indication of fillet size

WRONG
Measuring the larger of two legs gives a false indication of fillet size

Gage for convex fillets

1/4"

5/16"

Gage for convex fillets

Fibre Metal Fillet Gage
WRONG  not 3/8"
Do not use gage for convex fillets on concave fillets

RIGHT  5/16" fillet
5/16" isosceles right triangle can be inscribed within weld cross section

3/8"

5 1/16"
Gage for convex fillets

Fibre Metal Fillet Gage
Measuring Concave Fillets

WRONG  Not 5/16"
Do not use gage for convex fillets on concave fillets

RIGHT
1/4" isosceles right triangle can be inscribed within weld cross-section

5/16" Gage for concave fillets
Measuring 45° Flat Fillets With Equal Legs
(Ideal Fillet Shape)

Either type gage can be used.
Measuring Fillets When Shape Is Not Apparent

Check with both type gages to determine true size.

WRONG
This gage indicates fillet size is greater than 5/16"
this is incorrect

RIGHT
Correct size 5/16"

In this example – Gage for concave fillets touches bottom leg, before it touches vertical plate. Bottom leg is larger than vertical leg. The important thing is to:

1. check with both gages and
2. check both legs with the convex gage

Fibre Metal Fillet Gage
CONVEX WELDS

CONCAVE WELDS

Fibre Metal Fillet Gage
Undercut Gauge

Checks undercut depth

Checks amount of porosity per linear inch

Checks porosity comparison

Checks crown height

Gal Gage Co.
Palmgrin Gauge

1. TO DETERMINE THE SIZE OF A FILLET WELD

Place the gauge against the toe of the fillet weld and slide pointer out until it touches structure as shown. Read "Size of the Fillet Weld" on face of gauge as indicated by arrow.

2. TO CHECK THE PERMISSIBLE TOLERANCE OF CONVEXITY

After the size of a convex weld has been determined, place the gauge against the structure and slide pointer until it touches face of fillet weld as shown. The maximum convexity should not be greater than indicated by "Maximum Convexity Scale" as indicated by arrow for the size of fillet being checked.

3. TO CHECK THE PERMISSIBLE TOLERANCE OF CONCAVITY AND UNDERFILL

Place gauge against structure and slide pointer out until it touches the face of the fillet weld as shown. If the pointer does not touch as shown, the fillet requires additional weld metal.

4. TO CHECK THE PERMISSIBLE TOLERANCE OF REINFORCEMENT

Place gauge so that reinforcement will come between legs of gauge and slide pointer out until it touches the face of weld as shown.
Magnifying Glass

Used to read small scales
Flashlight

Used to cast shadows to find porosity, undercut and overlap.