• Is
  ▪ 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.
Defect

- Is
  - a flaw or flaws
  - by nature or accumulated effect renders a part or product unable to meet minimum applicable acceptance standards or specifications.
  - the term designates rejectability.
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
  - Under-bead and Heat-affected zone
  - Hot
  - Cold or delayed

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

- Porosity
  - Uniformly Scattered
  - Cluster
  - Linear
  - Piping

- HAZ microstructure alteration

- Size or dimensions
Discontinuity Classifications

- Design Related
- Weld Process related
- Metallurgical
Design Related

• Incorrect detail
• Wrong joint application
• Undesirable change in cross section

• These are *Engineering Problems*
• Typically beyond the realm of *INSPECTOR* knowledge unless a specific *Code* applies
• Engineers can make mistakes?
  ▪ Lack familiarity with welding
  ▪ Misinterpret design intent
    • Applied stresses
    • Fabrication sequence
    • Weld process capabilities
    • TYPICALLY show up in first-part manufacture or
    • After service failure
• The knowledgeable INSPECTOR may find these problems and needs to work with engineering to resolve
Weld Process Related

(LOTS OF FAIR QUESTIONS HERE)

- Undercut
  - Groove melted in basemetal adjacent to weld edge and left unfilled
- Slag Inclusion
  - Nonmetallic solid entrapped in weld
- Porosity
  - Gas cavity trapped during solidification
- Overlap
  - Weld metal protrusion beyond toe, face or root
- Tungsten inclusion
  - Tungsten electrode particles entrapped in weld
- Melt-through
  - Condition where arc melts through weld root
- Spatter
  - Metal particles expelled during welding that do not become part of the weld.
- Backing piece left in place
  - Failure to remove backing
- Shrinkage voids
  - Cavities formed by shrinkage at solidification
- Oxide Inclusions
  - Un-melted surface oxide particles
- Lack of fusion (LOF)
  - Less than complete fusion
- Lack of Penetration
  - Less than the specified penetration
- Craters
  - Depressions at the termination of the weld bead
- Arc strikes
  - Localized re-melted or heat affected metal resulting from an errant arc
- Under fill
  - A depression of the weld below the intended profile
Metallurgical Discontinuities

- **Cracks**
  - Fracture type discontinuities characterized by a sharp tip and a high length to depth ratio

- **Fissures**
  - Small crack-like discontinuities with only slight separation of the fracture surfaces

- **Fisheye**
  - Discontinuity found on the fracture surface of a steel weld consisting of a small pore surrounded by a bright round area

- **Segregation**
  - Non-uniform distribution or concentration of impurities or alloying elements during solidification

- **Lamellar tearing**
  - Cracking that occurs in the basemetal or heat affected zone of restrained weld joints
**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.
• **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
• 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.
• 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).
Cause for Insufficient Fill at the Root

• Ideally
Remove root pass by grinding

- Recreate the groove geometry as closely as possible.
- Use a saw or die grinder and 1/16 - 1/8” cut off wheel to recreate root opening.
  - Repairs sometimes require a smaller electrode.
- Open the groove angle. Be careful to leave the proper root face dimension.
- 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 exceeding specified 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.
EXCESSIVE CONCAVITY
Convexity
EXCESSIVE CONVEXITY
• The amount a groove weld extends beyond the surface of the plate
  • Excessive
  • Insufficient
  • Improper contour

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**Reinforcement**

- Face Reinforcement
- Root Reinforcement
Excessive Reinforcement

- **Definition:** Specifically defined standard.
- **Typically,** 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 weld toes to a smooth transition to the base plate.
EXCESSIVE WELD REINFORCEMENT
Insufficient Reinforcement

• Definition: Specifically defined standard.
• Typically, None or 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: Open 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 re-weld.
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.
UNACCEPTABLE
WELD PROFILES
UNACCEPTABLE WELD PROFILES
Overlap

• Definition: When the face of the weld extends beyond the weld toe
• 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 is measured with a square edge such as a 6” rule. No amount of overlap is typically allowed.
OVERLAP
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 with further processing.

• Cause: Excessive heat input.

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

• Repair: Will be defined by standards. Filling may suffice. Otherwise, removal and re-welding 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 & EXCESSIVE PENETRATION
Incomplete Penetration of Double Weld
Incomplete (or Lack of) 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 potential causes.

• Repair: remove and re-weld, being careful to completely remove the defective area. This is sometimes extremely difficult to find.
Lack of Fusion

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
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
• Wagon-tracks
• 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.
Slag

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
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
Tungsten Inclusion

- Very hard entrained particle
- Imparts local mechanical and thermal stresses
Inclusions

- Fix when you see it (welder)
- Otherwise grind out & fix
Whiskers

• Typically GMAW, can be GTAW
• Unconsumed weld-wire passes or pushes through weld joint and is caught in root penetration
  ▪ Unsightly
  ▪ Inhibits material flow in piping
  ▪ Can break off in pipes and damage equipment downline
  ▪ Considered inclusions
Spatter

• Definition: Small particles (droplet) 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.
SPATTER
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: Improve technique or use equipment function
• Repair: If no cracks exist, simply fill in the crater. Generally welding from beyond the crater back into the crater.
Cracks

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
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
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: 

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
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.
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:**
Transverse Crack

• Definition: A crack running into or inside a weld, transverse to the weld axis direction.
• Cause: Weld metal hardness problem
• Prevention:
• 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 un-melted 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.
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**
  - A crack during application of a welding process is an indicator of a bigger **PROCESS PROBLEM**

• Correct the problem

• Take precautions to prevent reoccurrence

• Generally required to repair using a smaller electrode
Base Metal Discontinuities

- Laminations and De-laminations
- Lamellar tearing
- Laps and Seams
Laminations

- Base Metal Discontinuity
- Typical of rolled plate and strip
- May require repair prior to welding
- Formed during the milling process
- De-lamination - a lamination opened under stress
Effect

• Lamination effects can be reduced by joint design:
Laps and Seams

• A mill-induced discontinuity resulting 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
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
Hammer marks

- Stress risers
- Unsightly
- Unnecessary
Heat-affected zone microstructure alteration

- Metallurgical change in HAZ - may include
  - grain refinement
  - grain growth
  - hardened areas
  - softened areas
  - precipitate susceptible areas.
Defect vs. Discontinuity

• Discontinuity - if it renders the part unusable, it is a defect.
• Defect - it is outside the allowable limit, it renders the part unusable.
• Design must recognize - things don’t have to be perfect, just within acceptable tolerance.
• Perfection is time consuming and costly
REPAIR TECHNIQUES

• May involve:
  ▪ different process
  ▪ different procedure
  ▪ different preheat/PWHT
  ▪ different electrode
  ▪ smaller electrode
Repairs

• Only repair defects.

• Discontinuities are, by definition, acceptable.
  • Discontinuity pair is unnecessary and not cost effective.