Discontinuities and Defects

Discontinuity

- 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 ***<u>Engineering Problems</u>***
- Typically beyond the realm of ***<u>INSPECTOR</u>*** knowledge unless a specific *Code* applies

Engineering Problems?

- 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

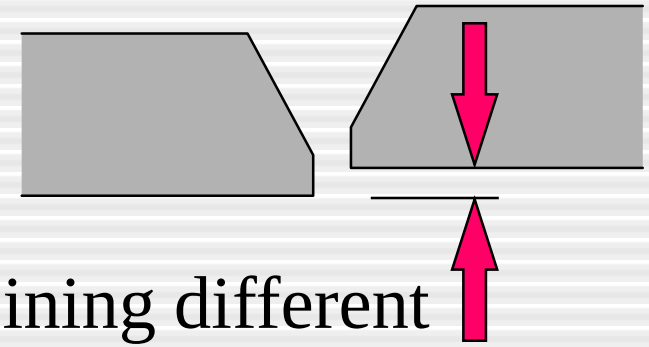
(LOTS OF FAIR QUESTIONS HERE)

- 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

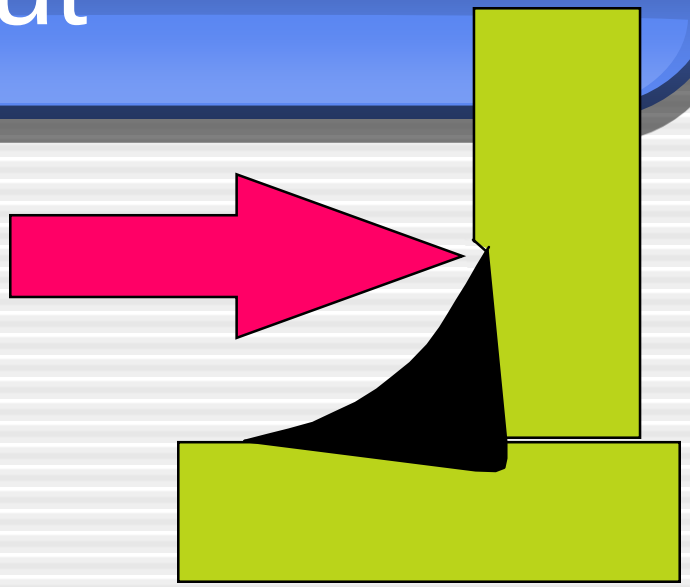
- Cracks
  - Fracture type discontinuities characterized by a sharp tip and a high length to depth ratio
- Fissures
  - Small crack-like discontinuities with only slight separation of the fracture surfaces
- Fisheye
  - Discontinuity found on the fracture surface of a steel weld consisting of a small 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

Misalignment (hi-lo)



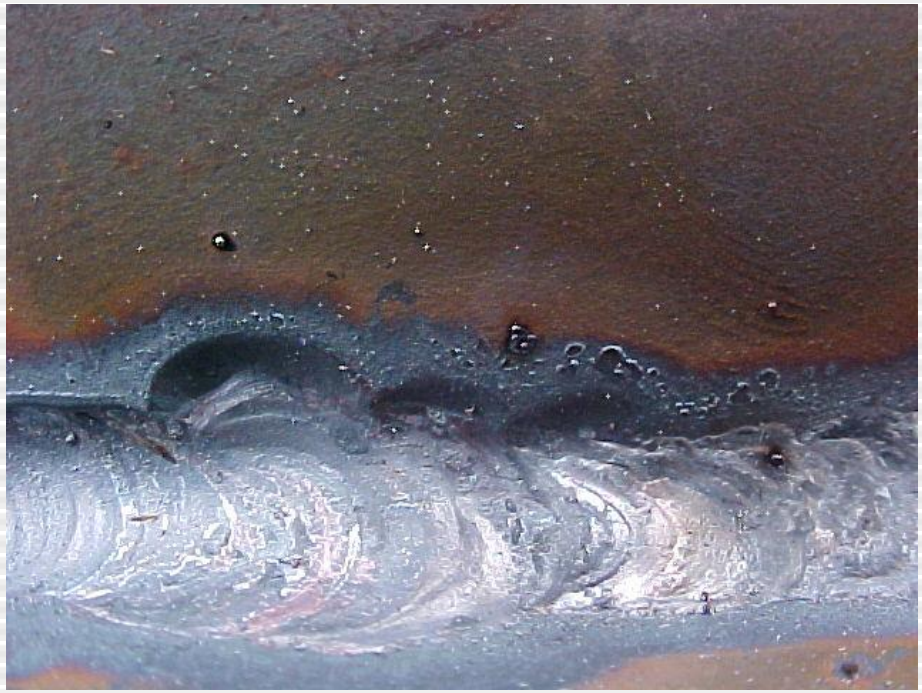
- **Definition:** Amount a joint is out of alignment at the root
- **Cause:** Carelessness. Also due to joining different thicknesses (transition thickness)
- **Prevention:** Workmanship. Transition angles not to exceed 2.5 to 1.
- **Repair:** Grinding. Careful on surface finish and direction of grind 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



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.

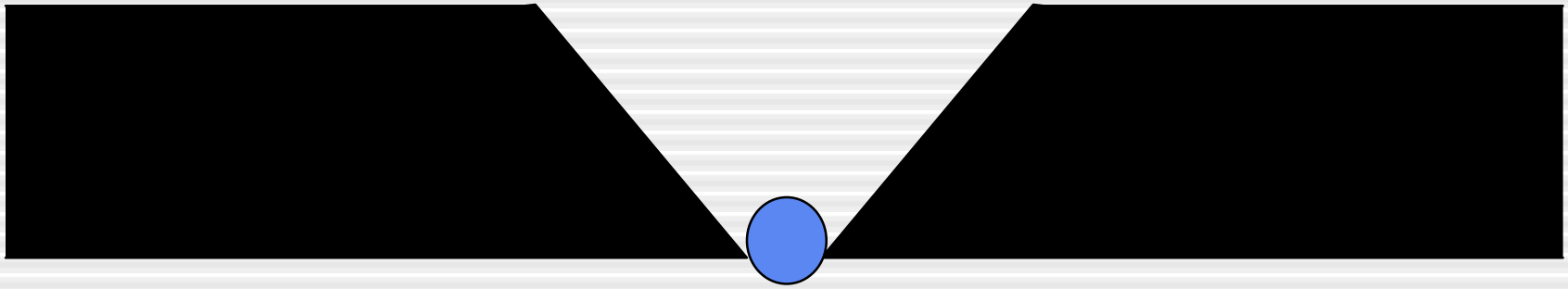
UNDERFILL

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.

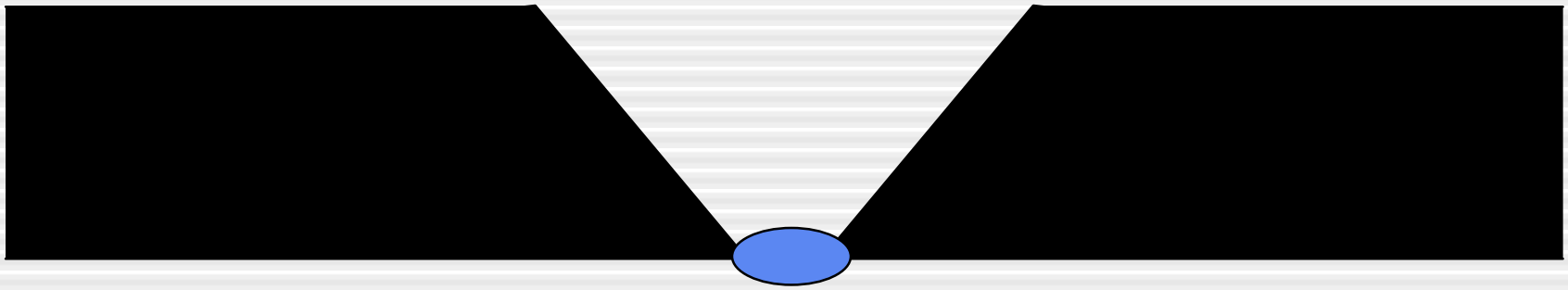
Cause for Insufficient Fill at the Root

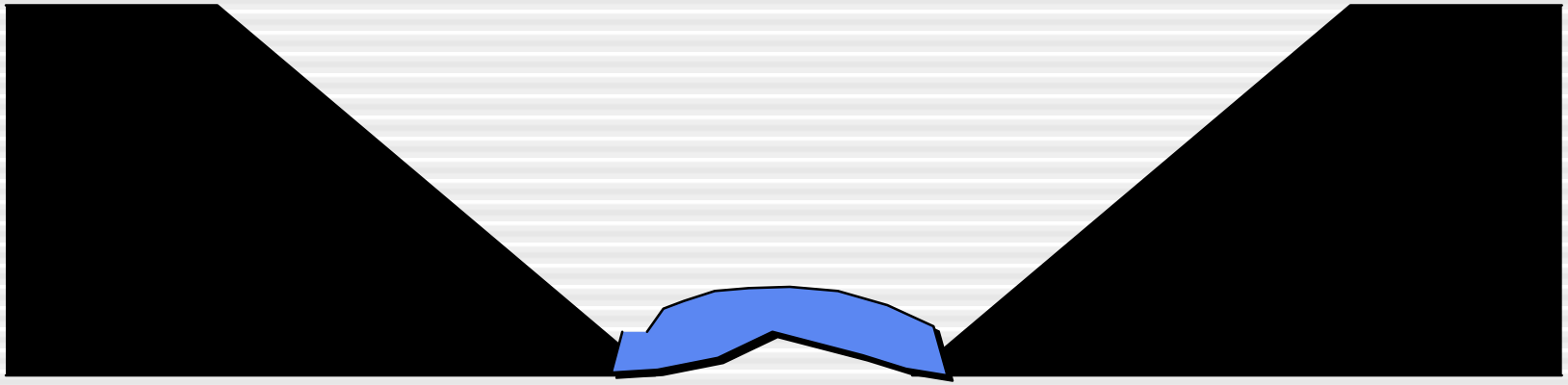
- Some liquids, like water or molten steel, try to cover as much surface area of whatever they are in contact with as possible.
- Welding a root pass too wide can also cause the bead to sag (overhead position).



Cause for Insufficient Fill at the Root

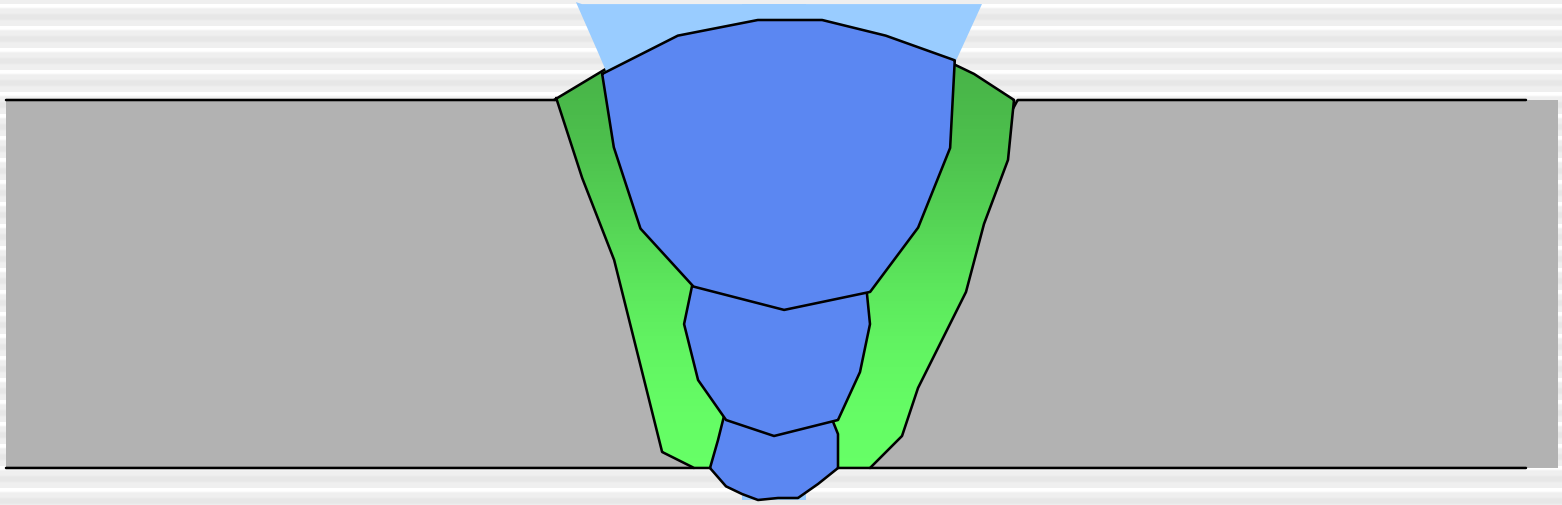
- Ideally





Remove root pass by grinding

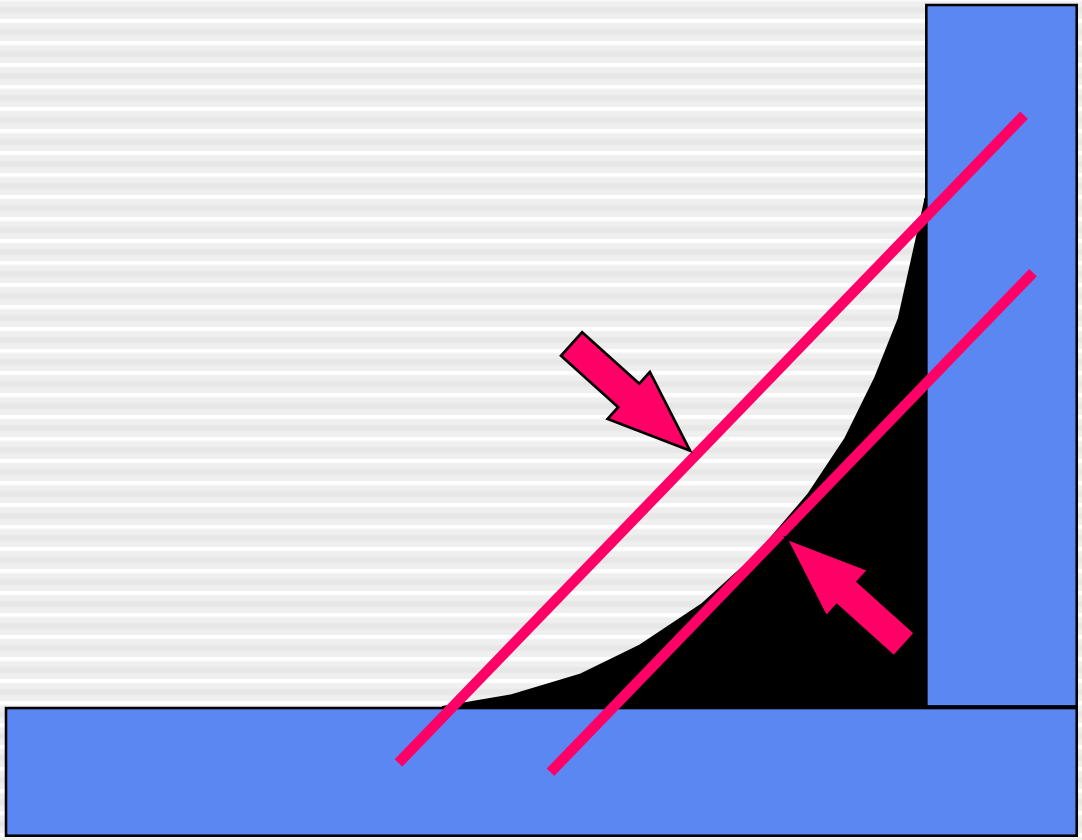
- Recreate the groove geometry as closely as possible.
- Use a saw or die grinder and 1/16 - 1/8” cut off wheel to recreate root opening.
  - Repairs sometimes require a smaller electrode.
- Open the groove angle. Be careful to leave the proper root face dimension.
- Feather the start and stop to blend smoothly into and out of the existing weld.



Excessive Concavity or Convexity

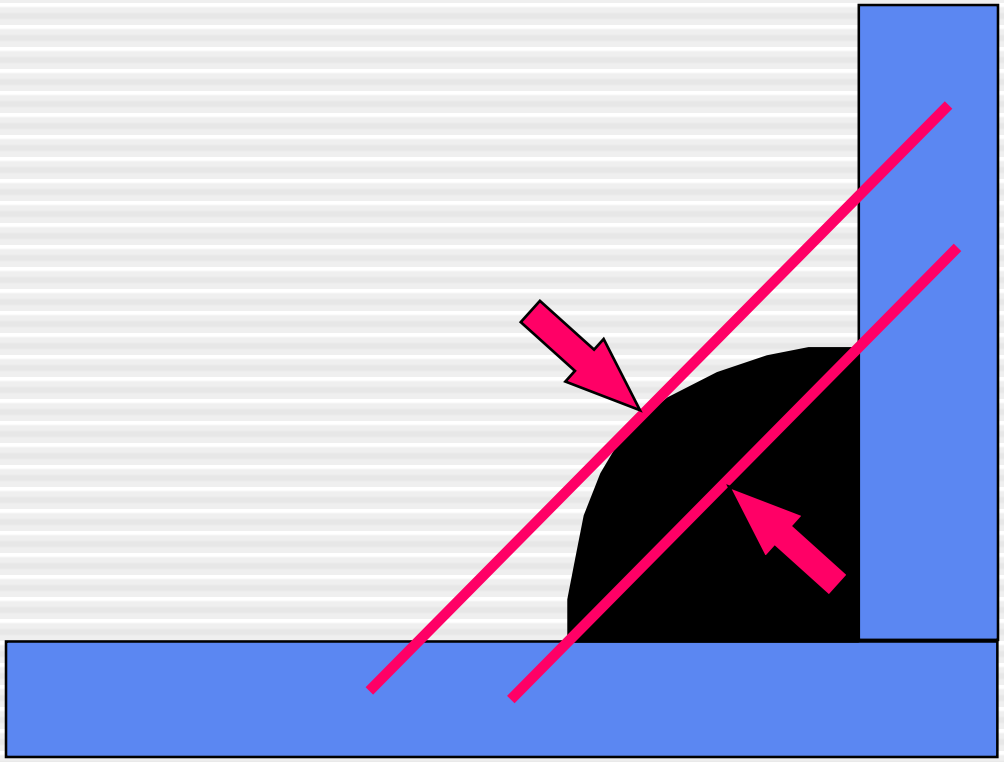
- **Definition:** Concavity or convexity of a fillet weld exceeding specified limits
- **Cause:** Amperage and travel speed
- **Prevention:** Observe proper parameters and techniques.
- **Repair:** Grind off or weld on. Must blend smoothly into the base metal.

Concavity



EXCESSIVE CONCAVITY

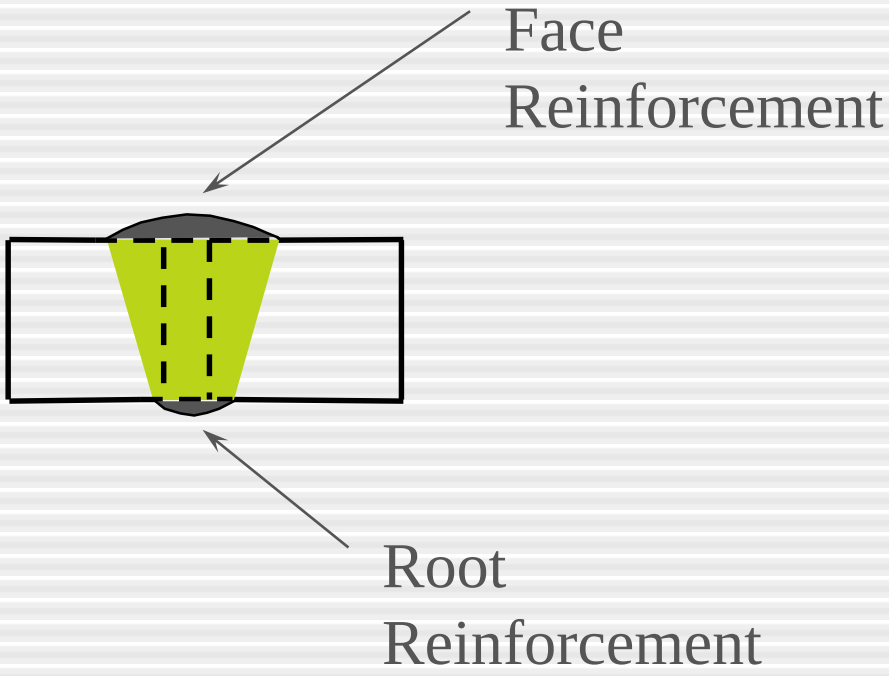
Convexity



EXCESSIVE CONVEXITY

Reinforcement

- The amount a groove weld extends beyond the surface of the plate
  - Excessive
  - Insufficient
  - Improper contour



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.

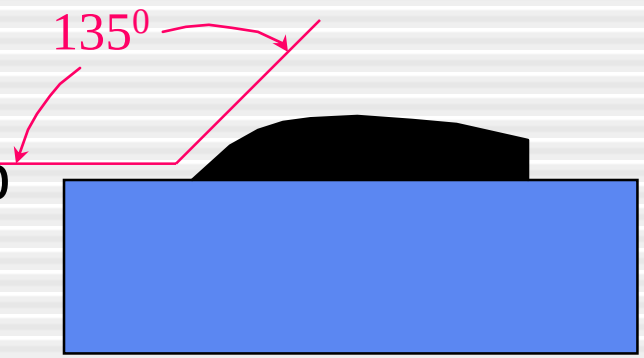
EXCESSIVE WELD REINFORCEMENT

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

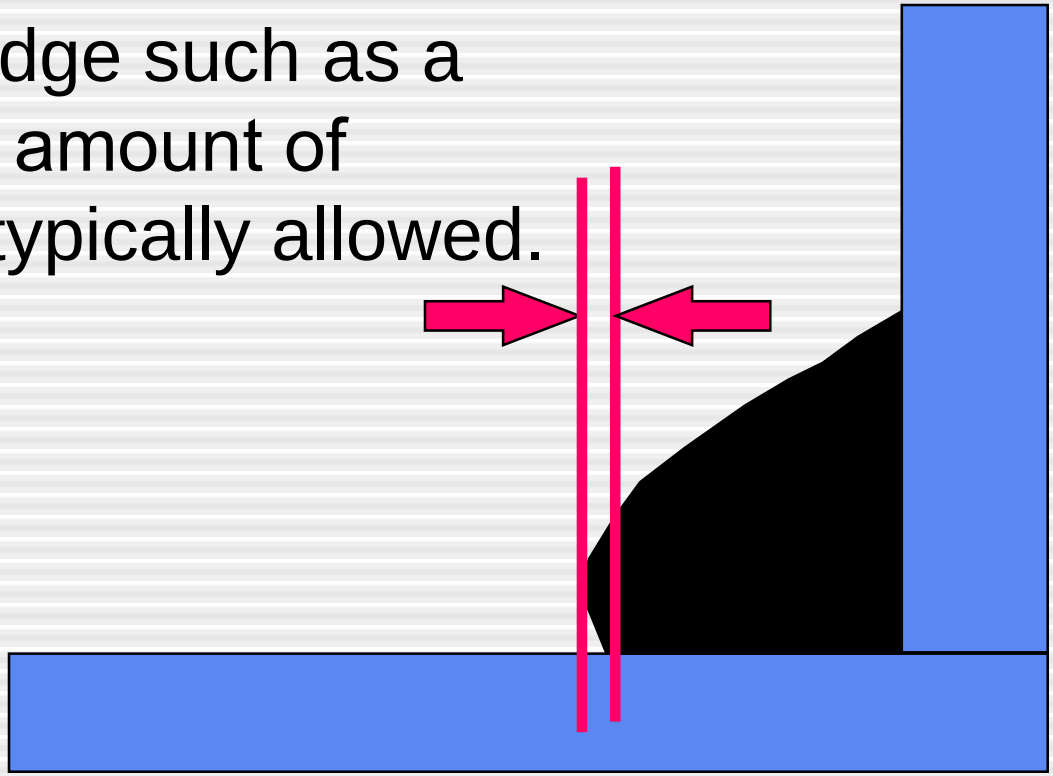
UNACCEPTABLE WELD PROFILES

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

•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

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

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

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INCOMPLETE FUSION

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

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

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
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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

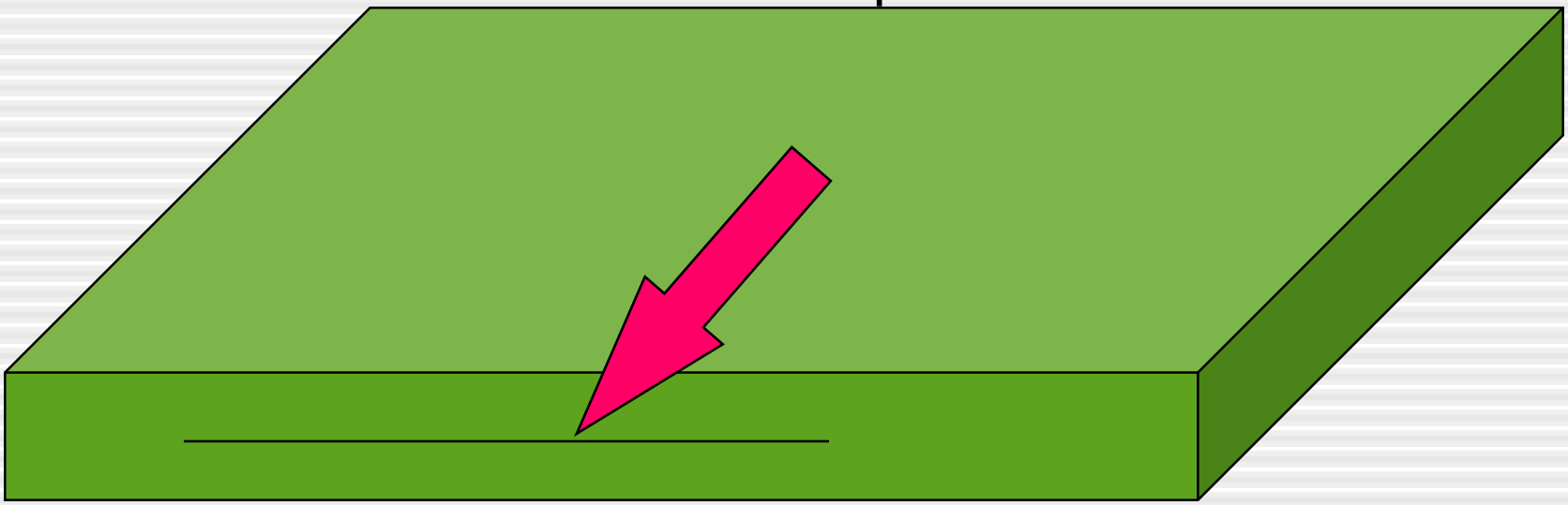
- ***<u>Determine the cause</u>***
  - A crack during application of a welding process is an indicator of a bigger ***PROCESS PROBLEM***
- Correct the problem
- Take precautions to prevent reoccurrence
- Generally required to repair using a smaller electrode

Base Metal Discontinuities

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

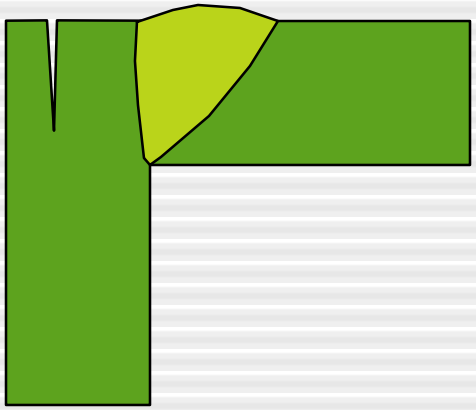
Laminations

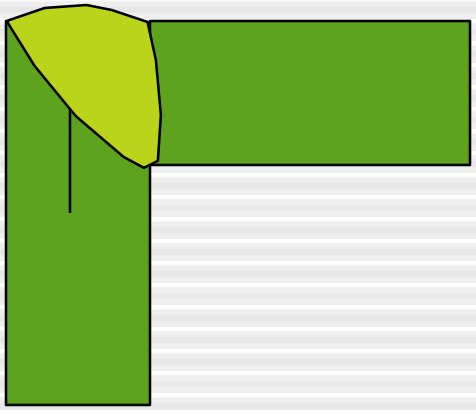
- Base Metal Discontinuity
- Typical of rolled plate and strip
- May require repair prior to welding
- Formed during the milling process
- De-lamination - a lamination opened under stress



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 suseptable 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.