American Petroleum Institute
Individual Certification Programs: ICP™

Technician ERW Weld Discontinuity Characterization Guide

For the API Long Seam Pipeline (LSP) exam

Electronic Resistance Welded pipe

Electric resistance welded (ERW) pipe is manufactured by cold-forming a sheet of steel into a cylindrical shape. Current is then passed between the two edges of the steel to heat the steel to a point at which the edges are forced together to form a bond without the use of welding filler material. Initially this manufacturing process used low frequency A.C. current to heat the edges. This low frequency process was used from the 1920's until 1970. In 1970, the low frequency process was superseded by a high frequency ERW process which produced a higher quality weld.

Over time, the welds of low frequency ERW pipe was found to be susceptible to selective seam corrosion, hook cracks, and inadequate bonding of the seams, so low frequency ERW is no longer used to manufacture pipe. The high frequency process is still being used to manufacture pipe for use in new pipeline construction. (primis.phmsa.dot.gov)

Below: Cross Sectioned and acid etched ERW weld

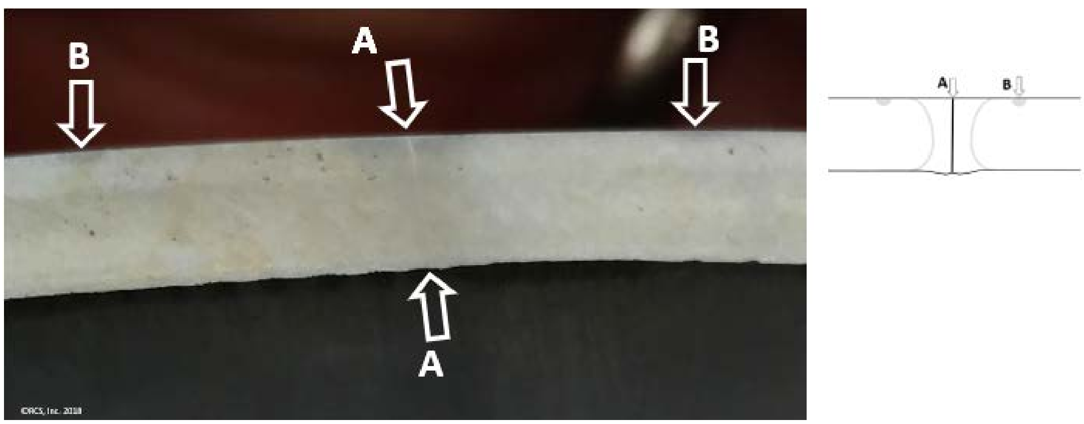


Figure 1 *(Courtesy of Riccardelli Consulting Services)*

Above: A: ERW Bondline B: Heat affected material from electrical induction (position of contact marks)

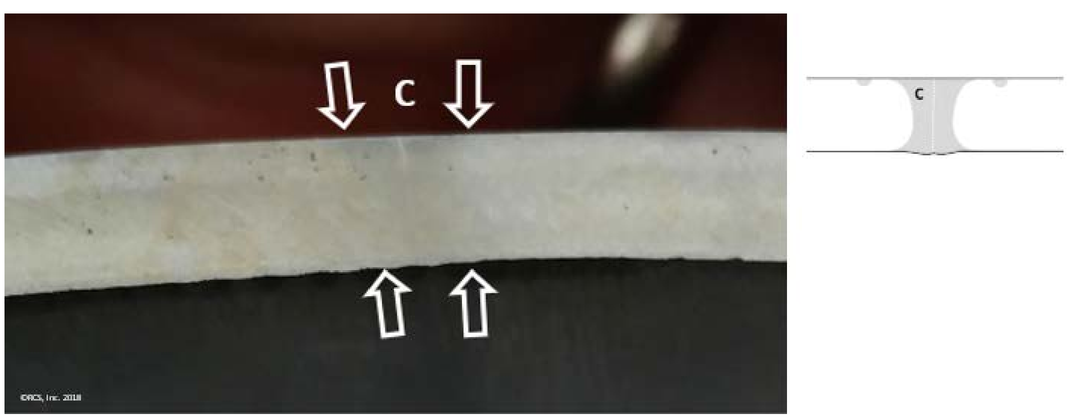


Figure 2 *(Courtesy of Riccardelli Consulting Services)*

Above: C: Heat affected zone (extends beyond discoloration by acid etching). Area of greatest material upset due to ERW welding

Weld feature characterization guide.

In this guide, weld discontinuities are identified by their features. For the NDE technician, these characteristics must match what is detectable and discernable by NDE inspection and data. Factors important to the technician include:

1. Feature location in the weld (ex, vertical height, length, interaction rules, OD connected/ID connected/Midwall/embedded)
2. Characterization of the feature.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

During the API longseam examination, the candidate technician shall use this guide to determine the categorized common name for the discontinuity they observe. The list of common names is following, with a page dedicated to the details of each.

Examples of discontinuities existing in ERW longseam welds are found in API 5T1. The following list are categories of discontinuities labeled with common terms, followed by features as described in 5T1 and the paragraph where they appear.

A. *Bondline - Lack of Fusion* (LOF-ID/OD/MW) including "black spot" (API 5T1 3.2.1) / open seam (API 5T1 3.2.10) / penetrator (API 5T1 3.2.11) / stitching (API 5T1 3.2.13)
    a. *Incomplete Fusion* (IF) (3.2.9)
B. *Lamination* (LAM)
    a. *Plain*
    b. *Sloping/oriented* (axial/circumferential-ID/OD/MW) also lap (3.1.10)
    c. *Stringer*(s)
C. *Crack* (API 5T1 3.1.3) (CR-Axial/circumferential/oriented-ID/OD/MW) Crater, Shrinkage, HAZ, Stress, SCC) including Edge Damage (API 5T1 3.2.3) / weld area crack (API 5T1 3.2.14)
D. *Hook Crack* (HC-ID/OD/MW) (API 5T1 3.2.6)
E. *Offset (Geometric feature)* – including edge misalignment (API 5T1 3.2.4)
F. *Trim* (ID/OD – Over (excessive trim- API 5T1 3.2.5)/Under (inadequate flash trim- API 5T1 3.2.7))
G. *Contact Marks* (OD) (API 5T1 3.2.2)
H. *Inclusion* (API 5T1 3.1.8)
I. *Metal Loss* (IML, EML) / pit (API 5T1 3.1.11)
J. *Surface discontinuity* (or, near surface discontinuity)

    Represented by a change in the material which is visible on the OD surface or detectable on the ID surface. Descriptions and examples of each are found in API 5T1.

    a. Plug Scores (API 5T1 3.1.12)
    b. Roll mark (API 5T1 3.1.14)
    c. Scab (API 5T1 3.1.15)
    d. Scale (API 5T1 3.1.16)
    e. Seam (API 5T1 3.1.17)

f. Sliver (API 5T1 3.1.18)
g. Slug (API 5T1 3.1.19)
h. Stretch mill indentation (API 5T1 3.1.20)
i. Stretch mill overfill (API 5T1 3.1.21)
j. Tear (API 5T1 3.1.22)
k. Upset Underfill (API 5T1 3.1.23)
l. Upset wrinkles (API 5T1 3.1.24)
m. Gouge (API 5T1 3.1.6)

A. Bondline LOF (LOF-ID/OD/MW)

including “black spot” (API 5T1 3.2.1) / open seam (API 5T1 3.2.10) / penetrator (API 5T1 3.2.11) / stitching (API 5T1 3.2.13)

1. Found exclusively at the bondline. May be connected to the ID or OD surfaces, found subsurface with no surface breaking connection or through material in stacked, intermittent discontinuities.
2. Generally, planar and found along a path perpendicular to the ID or OD surface following the bond line through wall.
3. Material from adjoining edges are forced together and material extruded past the ID and OD surface. The extruded materials are trimmed, and an indication exists at the bondline where the edges failed to fuse. The Lack of Fusion (LOF) may be intermittent and stacked through the part thickness and found with areas of Incomplete Fusion. Due to a weakened material state, LOF is often sized to the deepest point where material separation is detected and reported based on conservative characterization.
4. A manufacturing defect which may be attributed to defective equipment/operation, contamination and/or process.
5. Will follow weakest material; likely the bondline.
6. Hoop Stress, Corrosion
7. High for surface breaking, low for non-surface breaking. Through wall height sizing may be difficult with some NDE methods.

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

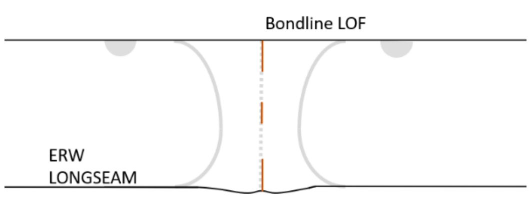


Figure 3: Visually Verified Bondline LOF *(Courtesy of Riccardelli Consulting Services)*

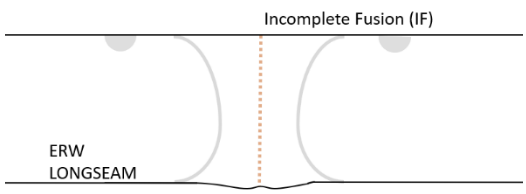
1. a. Incomplete Fusion (IF) (API 5T1 3.2.9)Found exclusively at the bondline.
2. Generally, along a path perpendicular to the ID or OD surface, following the weld bond through wall.
3. Material from adjoining edges are forced together and material extruded past the ID and OD edges. The extruded material is trimmed and no, or very weak, visual indications are present with enhancing NDE methods. Degree of partial fusion is often varying and

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

intermittent through material thickness. Generally, will not be detected when inspecting at normal sensitivity levels.

4. A manufacturing anomaly which may be attributed to defective manufacturing equipment/operation, contamination and/or process.
5. Generally, follows bondline through material and axially.
6. Driven by failure of another defect type.

7. Low at normal sensitivity levels. Possible at excessive sensitivity levels.

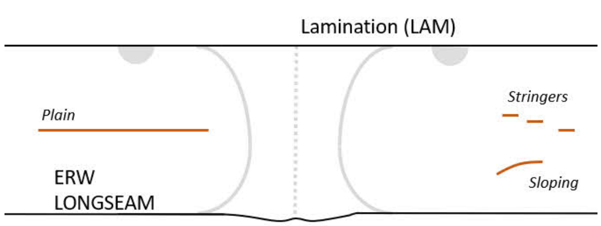


B. Lamination (LAM)

   a. Plain
   b. Sloping/oriented (axial/circumferential-ID/OD/MW) also lap (API 5T1 3.1.10)
   c. Stringer(s)

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
5. Propagation drivers
7. Detection potential

1. Anywhere in the weld, except when altered by longseam weld manufacturing material upset (see Hook Crack).
2. Generally flat, and
   a. Plain- parallel to part surface, at any depth, and usually large enough to block signals from a penetrating NDE method.
   b. Sloping/oriented - other than parallel to part surface.
   c. Stringer(s) - generally, thin, with much greater length than width. May be plain or sloping/oriented.
   Lamination has a measurable width.
3. Material separation which may be partially bonded or completely disbonded and may appear as intermittent.
4. A manufacturing defect from flattened inclusions during plate manufacturing, zones of material inconsistency, and/or defective equipment/operation/process.
5. Generally, propagates as crack(s) and may crack at subsurface termination(s) when in close proximity to traction from attachment welds. Although uncommon, when laminations become blisters, they will often distribute pressure by tearing outward, then in towards ID by material deformation and eventual relief by cracking.
6. Generally, driven as failure of another defect type. In certain services, may tear and crack by introduction of hydrogen and subsequent pressure from trapped hydrogen or methane gas.
7. High, depending on technology and proper application. Detection potential decreases with sloping and orientation.



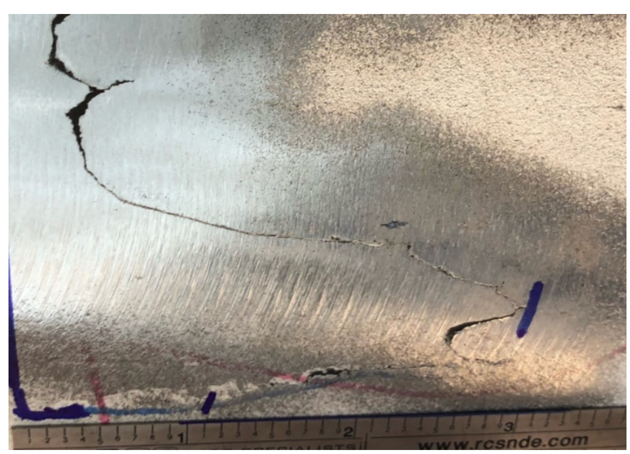


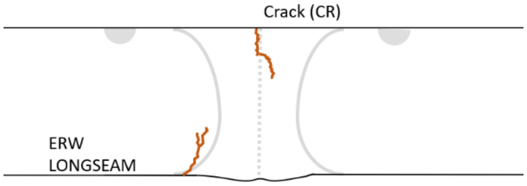
Figure 4: Surface breaking, sloping and oriented lamination
(Courtesy of Riccardelli Consulting Services)

C. Crack (CR-Axial/circumferential/oriented-ID/OD/MW) (API 5T1 3.1.3)

Crater, Shrinkage, HAZ, Stress, SCC including Edge Damage (API 5T1 3.2.3) / weld area crack (API 5T1 3.2.14)

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Anywhere in the weld.
2. May have any shape or orientation, but generally will follow a direction by relief of driving stresses.
3. Forced material separation that often follows grain boundaries and may prefer areas of change in molecular structure such as heat hardened material, parallel inclusion zones and weld fusion lines. Cracks are often characteristically branched and/or faceted, and internal terminations are referred to as "tips".
4. Multiple factors cause cracks, a product of a stress relief. Stress can be physical, material, or temperature and generally involve a relatively rapid change in material properties and/or a stress riser.
5. Wherever the stress driver and material properties lead. As propagation occurs, stresses change, which may, and often do, cause the stress relief to follow multiple paths, some short and others longer.
6. Stress
7. Very high, depending on technology and application.



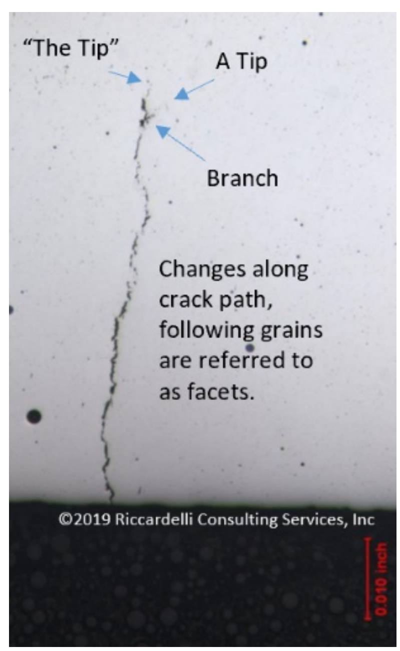


Figure 5 *(Courtesy of Riccardelli Consulting Services)*

D. Hook Crack (HC-ID/OD/MW) (API 5T1 3.2.6) aka J-Crack

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Anywhere material upset occurs during ERW weld manufacturing.
2. Shape is determined by the origin lamination. If the lamination was plain, orientation is generally parallel to the bondline. If the lamination was sloping or oriented, orientation may be other than parallel to the bondline. Through material thickness, the defect may resemble a “J” or hook, but is still considered a Hook Crack, if 1. Modified by a longseam welding process which does not involve filler metal, and 2. Appearing outside the weld bond line. May be connected to ID or OD, or MidWall.
3. May not be cracked.* May find more than one hook crack circumferentially. Anywhere there are parallel surface breaking indications, there exists a high probability that one or more are HCs. The parallel portion of Hook cracks may extend well beyond the longseam boundaries, depending on width of the origin lamination. Anytime very included longseams exist, there is a high probability of hook cracks.
4. A lamination existing at or near the plate edge is pushed out towards the ID or OD, with material extrusion, due to the ERW weld manufacturing process. After trim, this often forms a visibly detectable indication on the OD.
5. Generally, considered a volatile stress profile, with cracking potential at the apex of the curve and/or the internal termination. Stress dictates direction of propagation.
6. Generally, hoop stress. As propagation occurs, stresses change, which may, and often do, cause the stress relief to follow multiple paths, some short and others longer.
7. High, depending on technology and application. Characterization often challenging. Low for subsurface (MW) hook cracks.

*More recently the term “Hook Flaw” has been used by some in the Oil and Gas industry to describe those instances where cracking is not detected. The term “Hook Flaw” relates to manufacturing feature such as an inclusions or laminar type base metal discontinuities curved by plastic flow during ERW or Flash welding and do not visually look like cracks.

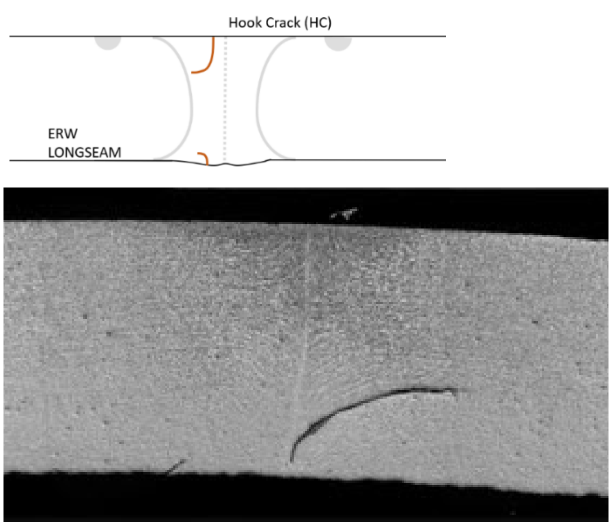


Figure 6 *(Courtesy of Riccardelli Consulting Services)*

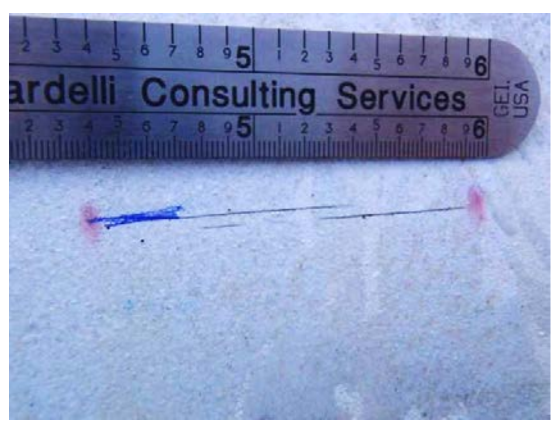
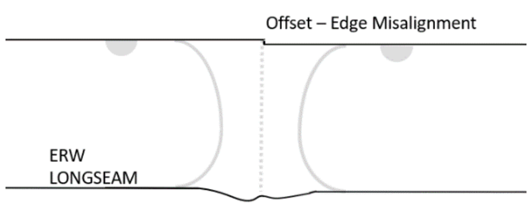


Figure 7: Multiple lines of surface breaking linear indications in close proximity to ERW Bondline suggests extreme probability of hook cracks. *(Courtesy of Riccardelli Consulting Services)*

E. Offset (Geometric feature) – including edge misalignment (API 5T1 3.2.4)

1. At weldzone (bondline) the area affected by the welding process
2. One edge does not align with opposing edge, where a protrusion of material is present on the ID and/or OD. May appear notch-like.
3. If bonding is complete, with no stress risers, may not be considered detrimental. The through wall bonded height of the weld is usually less than where weld is properly aligned. No material loss is recognized on either side of the weld.
4. Manufacturing equipment failure.
5. Weldzone (Bondline)
6. Generally, not known to fail. Hoop stress can drive cracking.
7. Often detected visually.

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential



F. Trim (ID/OD – Over (excessive trim- API 5T1 3.2.5)/Under (inadequate flash trim- API 5T1 3.2.7))

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Generally, to the side of the bondline and at the ID or OD surface
2. Appears notch-like and may affect one or both sides of the bondline.
3. Different from offset in that material is either extruded (under-trim) or removed (over-trim) due to trim tool failure. Often has defined and clean corners. Will often be a smooth transition axially to a thickness change with defined circumferential edges.
4. Manufacturing process, where trim tool becomes loose, out of adjustment or there is an upset in pipe handling.
5. Generally, no mechanism for propagation unless considered a stress riser, due to shape and other properties. May be an origination location for Corrosion/Erosion.
6. Hoop stress
7. High probability of detection.

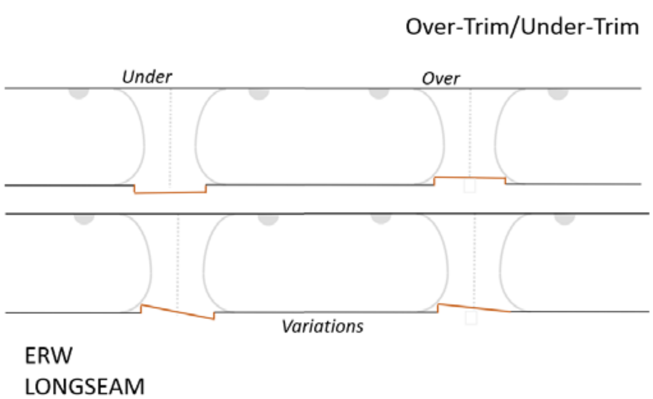


Figure 8: Under trim producing erratic ID protrusion. *(Courtesy of Riccardelli Consulting Services)*

G. Contact Marks (OD) (API 5T1 3.2.2)

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Exclusively to either side of bondline and most commonly to both sides, when present. Width is majoritively between 0.5 in. and 1 in. and generally evenly spaced circumferentially from bond line of longseam weld.
2. Potentially many shapes, with most a series of small, intermittent, crack-like indications. Sometimes these are linked to formed larger indications and at times are straight and appear like LOF, but at the edge of the trim area. Can also be combined with a tearing of metal and loss of material associated with the same event and stage of manufacturing.
3. Where these occur, there is a local hardening of the material, generally around 10%-15% of wall thickness and in a half-moon shape. They are often wide and seen with the naked eye, but equally often will not be seen visually without an enhancing NDE method. Since found in most ERW pipe, they are often treated as non-detrimental if passing hydro-testing.
4. A manufacturing anomaly which is a product of superheating from electrical induction into the part immediately before the bonding process. They may be worsened by the trimming process and show signs of tearing, such as metal loss.
5. Very low probability of propagation, but if propagation occurs there generally is no way to predict growth path. In most cases, a failure caused by another anomaly type will choose the bondline to propagate as it is hardened through the material thickness.
6. Can often detect these with NDE methods, especially when the orientation is favorable.

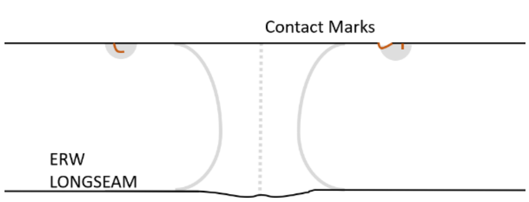
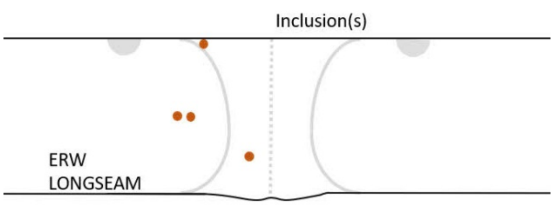


Figure 9: Arrows point to line of contact marks on single side of the ERW weld. Also, linear visual indication showing at centerline of weld. *(Courtesy of Riccardelli Consulting Services)*

H. Inclusion (API 5T1 3.1.8)

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Any location or depth
2. Any shape and orientation. Generally considered to have a similar length/width/height ratio.
   Inclusions do not typically have a measurable width.
3. Considered to contain some foreign matter within its volume, usually non-metallic or air. Most are pressed into and become lamination during plate manufacturing, however, if small enough or of sufficient density, maintain a more volumetric shape. These are often labeled the general description of inclusion.
4. Original steel production introduces inclusions. There is possibility that contamination at the plate edge could produce inclusions, however most would be pushed out with material extrusion.
5. Very low probability of propagation. They can act as origins of hook flaws if they are inside the flow area.
6. No known driver.
7. Depends on size, shape, and orientation.



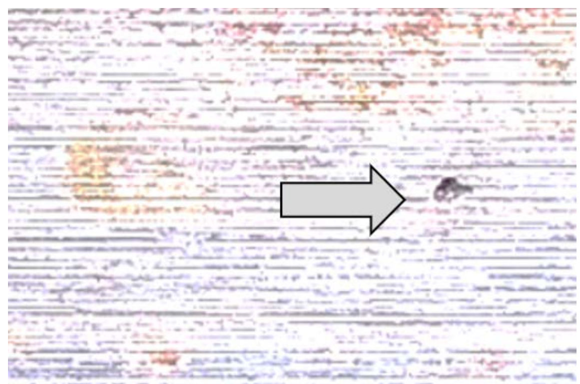


Figure 10: Cross-section showing an inclusion *(Courtesy of Riccardelli Consulting Services)*

Figure 11 *(Courtesy of Riccardelli Consulting Services)*

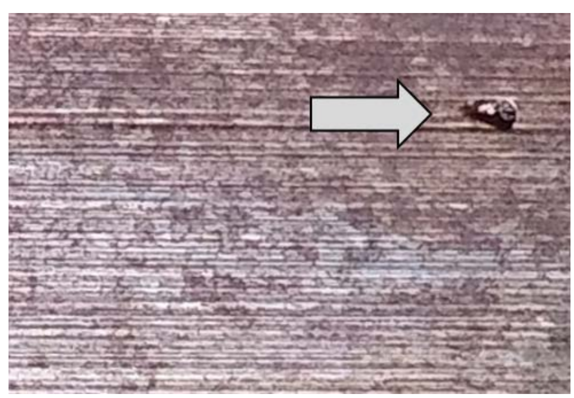
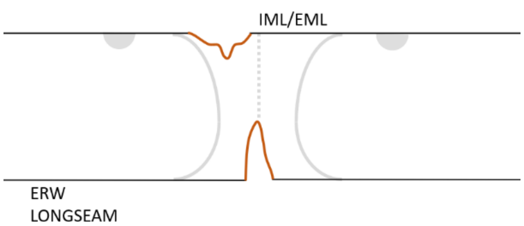


Figure 12: Cross-section showing an inclusion *(Courtesy of Riccardelli Consulting Services)*

I. Metal Loss (IML, EML) / pit (API 5T1 3.1.11)

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Any location and occasionally preferential; generally found on OD (EML) or ID (IML).
2. Any morphology, shape, and orientation. Detectable width.
3. Any area where a loss of material, from normal homogenous structure, is recognized. Some surface discontinuities (K.) can also be detected and labeled by the general term metal loss.
4. Including corrosion, erosion, manufacturing, and incidental contact.
5. In-service conditional metal loss will often increase where most favorable to the driving mechanism. Harder material, found near the bondline and where electrical induction occurs, may corrode before the parent material (often referred to as preferential corrosion and Selective Seam Weld Corrosion (SSWC)).
6. In-service conditional metal loss growth is generally driven by the mechanism which caused the metal loss.
7. High, depending on location and accessibility.



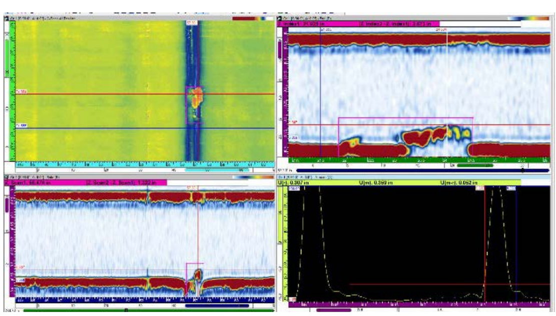


Figure 13: IML at ERW weld *(Courtesy of Riccardelli Consulting Services)*

Figure 15: EML across ERW weld *(Courtesy of Riccardelli Consulting Services)*

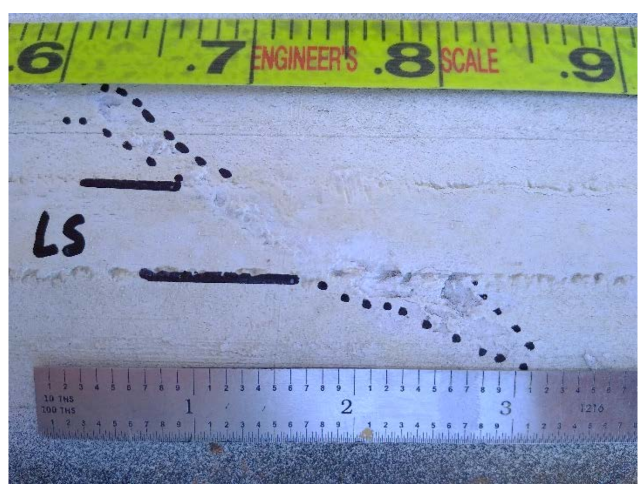


Figure 14 EML across ERW weld *(Courtesy of Riccardelli Consulting Services)*

J. Surface discontinuity (or, near surface discontinuity)

1. Location in the weld.
2. Overall shape and orientation.
3. Unique properties
4. Origination
5. Potential propagation path
6. Propagation drivers
7. Detection potential

1. Please refer to the API 5T1 for surface discontinuities listed here.
2. Refer to API 5T1
3. A disruption to homogenous material attributed to manufacturing and may be detected and described as IML, EML or Manufacturing Anomaly by ILI tools.
4. Manufacturing process
5. Intrinsically unlikely to grow, however, may present an initiation point for in-service damage mechanisms, like corrosion, erosion, or stress riser for crack initiation.
6. Generally, requires an additional damage mechanism, unless intrinsic severity weakens the pipe structure.
7. High, depending on shape, location, and accessibility.