Global Tubing

GLOSSARY OF COILED TUBING DAMAGE

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Introduction

Coiled tubing damage is common in the industry, but many of the types of damage included in this Glossary can be avoided and/or repaired if identified early. This document aims to summarize the types of damage observed in the field and provide guidance on how to fix the tube as well as how to avoid causing the damage from the beginning. Several terms are defined below which are used throughout the glossary.

- **Galling:** a form of surface damage arising between sliding solids, distinguished by microscopic, usually localized, roughening and creation of protrusions above or below the original surface.
- **Abrasive wear:** the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface (ex: sanding with sandpaper or surface gouging)
- **Erosive wear:** caused by the impact of particles of solid or liquid against the surface of an object. The rate of erosive wear depends on: the material characteristics of the particles, such as their shape, hardness, impact velocity and impingement angle, as well as the material properties of the eroded material. For ductile materials like all grades of coiled tubing, the maximum wear rate occurs when the impingement angle is normal (90 degrees) to the surface.

DAMAGE TYPES INCLUDED IN THIS GLOSSARY

TYPE: Abrasion (Longitudinal Abrasion and Completion Abrasion)

POSSIBLE SOURCE: Running into completion with high deviation, running into a completion with no fluid or other friction reducing agent, running into chrome completions, local bends in pipe near BHA.

DESCRIPTION: Abrasion damage can be a combination of galling and abrasive wear. Normally, the orientation of this damage is in the longitudinal direction.

EFFECT ON FATIGUE LIFE: Because the orientation of most completion damage is in the longitudinal direction, the detrimental effect on fatigue life due to the damage itself is minimal if the wall loss is minimal. The primary failure mode is burst or collapse as shown below.

REPAIR: Repairing longitudinal abrasion damage will have a minimal improvement in fatigue life. If wall thicknesses are within specification, it is better to not repair. If wall thickness are below specification, then it is recommended the section be removed completely.

MITIGATION: Constant pipe movement is essential especially when in the horizontal section of the well. Watch for abrasion, especially in close proximity to the coil connector. Trim pipe on a regular basis regardless of any indication of abrasion. Use of friction reducers can also reduce the propensity to this type of damage.

EXAMPLES:

TYPE: BHA Connector Failures

POSSIBLE SOURCE: BHA connector failures can come from several sources including welding technique, groove rolling technique, dimpling technique, tube cropping technique, localized abrasion etc.

DESCRIPTION: Partial failure or complete separation of the BHA from the UH portion of the tube.

MITIGATION: The following areas are addressed individually, Weld Failure, Groove/Dimple Failure, pin end connection failure, and abrasion failure.

EXAMPLES:

Weld Fracture

Groove/Dimple Failure

Pin End Fracture

TYPE: Collapse

POSSIBLE SOURCE: Over pressure in annulus, or reduction in wall thickness can initiate collapse.

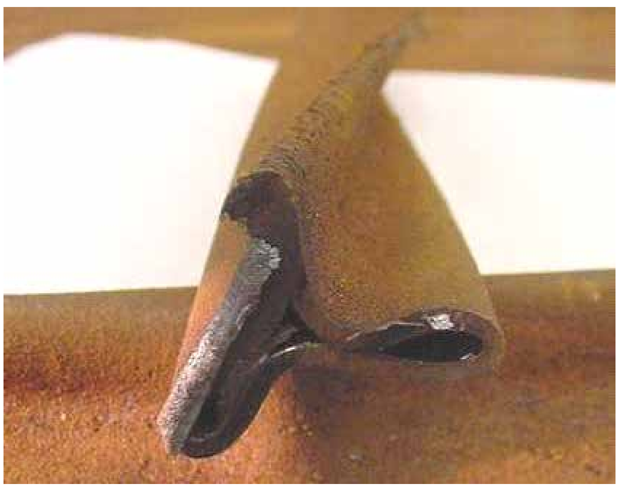
DESCRIPTION: Annulus pressure exceeds capacity of tube.

EFFECT ON FATIGUE LIFE: Not Repairable.

REPAIR: Normally, this sort of damage is considered irreparable. Recommend action is to remove the collapsed sections.

MITIGATION: Constantly monitor pressure and ensure conditions stay within acceptable von mises stress limits. Keep in mind, that the worst-case condition may not be on surface, but downhole.

EXAMPLES:



TYPE: Corkscrew

POSSIBLE SOURCE: Over torque or sudden increase in compressive force that exceeds the limits of the tubing.

DESCRIPTION: Corkscrew is a type of deformation where the tubing is plastically deformed in a twisted shape.

EFFECT ON FATIGUE LIFE: Corkscrew deformation is considered detrimental to the affected sections and continued use will lead to abrasive damage against the well tubing/casing which can substantially reduce the wall thickness.

REPAIR: Normally, this sort of damage is considered irreparable. Recommended action is to remove the corkscrewed sections.

MITIGATION: Correct motor selection based on max torque output and CT torque capacity is essential. When moving after a motor stall, reduce pump rate temporarily to reduce pressure and decrease any counter rotation. Monitor weight while RIH, especially during operations with large casing size compared to CT OD.

EXAMPLES:




TYPE: Corrosion (Acid Corrosion)

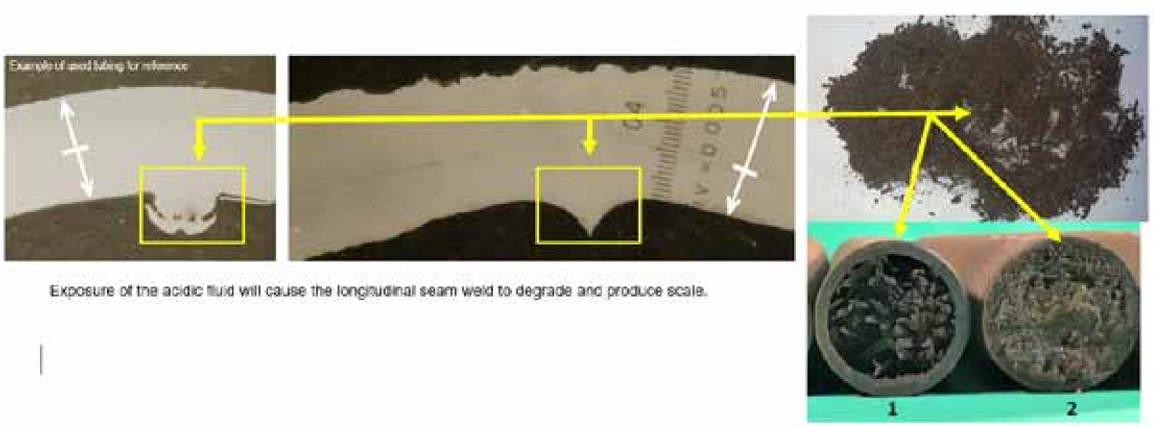
POSSIBLE SOURCE: The result of extended and unmitigated exposure to low pH (acidic) fluid. Improper and/or lack of adequate acid inhibition program allows for dissolution of CT material.

DESCRIPTION: Corrosion pitting comprised of multiple hemispherical overlapping pits. The pitting may severely reduce the wall thickness on either OD or ID surface depending on the exposed surface.

EFFECT ON FATIGUE LIFE: Not repairable.

MITIGATION: Proper chemical treatment and fluid management.

EXAMPLES:



Exposure of the acidic fluid will cause the longitudinal seam weld to degrade and produce scale.

ID surface showed severe cavernous pitting

TYPE: Corrosion (Internal Corrosion)

POSSIBLE SOURCE: Inadequate corrosion inhibition during job or improper storage after job with residual fluids inside, no purging procedure, uncapped ends during storage, and uninhibited fluids left from previous jobs.

DESCRIPTION: Internal corrosion from residual fluids or corrosive environment inside the string.

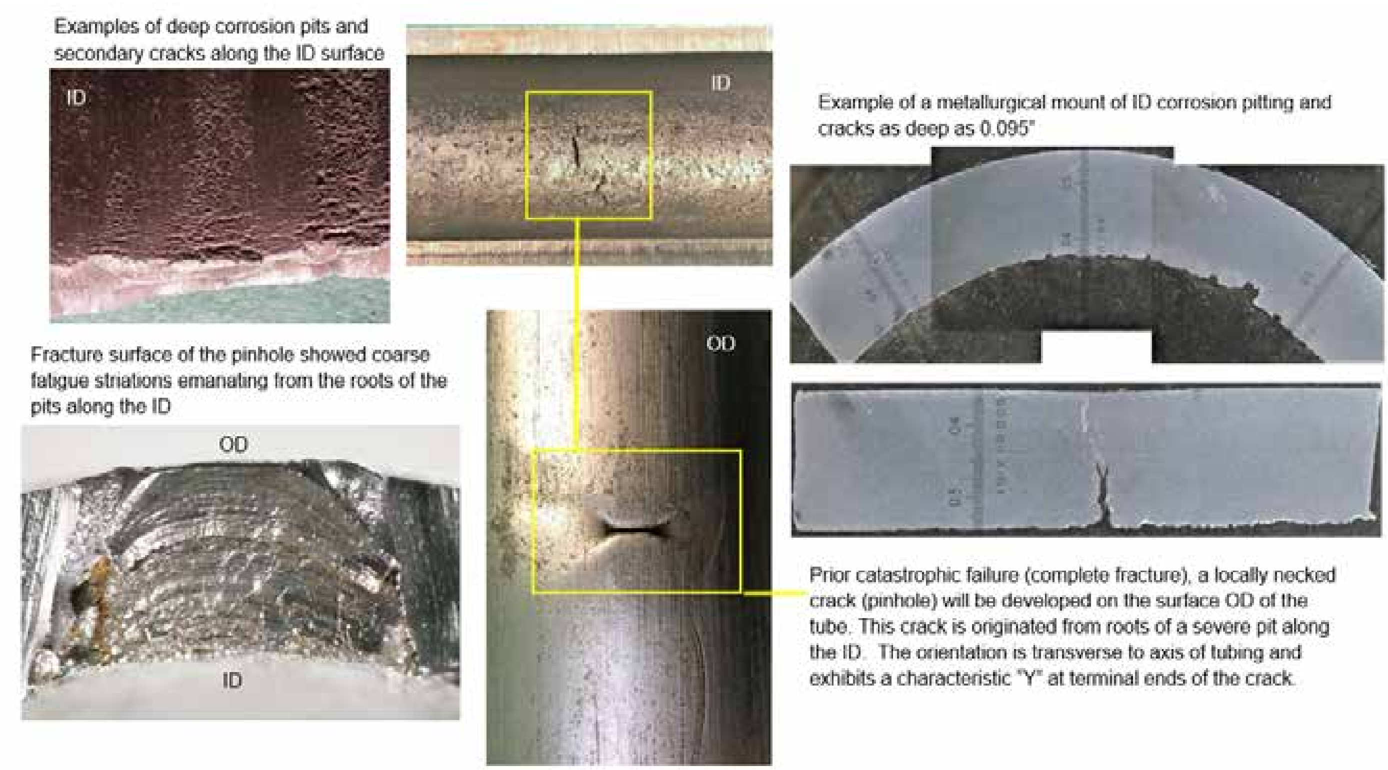
EFFECT ON FATIGUE LIFE: Corrosion can substantially reduce fatigue life because cracks propagate from the roots of the corrosion pits.

REPAIR: Normally, repair is not possible. Prevention and maintenance are the key to minimizing corrosion damage.

MITIGATION: Use a combination of wiper balls, wire brush pigs, biocides, inhibitors, and high-quality nitrogen to store strings between jobs. Proper chemical treatment will depend on the types of jobs performed, the fluids pumped, and the time between jobs.

Note: Circulation of Nitrogen only without a wiper or pig, generally leaves 2-3bbls of fluids inside the reel.

EXAMPLES:



TYPE: Corrosion (Storage Corrosion)

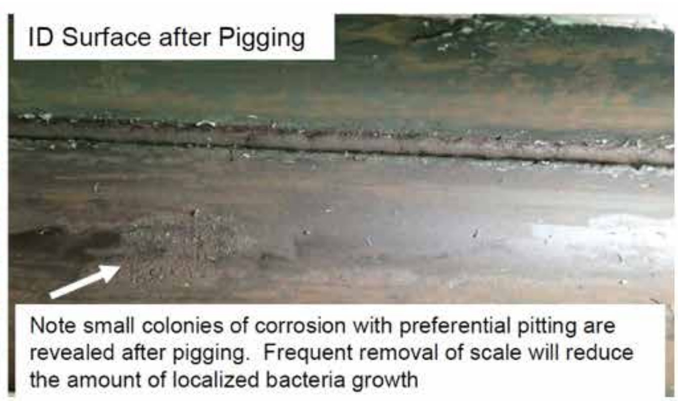
POSSIBLE SOURCE: Improper pigging and/or lack of adequate corrosion inhibition program allows for biofilm buildup.

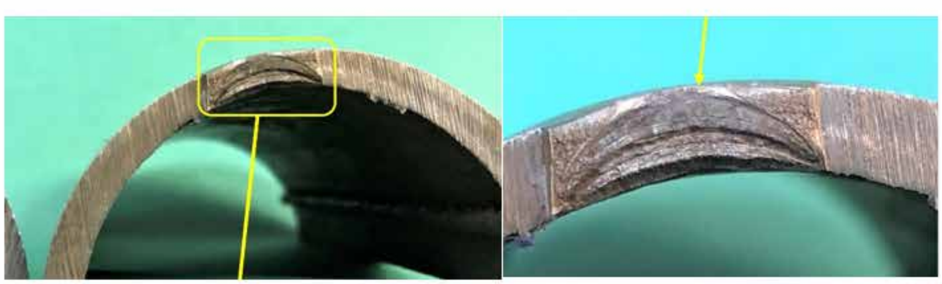
DESCRIPTION: IBetween jobs, 2-3bbl of fluids are typically left in strings even after N2 purge. This fluid allows for a development and build-up of a biofilm that creates scale and corrosion pits.

EFFECT ON FATIGUE LIFE: Not repairable.

MITIGATION: Frequent pigging of the coil will reduce scale buildup and limit ponding corrosion by breaking up biofilm and allowing chemical treatments to penetrate to the surface of the tubing.

EXAMPLES:





TYPE: Galling Damage

POSSIBLE SOURCE: Abrasion from contact with casing and/or coupling

DESCRIPTION: Galling is a form of abrasion where adhesion of the two contact surfaces removes material and adheres the material upon the adjacent contact surface.

EFFECT ON FATIGUE LIFE: Not repairable.

MITIGATION: Monitor supplied coiled tubing material properties in comparison of existing casing material properties as well as use of friction reducers.

EXAMPLES:

TYPE: Injector Damage

POSSIBLE SOURCE: High injector chain pressure and loose chains during snubbing, injector shoe misalignment, Ballooning of pipe can cause interference between injector shoes and pipe

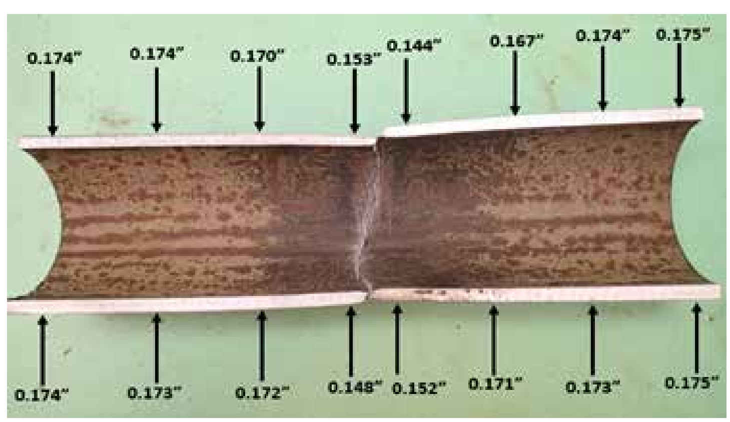
DESCRIPTION: Injector damage can be a combination of galling and abrasive wear. Normally, the orientation of this damage is in the transverse direction. The depth of the damage can be inconsistent depending on the tubing mechanical properties and injector parameters. Generally, damage of this type is shallow (<10% of base wall thickness) but can cause subsequent failure due to fatigue and subsequent wall reduction.

EFFECT ON FATIGUE LIFE: Transverse marks are detrimental to low cycle fatigue life. Normally, the shallow depth of such damage limits the reduction in fatigue life.

REPAIR: Repair of transverse injector damage is recommended when possible. Remove the damage per Global Tubing's "Field Damage Repair Guidelines" at the end of this document. However, many of these exceed 10% in depth or thin down with subsequent fatigue causing early failure.

MITIGATION: Follow injector head manufacturer's guidelines for chain tension based on snubbing forces seen during operations. As conditions change during operations, be sure to adjust chain tension.

EXAMPLES:



TYPE: Injector Damage (Semi-Circumferential Indentions)

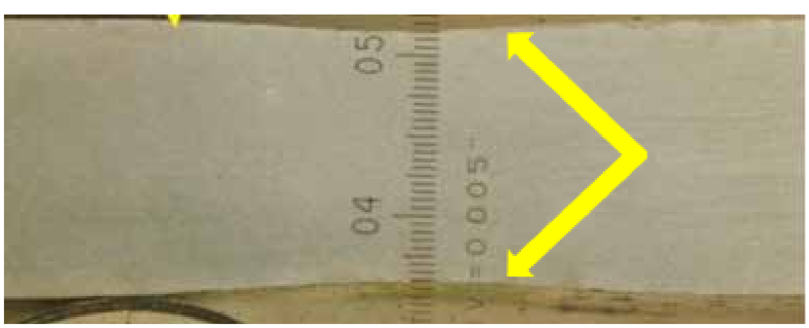
POSSIBLE SOURCE: Suspected source of damage is surface equipment

DESCRIPTION: Periodic OD indentations causes the ID to become smaller (red arrows) which causes a hinge effect and subsequent bending causes the wall thickness to neck down (yellow arrows).

EFFECT ON FATIGUE LIFE: Not repairable. Reduction in wall thickness and localized changes in hardness causes a reduction in tensile capacity.

MITIGATION: Frequent inspection of surface equipment and monitoring skate pressure and chain tension.

EXAMPLES:



TYPE: Injector Damage (Crescent Moons or Swoop Marks)

POSSIBLE SOURCE: Misaligned gooseneck, incorrect mounting of gripper block, wrong size of gripper block.

DESCRIPTION: Crescent moons are a form of abrasive/galling wear and are relatively smooth and uniform. This damage is imposed by the corner edge of coiled tubing injector head gripper blocks.

EFFECT ON FATIGUE LIFE: The orientation of this damage and the method of imposition result in minor reduction in low cycle fatigue life. Normally, the depth of this damage is less than 10% of the base wall thickness. More severe instances of this damage (10% or more of base wall thickness) may decrease fatigue life.

REPAIR: Repairing this damage type is recommended for the most severe cases. Remove the damage per Global Tubing's "Field Damage Repair Guidelines" at the end of this document.

MITIGATION: GOOSENECK ALIGNMENT – Ensure gooseneck is properly aligned in relation to the coiled tubing unit, as well as the injector head itself. GRIPPER BLOCKS – Monitor gripper block condition and securement to the chains on a regular basis. Follow IH equipment manufacture guidelines for chain lubrication and gripper block securement.

EXAMPLES:

TYPE: Pipe Waviness

POSSIBLE SOURCE: Loose or uneven wrap during spooling, gaps or overlapping wraps, flange interference causing overlapping and localized waviness.

DESCRIPTION: Waviness in the tubing is a type of deformation that is apparent by gradual undulation in the tubing. Waviness is a product of either poor wrapping quality (abrupt changes in the tubing wraps or gaps) or at crossovers (the change in spooling direction at the flanges).

EFFECT ON FATIGUE LIFE: Wave deformation is not considered detrimental to the mechanical properties of the tubing.

REPAIR: Subsequent plastic deformation (normal spooling) will reduce the appearance of this type of anomaly. Inducing a reverse bend will expedite removal of the wavy appearance.

MITIGATION: Use good spooling practices; wraps should be tight, and even throughout the reel. Avoid crossing over previous wraps and any gaps in the corners of the reel. Coiling similar to lower left photo should be avoided. Lubricate pipe on reel while spooling.

EXAMPLES:

TYPE: Plow Marks (Fish Scale or Chatter Marks)

POSSIBLE SOURCE: Injector head gripper blocks, downhole debris, well completion components

DESCRIPTION: Injector damage can be a combination of galling and abrasive wear. Normally, the orientation of this damage is in the transverse direction. The depth of the damage can be inconsistent depending on the tubing mechanical properties and injector parameters. Generally, damage of this type is shallow (<10% of base wall thickness) but can cause subsequent failure due to fatigue and subsequent wall reduction.

EFFECT ON FATIGUE LIFE: Transverse marks are detrimental to low cycle fatigue life. Normally, the shallow depth of such damage limits the reduction in fatigue life.

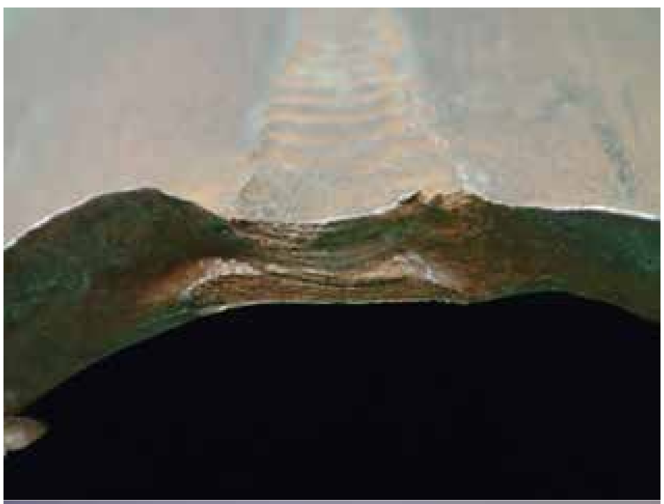
REPAIR: Repair of transverse injector damage is recommended when possible. Remove the damage per Global Tubing's "Field Damage Repair Guidelines" at the end of this document. However, many of these exceed 10% in depth or thin down with subsequent fatigue causing early failure.

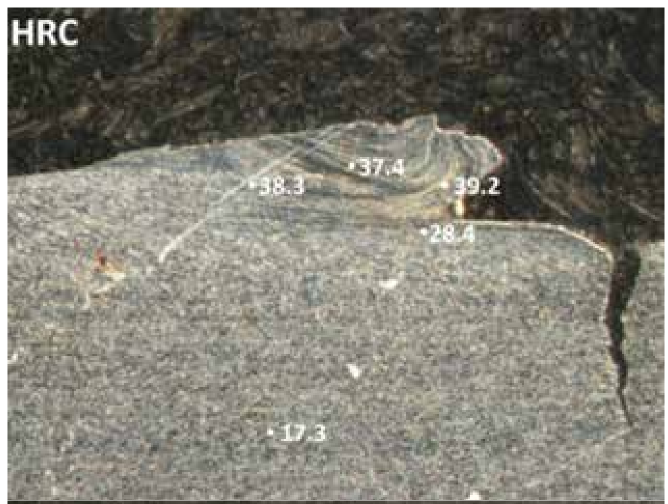
MITIGATION: Follow injector head manufacturer's guidelines for chain tension based on snubbing forces seen during operations. As conditions change during operations, be sure to adjust chain tension.

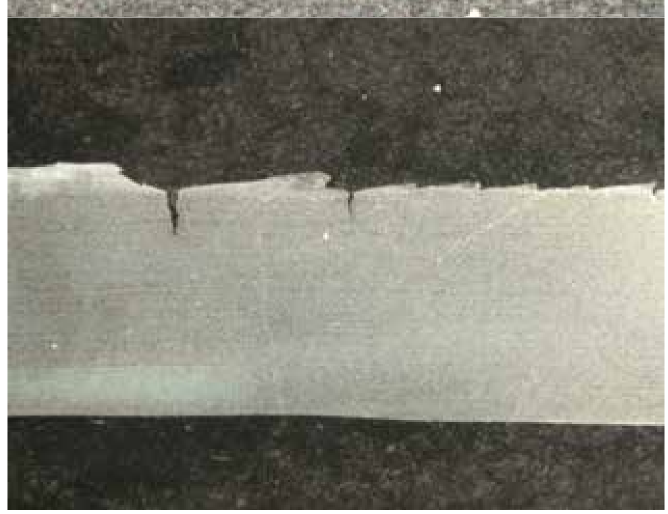
EXAMPLES:

TYPE: Plow Marks (Fish Scale or Chatter Marks)

EXAMPLES (Continued):







Plow Marks: Note the increase in hardness and fractures emanating from the root of the mechanical damage. Immediate repair is critical to reduce the amount of cracking at the root of this damage followed by non destructive examination such as Magnetic Particle or Liquid Penetrant Inspection to assure complete removal of the cracking.

TYPE: Spooling Damage

POSSIBLE SOURCE: Tight wrapping during spooling especially while making the change from one layer to the next, spooling while the tubing is dry, yard spooling with large angle from one spool to the other, loose spooling of the tubing, misalignment of gooseneck while reeling.

DESCRIPTION: Spooling damage is normally transverse galling. The orientation of this damage on the tubing is generally either the outer surface of the tube, or 90 degrees from the outermost surface of the tubing while on the spool. The depth of spooling damage ranges from 0-20% of base wall thickness. High grade (90+ksi yield strength) and large OD (2" +) have a greater propensity for spooling damage due to increased contact forces involved during spooling.

EFFECT ON FATIGUE LIFE: The orientation of this damage on the tube effects fatigue life. Because the damage is transverse, the reduction in low cycle fatigue life is moderate. Quantifying the reduction in fatigue life is difficult due to the varying depth and length of damage.

REPAIR: Repairing spooling damage is recommended. Remove the damage per Global Tubing's "Field Damage Repair Guidelines" at the end of this document. Check for cracking after repair by MPI or LPI after spooling to assure the entire crack is removed.

MITIGATION: Use good spooling practices. Wraps should be tight, and even throughout the reel. Avoid crossing over previous wraps and any gaps in the corners of the reel. Lubricate pipe on reel while spooling. seen during operations. As conditions change during operations, be sure to adjust chain tension.

EXAMPLES:

TYPE: Stripper Failure

POSSIBLE SOURCE: Stripper packer failure lodged in between tube and stripper causing compressive damage on tube surface.

DESCRIPTION: Stripper lubricator failed and packer dried out causing failure. A section of the stripper spalled off and wedged in between the tube and the stripper causing multiple dents in the tube as it was running in hole.

EFFECT ON FATIGUE LIFE: Not Repairable.

MITIGATION: Assure maintenance of the stripper and the lubricator to prevent failure.

EXAMPLES:

TYPE: Washout / Erosion

POSSIBLE SOURCE: Static coiled tubing downhole in close proximity to perforations, flow tees, broken casing collars, or other jetting sources with sand (or other abrasive) and fluid. Move string frequently to prevent localized abrasion.

DESCRIPTION: Washout damage is a type of erosive wear. Washouts are typically very smooth and non-uniform in shape and depth. They are also independent of tube grade and hardness.

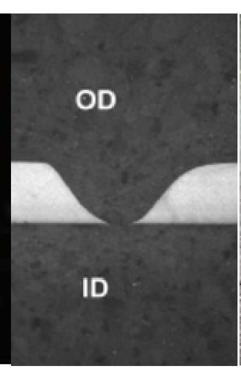
EFFECT ON FATIGUE LIFE: Washout damage reduces fatigue life by reducing the tubing wall thickness. The smooth nature of washout damage is less detrimental than damage of the same depth with jagged, point contacts, but because the shape and depth of washouts are impossible to predict, the reduction of fatigue life is also difficult to predict. Most likely, the reduction in fatigue life is large due to the aggressive nature of erosion.

REPAIR: Normally, this sort of damage is considered irreparable. If chosen to remove the damage, use Global Tubing's "Field Damage Repair Guidelines" at the end of this document, or remove completely and perform a tube to tube butt weld.

MITIGATION: Keep pipe moving at all times during the operation, especially when cleaning/returning a high volume of abrasive debris or taking returns at a high velocity. Using a flow cross instead of a flow tee at the well head which allows for multiple fluid flow paths and reduces the chances of flow path impingement.

EXAMPLES:



APPENDIX

TYPE: Field Defects; Managing and Repairing Field Defects

Repairing Field Failures (Applicable for Plow Marks and minor surface damage)

In the event of a plow mark or other surface damage believed to be less than 10% of nominal wall thickness, the surface indication can be removed. The removal of this defect can be performed as follows:

Identification

1. Visual inspection and/or electromagnetic inspection can aid in the detection of the damage as required.

2. Once the defect is identified, measure the outside diameter of the location and determine the wall loss. (UT measurement tools, and/or pit or depth gauge tools can be utilized if available)
   a. The remaining wall thickness after repair should not be less than 90% of the nominal wall thickness.

Repair Technique

1. Using manual or power tools, remove surface material from the tubing to expose and eliminate the flaw.
   a. Regardless of the type of tool used, pay attention to HOW the material is removed.
      i. See Figure 1
   b. Sanding media used to remove the material from the surface should only move in the direction parallel with the length of the tubing and never at any angle. Circumferential sanding marks due to initial sanding shall be removed in the longitudinal direction during final sanding.

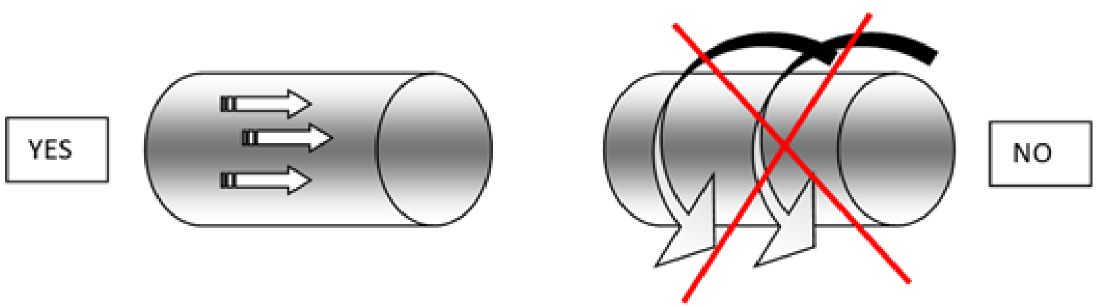


Figure 1: Correct (left) and Incorrect (right) sanding directions

   c. To avoid excess heating from friction, use low pressure while removing material
   d. Macroscopic and microscopic marks left on the surface shall be parallel to the axis of the tubing. (The goal is to finish this step with the smoothest possible finish.
      i. See Figure 2
   e. The length of the repaired area should be at least two times the diameter of the tubing. (Avoid excessive removal of the parent material, especially if applications call for high pressure service for the tubing string.)

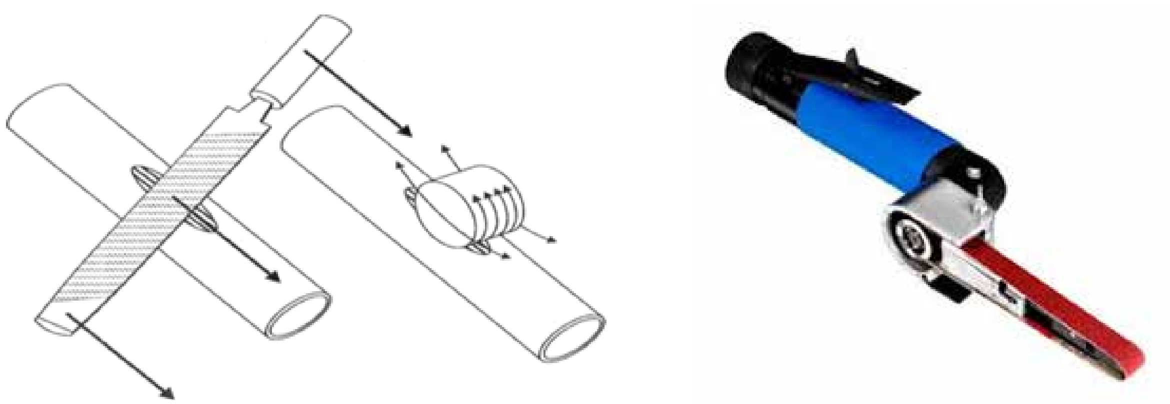


Figure 2: A file or rotary stone/pencil sander should be used in the longitudinal direction to assure all transverse scratches are removed and no additional transverse scratches are generated.

f. Figure 3 illustrates the proper and improper profiles of the final surface after repair.

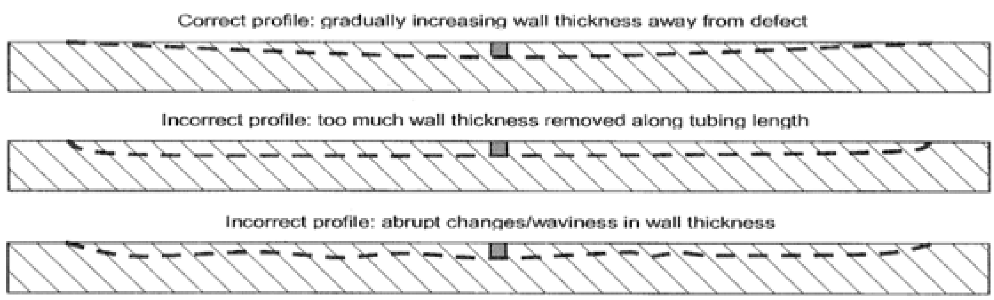


Figure 3: Tube profile examples after defect removal. Take note that the gradual profile change is preferred as seen in the top illustration. While the bottom two illustrations show undesirable profiles with abrupt changes and transitions in wall thickness.

2. The exposed surface should then be polished LONGITUDINALLY with progressively finer sandpaper or, preferably, with emery cloth. The progression of finer grit should eliminate potentially harmful sanding marks left by previous grit. Emery cloths range from 180 to 400.
3. The surface roughness in the axial direction should be a smooth finish and be free of any injurious scratches. High polishing of flaw is not necessary.
4. Final inspection by Liquid Penetrant or Magnetic Particle Inspection along with dimensional inspection is critical to assure the indication is completely removed and min. wall is acceptable. Ideally, the area should be reeled several times, then re-inspected using LP or MPI to assure full removal and the crack has not continued to propagate. (See “plow marks” section and note potential cracks emanating from surface damage. The aim is to assure all cracks are eliminated in the repair process.)

Managing Field Failures:

If a field failure occurs, Global Tubing recommends welding a patch over the top of the coil using a tube section of similar size. This protects the fracture surface and allows for easy analysis after shipping to the Laboratory. Avoid welding the fracture surface if possible.

APPENDIX

TYPE: Field Defects; Managing and Repairing Field Defects

After patch is removed as shown below, the fracture surface can be analyzed to perform root cause analysis.

In addition, chains can be welded to both sides after the patch to assure control of the tube as shown below.

Global Tubing recommends a minimum of 1m sample with the failure in the center and 1m on either side for mechanical testing. As much field data as possible before and during the failure is helpful in evaluation. See next page for proper marking

APPENDIX

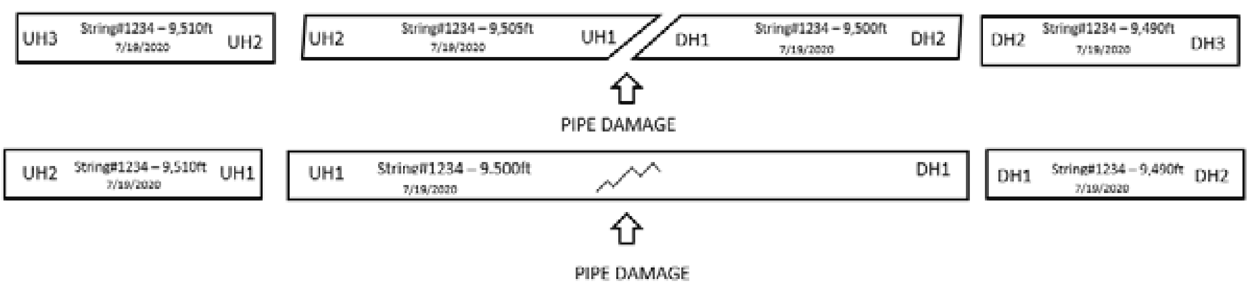
TYPE: Field Samples; Preparing Field Sample for Failure Analysis

Labelling Failure Samples

It is extremely important to clearly and accurately label all samples related to a pipe failure investigation. Each failure sample should be marked with the following information:

- Global Tubing String Number
- Footage location where sample was taken from
- Date of Extraction
- Uphole/Downhole designation with matching ends at each cut to assure continuity

If multiple samples are taken from a string, their matching faces should be designated with uphole (UH) and downhole (DH) labels as shown below.



Example of properly labelled failure samples to be sent for analysis

Global Tubing

OUR CORE VALUES

No One Gets Hurt

The safety of our employees and customers is our first priority coupled with a healthy respect for the environment.

Integrity

In everything we do, in every interaction, both internally and externally, we strive to operate with the utmost integrity and mutual respect.

Customer Focused

Our products enhance our customer's performance and we listen to their needs and work with them to solve their challenges.

Good Place To Work

We are committed to creating a workplace that fosters innovation, teamwork and pride. Every team member is integral to our success and is treated equally and fairly.

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