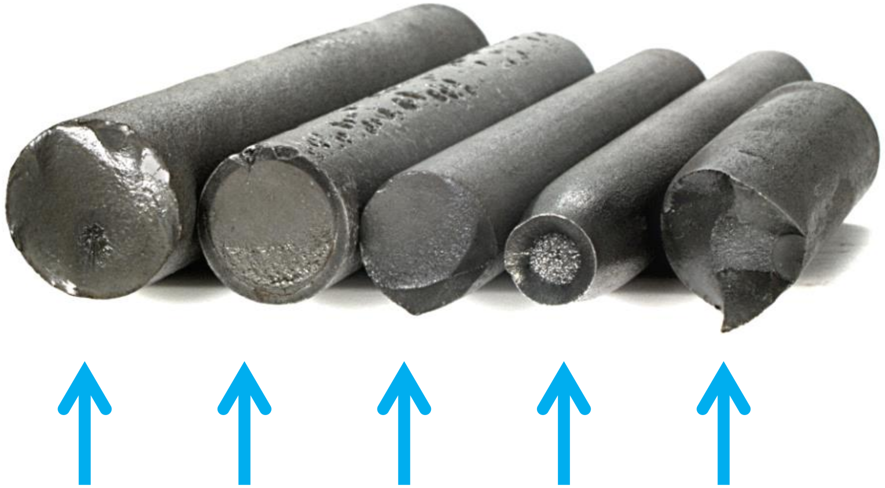
LPS LIGHTNING PRODUCTION SERVICES®

Failure Analysis Continuous Sucker Rod

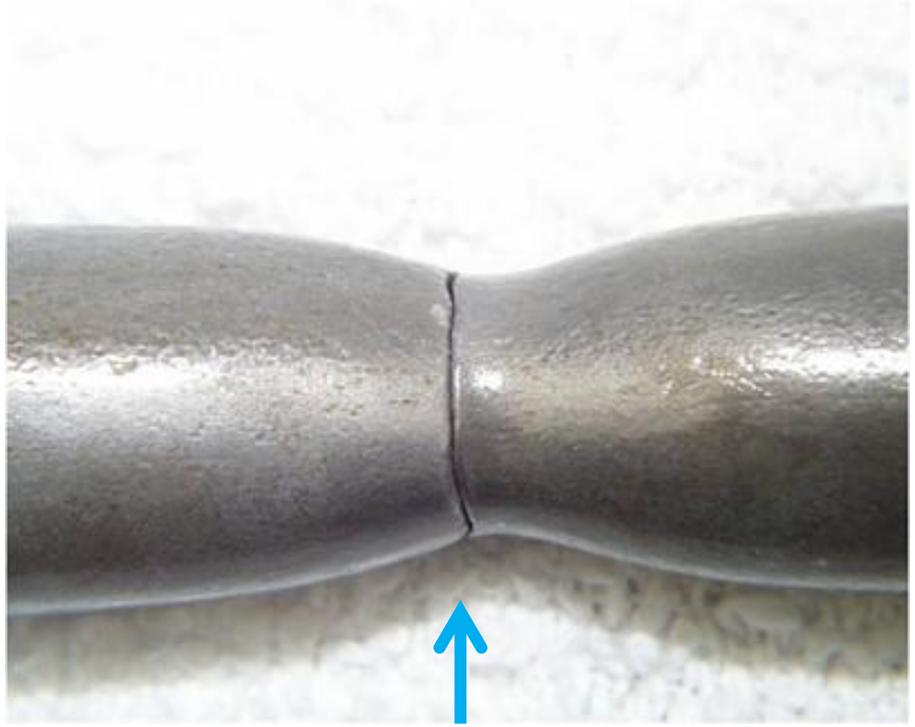
Lighting Production Services

FRACTURE MODES



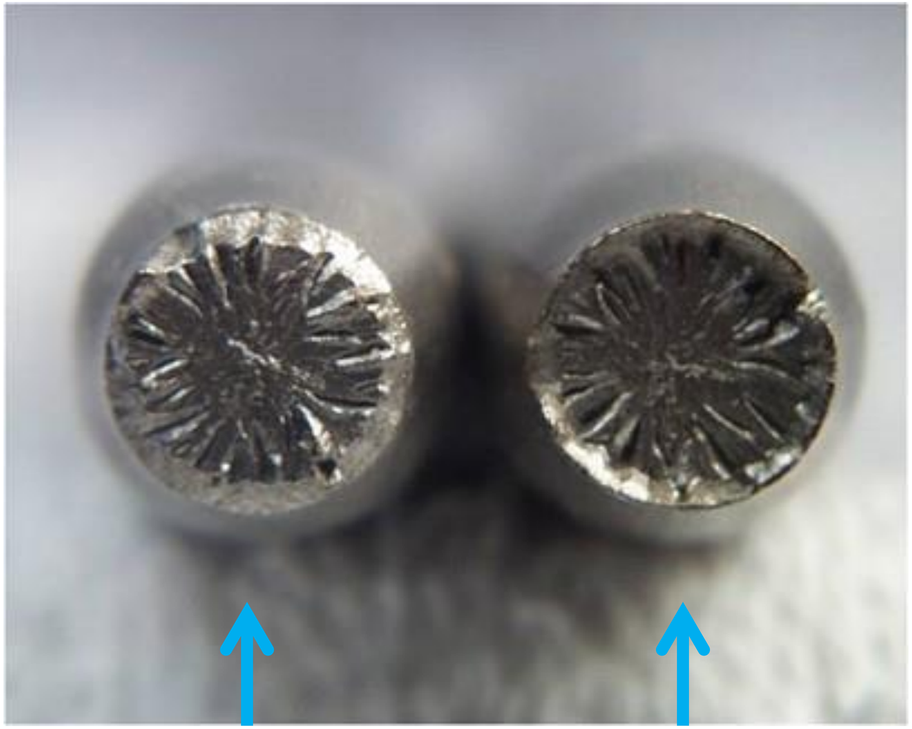
- Failures in the rod string resulting in fracture are either a tensile fracture or a fatigue fracture.
  - Tensile Fractures.
  - Fatigue Fractures.

TENSILE FRACTURES



- Tensile fractures are characterized by a reduction in the cross-sectional area at the point of rupture or complete separation.

TENSILE FRACTURES



- Tensile fractures are also known as cup/cone fractures by the appearance of their fracture surfaces.
  - Cup.
  - Cone.

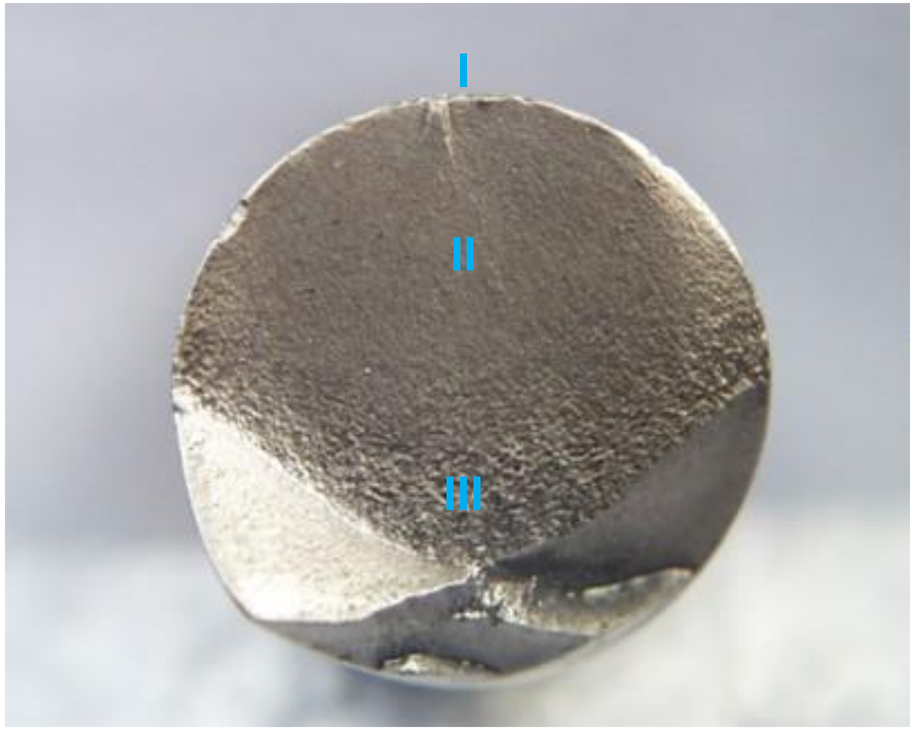
FATIGUE FRACTURES

- ASTM E1150-87 broadly defines fatigue as: “The progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses or strains at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations.”

FRACTURE-SURFACES

- Fatigue fractures originate from a local increase in stress or strain (aka a stress concentration or a stress-raiser) as small progressive cracks that advance, on each application of applied load, with the action of fluctuating stresses or strains to complete separation or shear tear.

STAGES OF FATIGUE



- The process of fatigue consist of three (3) stages:
  - Crack nucleation and crack initiation.
  - The stable or slow advance of the crack on each cycle of applied load.
  - The unstable or rapid advance of the crack during one applied load to complete separation of the component.

STAGE I

- Stage I of fatigue is the initial crack nucleation and crack initiation site.

STAGE II

- Stage II is the progressive cyclic advance of the crack until the remaining un-cracked cross-section becomes too weak to support the next applied load.
  - Ratchet Marks.
  - Beach Marks (aka the crack-front or fatigue marks).

RATCHET MARKS

- Ratchet marks are the ridges formed by the intersection of multiple cracks advancing on parallel but separate axial planes during fluctuating stresses. After initiation, the cracks propagate radically inward, each producing a separate fatigue crack zone, until accommodation occurs to join the individual cracks into one larger crack on the same plane. As two approaching cracks meet, a small step is formed on the fracture-surface.

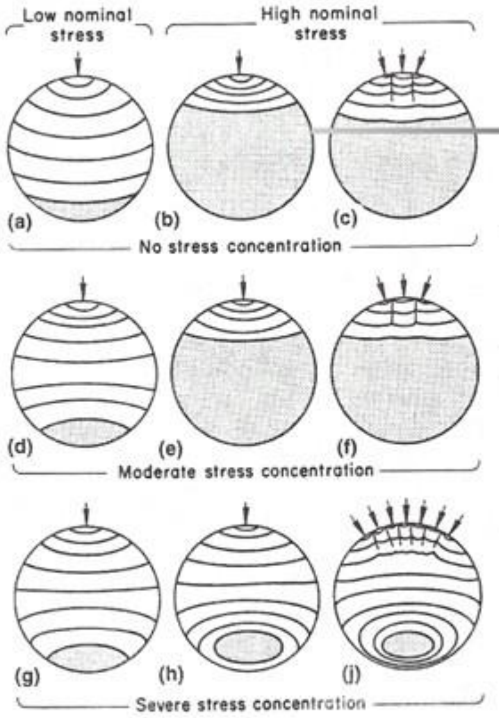
BEACH MARKS

- Beach marks are the elliptical, or semi-elliptical rings that radiate outward from the fracture origin and may be caused from such factors as variations in crack velocity, surface oxidation, corrosion, et cetera. Centered around a common point that corresponds to the fatigue-crack origin, beach marks are surface topography changes that vary locally on the fracture-surface and indicate the successive cyclic position of the advancing crack growth.

BEACH MARKS

- Beach marks are produced by changes in crack-growth rates from constantly changes stress-intensity at the crack-tip. The initial crack-growth rate is slow but increases with the increasing stress intensity at the crack-tip as the crack extends further into the cross-sectional area.

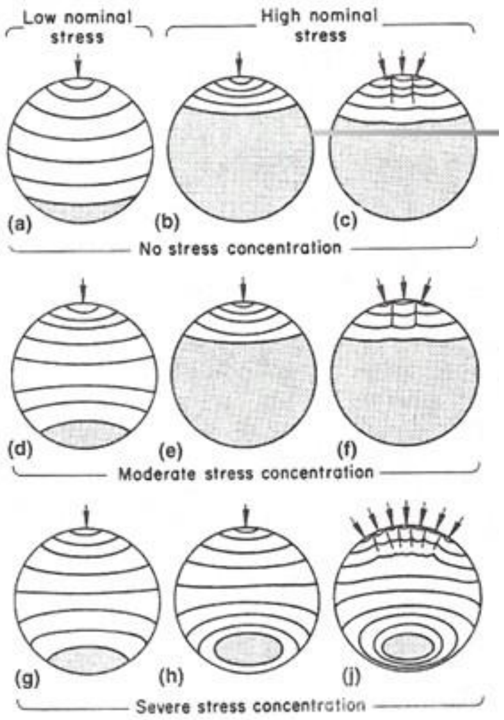
TEXTBOOK BEACH MARKS



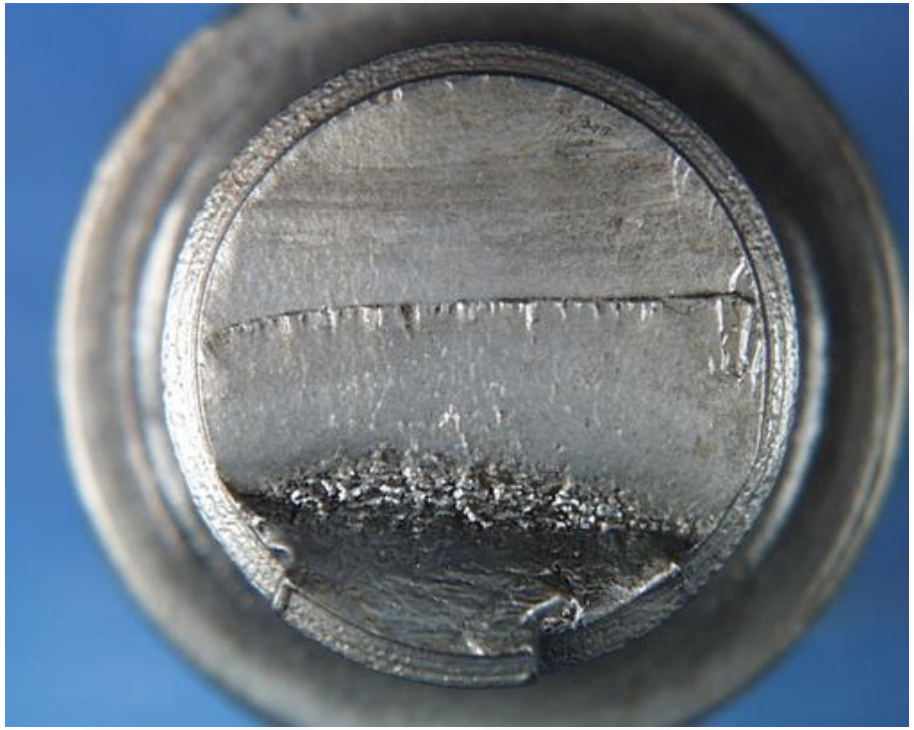
ASM Handbook, Volume 11, 2002, Page 702

- The example of beach marks shown at the left are produced from single origins at low and high nominal stresses and from multiple origins at high nominal stresses in a cylindrical bar that is subjected to cyclic unidirectional bending stresses.

TEXTBOOK BEACH MARKS VS. FIELD FAILURE



ASM Handbook, Volume 11, 2002, Page 702



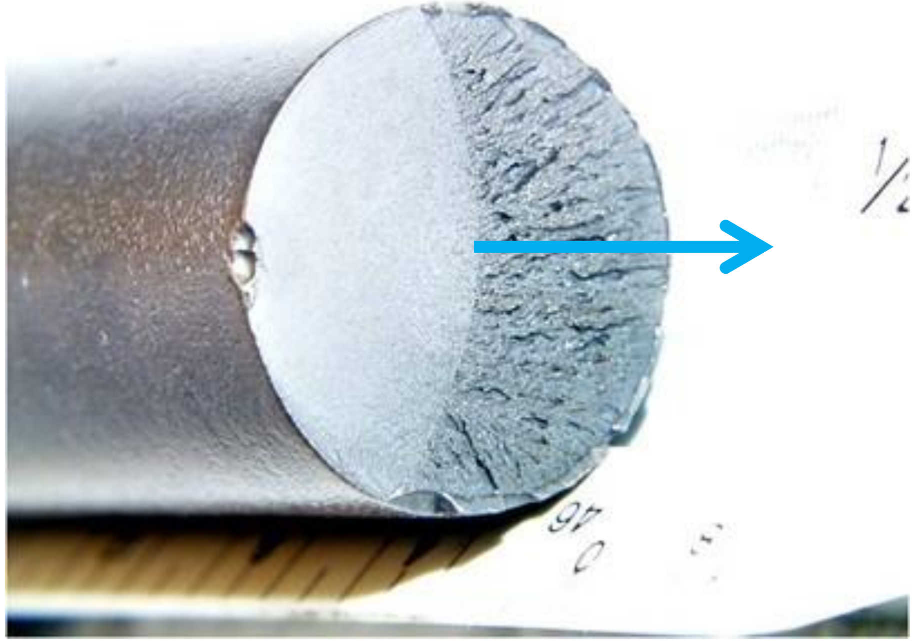
STAGE III

- Stage III of fatigue is the unstable or rapid advance region that occurs during complete separation of the component. The size of the final fracture-zone depends on the magnitude of the loads involved and its shape depends on the shape and size of the component and the direction of loading.

STAGE III FRACTURE-SURFACE

- The final fracture-zone is rough and fibrous and will consist of fracture by two (2) distinct modes:
    - Mode I – plane-strain loading conditions.
    - Mode II – plane-stress loading conditions.

MIXED MODE I LOADING CONDITIONS

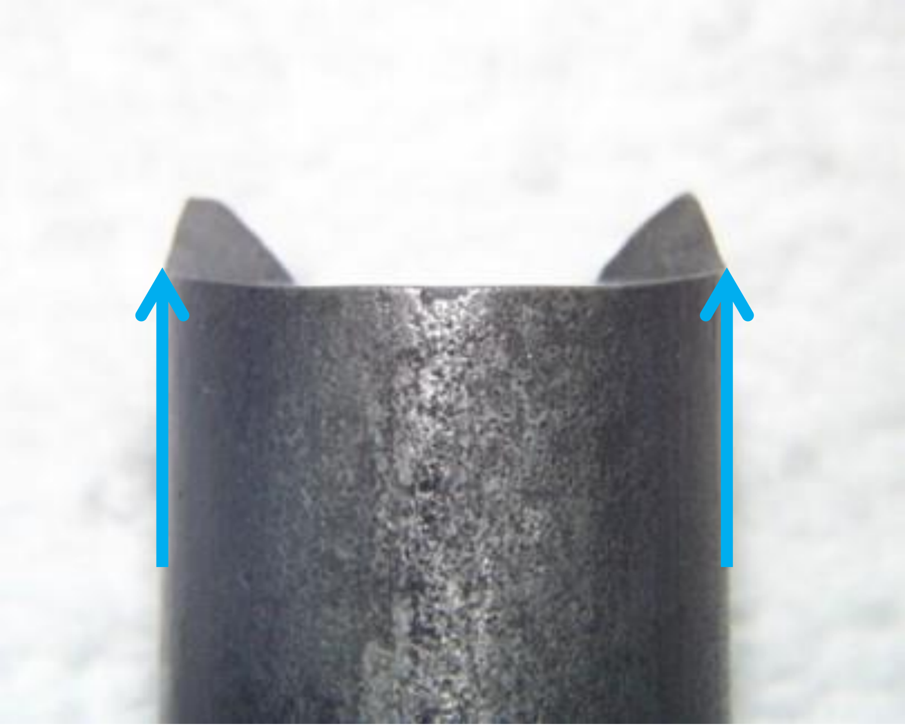


- A stage III final fracture-zone with a flat, fibrous tear essentially normal to the axis of the tensile load with little-to-no slant fracture indicates plane-strain loading conditions; where the crack-tip is constrained by the adjacent material – which is not as highly stressed.
    - Little-to-no Slant-fracture.

MIXED MODE II LOADING CONDITIONS

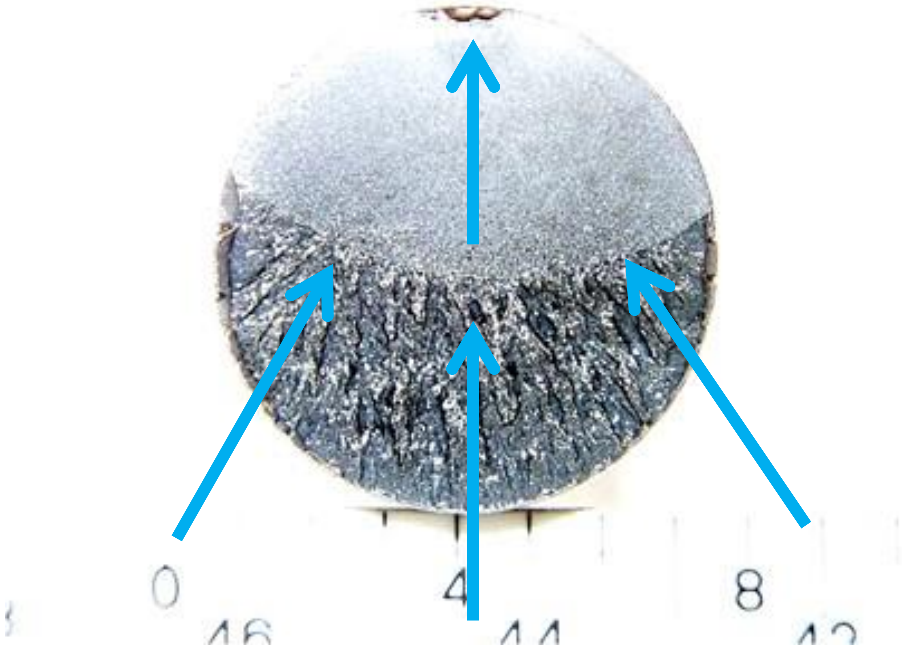
- A stage III final fracture-zone with a flat, fibrous tear essentially normal to the axis of the tensile load with a sharply defined slant-fracture indicates plane-stress loading conditions; where stress cannot increase beyond the elastic limit (yield) of the steel until the entire area affected by the crack-tip is plastically deformed.
  - Slant-fracture (aka shear-lip tear).

MIXED MODE II LOADING CONDITIONS & UNIDIRECTIONAL BENDING STRESS



- When unidirectional bending stress is involved with mixed mode II loading conditions, the final rupture or complete separation pulls from the backside during a bending moment; leaving unique double slant-fractures or shear-lip tears on the fracture-surface.
  - Double Slant-fracture.

STAGE III FRACTURE-SURFACE

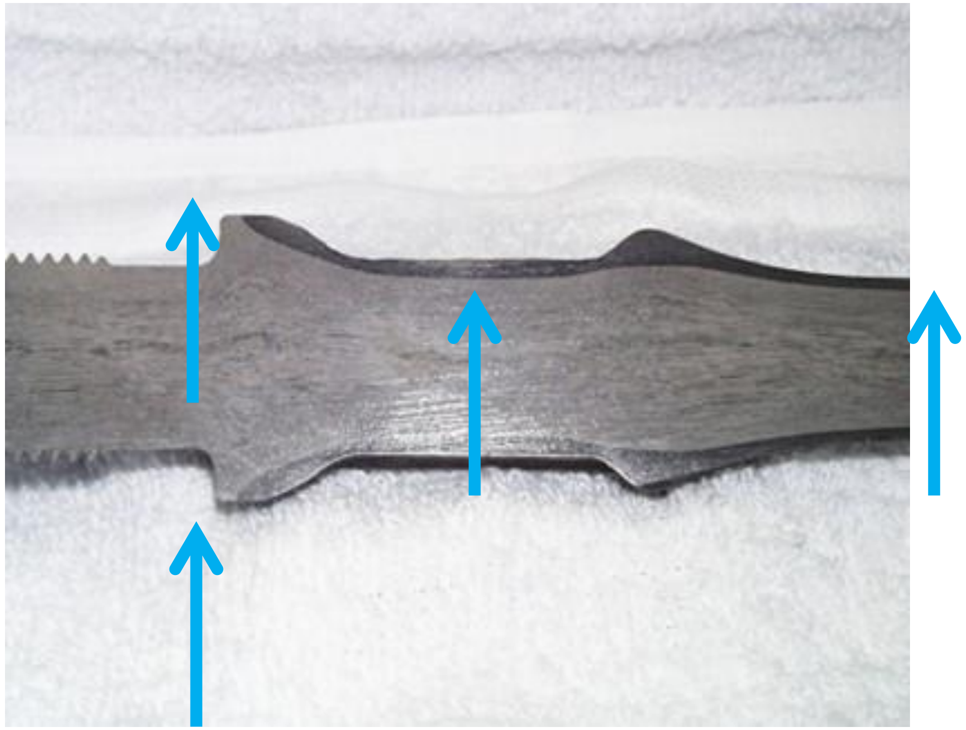


- Two (2) features of the final fracture-zone aid in determining the origin of the fracture.
  - Fatigue usually originates at the surface and therefore the fatigue origin is not included in the final fracture-zone.
  - Chevron marks in the final fracture-zone point back to the origin of the fatigue initiation-site.

FATIGUE FRACTURE OR TENSILE FRACTURE?

- A high strength sucker rod made by an induction hardening process in which only the surface layer of the rod body is heated by electromagnetic induction heating. Quenching immediately after heating produces a sucker rod with an outside case of extremely hard, fine-grained, needlelike martensite with a soft, ductile inner core.

CASEHARDENED SUCKER ROD



- Case run-out is on the pin-shoulder – weaker pin.
- Even case-depth is hard to control – quality control is a critical factor.
- The metallurgy and heat-treatment changed in 1993 – not the original chemistry with the addition of nickel nor the original heat-treat condition.

TIME TO FAILURE

- The time to failure is influenced by many variables; of which the chemistry, heat treatment, operating environment and type and orientation of the discontinuity are some of the more important factors.

STRESS INTENSITY FACTOR

- The type and orientation of the discontinuity (stress intensity) helps determine the level of stress concentration (local stress intensity) to applied load.
  1. Sharp, transverse discontinuity with metal removed.
  2. Sharp, longitudinal discontinuity with metal removed.
  3. Broad-based, shallow depressions.

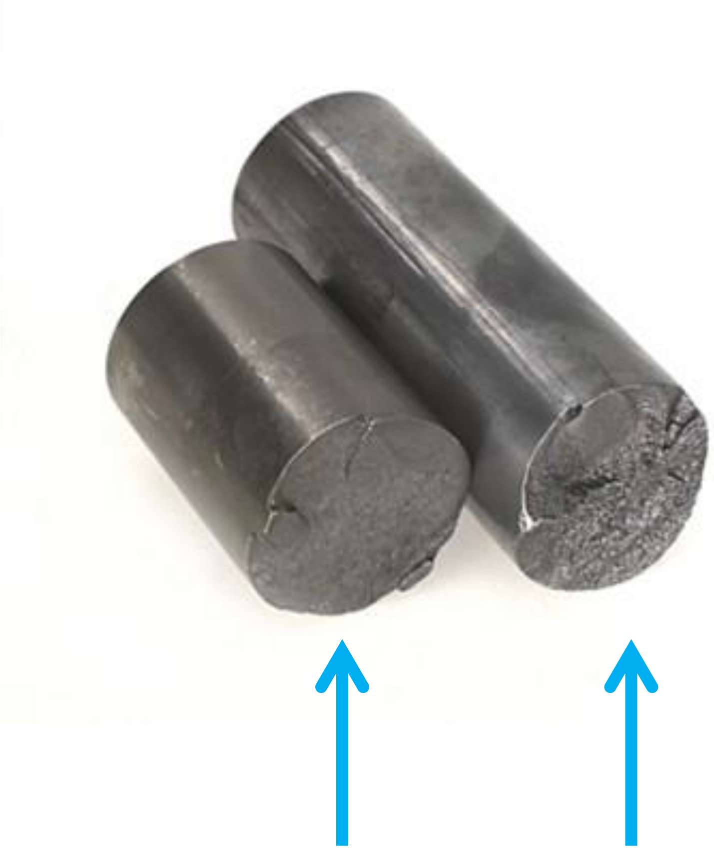
FIELD FAILURES

- Identifying the failure cause in the field is difficult, if not impossible, without the proper tools.
  - The rod string is covered with hydrocarbons (i.e., oil, paraffin, etc.).
  - Discontinuities may be covered or filled with corrosion deposits (i.e., iron carbonate scale, iron sulfide scale, etc.)

Common Failure Causes

- Local areas of stress concentrations or stress raisers (i.e., failure initiation sites) are introduced into the rod string through:
  - Handling and makeup procedures.
  - Design and operating conditions.
  - Material or workmanship defects.

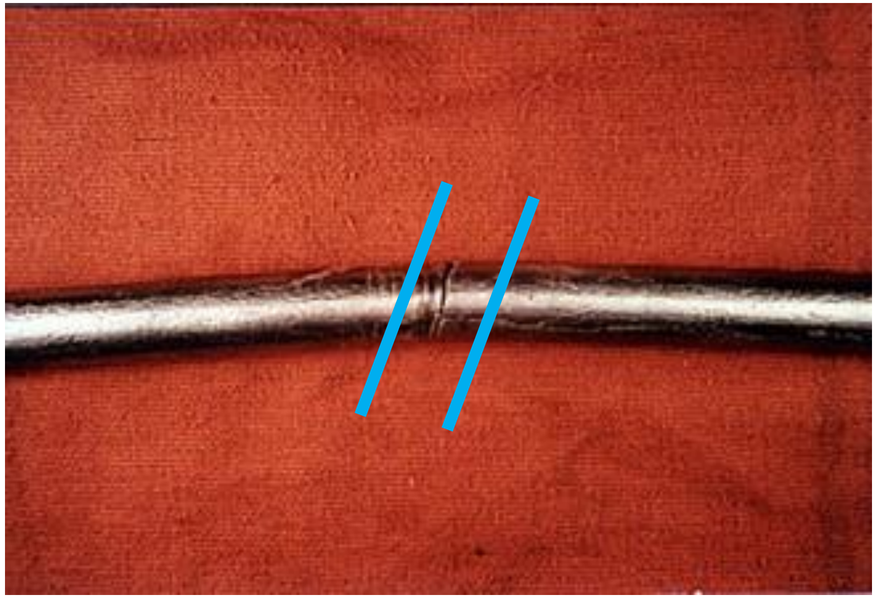
APPLICATION



- Misaligned carrier bars, load cells, polished rod clamps and pumping units can lead to unidirectional bending failures.
- Metal-to-metal contact, excessive bolt-torque and clamping on the sprayed portion of polished rods can lead to mechanical damage failures.

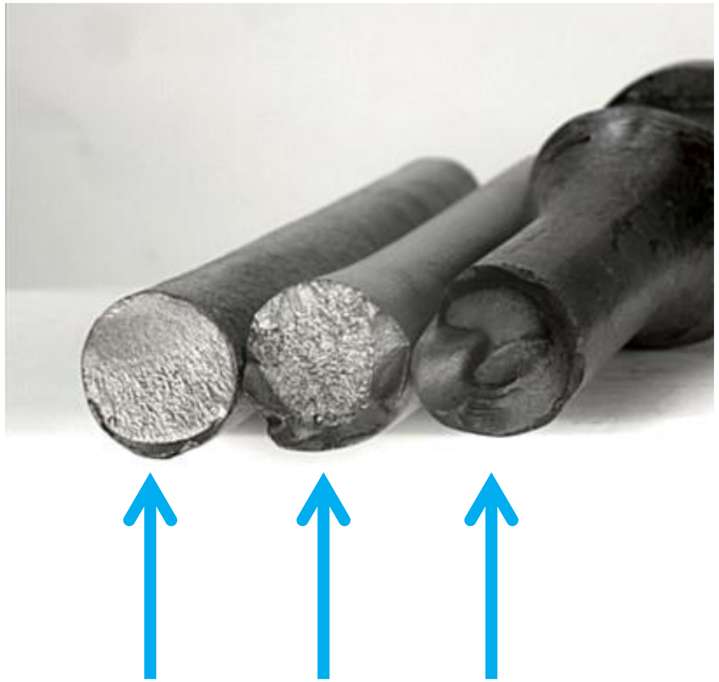
UNIDIRECTIONAL BENDING FAILURES

MECHANICAL DAMAGE



- Failures due to bent rods can be identified by the angled fracture-surface or break-face; which will be at some angle other than 90-degrees to the longitudinal axis of the rod body.
  - Angled break-face.

MECHANICAL DAMAGE



- The time to failure is dependent upon the applied load and the degree of bend in the sucker rod.
- As a general rule, the greater the bend in the sucker rod, the rougher and more convoluted the fracture-surface will be; and the time to failure will be quicker.

MECHANICAL DAMAGE

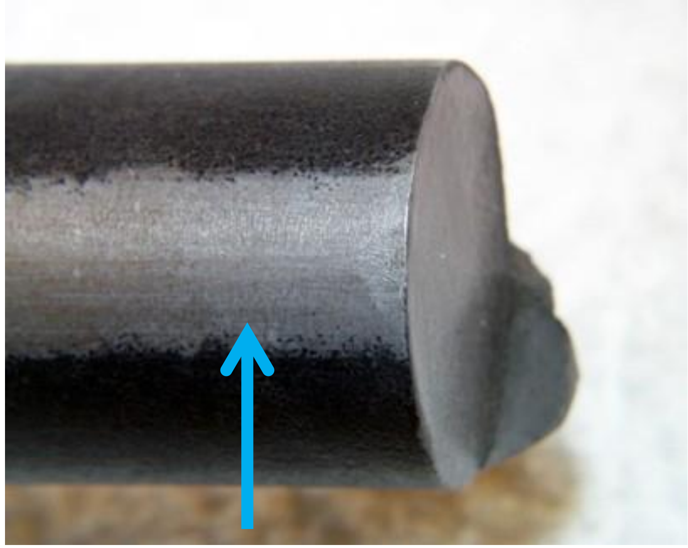
- Using forklifts without spreader bars and tee hooks can result in mechanical damage to the sucker rods.
  - Mechanical damage to the body of the sucker rod from the tines of a forklift while moving rod bundles without the use of a spreader bar and tee hooks!

MECHANICAL DAMAGE

- Mechanical damage increases local stress concentrations during applied load; initiates a stress crack.
- Scratches or roughened areas are more anodic to smooth surfaces; results in a higher tendency to corrode.
  - Surface dent.
  - Pipe wrench damage.
  - Scratch.
  - Transverse surface damage.

DESIGN AND OPERATING CONDITIONS

ABRASIVE-WEAR

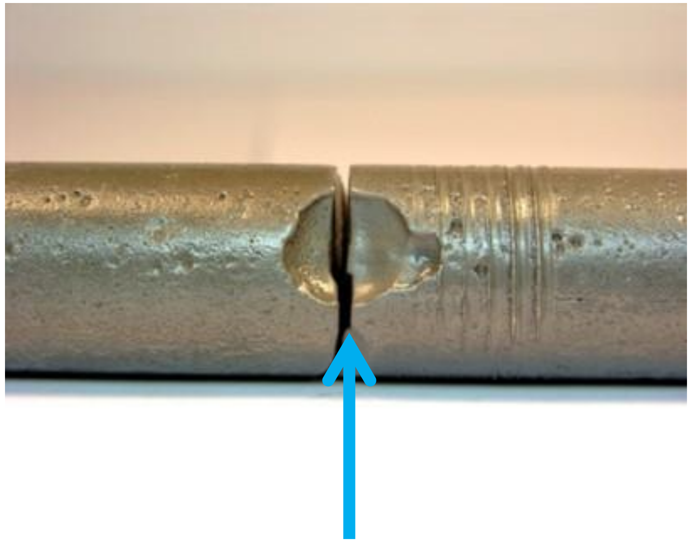


- Abrasive-wear causes rod body and coupling failures by reducing the cross-sectional area of the steel and LOD connection failures from impact and shoulder damage.
    - Small, transverse stress cracks initiate in the wear pattern.

ABRASIVE-WEAR

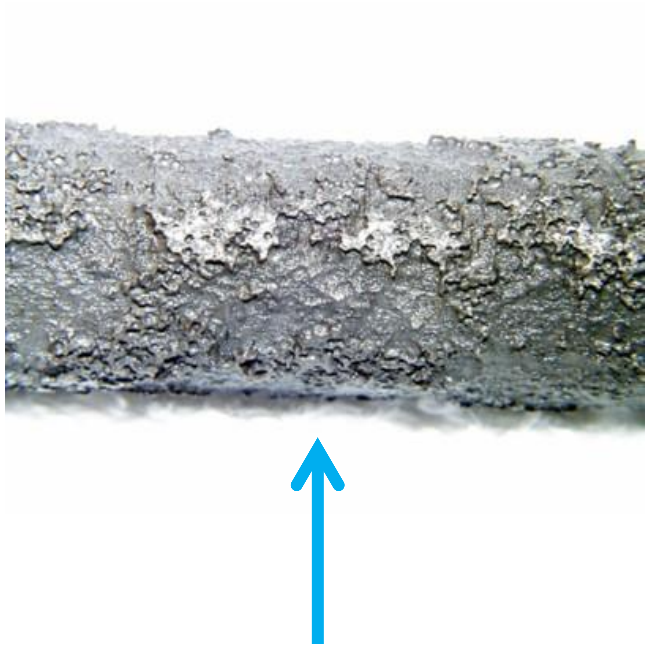
- Abrasive-wear causes rod body and coupling failures by reducing the cross-sectional area of the steel and LOD connection failures from impact and shoulder damage.
    - Abrasive-wear causes connection failures by reducing the cross-sectional area of the steel and LOD failures by reducing the contact area of the pin-shoulder.

CORROSION-FATIGUE



- Corrosion-fatigue results from the combined synergistic effects of repeated or fluctuating stresses and a corrosive operating environment.
    - CO2 corrosion pit.

CORROSION-FATIGUE



- Acid corrosion is identified by the appearance of sharp, feathery or web-like residual metal nodules. Corrosion deposits are not formed by acid corrosion.
  - Damage to a rod body from acid corrosion.

CORROSION-FATIGUE

- Carbon dioxide (CO2) corrosion pits are round-based with steep-walls and sharp pit-edges. Pitting from CO2 corrosion is usually interconnected in long lines but will occasionally result in singular and isolated pits. Iron carbonate scale, a byproduct of CO2 corrosion, will be found in the pit.

CARBON DIOXIDE (CO2) CORROSION

- Naturally occurring.
- Used as injection gas for enhanced oil recovery (EOR).
- Combines with water (H_2O) to form carbonic acid (H_2CO_3).
- Stronger acid than H_2S.
- Byproduct is iron carbonate scale ($FeCO_3$).
- Increases the likelihood for calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$) scale.

CORROSION-FATIGUE

- Chlorides contribute to the likelihood for an increase in corrosion related failures. Corrosion tends to evenly pit the entire surface of the sucker rod with flat-bottomed, irregular-shaped pits that have steep pit-walls and sharp pit-edges.

CORROSION-FATIGUE

- DMC results when one steel has a marked tendency to corrode in preference to the other steel in certain aqueous environments.
  - DMC is often reported as the cause of the failure but DMC seldom occurs in the rod string and is rarely the failure cause.

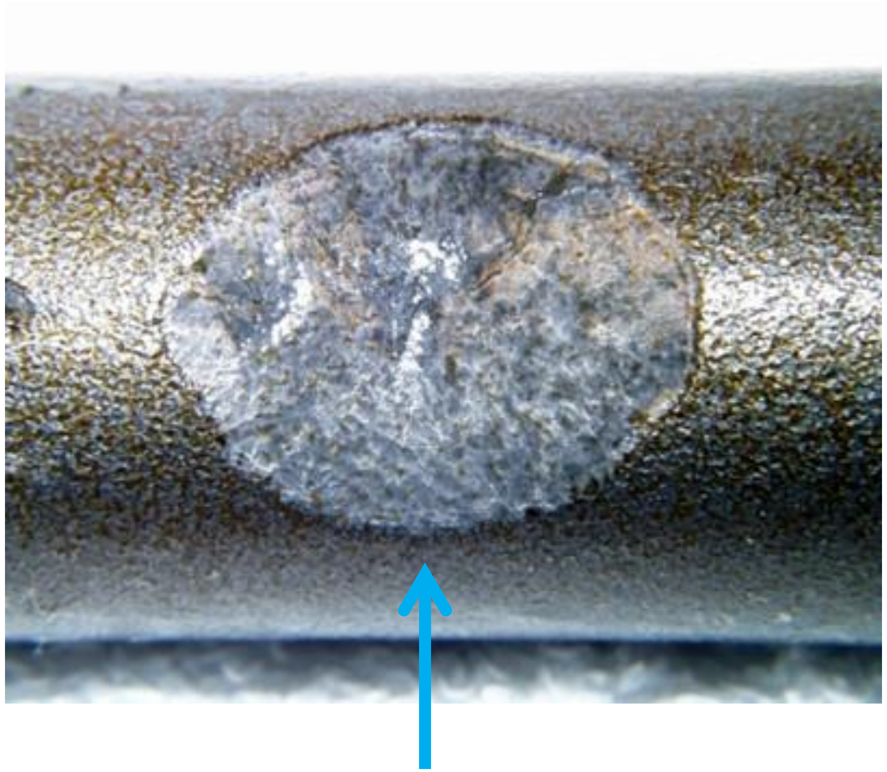
DISSIMILAR METALS CORROSION (DMC)

- Dissimilar metals corrosion (aka galvanic corrosion) is the less noble of the metals leeching toward the noble metal leaving a somewhat tapered appearance.

CORROSION-FATIGUE

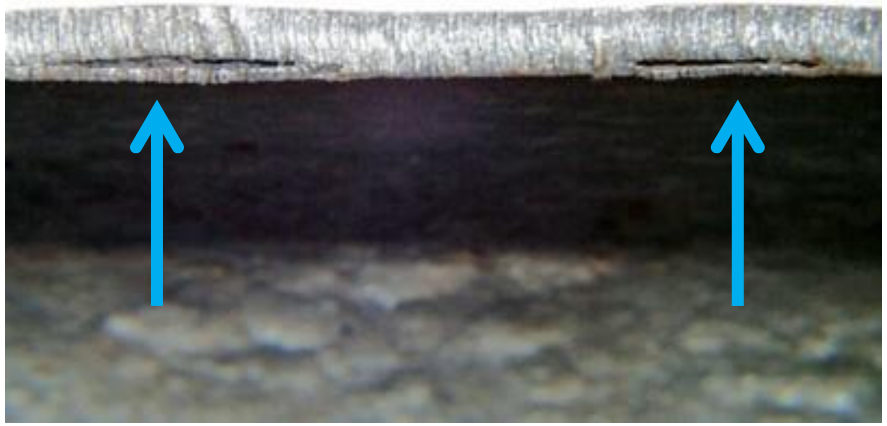
- Hydrogen sulfide (H2S) corrosion pits are round-based, deep with steep pit-walls and beveled pit-edges. H2S corrosion pits are usually small, random and scattered over the entire surface of the sucker rod. Both the surface of the sucker rod and the base of the H2S pit will contain iron sulfide scale.

HYDROGEN SULFIDE (H2S) CORROSION



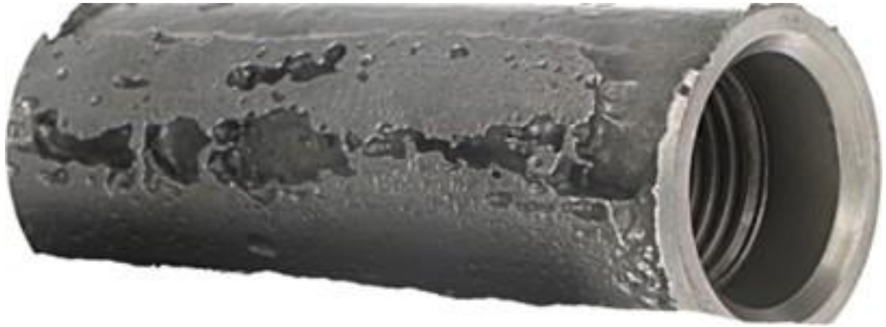
- Naturally occurring.
- Byproduct of microbiologically induced corrosion (MIC).
- H2S forms a weaker acid than CO2.
- H2S can cause hydrogen embrittlement failures.
- H2S can lead to hydrogen blistering failures.
- The byproduct of H2S corrosion is iron sulfide scale.

HYDROGEN BLISTERING



- The formation of blisters on or below the surface of the metal is from pressure buildup due to the hydrogen leaching into the metal lattice.
  - Hydrogen blistering.

CORROSION-FATIGUE



Acid Producing Bacteria (APB)

- Microbiologically induced corrosion (MIC) from acid producing bacteria (APB) has the same basic pit-shape characteristics as CO2 corrosion pits except APB has a cavernous or tunneled appearing pit-wall and the pit-base is usually striated or grainy in appearance.

CORROSION-FATIGUE

Sulfate Reducing Bacteria (SRB)

- Microbiologically induced corrosion (MIC) from sulfate reducing bacteria (SRB) has the same basic pit-shape characteristics as H2S corrosion pits. SRB corrosion pits often have multiple stress cracks in the pit-base, tunneling around the pit-edges (pits-within-pits), pit-clustering and/or unusual surface anomalies (i.e., shiny splotches on the surface of the cleaned sucker rod).

MICROBIOLOGICALLY INDUCED CORROSION (MIC)

Acid Producing Bacteria (APB)

Sulfate Reducing Bacteria (SRB)

- Bacteria are native to the formation.
- Bacteria can be introduced into the well during drilling or an intervention after drilling (i.e., from truck treatments, hot water treatments, pressure testing tubing, wash waters, sump and pit waters, injection waters, etc.).

CORROSION-FATIGUE

- Oxygen (O2) enhanced corrosion is broad-based, shallow-depth pitting with the tendency for one pit to combine with another. Pit-shape characteristics may include steep pit-walls and sharp pit-edges when combined with CO2 or large smooth-craters and beveled pit-edges when combined with H2S.

OXYGEN (O_2) ENHANCED CORROSION

- O2 typically affects high velocity flow area of the sucker rod (i.e., rod guides, couplings and upsets, etc.).
- 1 ppm of O2 is as corrosive as 50 ppm of CO2 or 100 ppm H2S.
- 8 ppm of O2 is roughly five (5) time more corrosive than eight-hundred (800) ppm of H2S.
- Combinations of O2 with CO2 and/or H2S can cause aggressive corrosion with high rates of metal loss – even at trace amounts of O2 (100 ppb).

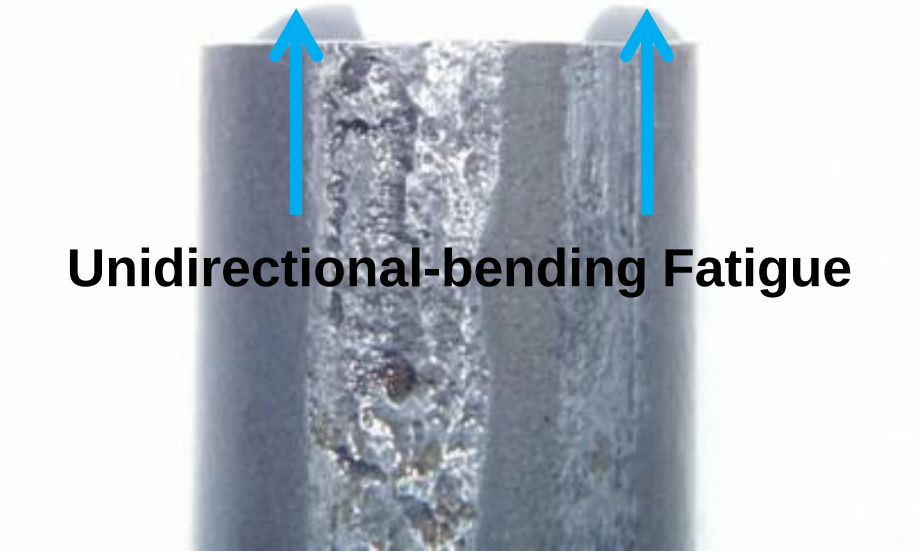
CORROSION-FATIGUE

- Under-deposit corrosion is a general thinning of the entire surface. Pitting results when the scale deposits are cracked or removed during a bending moment and/or from contact with the production tubing.

UNDER-DEPOSIT CORROSION

- Scale deposits tend to slow down the overall corrosion penetration rate but also reduces the effectiveness of chemical inhibitors.
- Under-deposit corrosion can result in pits that corrode at a much higher rate than free exposed steel (10 to 100 times higher have been reported).
- Iron sulfide scale is highly cathodic to steel.

CORROSION-ABRASION



- Abrasive-wear exposes new metal surfaces in which an electrochemical reaction with the corrosive environment is significant.
- Pit-shape characteristics include steep pit-walls and sharp pit-edges if accompanied by CO2 or broad-based, smooth pits with beveled pit-edges if accompanied by H2S; or some combination thereof if accompanied by both CO2 and H2S.

HI RISE SYSTEM

THANK YOU

info@lpsus.com
(281) 446-8020
Houston, TX
Midland, TX
Bakersfield, CA

www.lpsus.com

LPS LIGHTNING PRODUCTION SERVICES