Sucker Rod Failure Analysis
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Root Cause Failure Analysis

Root Cause Failure Analysis (RCFA) is Essential for Failure Frequency Reduction in Wells with Artificial Lift.

Most failures associated with the sucker rod form of artificial lifted wells using the sucker rod lift method can be attributed to one of three primary downhole components—subsurface pump, sucker rod string or tubing string. All of these components is defined as any catastrophic event requiring servicing personnel to pull or change-out one or more of these components.

By this definition, the failure frequency rate is the total number of component failures occurring per well, per year in a producing field. Marginally producing wells with high failure frequency rates are often classified as “problem” wells. Thus, effective failure management practices can mean the difference between operating and plugging these wells. Failure management includes: identifying the problem(s), recording the “real” root cause of each failure, implementing the appropriate change(s), and preventing future failures from occurring. This process is central to overall cost-effective asset management. For the purpose of this special report, we will deal only with sucker rod string related failures.

Cost-effective failure management begins with prevention, and the time to stop the next failure is now—prior to the next incident! Simply fishing, hanging the well on after a sucker rod failure and replacing with the same type of component that failed will not prevent failure recurrence. In fact, most failures continue with increasing frequency until the entire rod string must be pulled and replaced.

Failure Mechanisms

All sucker rod, pony rod and coupling failures are either tensile or fatigue failures

All sucker rod, pony rod and coupling failures are either tensile or fatigue failures. Tensile failures occur when the applied load exceeds the tensile strength of the rod. The load will concentrate at some point in the rod string, create a necked-down appearance around the circumference of the rod, and fracture occurs where the cross-section is reduced. This rare failure mechanism only occurs when pulling too much load on the rod string—such as when attempting to unseat a stuck pump. To avoid tensile failures, the maximum weight indicator pull for a rod string in “like new” Condition should never exceed 90% of the yield strength for the known size and grade of the smallest diameter sucker rod in the string. If the sizes, grades, or conditions of the sucker rod string components are unknown, then a sufficient de-rating factor should be applied to the maximum weight that is pulled. All other sucker rod, pony rod and coupling failures are some form of fatigue failures.

Achievable failure frequency reductions require accurate failure root cause analysis and the implementation of corrective action measures to prevent failure recurrence. A database capable of querying the well “servicing” history is needed to track and identify failure trends. Once a failure trend is identified, remedial measures should be implemented during well servicing operations to prevent premature rod string failures. The database failure history should include information on the failure type, location, depth, root cause and the corrective action measures implemented.

Fatigue failures are progressive and begin as small stress cracks that grow under the action of cyclic stresses. The stresses associated with this failure have a maximum value that is typically less than the yield strength of the sucker rod steel in
SUCKER ROD FAILURE ANALYSIS

the final, heat treated condition. Since the applied load is distributed nearly equally over the full cross-sectional area of the rod string, any damage that locally reduces the cross-sectional area will increase the load or stress at that point and is considered a stress raiser. A small stress fatigue crack typically forms at the base of the stress raiser and propagates perpendicular to the line of principle stress. This typically is along the axis of the rod body. However, when there are dog legs, rod buckling and well bore deviations etc., the principle axis may not be along the rod string length and a resulting tri-axial stress state may occur. As the stress fatigue crack gradually advances, the mating fracture surfaces opposite the advancing crack front try to separate under load. Then the mating fracture surfaces become smooth and polished from subsequent rubbing or chafing. As the fatigue crack progresses, it further reduces the effective cross-sectional area of the sucker rod or coupling until insufficient metal remains to support the load. Then the sucker rod or coupling simply fractures in two. The fracture surfaces of a typical fatigue failure have a fatigue portion, tensile tear portion and final shear tear portion.

Fatigue failures are initiated by a multitude number of stress raising conditions. Stress raisers are visible or microscopic discontinuities that cause an increase in local stress on the rod string during loading. Typical visible stress raisers on sucker rods, pony rods, and couplings are bends, corrosion pits, cracks, mechanical damage, threads and wear or any combination of the preceding. This increased stress effect is the most critical when the discontinuity on the rod string is transverse (normal) to the principle tensile stress.

In determining the origin of a stress raiser in a fatigue failure, the fatigue portion opposite the final shear tear protrusion must be carefully cleaned and thoroughly examined. Fatigue failures have visible or macroscopic identifying characteristics on the fracture surface, which help to identify the location of the crack origin and type of stress raiser. Ratchet marks and beach marks are arguably two of the most important features in fatigue failure identification. Ratchet marks are lines that result from the intersection and connection of multiple stress fatigue cracks while beach marks indicate the successive position of the advancing fatigue crack. Ratchet marks are parallel to the overall direction of crack growth and lead to the initiation point of the failure. Beach marks are elliptical or semielliptical rings radiating outward from the fracture origin and indicate successive location of the advancing stress fatigue crack growth.

Figure 1 shows examples of fatigue and tensile failure mechanisms. The Fig 1C rod failure is typical in appearance for most fatigue failures. Typical fatigue failures have a fatigue portion, tensile portion and final shear tear. The width of the fatigue portion is an indication of the loading applied when the final fracture occurs. Mechanical damage can prevent or hinder failure analysis by destroying the visual clues and identifying characteristics normally found on a fatigue fracture surface. Care must be exercised when handling the fracture halves. It is very important to resist the temptation to fit the mating fracture surfaces together since this almost always destroys (smears) microscopic features that aid in determining the failure cause. To avoid mechanical damage, fracture surfaces should never actually touch during fracture surface matching.
The 1B rod body is a casehardened fatigue failure. The case encircling the rod body diameter carries the load for this high tensile strength sucker rod and if the case is penetrated, the load-carrying capability of this type of manufactured sucker rod is effectively destroyed. The stress fatigue crack advances around the case and progresses across the rod body until complete fracture occurs. A fatigue failure on a casehardened sucker rod generally exhibits a small fatigue portion and a large tensile tear (unless lightly loaded).

The example shown in 1A is a torsional fatigue failure from a progressing cavity pump. Ratchet marks found in the large fatigue portion, and originating from the surface of the rod body, completely encircle the fracture surface with the small tensile tear portion shown slightly off middle-center. The two examples on the right, 1D and 1E, are tensile failures. A tensile failure is characterized by a reduction in the diameter of the cross-sectional area at the point of fracture. The rod body shown in 1D is a typical tensile failure showing cup-cone fracture halves. The second example in Fig 1E is not typical in appearance for tensile failures. Fractures from tensile failures rupture, or shear, on 45° angles to the stresses applied. A good example of the shear is the characteristic cup-con fracture surfaces of a typical tensile failure.

The 1E body failure is an excellent example of needing to look past the obvious for the not-so-obvious. A stress fatigue crack is primarily responsible for this failure even though fracture occurred while trying to unseat the pump. Visual examination of the fracture surface reveals a small, semi-elliptical, stress fatigue crack on the rod body surface. This sucker rod had preexisting, transverse stress fatigue cracks, from in-service stresses. One of the stress fatigue cracks opened during the straight, steady load applied in attempting to unseat the pump, and fracture occurred. The tensile failure is secondary and results in the unusual appearance of the fracture surface with the small fatigue portion, large tensile portion and unusually large 45° double shear-lip tears.
Design and Operating Failures

Sucker rod failure prevention begins with design. It is possible for poorly designed rod strings to contribute to other component failures in the artificial lift system, such as rod cut tubing resulting from out of axial load plane displacing of the rods and/or tubing or from well bore deviations and even dog legs that were not included in the rod string design.

Designing the artificial lift system is a compromise between the amount of work to be done and the expense of doing this work over a cost-effective period of time. Numerous combinations of depths, tubing sizes, fluid volumes, pump sizes and configurations, pumping unit sizes and geometries, stroke lengths, pumping speeds and rod string tapers are available to the system designer. Sucker rod size and grade selection is dependent upon many factors including predicted maximum stresses, stress ranges, and operating environments.

Commercially available computer design programs allow the system designed to optimize production equipment at the least expense for the well conditions existing at the time of the design. However, after the initial design and installation of the rod string, periodic dynamometer surveys should be utilized to confirm that equipment load parameters are within those considered acceptable. A good initial design may become a poor design if well conditions change. Changes in the pump fillage, fluid volume, fluid level, stroke length, strokes per minute or pump size severely impact the total artificial lift system. Changes in fluid corrosiveness can affect the fatigue endurance life of sucker rods and may lead to premature failures. When one of the preceding conditions change, the design of the artificial lift system must be re-evaluated.

Figures 2 and 3 are examples of design and operationally induced mechanical failures. Wear, unidirectional bending fatigue and stress-fatigue failures indicate rod and/or tubing buckling, deviated well bores, fluid pound, gas interference, highly stressed sucker rods, unanchored or improperly anchored tubing or some combination of the preceding.

Abrasive wear causes rod string failures by reducing the cross-section of the metal, exposing new metal surfaces to corrosion and causes sucker rod connection failures from impact and shoulder damage. In Figure 2, the Class T coupling on the left and the Class SM couplings (2A and 2B) are examples of abrasive wear.

The Class T coupling on the far right (2C) has a work-hardened ridge from tubing-slap. Tubing-slap is the result of the rod string “stacking out” — probably as a result of severe fluid pound, gas interference or pump tagging. The work-hardened material doesn’t wear as fast as the softer material on either side of the work-hardened area and it leaves a ridge of material as the rest of the softer material wears.
In Figure 3, the rod body on the left (3A) is an example of abrasive wear. Abrasive-wear on the rod string is defined as the progressive removal of the surface metal by contact with the tubing string. Abrasive-wear that is equal in length, width and depth usually suggests a deviated or crooked well bore. Angled abrasive-wear patterns indicate rod strings that are aggressively contacting the tubing at an angle, usually as a result of fluid pound, gas interference, severe pump tagging, or unanchored or improperly anchored tubing. The middle rod body in figure 3C represents corrosion-abrasion. Abrasive wear also removes corrosion inhibiting films and exposes new surface metals to corrosive fluids—which accelerates the rate of corrosion.

The second rod body from the left and the first rod body from the right in Figure 3 are unidirectional bending fatigue failures. Unidirectional bending fatigue failures occur from the motion of the rod string having a constant lateral or side movement during the pumping cycle. Stress fatigue cracks will concentrate along the area of the sucker rod where the greatest bending stresses occurred. The fine, transverse, stress fatigue cracks will be on one half of the circumference of the rod body, closely spaced near the rod upsets and gradually spreading apart moving toward the middle of the rod body. Most unidirectional bending fatigue failures occur above the connection in the transition zone of the rod body—between the rigid coupling and upset area and the more flexible rod body. Unidirectional bending fatigue failures will not show permanent bends since this problem occurs while the rod string is in motion.

The example on the far right (3E) is a unidirectional bending fatigue failure. This type of failure generally has two tips protruding above the fracture surface. These distinct failure characteristics indicate a double shear-lip tear. Double shear-lip tears are the direct result of unidirectional bending stresses, with fractures occurring under tri-axial rod loads. These loads may be the result large bore pumps with small diameter sucker rods or multiple tapers in shallow wells.

The second rod body failure (Figure 3B) is a stress-fatigue failure. Stress fatigue failures occur on highly stressed sucker rods as a result of worn out sucker rods, overloads or extremely high rod loads for short periods of time. Stress-fatigue failures have closely spaced, fine, transverse stress fatigue cracks that completely encircle the circumference of the rod body. The stress fatigue cracks will be on the wrench square and over the entire length of the rod body. With very old worn out sucker rods, stress fatigue cracks and failure may occur within normal everyday operating loads.
Figure 4 is an example of coupling-to-tubing wear. Downhole, the coupling may slap and then rub against the tubing and may cause extremely aggressive angle contact to the tubing by the rod string. This aggressive contact is the direct result of severe fluid pound, unanchored (or improperly anchored) tubing, sticking (or stuck) pump plungers, rod buckling from over pumping the well, lack of sufficient sinker bars to help keep the section of the rod string above the sinker bars in tension, or any combination of the preceding.

One thing that must be clarified is that buckling or bending in the rod string does not mean the rods are going into compression. Compressive loading means the minimum loads are less than zero, which is a difficult thing to happen when the rods are designed to be kept and operated in tension. While bending and buckling are similar since both require bending moments to be applied, bending is due to transverse loading applied to the normally applied axial loads. Buckling requires axial compression loading to occur and results in a local instability and ultimately causes a failure or collapse of the supporting structure.

Many years ago there was a misnomer typically shown on dynamometer card interpretation that the rods go into compression on the downstroke. This compression loading is difficult to do when the rest of the rods, pump, and fluid load act to continuously keep the rods in tension. Bending or an out of plane displacement can occur for a variety of reasons such as a local dog leg, or over-pumping, tapping or tagging bottom, etc. The bending moment of the rods is constrained or resisted by the tubing ID as well as rod guides and the assistance of sinker bars.

The fracture surface of the rod in Figure 5A is an example of rod guide related damage. This example on the left is a reconditioned, high tensile strength sucker rod. Turbulent fluid flow, associated with short, blunt-end injection molded rod guides, allowed crevice corrosion in the critical wash area around the end of the guide. Prior to inspecting, the mold-on rod guides were removed from the rod body for reconditioning.

Class1 reconditioned sucker rods cannot have discontinuities greater than 20 mils (0.020") per API Standard 11BR. The crevice corrosion was under the 0.020 inch allowed in a Class 1 reconditioned sucker rods. However, the notch sensitivity (discontinuity intolerance) of a high tensile strength sucker rod is high. In other words, small pits can be detrimental to the high tensile stresses associated with the high strength sucker rod. As such, reconditioned high strength sucker rods should be de-rated for future design loads.

The example in the middle is an erosion-corrosion failure resulting from short, blunt-end, field-applied rod guides in small tubing with high fluid velocities. Erosion-corrosion pits will be “fluid cut” with smooth bottoms. Pit shape characteristics may include sharp edges and steep sides if accompanied by CO2 or broad smooth pits with beveled edges if accompanied by H2S. The example on the right is abrasion-wear from a field applied rod guide moving up and down on the rod body during the pumping cycle. Generally speaking, mold-on rod guides provide better laminar flow, a minimum of three to four times more bonding and retention and are more cost-effective than are field-applied rod guides.
Mechanical Failures

Mechanical failures account for a large percentage of the total number of all rod string failures. Mechanical failures include every failure type except corrosion-fatigue failures and manufacturing defects. Mechanical damage to the rod string causes a stress raiser which ultimately will cause the sucker rods or coupling to fail.

The time to failure will be influenced by many variables. These typically include: maximum stress, operating environment, orientation of the damage, sucker rod chemistry, sucker rod heat treatment, stress range and type of damage are the most important variables. Mechanical damage can be caused by poor artificial lift design, improper rod care & handling procedures, careless makeup & breakout procedures, out-of-date operating practices, or any combination of these conditions.

Bent Rod Failures

Bending fatigue failures account for a significant number of all mechanical failures. It is a fact that all bent sucker rods eventually fail. New sucker rods are manufactured to a body straightness of no less than 1/16 inch in any twelve inches of rod body length. Sucker rods within this tolerance of straightness will roll easily along a rack with five level supports. Any degree of bend greater than this amount will cause an increase in local stress at the point of the bend during applied load.

When the bent rod body is pulled straight during loading, the ultimate strength of the material is quickly reached. The cycle of continually exceeding the material strength is repeated during the pumping cycle and causes stress fatigue cracks on the concave side of the bend. These stress fatigue cracks progress across the bar, during loading, until insufficient metal remains in the bar to support the load, then fracture occurs.

Heat treatment changes the metallurgical structure of the forged ends to match that of the rod body and also controls the mechanical properties of the sucker rod. Any rod body bend created after heat treatment causes work hardening, which creates an area of hardness different than the surrounding surfaces. This condition is referred to as a “hard spot” and is a stress raiser to load. Mechanical processing, such as passing the finished bent sucker rod through a system of rollers, will attempt to remove the bend so the rod body appears to be straight. However, reconditioning processes are not capable of stress relieving bent sucker rods. A bent sucker rod is permanently damaged and should not be used because all bent sucker rods will eventually fail.

Figure 6 (with inset Figure 7) show examples of bending fatigue failures. Bending fatigue failures can be identified by the angled fracture surface, which will be at some angle other than 90° to the axis of the rod body. The example on the left (6A) illustrates a fracture caused by a long radius bend, or gradual sweeping bow in the rod body (Figure 7B). The fracture
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Surface is normal in appearance, but has a slight angle exists when compared to the axis of the rod body. The middle example (6B) is a short radius bend (Figure 7A). The fracture surface is at a greater angle to the axis of the rod body with a small fatigue portion and a large tensile tear portion. The example on the right (6C) is the result of a corkscrewed sucker rod. Notice how convoluted the fracture surface is in appearance. As a general rule, the greater the bend in the rod body, the more convoluted the fracture surfaces appear. In operation, the time before the rod fractures is greatly shortened. Poor care & handling procedures usually cause bent sucker rods even before the rods have been run in a well.

Surface Damage Failures

Everything possible should be done to prevent mechanical surface damage to sucker rods, pony rods and couplings. Surface damage increases stress during applied loads, potentially causing rod string failures. The type of damage, and its orientation, contributes to this increased stress effect. The orientation of the damage contributes to higher stresses with transverse damage resulting in increased stresses over those associated with longitudinal damage for the same applied stress. A sharp nick will create a higher stress concentration and would be more detrimental to load than a shallow, broad-based depression. Sucker rods with indications of surface damage should not be used and should be replaced in the rod string to provide long term operating life.

Care should be used to avoid all metal-to-metal contact that might result in dents, nicks or scratches. To prevent potential sucker rod damage, strips of wood should be placed between metal storage racks and between each layer of sucker rods so metal-to-metal contact can be avoided. Sucker rods should be used for what they were designed - to lift a load. Sucker rods should never be used as a walkway or workbench. Keep metal tools not intended for use on sucker rods and all other metal objects away from the sucker rods. Make sure the tool you use is intended for the purpose and ensure that it is in proper working order.

Figure 8 shows various surface damage failures. The example on the left (8A) shows a slight depression from a wrench, tool, or other metal object. The second example (8B) is damage from a pipe wrench used in applying field-installed rod guides. The example shown in 8C has a small longitudinal scratch from metal-to-metal contact; possibly by allowing sucker rods to run down other rods in a rod bundle during installation. The example on the right (8D) shows transverse surface damage.
Figure 9 shows examples of surface damage caused by sucker rod elevators. Bent sucker rod failures that occur below the surface upset bead may be from bad elevator seats. The top example (9A) shows damage caused by the elevator latches. This type of damage normally occurs as a result of picking up or laying down in doubles. Never pick up or lay down anything more than one single sucker rod. Anything else causes the elevator latches to act as a fulcrum and allows bending stresses to concentrate in the transition zone of the rod body and the forged upset.

The example shown in 9B is damage from worn or misaligned elevator seats. After an extended period of service, the elevator seats become so worn and damaged that they develop an oval shape rather than a round shape.

As the oval shape grows from wear, the tangency ring of the rod upset to the elevator seat face is lowered in the front half of the seat. As the seat continues to wear, the seating position of the rod upset is moved forward of the elevator trunnion centerline. This causes an offset in the elevator lifts the rod string load, the hook load will bend the sucker rod centerline to coincide with the elevator trunnion center-line. As the rod string weight increases, the hook load will bend every sucker rod engaged by this elevator until it is replaced.

**Connection Failures**

The API sucker rod connection is designed as a rotary shouldered, liquid free, friction preloaded connection. Since the fatigue endurance of the sucker rod connection is low when subjected to cyclic loads, it is necessary to limit cyclic loading by applying a preload between the pin and coupling. If the connection preload is greater than the applied load during producing the well, the load in the connection remains constant and no fatigue occurs in the connection from cyclic loads.

The friction load that develops between the pin shoulder face and the coupling shoulder face helps lock the connection together to prevent it from coming loose downhole. However, if the preload is less than the applied load, the pin shoulder face and the coupling shoulder face will separate under load during the cyclic motion of the pumping unit. Once these faces separate the connection is cyclically loaded and will result in a loss of displacement, or loss of tightness/make-up failure. Loss of displacement failures may be caused from improper lubrication, inadequate makeup, over-torque, tubing-slap wear, over pumping the well, gas interference and fluid (liquid or gas) pounds or any combination of these conditions.

Figure 10 is an example of pin failures due to a loss of displacement. The sample on the right (10C) is typical in appearance for a loss of displacement pin failure. Insufficient makeup, or the loss of tightness, caused the pin shoulder face and the coupling shoulder face to separate.
When these faces separate, a bending moment is added to the tensile load in the pin. The threaded section of the pin is held rigid while the rest of the pin flexes. The motion of the rod string causes stress fatigue cracking to start in the first fully formed thread root above the undercut.

Small stress fatigue cracks begin to form along the thread root during applied load and eventually consolidate into a major stress fatigue crack. The fracture surface of a typical loss of displacement pin failure has a small fatigue portion covering approximately one-third of the fracture surface with the tensile tear portion and final shear tear covering the remaining fracture surface. The examples on the left and in the middle (10 A & B) will occur as a result of stress loading when stress-raising factors such as corrosion or mechanical damage is present on the surface of the stress relief or pin undercut.

Figure 11 is another example of two types of pin failures. The sample on the left (11A) is typical in appearance for a loss of displacement pin failure. However, this pin fracture was caused by the hydraulic rod tongs during makeup as is evidenced by the stair-stepped tensile tear. It is not uncommon for pin fractures to occur at makeup, if the pin has a preexisting stress fatigue crack, due to the high torque required with large diameter Class D and all sizes of high tensile strength sucker rods. The sample on the right (11B) is an example of excessive torque on a soft pin. The fracture surface has a large fatigue portion, with multiple ratchet marks in the pin-thread root, and a small tensile portion.

Figure 12 shows an example of a loss of displacement coupling failure. The fracture initiated in the coupling-thread root opposite the first fully-formed pin starting-thread. One-third/two-third fracture halves, in length, with ratchet marks originating in the thread-root indicate a loss of displacement coupling failure. The fracture surface of a typical loss of displacement coupling failure has a small fatigue and large tensile tear portion.

Loss of displacement coupling failures are primarily associated with Class D sucker rods and high tensile strength sucker rods.

Mid-length coupling fractures, with ratchet marks leading from the outside, indicate another type of failure. The stress fatigue crack starts from the outside coupling surface, progressing inward toward the threads, then around the coupling wall to a tensile fracture. Mid-length fractures from mechanical damage to the coupling surface, exceeding the stress fatigue endurance limit of the material, or a manufacturing defect. Most mid-length coupling fractures are the result of mechanical damage or overload. Mid-length coupling fractures due to overload have a small fatigue portion and large tensile tear portion. This failure is common with high strength sucker rods and Class SM couplings. Full sized API Class T couplings or, preferably, high strength couplings should be used with high strength sucker rods to avoid mid-length coupling failures.
Figure 13 is an example of thread galling in the sucker rod connection. Thread galling is mechanical damage to the pin and/or coupling threads. Thread galling is the result of damaged or contaminated threads causing the interference between the threads to be great enough to rip and tear the thread surfaces. The threads weld together during makeup and strip apart at breakout and the connection is damaged and destroyed beyond use. Hard stabbing damage to the leading thread and contaminated threads are the primary causes of thread galling. Cleaning the threads prior to makeup, properly lubricating the threads and following careful makeup procedures will prevent most problems with thread galling.

Figure 14 is an example of a wrench square failure. Wrench square failures are extremely rare and seldom occur unless from mechanical damage, corrosion or manufacturing defects. The example shown is a wrench square failure from severe mechanical damage. Loose or sloppy backups on the hydraulic rod tongs have rounded the wrench square corner. The stress fatigue crack began in the corner of the wrench square and progressed to final rupture or fracture.

Figure 15 is an example of the damage that occurs as a result of severely over-tightening the sucker rod connection. The example shown is an over-tightened coupling that has flared out or bulged near the contact face. Slim-hole couplings are more susceptible to this type of over-tightened damage than are full-size couplings. Over-tightened full-size couplings on Class D and high strength sucker rods generally exhibit slight bulges and have the concentric deformation ridge of material on the coupling should face from the impression of the pin shoulder face.

Over-tightening with hydraulic rod tongs will twist off soft pins resulting in a tensile failure appearance. The pin undercut will neck down and fracture occurs rapidly. With Class D sucker rods, an indication of over-tightening is the concentric deformation ridge of material on the pin shoulder face from the impression of the coupling shoulder face. Over-tightening on normalized and tempered high tensile strength sucker rod will begin to pull the threads out of the coupling.
Figure 16 is an example of impact cracks on couplings. The practice of “warming up”, or hammering, on couplings in order to loosen them should not be allowed. This example shows how impact damage to a Class T coupling causes stress fatigue cracks around the impact points and accelerated localized corrosion. Hammering on Class SM (spray metal) couplings cause stress fatigue cracks in the hard spray surface and results in coupling failures due to corrosion-fatigue.

Figure 17 is an example of polished rod failures. The majority of all polished rod failures occur either in the body, just below the polished rod clamp, or in the pin. Polished rod body failures below the polished rod clamp result from the addition of bending stresses. These bending stresses may be imposed by pumping units out of alignment, carrier bars that do not set level, worn carrier bars, misaligned load cells, or incorrect polished rod clamp installation. The polished rod failure on the left is an example of a polished rod clamp on the sprayed portion of a spray metal polished rod. Spray metal polished rods have an unsprayed portion for polished rod clamp placement.

Never put a polished rod clamp on the sprayed portion of a spray metal polished rod. The polished rod failure on the right has small, longitudinal scratches caused from mishandling.

Polished rod pin failures generally occur due to the installation of sucker rod couplings. Polished rod pins have a 9° thread taper between the straight-threaded section and the shoulder. Sucker rod couplings have a 30° starting thread and a deep recess that doesn’t engage all the polished rod pin threads. Polished rod couplings have a 9° starting threads and a profile designed to properly fit the polished rod pin. The shallow recess to the first thread easily distinguishes polished rod couplings from sucker rod couplings and allows every polished rod pin thread to be engaged.
Q & A

Why do new sucker rods seem to corrode faster than older rods in the same rod string?

Two sucker rods with the same chemical composition will form a galvanic corrosion cell if the physical condition of one is different from the other. Physical differences in a sucker rod may be caused from poor care & handling practices (i.e. surface damage resulting in depressions, nicks, scratches, bends, etc.) and/or corrosion deposits (iron oxide, carbonate and sulfide scale, etc.). Since new sucker rods go into the well without corrosion deposits, they often corrode preferentially in relation to sucker rods that are coated with corrosion deposits. Corrosion on steel starts very aggressively but often slows down as soon as an obstructive surface film of corrosion deposit (scale) is formed upon the metal surface.

For example, CO2 generates iron carbonate scale as a by-product of its corrosion. This scale coats the sucker rod and retards the corrosion penetration rate—which tends to slow down corrosion. However, if this deposit is continuously cracked and removed by a bending movement or by abrasion, aggressive local corrosion continues on the area of the sucker rod with the scale removed—which results in deep corrosion pitting.

Can high tensile strength sucker rods be used in a corrosive environment?

Generally soft rods tolerate corrosion better than hard rods and, as a rule of thumb; you should always use the softest rod that will handle the load. However, if load requirements dictate the use of high tensile strength sucker rods then it is important to protect the rod string with an effective surface film of corrosion inhibitor. In most cases, if you can adequately protect downhole equipment from corrosion, you should be able to adequately protect high tensile strength sucker rods from corrosion by increasing the application frequency of the corrosion- inhibitor program. In other words, if you effectively batch treat once a week with 40 parts per million (ppm) of corrosion inhibitor for Class D sucker rods, you will need to batch treat twice weekly with 40 ppm of corrosion inhibitor for high tensile strength sucker rods. Treatment volumes vary and are dependent upon many factors too numerous to list here. Always consult with a corrosion control specialist prior to the installation of every rod string, especially when corrosion-fatigue is suspected as a potential issue.
Corrosion-fatigue Failures

Corrosion is one of the greatest problems encountered with produced fluids and accounts for about two-thirds of all sucker rod failures. Corrosion is the destructive result of an electrochemical reaction between the steel used in making sucker rods and the operating environment to which it is subjected. Simply put, corrosion is nature’s way of reverting a man-made material of a higher energy state (steel), back to its basic condition (native ore) as it is found in nature. The elemental iron in steel combines with moisture or acids, to form other compounds such as iron oxide, sulfide, carbonate, etc. Some form and concentration of water is present in all wells considered corrosive and most contain considerable quantities of dissolved impurities and gases. For instance, carbon dioxide (CO2) and hydrogen sulfide (H2S) acid gases, common in most wells, are highly soluble and readily dissolve in water — which tends to lower its pH. The corrosively of the water is a function of the amount of these two gases that are held in solution. All waters with low pH values are considered corrosive to steel, with lower values representing greater acidity, or corrosiveness.

All downhole environments are corrosive to some degree. Some corrosive fluids may be considered non-corrosive if the corrosion penetration rate, recorded as mils of thickness lost per year (mpy), is low enough that it will not cause problems. However, most producing wells are plagued by corrosion problems and no currently manufactured sucker rod can successfully withstand the effects of this corrosion alone.

While corrosion cannot be completely eliminated, it is possible to control its reaction. All grades of sucker rods must be adequately protected through the use of effective chemical inhibition programs (reference current editions of API Recommended Practice 11BR and NACE Standard RPO195). Some sucker rod grades, due to different combinations of alloying elements, microstructures and hardness levels, are capable of longer service life in inhibited corrosive wells than other grades of either low or high tensile strength.

![Fig. 18 - CO2 Acid Gas Corrosion Fatigue](image)

Figure 18 is an example of corrosion-fatigue from CO2 acid gas corrosion. The size of the pit, as far as when it becomes detrimental to the sucker rod, depends on three factors—load, material type and hardness. Class K sucker rods may develop deeper and larger pits than a Class D sucker rod before it becomes detrimental to the sucker rod. Class D sucker rods may develop deeper and larger pits than a high tensile strength sucker rod before it becomes detrimental to the sucker rod. Softer materials with lower rod stress tolerate larger pits than do harder materials with higher rod stress. Therefore, small pits can be detrimental to higher tensile strength sucker rods as opposed to a softer sucker rod that does not have as much rod stress.

Acid Corrosion

The left-most rod in Figure 19 shows an example of acid corrosion of a sucker rod. Service companies use acids for well stimulation and cleanout work. All acid work should have an effective inhibitor mixed with the acid prior to injection into the well. Spent acids are still corrosive to steel and the well should be “flushed” long enough to recover all spent acid. In rare instances, some produced waters contain organic acids that have formed downhole, such as acetic, hydrochloric and sulfuric acids. Corrosion from acid is a general thinning of metal, leaving the surface with the appearance of sharp, feathery or web-like residual metal nodules. Metallic scale will not be formed in the pits.
Chloride Corrosion

Chlorides contribute to the likelihood of an increase in corrosion related sucker rod failures. The corrosivity of water increases as the concentration of chlorides increase. Corrosion inhibitors have more difficulty reaching and protecting the steel surface of sucker rods in wells with high concentrations of chlorides. Corrosion, from water with high concentrations of chlorides, has a tendency to be more aggressive to carbon steel sucker rods than to alloy steel sucker rods. Chloride corrosion tends to evenly pit the entire surface area of the carbon steel sucker rod with shallow, flat-bottomed, irregular shaped pits. Pit shape characteristics include steep walls and sharp pit edges.

CO2 Corrosion

CO2 acid gas corrosion combines with water to form carbonic acid—which lowers the pH of the water. Carbonic acid is very aggressive to steel and results in large areas of rapid metal loss that can completely erode sucker rods and couplings. The corrosion severity increases with increasing CO2 partial pressure and temperature. CO2 corrosion pits are round based, deep with steep walls and sharp pit-edges. The pitting is usually interconnected in long lines but will occasionally be singular and isolated. The pit bases will be filled with iron carbonate scale, a loosely adhering gray deposit that is a by-product of CO2 acid gas corrosion.

Dissimilar Metals Corrosion

An extremely rare failure, dissimilar metals corrosion may result when joining two metals with differences in solution potentials together in the same solution. One metal has a marked tendency to corrode in preference to the other, and under certain fluid conditions, the less noble metal corrodes at a higher rate. Dissimilar metals corrosion is usually greatest near the joining of the two metals. Since most sucker rod materials are compatible, this failure is seldom seen in the rod string.

H2S Corrosion

H2S acid gas corrosion results in round based pits that may be deep with beveled pit edges. Sometime these pits may be small, random and scattered over the entire surface of the sucker rod. A second corrodent generated by H2S acid gas corrosion is iron sulfide scale. The surfaces of both the sucker rod and the pit will be covered with the tightly adhering black scale. Iron sulfide scale is highly insoluble and cathodic to steel. This tends to accelerate corrosion penetration rates. A third corroding mechanism is hydrogen embrittlement, which causes the fracture surface to have a brittle or granular appearance. A crack initiation point may or may not be visible and a fatigue portion may or may not be present on the fracture surface. The shear tear of a hydrogen embrittlement failure is immediate during fracture due to the absorption of hydrogen and the loss of ductility in the steel. Although a relatively weak acid (when compared with CO2 acid gas), any measurable trace amount of H2S acid gas is considered justification for chemical inhibition programs when any measurable trace amount of water (H2O) is also present.
Figures 22 and 23 are examples of H2S acid gas corrosion. The three rod body samples on the left (22 A, B and C) are examples of localized corrosion (pitting) and the two rod body samples on the right (22 D and E) are examples of general thinning corrosion from scale-deposit corrosion. The sample in Figure 23 is an example of a pin failure due to hydrogen embrittlement where a flat, brittle fracture surface is shown.

Microbiologically Influenced Corrosion (MIC)

Figure 24 shows several examples of microbiologically influenced corrosion (MIC) on rod bodies. Some amount of microscopic life form is present in essentially every producing well. Of primary concern to the rod string are the single celled organisms capable of living in all sorts of conditions and multiplying with incredible speed. This is commonly referred to as bacteria or “bugs”. Bacteria are classified according to their oxygen (O2) requirements: aerobic (requires O2), anaerobic (does not require O2) and facultative (either). Some bacteria generate H2S, produce organic acids or enzymes, oxidize soluble iron in produced water, or any combination of the preceding.

MIC is very aggressive and all sucker rod grades corrode rapidly in downhole environments containing bacteria. Suspect fluids should be monitored continuously by sampling, identifying and counting the bacteria. The extinction dilution technique is commonly used to culture bacteria for an estimation of the number of bacteria present in the well. Bactericide or biocide should be used on all suspect fluids to control bacteria populations.

- Acid-Producing Bacteria (APB)

Corrosion pitting due to Acid-Producing Bacteria (APB) has the same basic pit shape characteristics of CO2 acid gas corrosion. Corrosion pitting from APB has a cavernous appearing pit-wall with sharp pit edges and the pit-base is usually striated or grainy. The pit will not contain scale deposits.
• **Sulfate Reducing Bacteria (SRB)**

Sulfate Reducing Bacteria’s, (SRBs), are those that produce H2S. SRBs probably cause more problems to downhole equipment than do any other type of bacteria. Corrosion due to SRBs have the same basic pit shape characteristics of H2S acid gas corrosion, often with multiple stress cracks in the pit-base, tunneling around the pit-edges (pits-within-pits), pit clustering and/or unusual anomalies (i.e. shiny splotches on the steel surface). The multiple cracking in the pit-base results from the hydrogen sulfide by-product of the bacterial lifestyle. This not only corrodes the steel but can embrittle the surface of the steel under the colony.

**Oxygen-Enhanced Corrosion**

Oxygen-enhanced corrosion will be most prevalent on couplings, with a few instances found on rod upsets. This type of corrosion is rarely seen on the rod body. In fact, aggressive oxygen-enhanced corrosion can erode couplings without harming the sucker rods on either side.

The rate of corrosion is directly proportional to the dissolved oxygen (O2) concentration, chloride content of the produced water and/or presence of other acid gases. Dissolved O2 can cause severe corrosion at extremely low concentrations and erode large amounts of metal. Pitting is usually shallow, flat-bottomed and broad-based with the tendency of one pit to combine with another. Pit shape characteristics may include sharp edges and steep sides if accompanied by CO2 or broad, smooth craters with beveled pit-edges if accompanied by H2S. Corrosion rates increase with increased concentrations of dissolved O2. Figures 25 and 26 are examples of oxygen-enhanced corrosion. The coupling on the left in Figure 25 is an example of the effects of oxygen-enhanced CO2 acid gas corrosion. The slim-hole coupling in the middle and the full-size coupling on the right are examples of the effects of oxygen-enhanced H2S acid gas corrosion. The sucker rod samples in Figure 26 show the effects of oxygen-enhanced CO2 acid gas corrosion near the upset (left) and on the rod body (right).

**Stray Current Corrosion**

Rarely seen in most wells, stray current corrosion refers to the induced, or stray, electrical currents that flow to or from the rod string. Stray current corrosion can be caused by grounding electrical equipment to the well head, casing or from nearby cathodic protection systems (pipelines). Arcs originating from the rod string leave a deep, irregular shaped pit with smooth sides, sharp pit-edges and a small cone in the base of the pit. Arcs originating from the tubing leave deep pits with smooth sides and sharp edges that are random in dimension and irregular in shape. Stray current corrosion pits are usually singular and isolated in a row down one side of the sucker rod near the upsets.

**Under-deposit Corrosion**

Scales such as barium sulfate, calcium carbonate, calcium sulfate, iron carbonate, iron oxide (rust), iron sulfide, and strontium sulfate should be prevented from forming on sucker rods. Although scale on a sucker rod slows down the corrosion penetration rate, it also reduces the effectiveness of chemical inhibitors. Severe localized corrosion, in the form of pitting, results anytime the scale is cracked by a bending movement or removed by abrasion.

*Fig. 26 - Oxygen-Enhanced Corrosion*
Manufacturing Defects

Failures due to a manufacturing defect seldom occur. Manufacturing defects are easily recognized and it is important that you understand what these defects look like if you are to file accurate claims for warranty reimbursement. The original steel mill or supply and the manufacturer of sucker rods and couplings cannot be excluded from the possibility of defects in material or workmanship. The following examples include defects from several different manufacturers.

Mill Defects

Figure 27 is an example of mill defects. Mill defects occur along one side of the rod body and these discontinuities normally have longitudinally tapered bottoms and sharp edges with indications of the longitudinal seam in the base of the discontinuity.

The example on the far left and the rod body third from the left are examples of a sliver. (In the example third from the left, the protrusion folded against the fracture surface during “fishing”). The rod body second from the right is an example of a scab. A sliver is a small loose or torn segment and a scab is a large loose or torn segment of material longitudinally rolled into the surface of the bar.

One end of the sliver or scab is normally metallurgically bonded into the rod body while the remaining end is rolled into the surface and physically attached.

Fatigue failures, which result from slivers or scabs, will have a piece of loose material protruding over the fatigue portion of the fracture surface. The rod body second from the left is an example of rolled-in-scale. Rolled-in-scale is a surface discontinuity caused when scale (metal oxide), formed during a prior heat, has not been removed prior to bar rolling. The rod body on the far right is an example of a rolling lap. Rolling laps are longitudinal surface discontinuities that have the appearance of a seam from rolling, with sharp corners folded over and rolled into the bar surface without metallurgical bonding.

Forging Defects

Figure 28 is an example of forging defects. The fracture begins internally below a forging crack in the upset area and is brittle or granular in appearance. A crack initiation site may or may not be visible and a fatigue portion may or may not be present on the fatigue fracture surface. The examples on the left and in the middle occur as a result of low forging temperatures. The example on the left is from a cold-shut and the example in the middle is from a forging crack. The fracture on the right is a failure caused by a subsurface longitudinal seam located near the end of the raw bar. During the forging process the orientation of this discontinuity was changed transversely.
Figure 29 is an example of incipient grain boundary melting. This is an extremely rare manufacturing defect. This condition is caused by forging the upset end of the rod at too high a temperature for the steel. Unfortunately, no inspection exists that will catch this before the rod is shipped. Fortunately, these brittle pins usually snap off during makeup so failure typically do not occur downhole. No crack initiation point is visible and no fatigue portion will be present on the fracture surfaces. Optical pyrometers on forging equipment have virtually eliminated this problem.

Figure 30 shows examples of processing defects. The example is a casehardened sucker rod and the other example is a coupling that has been processed through a grinding operation to reduce the diameter. In both examples, a difference in the material hardness has resulted in preferential corrosion attack.

Figure 31 shows examples of a mill defect and a machining defect. The lower example (31 A) is a failure due to a large, internal, nonmetallic inclusion in the pin. The fracture began internally and the fracture surface is brittle or granular in appearance. A crack initiation site may or may not be visible and a fatigue portion may or may not be present on the fracture surfaces. The upper example (31 B) is a “ran-twice” defect from rolling the pin threads twice. Rolling the threads twice has flattened the pin thread-crest and will not be capable of achieving the correct connect preload required for makeup.
The Bottom Line

Your initial investment in sucker rods is substantial. Moreover, the costs related to replacing damaged sucker rods generally outweigh the original cost of the new rod string. Protecting your investment and getting the maximum service life out of your sucker rods just makes good sense. It is important to diagnose rod failures accurately and to implement corrective action measures to prevent future failure occurrences.

This photo essay is intended for use as a reference guide in sucker rod failure analysis. It explains how rod failures occur and expounds methods for identifying the characteristics of the failure mechanisms. Where sucker rod failures are concerned, there are no absolutes and no two failures look exactly alike in appearance.

But, by recognizing the visual clues and identifying characteristics of the different failures, corrective action measures can be taken to prevent sucker rod failures, thus allowing the operator to produce marginally profitable wells more cost effectively.
FAILURE ANALYSIS REQUEST
When requesting a failure analysis, please fill out this form as accurately and completely as possible. This information and the accompanying samples will serve as the basis for determining the failure cause.

Company: ____________________________ Contact: ____________________________
Lease & Well Number: __________________ Location: ____________________________
Office Telephone: ____________________________ Office Facsimile: __________________
Cellular Telephone: ____________________________ Email Address: _____________________

Samples
Include the following:
1. **Coupling Failures**: Include both halves of the coupling or the entire coupling, depending upon the type of failure.
2. **Pin and Upset Failures**: Include the pin end with the broken pin and the coupling with the broken pin stub or the pin end with the galled pin threads and the coupling with the galled threads.
   a. All failures should include the stamped end for identification of the sample. (Only one end is stamped for identification and traceability.)
3. **Sucker Rod Body and Sinker Bar Body / Elevator Neck Failures**: Include approximately 18” on either side of the failure. If the failure is within 18” of the pin end, include the pin end and 18” of the sucker rod body / sinker bar body on the other side of the failure.
   a. All failures should include the stamped end for identification of the sample. (Only one end is stamped for identification and traceability.)
4. **Rod Guide Failures**: Include the entire rod guide or pieces of the rod guide, depending upon the type of failure. If the rod guide is still on the rod body but has cracked, moved, or is starting to break apart, cut the rod body leaving 6” of rod body on either side of the rod guide.

Data
You will be contacted if further information is required to complete our analysis.

Application: ____________________________ Install Date: ____________________________ Failure Date: ____________________________
Failure Depth (FS): ______________________ Manufacturer: __________________________ Size: __________________________
Length: ________________________________ Type / Class: ____________________________ Grade: __________________________
Product: ______________________________ Heat Code: ____________________________ Manufacturing Date: __________________________

Additional Comments

Shipment
Please contact the service center in advance to advise us that you will be shipping a sample for analysis.

☐ International
Norris
PO Box 1496
(4801 West 49th Street (74107))
Tulsa, OK 74101-1496
Attn: Technical Service
Telephone: (918) 445-7600
Facsimile: (918) 445-7632

☐ Mid Continent Region (USA)
Norris
PO Box 60575
(7902 West I-20 (79706))
Midland, TX 79711-0575
Attn: Technical Service
Telephone: (432) 561-8101
Facsimile: (432) 561-8182

☐ Western Region (USA)
Norris
200 Carver Street
Shafter, CA 93263
Attn: Technical Service
Telephone: (661) 399-0628
Facsimile: (661) 393-2597

☐ Canada
Alberta Oil Tool
9530 - 60 Avenue NW
Edmonton, Alberta, Canada T6E0C
Attn: Technical Services
Telephone: (780) 434-8566
Facsimile: (780) 485-4243

Information and/or Samples Furnished By:

Company: ____________________________ Location: ____________________________ Contact: ____________________________
Office Telephone: ____________________________ Office Facsimile: ____________________________ Cellular: ____________________________
Email Address: ____________________________

Subsequent to analysis, DAL – Norris/AOT will email, mail, or fax you a report of the findings. Questions and/or concerns should be directed to the service center that received your shipment.