FROM FAILURE TO SUCCESS: A METALLURGICAL STORY ON SUCKER ROD PUMP BARRELS

Pinar Karpuz-Pickell, Ph.D., Ricky Roderick
Don-Nan Pump & Supply

ABSTRACT

Sucker rod pumping applications are the oldest and most widely used means of artificial lift for oil wells. The pumping performance and the longevity of the pumping systems with their corresponding pump parts have improved significantly throughout the years, but the failures remain inevitable. These failures are costly and time consuming for operators, but analyzing those enables us to improve the part design and the decision process of part selection for certain well conditions, and minimize future failures.

This paper focuses on pump barrel selection and operation with regards to base metallurgies coupled with various plating processes. It aims to inform the reader of common pump barrel failures and their causes, along with educating operators about available barrel types and their optimum operating environments.

INTRODUCTION

Beam pumping systems are specifically designed parts and tools working together in unison. Surface equipment, polished rods, sucker rods, tubings, pumps, specialty tools, all work in accordance to lift the fluids to the surface. This complex system, composed of many components, would stop functioning even if only one of the components fail to do its job properly. Beam pumping failures are very impactful to cost and performance efficiency of production, and as such have been the subject of many studies. Norris published a sucker rod failure analysis report that discusses the failure mechanisms and remedies for sucker rods [1]; Sandia Labs published a very detailed document on mechanical analysis of sucker rod and sinker bar failures [2]; API Vocational Training Series discuss the general problems caused by corrosion in the oilfield [3]; and the University of Texas at Austin's Well Servicing and Workover series is a very detailed lesson that discusses the common failures in the oilfield [4]. Besides these, many papers presented at SWPSC provide a lot of practical information about oilfield failures, their reasons and ways to manage them. Some of these documents date back to the 1950s, yet failures remained inevitable. This current study aims to contribute to this literature by studying such failures from a metallurgical point of view. This different point of view is anticipated to explain the failure behavior in a different and detailed way, and intends to be a valuable tool for pump operators, designers and manufacturers for further reducing future failures.

Besides the publications mentioned above, Gantz has summarized the failures on the pumping unit components in his 1997 paper he presented in SWPSC [5]. He summarized the main failure reasons for polished rods as operator error such as misalignment of the unit and poor seating of the clamp's base, as well as general fatigue induced during service. The primary causes for sucker rod body failures are listed as corrosion, improper rod design, fatigue, rod versus tubing wear, mishandling, pump tagging and fluid pounding. Rod couplings and pins are reported to fail mainly due to improper makeup, corrosion and erosion, wear against the tubing wall, tool marks, and general fatigue. Tubing failures are attributed to excessive rod wear, corrosion pitting, hydrogen embrittlement and improper-application of the string in sour wells. This detailed document also discusses the main root causes for pump failures, but does not review failures of the individual pump parts. Alternatively, this study aims to examine the failures of individual pump parts by using the extensive failure and service data stored within Don-Nan Pump&Supply's databases, for which serves the purpose of minimizing future failures.

SUCKER ROD PUMP BARRELS

Failures in rod pumps can be studied in terms of individual part failures, or the general cause for failures in overall pumping performance, like fluid pounding, gas interference, etc. These general causes may affect a single or multiple parts, and were studied extensively in the past. Taking this into consideration, this study chose to take the other approach to analyze the pump failures by attempting to study the individual pump part failures, and their root causes. According to Conyers [6], for a pump to lift fluid to surface, the following basic components must be in good working condition: the barrel, the plunger, standing valve, travelling valve, and the hold-down assembly. Among these components, failures in pump barrels are the subject of this paper. Specialty tools like on-off tools and shear tools are also reported to experience failures, but the reported failure rate on the tools decreased significantly after the publication of Samayamantula and Roderick [7].

A sucker rod barrel is a single piece, hollow tube with threads on both ends. The threads can be of box or pin type. The barrel and the plunger inside it move in a relative up and down motion to pump the fluid out. The structure of the barrel can be studied in two groups in terms of the materials; base materials and coating/surface treatment layer. The most common base materials are plain steel, brass, 4/6 Chrome steel (501 stainless), Monel and low alloy steel. These base materials' abrasion and corrosion resistances are enhanced by plating and other surface treatment processes. The most common coatings and treatment processes are Chrome plating, electroless Nickel Carbide composite plating (NyeCarb®), carbonitriding, carburizing and induction case hardening. Many barrels with different base metals and coating combinations are readily available in market and their properties and advantages were subject of a very valuable publication by Williams [8]. API also specifies surface conditions and other mechanical requirements for these combinations [9].

When the market data was studied, it was observed that the coated/plated barrels have the largest share. This is fairly expected since barrels are the parts that experience the most wear in the pump and suffer from severe abrasive and corrosive environments, depending on well conditions. Accordingly, coatings and surface treatments have a very important role to improve corrosion and abrasion properties. The data state that the most commonly sold and failed barrel types are as follows:

- Stainless steel, Chrome plated
- Plain steel, Chrome plated
- Brass, Chrome plated
- Brass, Nickel Carbide coated
- Plain steel, Nickel Carbide coated

Chrome plating, being the oldest and most common plating method employed to battle severe well and service conditions, deserves special interest. Chrome plating is used to provide a very high degree of hardness on the surface of a metal to enhance wear resistance, reduce friction, provide anti-galling properties, and, in some cases, improve corrosion resistance. The chrome plating employed in sucker rod pump barrels falls into the hard chrome plating category, since the required coating thickness is by API is 0.003 in [9]. The coating, by nature, is porous and full of cracks, and formation of these cracks will increase as the coating thickness increases. Chrome plating operation and performance is critical for improving the abrasion and corrosion resistance, especially in terms of the factors below:

1. Quality of the Base Material Surface: The surface of the base material should be clean, homogeneous, and free of inclusions. It should be ensured that the surface does not have any honing residues or slivers before the plating operation, since these would result in variable deposit characteristics and non-reliable corrosion resistance. The surface condition of the base materials also controls the adhesion properties of the chrome coating.

2. Post-Treatment Parameters: Post-plating honing is not only important to ensure that the final plated part has the desired size, fit and finish, but also is very important for the final corrosion properties. It relieves the residual stresses introduced during the plating operation and increases the number of cracks in the coating structure, and these cracks, filled with oil during pumping, also improve the wear resistance of the part. Reducing the surface roughness of the coating by post -treatment operations including honing positively affects the salt spray test results and increases overall corrosion resistance significantly. It is also important to make sure that the finished surface should be free of honing marks and residues, since these can be corrosion initiation sites during service.

3. Nature of the cracks: Improved corrosion resistance means reducing the chance of corrosive media from reaching the base material. The cracks form during the plating operation on the chrome layer, and then are plated over to become micro-cracks. Micro-cracks are rather harmless since they are blunted, contained in a layer, and do not form an open path for the corrosive media to reach the base material. However, once the plating operation is over, the structure may have cracks that go through the whole plated layer. These cracks are called macro-cracks, and are detrimental in corrosion protection since they form a direct path for the corrosive media to reach the base material (Figure 1). As a rule of thumb, more and finer micro-cracks are preferred for better corrosion resistance. Since cracks form during the plating operation, their nature can be altered by changing the plating process parameters. However, as stated above, post-plating operations can also improve the crack characteristics.

These factors should be considered in detail and very carefully, since disregarding them may result in decreased coating quality, and may eventually lead to part failures during service.

Electroless nickel carbide composite plating (NyeCarb®) forms a composite layer on the base material that is formed of microscopic and uniformly sized silicon carbide particles in an electroless nickel-phosphorus matrix. Unlike chrome coating, it has a homogeneous coverage on the base material, and yields a very even coating and an almost perfectly smooth surface. The finished structure does not have any cracks or porosity like the chrome coating. This may be an advantage since cracks can act as open paths for the corrosive media to reach the base material. However, one needs to consider the improved wear resistance of chrome due to the cracks' lubricating behavior during the barrel's relative motion with the plunger, while comparing the efficiencies of the methods.

COMMON FAILURES IN SUCKER ROD PUMP BARRELS

Once a failed barrel is received, the condition of the outer surface is carefully inspected and documented. The barrel then undergoes vertical sectioning so that the inner surface conditions can also be studied. The pits, origins and surrounding areas of the splits, grooves and other wear marks are carefully documented. If the barrel has coating or other surface treatments, the quality of those are evaluated. Representative metallographic samples are prepared, and studied for the base metal microstructure, the coating thickness and hardness, adhesion properties, and crack characteristics (for chrome plated barrels). Metallographic analysis results are studied in accordance with well information and pumping performance data to determine the root cause of failure.

The results of these analyses, combined with pump service records are analyzed for 4 major companies operating in the Permian Basin in order to determine the failures in sucker rod pump barrels. This failure data is summarized in Figure 2. Examining the figure, the most common failures can be grouped as follows:

1. Internal pits
2. Grooved/scored
3. External pits
4. Worn
5. Plating Flaked
6. Plunger Stuck in Barrel

7. Split

As expected, the most widely experienced failures are due to corrosion and wear. It should be noted that more than one of these symptoms can occur in a single case.

Internal pits are very common on barrels, and appear with or without other signs of failure. The pits can be small or large, localized or homogeneously disturbed, deep or shallow. The pit characteristics, when studied together with the well conditions data, let us determine the reason of the failure in most cases.

Randomly distributed shallow pits are the most commonly observed pitting type on internal surfaces (Figure 3). The degradation of the protective coating is the main reason for the formation of these pits. This degradation may be due to harsh well conditions or poor coating performance. For chrome plated barrels, poorly executed acid jobs yield to severe corrosion damage through pit formation and flaking of the coating. Galvanic corrosion between the steel base metal and the coating can yield localized corrosion pits. Poor coating adhesion due to the bad base material surface conditions prior to plating yields to a rapid degradation of the coating and detrimental corrosion damage in the part. As stated in the previous chapter, presence of macro-cracks can also be the source of the corrosion, by forming a free path for the corrosive media to reach the base material for Chrome plated barrels (Figure 1). If the chrome plating is not finished properly, helical honing marks may remain on the inner surface of the barrel. These honing marks and especially their intersections results in a decreased coating thickness and degrade the overall coating quality, and thus act as origins of corrosion pits (Figure 4).

Another type of pitting observed has a very distinct characteristic of clean, well defined holes on the outer surface of the barrel. In most of the cases, these holes are not accompanied with outer surface corrosion evidence. Once the part is vertically sectioned, however, evidence of significant corrosion is observed around these pits while the remaining areas of the inner surface remains corrosion free (Figure 5). This pitting characteristic coincides with the effects of microbiologically influenced corrosion (MIC). MIC on the equipment and parts is primarily realized as localized attacks, usually in the form of pitting, occurring on the metal surface.

As mentioned above, for the chrome plated barrels, poorly executed acid jobs where the pump is sent back in the well too soon after the swabbing, are known to cause the dissolving and flaking of the coating (Figure 6). One of the key characteristics of chrome plating is that it is easily dissolved in hydrochloric acid. Hydrochloric acid, mixed with other chemicals is used to acidize the wells. The remnant acid from such acid jobs damages the Chrome coating rapidly and results in local degradation of the barrel’s inner surface.

In some cases, the pits are observed to be aligned on a straight line (Figure 7). When studied in detail, it is observed that this kind of pitting is generally accompanied by grooves and other abrasion marks aligned in the same direction. Such grooves that are formed on the surface due to abrasion and wear result in local deterioration and even removal of the protective coating. Once the protective coating is removed, the base metal becomes exposed to corrosive media and the corrosion pits form.

Abrasive wear in barrels is detrimental even without the presence of corrosion. Given current well conditions throughout the Permian Basin, abrasive wear is inevitable, but its harmful effects are aimed to be mitigated through measures like the application of protective coatings and surface treatments. Abrasive wear takes place due to hard particles that are forced against and move along a solid surface. This abrasive action may result in wear, which in turn, is defined as damage to a solid surface that generally involves progressive loss of material and is due to relative motion between that surface and contacting substance or surfaces. The abrasive contact in the pump can be considered a three body wear, where an abrasive is caught between one surface and another, i.e. the barrel and the plunger. The abrasive media can be any of the well solids; sand, iron sulfide, or even chrome plating flakes that are the lost from the barrel surface as a result of abrasive action. The clearance between the barrel and the plunger is very tight, and is critical for optimum pumping performance. The increase in this clearance due to material loss from abrasive wear significantly reduces the performance, which results in a decrease in the amount of fluids pumped to the surface.

External pitting takes place commonly in pump barrels as a result of both sweet and sour well conditions. Protective coatings generally are not applied to the outer surface of barrels with the exception of NyeCarb®. In the absence of protective measures, the base material is directly subjected to the corrosive media and forms pits.

When combined with stresses, localized reductions in wall thickness due to abrasion and corrosion effects discussed above can cause splits in all tubular products in the well. These stresses generally arise at the fluid level due to the fluid pounding in the pump, and are transferred to the barrel walls through the fluids. If the pounding or the other factors that induce these stresses is severe enough, the barrel will split vertically before its design load. Such failures that take place before the design load is reached occur at the areas of reduced wall thickness due to localized corrosion or abrasive wear.

SUMMARY

This paper aimed to focus on the metallurgical aspects of sucker rod pump barrel failures in order to give pump users and manufacturers another point of view in understanding the causes and remedies for those failures. The importance of quality of the plating/surface treatment is reviewed, and the detrimental effects of well conditions and operator errors on this quality are discussed. It was pointed out that the evidence of corrosion and other failures should be studied very carefully on pump parts. The user needs to be careful while employing chrome plated barrels in acid treated wells. Evidence of microbiologically influenced corrosion should be followed and treated extensively since its effects are detrimental even on the protective coatings. Pump manufacturers should pay close attention to their plating and post-plating processes, since the pre-treatment surface conditions, plating parameters and post-treatment polishing determine the quality of the coating and thus the resistance to the corrosive and abrasive effects of the well environment. The user also needs to remember that abrasive wear in pump barrels is inevitable due to the presence of well solids, but can be minimized by employing surface treated/plated parts. Accordingly, it can be concluded that extra care should be taken in choosing the right barrel for every application, considering in detail well conditions and previous failures while making this critical decision.

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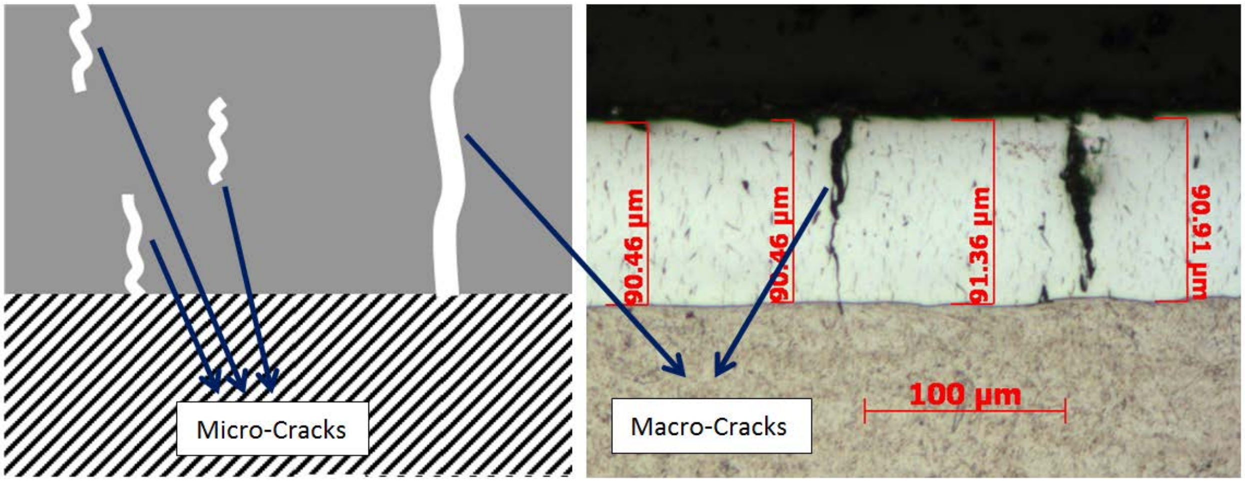

Figure 1. Micro and macro-cracks in Chrome plating.

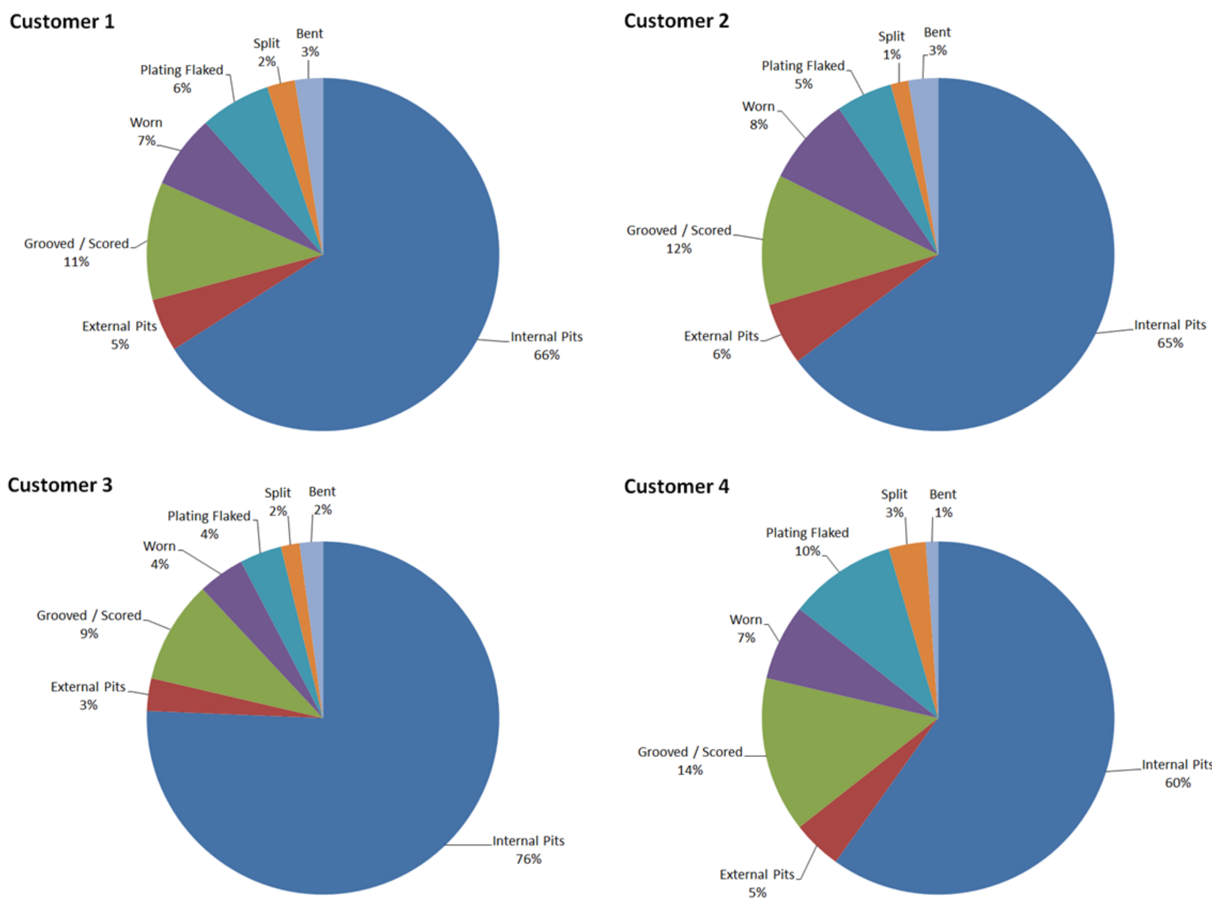

Figure 2.Failures modes in sucker rod barrels for 4 major companies at Permian Basin

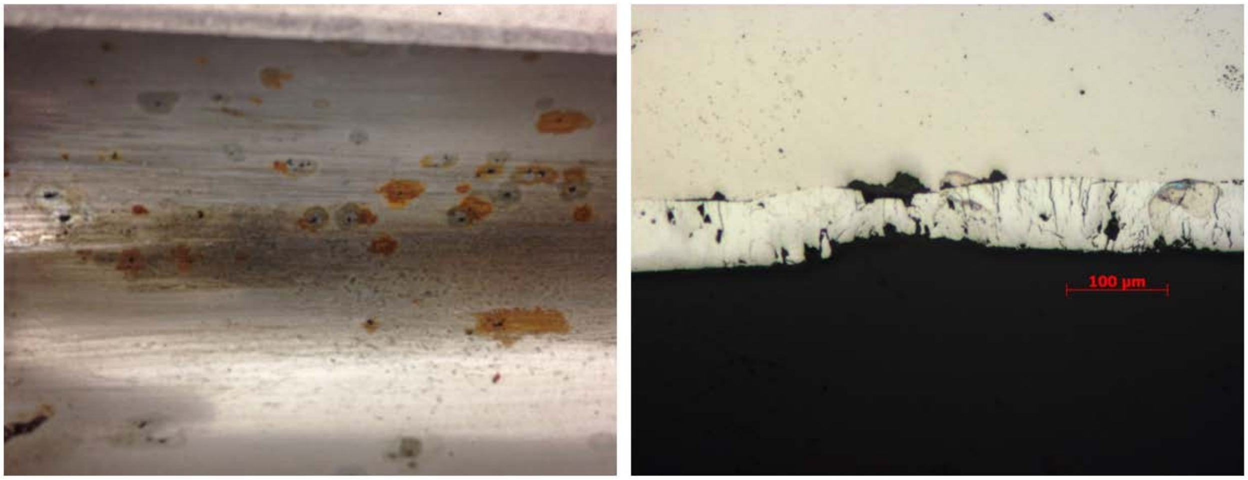

Figure 3. Random, shallow corrosion pits on the barrel surface.

Figure 4. Helical honing marks on the barrel surface.

(a) (b)

Figure 5. MIC evidence on the (a) outer and (b) inner barrel surface.

Figure 6. Flaked Chrome coating on the barrel surface.


Figure 7. Pits aligned on a straight line on the barrel surface.