STEEL – FACTORS THAT AFFECT RELIABILITY OF SUCKER RODS FROM MILL TO WELL

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INTRODUCTION

Failures in the sucker rod industry can be costly and time consuming. A thorough understanding of the critical factors affecting the overall reliability of steel is important to address these failures. Sucker rod manufacturing involves a lot of processes from different industries. The manufacturing and servicing of steel sucker rods involves a chain of processes starting with the steel mills, sucker rod manufacturer and eventually goes to the end user. There are a lot of critical factors involved in every step of the process before the product goes down hole. The goal of this paper is to prevent failures through awareness and education of critical factors affecting the overall reliability of steel products used in oil production. The topics addressed in this paper are as follows:

1. Methods of steel rolling (traditional ingots vs. modern continuous casting).
2. Induction heating & upsetting and factors affecting the final quality of the steel.
3. Heat Treatment and factors affecting quality and reliability of steel.
4. Shot peening vs. shot blasting.
5. CNC machining.
6. Factors affecting overall reliability in the field.

TRADITIONAL INGOT CASTING VS MODERN CONTINUOUS CASTING

The supply chain in the manufacturing of steel sucker rods starts at the steel mills. Steel is obtained or refined from iron ores, steel scrap or pig iron. Steel is rolled in two common ways, namely traditional ingot casting and modern continuous casting. Figure 1 represents the comparison of process flows between the two methods. In the traditional method, steel is refined and rolled to an ingot. Ingot is an intermediate product which is cooled off using appropriate cooling methods. The overall integrity and quality of steel is dependent on the uniformity of the cooling process across the cross section of steel. The molten steel gets solidified during the cooling process and as result the gases present in molten steel try to escape. During the escapement, some of the gases get trapped and lead to non conformances like pipes, blowholes etc. After this stage, the ingots are further rolled to a more semi finished form of steel known as billets. Billets are then rolled to a finished form of steel which becomes raw material for sucker rods.

The modern continuous casting is a more streamlined approach which eliminates some of the intermediate cooling steps seen in the traditional approach. The ingot stage is bypassed or streamlined in the modern approach and as a result the refined steel is directly rolled to billets. The billets are rolled to a finished form of steel. The grain structure is more uniform and homogenous because of the streamlined methods in modern continuous casting. The quality of steel is also superior in the modern methods when compared to traditional methods of steel production. The quality of steel is one of the basic critical requirements to achieve higher levels of reliability and quality.

SUCKER ROD MANUFACTURING PROCESSES

The first step involved with steel in a sucker rod manufacturing plant is cold straightening. This is done to remove any end bends created by the shearing process or handling damage. The steel is inspected for surface abnormalities using an eddy current system after the straightening process.

The next step in the manufacturing process is induction heating and upsetting. In this process, the ends of the steel are heated to a temperature of 2100-2300°F and upset to desired shape and dimension. Temperature control at the induction heating stage is very critical in deciding the final reliability of steel. The optimal temperature for upsetting should be a balance between forgeability and overheating. The steel molecules will not be condusive to hot forming or upsetting if the temperature is too low. On the other hand, if the temperature is too high, the risk of overheating and burning occurs in steel. Overheating and burning are two common terminologies used in the heat treatment industry; they are nothing but different degrees of exposure to excess heat. Over heating is the first stage of exposure to excess heat and burning is an advanced stage of exposure to excess heat. Burning in steel leads to undesirable changes in grain structure and grain boundaries which lead to detrimental effects on the physical properties of steel. The detrimental effects on the physical properties of steel due to burning will be permanent and cannot be reversed by heat treatment. Temperature control is very critical in the induction heating stage. The steel is hot formed to the desired shape and dimension at the forging temperature and checked for dimensional accuracy.

Heat Treatment

The upsetting process induces residual stresses in the sucker rod which tend to decrease the physical capabilities of the rod. The goal of the heat treatment process is to minimize the effect of residual stresses and impart the desired physical and toughness properties. The physical and toughness properties can be explained using a stress strain curve illustrated in Figure 2. The vertical axis represents stress which is the load applied per unit cross sectional area. The horizontal axis represents strain which is the amount of stretch a sucker rod undergoes when it is subjected to a load. There are two distinct regions in a stress strain curve. They are as follows:

a. Elastic region of the curve
b. Plastic region of the curve

In the elastic region of the curve, the amount of stress or load is directly proportional to the amount of strain or elongation. In other words, when a sucker rod is subjected to a load in the elastic region of the curve, it does not undergo any permanent physical deformation. All design ratings, displacement values and load calculations need to be within the elastic region of the curve. This portion of the curve can be termed as the safe operating region for sucker rods.

In the plastic region of the curve, a sucker rod will undergo a permanent physical deformation. As a result of this, the load carrying capability of the sucker rod will be comprised. The horizontal distance in the plastic region of the curve represents the stretching (toughness property) of a sucker rod before failure. The vertical height illustrated in the elastic region of the curve represents the load carrying capability (physical property) of a sucker rod. The physical and toughness properties are inversely proportional to each other. It is imperative to achieve a correct balance between physical and toughness properties. Heat Treatment is a special process which helps to achieve the balance between physical and toughness properties.

Normalizing and Tempering

Heat treatment is done as a two step process on most grades of sucker rods. The first step is normalization and the second step is tempering. The two critical parameters or reliability factors at the heat treatment process are temperature control and soak time.

Figure 3 gives a summary of the sucker rod heat treatment process. The atoms and molecules after upsetting are in an unstable state due to residual stresses. The atoms and molecules are soaked in an austenizing range during the normalization process which is typically performed at 1600 – 1650°F. The atoms and molecules in steel are allowed to cool down atmospherically after normalization process. The atoms present in steel get converted from austenite to untempered martensite during the cool down process.

The goal of the tempering process is to convert the atoms and molecules from an untempered to tempered form of martensite. Tempering process is conducted after the cool down process at a temperature of 1000 – 1320 °F depending on grade of steel. The chemistry for different grades of steel is unique. A correct balance between soak time and temperature for every grade and chemistry of steel is vital to the overall success of heat treatment. The heat treatment process is validated through destructive testing.

Sucker Rod Cleaning

The scale build up on the surface of steel due to heat treatment must be cleaned before machining the threads on sucker rods. The scale cleaning is either done by shot blasting or shot peening. The basic methodology involved in both the processes is the same. A series of steel shot is bombarded on the surface of steel thereby inducing compressive stresses on the surface of the rod. The compressive stresses built on the surface of the rod negate any tensile stress or residual stress built in the rod due to the prior manufacturing process. In the case of sucker rods, the tensile or residual stresses are removed at the heat treatment process. As a result, the end result on a new sucker rod due to shot peening or shot blasting will be the same. Shot peening, however improves the wear and corrosion resistance on a used sucker rod.

Sucker Rod Threading

The threads on a sucker rod can either be cut or rolled. Steel is made up of grains and flow lines. The flow lines of the grains are in a direction parallel to the axis of the rod body. In a cut thread application, these flow lines are getting cut and discontinued which leads to lower thread flank strength. In a roll thread application, the flow lines are transformed to the shape of the thread which results in higher flank strength of the threads.

The process of roll threads is done through cold formation of steel. Cold formation of steel tends to improve the fatigue resistance. Roll thread application is better for sucker rod threads due to cold forming and better flank strength of threads. Dimensional accuracy and preservation of straightness are critical reliability factors at the threading process. A rust preventive coating is applied to the non machined surfaces of the sucker rod to prevent atmospheric corrosion. The steel rods are packaged and transported to the end user for field applications. The critical reliability factors at this stage are traceability, preservation of surface quality and transportation.

FIELD APPLICATIONS

Field application issues contributed 86% of field failures and sucker rod manufacturing defects constituted 14% of field failures. This data was based upon on company's internal data from end users and encompasses a time period of five years. A breakdown of field failures is presented in Figure 4. The top modes or drivers for field failures were galled threads and unilateral bending fatigue due to mechanical reasons. The other modes of field failures are corrosion, loss of displacement and over displacement. The failures due to galled threads constitute 29%. A vast majority of galled threads were observed to be heat related galled thread failures. The causes for galled threads are typically improper care and handling, power tong issues and manufacturing defects. The common causes for unilateral bending fatigue are well head misalignment, rod string compression, fluid pound, stuck pumps and polished rod misalignment.

Recommended field practices

An understanding and implementation of good field practices is critical to minimize field failures. The usage of torque as a parameter in setting the torque providing devices is not the correct way to make up sucker rods. Circumferential displacement is the correct method to make up sucker rods. Torque is a parameter which varies during the make up process. Test results conducted at our facility indicate that there could be a potential variation of 70% in torque values based upon the choice of thread lubricant. Figure 5 illustrates the torque variation in the sucker rod coupling make up process.

A 1" sucker rod sample was subjected to repeated make ups and the amount of torque required for every make up was measured. There was an average variation of 22% in torque values due to repeated make ups on the same sucker rod. This illustrates the fact that torque is not a consistent parameter for makeup. Circumferential displacement should always be used for sucker rod coupling make up.

The choice of thread lubricant and application play a very important role in overall reliability of sucker rods. Test results indicate there could be an average variation of 40% in load carrying capability of the sucker rod based upon the choice of thread lubricant. The application of thread lubricant is also very critical in the overall reliability of the sucker rod string.

Normal and Shear Forces

To understand the differences in lubricant application methods, the concepts of normal and shear forces need to be understood and applied. There are two major forces acting on the joint:

a. Normal forces
b. Shear forces

Normal forces act in a direction parallel to the axis of the rod body. The amount of clamping force (force which keeps the sucker rod-coupling joint together) is directly proportional to the amount of normal forces generated in the system, and is a very desirable attribute in the make-up process.

Shear forces act in a direction perpendicular to the axis of the rod body, and tends to aid in the bending moment of the rod which may result in premature failure. Shear forces are a very detrimental attribute in a sucker rod-coupling make-up. The parameters in a sucker rod coupling process should be optimized in such a way that normal forces are maximized and shear forces are minimized.

Dry Face And Wet Face Connection

The common types of make-up in this industry are dry face and wet face. A dry face connection is a process where the thread lubricant is applied only on the threads of the sucker rod. A wet face connection is a process where the thread lubricant is applied on the threads and faces of sucker rod and coupling.

Torque

A test was conducted to study the effects of dry and wet face make up on the reliability of sucker rod. The amount of torque achievable in dry face was 41% higher when compared to wet face. The higher torque achieved in the case of dry face leads to more friction in the sucker rod coupling joint. The amount of friction available is responsible for a successful sucker rod coupling make-up. The torque achievable with a wet face make-up does not provide sufficient friction or clamping force to hold the sucker rod-coupling joint together.

Shear Forces

Shear strain or shear forces acts in a direction perpendicular to the axis of the rod body. Shear strain was observed to be 23% higher in the case of wet face when compared to dry face. The sucker rod-coupling joint with a wet face yielded in shear before the maximum displacement during its first make up. As a result of this, the load carrying capabilities of the sucker rod is compromised during the first make-up. The amount of friction available in the case of a wet face is very limited because of the lubricated faces (sucker rod and coupling) and as a result, the applied toque goes into shearing the pin and not into the friction fit of the joint.

Normal Forces

Normal forces or normal strain acts in a direction parallel to the axis of the rod body and is a very desirable attribute in sucker rod coupling make-up process. Normal Strain represents the load carrying capability of a sucker rod. The normal strain values were observed to be 9% higher in the case of a dry face.

Considering the torque, shear strain and normal strain values, dry face make-up is the best option available for sucker rod-coupling make-up process.

CONCLUSION

The overall reliability of sucker rods involves a chain of processes which starts at the steel mills. The reliability of sucker rods is decided by various processes which involves the steel mills, sucker rod manufactures and end users. Traditional ingot casting involves additional steps of cooling and rolling which leads to process variations and non conformances. Modern steel production methods are more streamlined and consistent in achieving superior levels of quality.

Sucker rod manufacturers have a critical role in deciding the final outcome and reliability of steel sucker. Process controls and quality management systems are critical factors in deciding the overall quality, integrity and reliability of steel sucker rods.

The end users should be aware of all the reliability factors which affect the performance of sucker rods. The knowledge of the reliability factors affecting sucker rods and implementation of good field practices will eliminate vast majority of field failures.

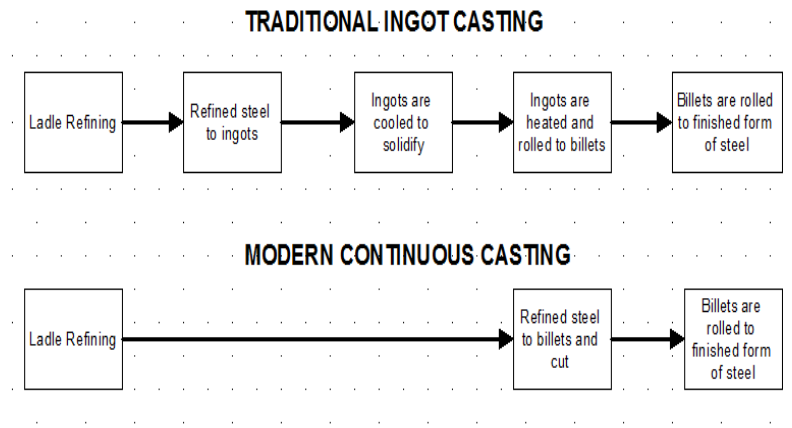


Figure 1 – Comparison of Process Flow Between Traditional and Modern Approaches for Rolling Steel

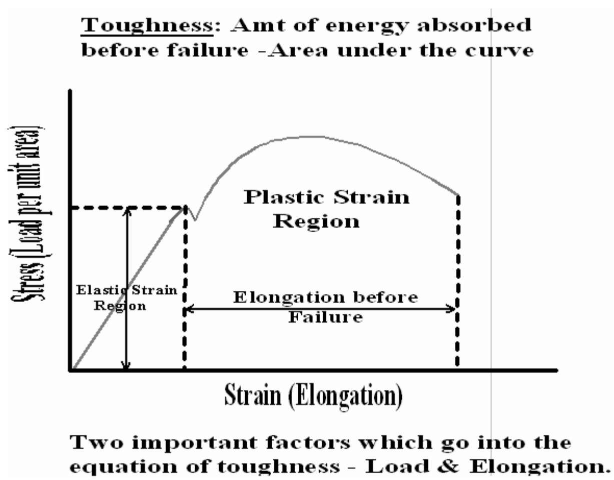


Figure 2

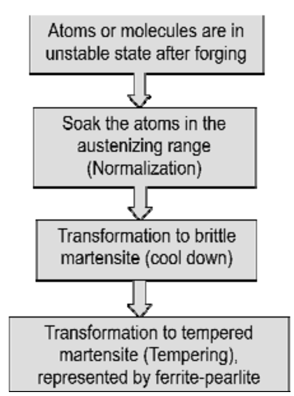


Figure 3

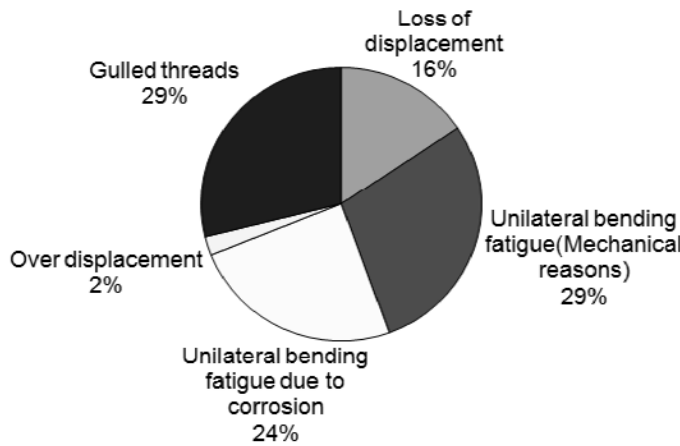


Figure 4

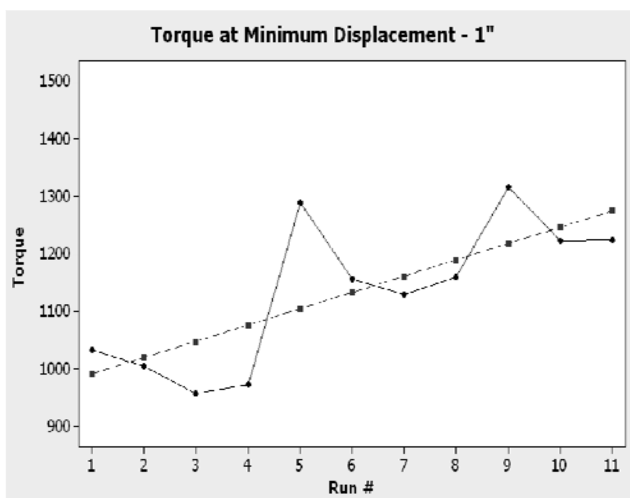
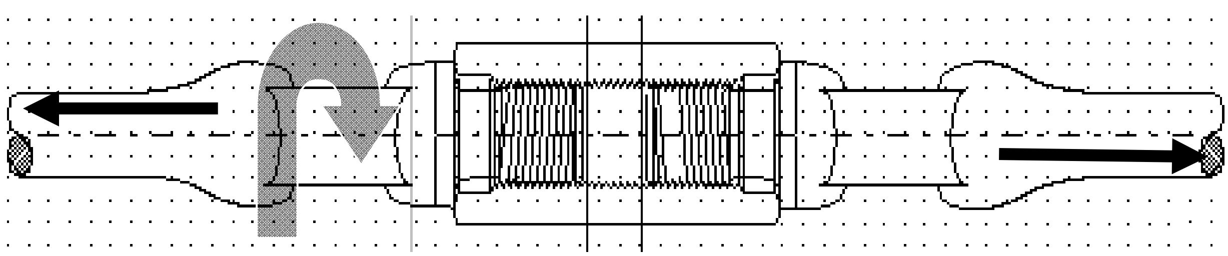


Figure 5



Normal and Shear Forces

Figure 6