DECREASING TUBING WEAR FROM SUCKER ROD COUPLINGS IN DEVIATED WELLS

Justin Galle and Christopher Lauden
Weatherford International

ABSTRACT

In a reciprocating rod lift application, production tubing failure due to metal-to-metal contact from the sucker rod couplings is a common problem in highly deviated sections of the tubing string. The coupling is forced to be the point of contact against the tubing wall, which causes high friction and excessive tubing wear during the reciprocating motion. This excessive tubing wear typically leads to a hole in the tubing wall, resulting in high workover costs for the producer. The coupling surface hardness, roughness, and coefficient of friction between the coupling and the tubing are all directly related to the resulting tubing wear generated at the contact region. Through in-house laboratory testing and preliminary field results, this study will demonstrate that when a lower-friction coating is applied to a sucker rod coupling tubing wear is decreased while tubing-string life is increased.

INTRODUCTION

When assembling a sucker rod string, API 11B states that individual sucker rods be coupled with either a cost effective, thru-hardened (T) coupling or a spray-and-fused (spray metal) coated coupling to help extend coupling life in harsher well environments. However, both accepted types of couplings have shown to be detrimental to the integrity of both the rod and tubing string when the rod string is forced through a deviated section of tubing. Depending on severity of the deviation, repeated pumping cycles over the same contact area between the sucker rod coupling and the tubing inner surface can produce either premature rod or tubing string failure due to adhesive wear.

Adhesive wear (see Figure 1) is defined as the localized bonding between two surfaces forced against one another in relative motion, leading to either material transfer or loss from each surface. Adhesive wear is seen downhole when a softer T coupling in a rod string is reciprocated against a deviated section of tubing. In most cases, the T coupling surface will wear faster than the tubing wall (grade L80). The loss of cross-sectional area of the coupling creates stress concentrations on the worn coupling, which can potentially cause a premature rod string failure. The conventional spray metal coupling may initially seem like a remedy for adhesive wear due to the harder and smoother surface finish. Even with these advantages, it is very difficult to eliminate all the surface porosity during the spray-and-fuse process. The peaks of the small surface imperfections when forced against a deviated tubing section will cut into the ID surface. In a severe deviation, the spray metal coupling can in fact cause a hole in the tubing wall.

To reduce the adhesive wear between the sucker rod coupling and the tubing string, it is known that the coefficient of friction (CoF) between the two surfaces needs to be reduced. The CoF can be optimized by either decreasing the surface roughness of either surface or eliminating all surface porosities in the spray metal coating. Increasing the hardness of one of the mating surfaces can also decrease the likelihood of material transfer when the surfaces are sliding against each other. It was determined that by applying a unique diamond-like carbon (DLC) coating to the outer surface diameter of a spray metal coupling, a very hard, yet slick surface was provided that satisfied the requirements to reduce adhesive wear. Comparative testing and field trials against currently offered couplings were required to confirm the validity of the DLC coating to alleviate adhesive wear.

DIAMOND-LIKE CARBON COATING

DLC is a class of amorphous carbon (meaning the carbon atoms are arranged in a free, non-crystalline structure) coating that exhibits typical properties of diamond. The coating is applied through either a plasma-assisted chemical vapor deposition (PACVD) or a physical vapor deposition (PVD) process. Many forms of DLC coatings have been used in various industries such as auto racing engine valves, tooling components, and medical prosthetic devices. The coating is chosen due to its ability to achieve high-hardness and low-friction surfaces that prevent wear due to friction. The non-crystalline structure of the coating means no brittle fracture planes are present throughout the coating. This provides a flexible and resistant surface, featuring a hardness close to that of diamond (see Figure 2).

Due to the high hardness of DLC coating and its thickness being only a few μm thick, a smooth substrate is necessary to achieve a strong bond. Applying the DLC coating to a spray metal coupling provides a two-fold advantage: The nickel-chromium (Ni-Cr) surface can be polished to achieve a mirror-like finish for better coating adhesion; and the much higher relative thickness of the Ni-Cr layer when compared to the DLC outer coating serves as a secondary wear layer that protects the coupling before the wear reaches the coupling base material.

LABORATORY TESTING

In order to verify that applying a sucker rod coupling with an amorphous DLC coating will improve tubing string life, a comparative wear test simulating a deviated condition was performed. While there are many American Standards for Testing and Measuring (ASTM) wear test standards for specific materials in specific applications such as ASTM G195 (Standard Guide for Conducting Wear Tests Using a Rotary Platform Abraser), D4060 (Standard test method for Abrasion Resistance of Coatings by the Taber Abraser), or D6279 (Standard Test Method for Rub Abrasion Mar Resistance of High Gloss Coatings), it was determined that building a specific in-house test that could simulate the reciprocating motion of the rod pump and the coupling/tubing interaction in a deviated well section was best suited to prove the benefits of the DLC coating. The in-house test plan included the simulated coupling/tubing reciprocating wear test in a deviated condition, and a CoF comparative test to see what frictional improvements are gained by applying DLC to a sucker rod coupling.

Tubing Reciprocating Wear Test Set-Up

The set up for the tubing reciprocating wear test included a weldment to support the overall test assembly with two hydraulically actuated cylinders mounted on top of the weldment to simulate the downhole reciprocating motion (Figure 3). A valve rod coupled to each hydraulic cylinder was inserted into a stuffing box threaded onto the tubing samples. Two 3-1/2-inch API EUE 8RD pup joints were used as the tubing test samples, allowing for two coupling wear tests to be run at the same time. The coupling fixture was fastened on the other end of the valve rod inside the tubing, which utilized a spring created side force of 74 lbs. against the tubing. This force value was determined by establishing a baseline test to see at what reasonable number of cycles an API spray metal coupling produced measurable tubing wear. Each cylinder was controlled by a position sensor/timing system that allowed each cylinder to be continuously actuated in a reciprocating motion. A variable frequency drive (VFD) was used to control the speed of the reciprocating motion. Water was pumped through the tubing during the test to help wash away metal from the contact site and keep the temperature at the contact site manageable.

Tubing Reciprocating Wear Test Couplings

The following couplings were tested in the reciprocating wear test previously described:

1. API Thru-hardened ‘T’ Grade
2. API Spray Metal
3. Currently available premium coupling marketed as a ‘Low-Friction Coupling’ (CuNi)
4. Low-friction, DLC-coated coupling

Each coupling was planned to be tested per established baseline of 450,000 complete strokes (cycles) against the tubing. After this number of cycles was reached, the test would be halted, and the tubing would be sectioned. The tubing wear width and depth was measured along the wear path. The coupling would also be inspected and measured at three locations to establish how much coupling material was lost. The couplings, tubing, and fixtures would be inspected after every 50,000 cycles or if any abnormalities were witnessed during the test.

Tubing Reciprocating Wear Test Results

All four test couplings were subjected to the same side force (74 lbs.) and the same heat applied to the tubing pup joints. The following results were recorded after the comparative wear test was completed:

API Thru-hardened T Grade

The T grade coupling only has a zinc-phosphate coating applied to the base material for corrosion protection during storage, transport, and mild to severe service. The coating is not ideal in a wear environment, as the coupling already experienced .0539 in. to .0510 in. of surface wear on either end after just 3,000 cycles. The tubing suffered approximately .026 in. of material removal in only 3,000 cycles. The test was decided to be halted at this point, as the coupling had already worn past serviceable use. The coupling only made it to 0.7% of the planned testing cycles.

API Spray Metal

The API spray metal coupling has a .15 to 20 in. NiCr outer layer with a surface hardness approximately 63 HRC. This harder coating was able to withstand the 450,000 cycles of the planned wear test, only losing .0028 to .0004 in. of coupling material. The tubing however was worn .033 in. or roughly 12% of the tubing wall thickness after 450,000 cycles. This test was used as the baseline for both the DLC coated coupling and CuNi.

CuNi

An industry available coupling was tested using the same parameters as the API spray metal coupling. This coupling only lasted a little more than half of the scheduled number of cycles, or 250,000. The coupling already showed significant surface wear of 143 to.128 in. on either end of the coupling. The CuNi coupling had experienced significantly more surface wear than the API spray metal coupling at just over half the number of cycles. The tubing wear was measured at .028 in. over this same number of cycles. At 250,000 cycles, the CuNi coupling had worn through the tubing nearly the same amount as the API spray metal coupling did at 450,000 cycles.

Low Friction DLC

DLC coating applied to the spray metal coupling was wear tested using the same parameters as the API spray metal coupling. The coupling showed no more than .0001 in. across the entire coupling at 450,000 cycles. The tubing wear after 450,000 cycles showed only .005 in. material removed. This is a near 85% tubing wear improvement over the API spray metal coupling. The DLC coating was not removed during testing and appeared to be polished smooth. The DLC coated coupling performed the best of the four tested couplings, as it showed the lowest tubing wear and coupling wear over the scheduled amount of test cycles (see Table 1).

Coefficient of Friction Testing

To obtain an idea of how much a reduction CoF at the coupling/tubing interface is when the DLC coating is applied, a lubricity test was performed using the same couplings that were tested in the reciprocating tubing wear test. Using a lubricity testing machine (Figure 4) that consists of an electric motor rotating at a calibrated RPM value and a cylindrical wear piece of the same material as L80 tubing. A coupling coupon with an OD section faced toward the rotating tubing sample was forced at a known torque value against the rotating tubing sample. The amount of resistive torque is then converted to a CoF value. Both a wet test and dry test were performed. The tests ran for 5 minutes with a CoF value recorded every minute. The point contact of the two curved surfaces did not allow much time before adhesive wear would skew the friction results.

Coefficient of Friction Testing Results

For both the wet (Figure 6) and dry (Figure 7) lubricity tests, the DLC coating had the lowest CoF over the length of each test. The CoF value for the DLC against L80 tubing is between .1 and .08. The spray metal coupling begins around .37 CoF value because of the initial smooth surface finish and then increases to .55-.60 CoF value as the surface roughness increases due to adhesive wear. The CuNi coupling does have a lower CoF than the spray metal coupling, however it is still nearly 85% higher than the DLC coated coupling. The T grade coupling starts out at .20 CoF value due to the slick zinc-phosphate coating, but once it is worn during testing to the bare base material, steel on steel resumes and the CoF approaches that of the spray metal coupling.

PRELIMINARY FIELD TRIAL RESULTS

Field trial wells were chosen to test the DLC coated couplings that had more than two tubing failures per year due to holes caused by couplings in deviated sections. Three wells were selected to run between 28 and 100 DLC coated couplings in each well (Table 2). The DLC couplings were installed in the high wear locations in the rod string where tubing failures have previously occurred. The wells were monitored to observe changes in time of tubing failures.

The historical average time between tubing failures for Well 1 was four months, while the historical average time between tubing failures in Wells 2 and 3 were six months apart. No change in the sucker rod string program occurred once the DLC couplings were installed in the well. All three wells showed a significant increase between 3.2 to 4 times the tubing life without a failure occurring (see Table 3). Wells 1 and 2 transitioned from rod pump and never saw another tubing failure while the DLC couplings were installed. Well 3 had significant amount of sand in the well and even though sand was not a variable in the lab testing, the DLC couplings still increased the life of the tubing string. A tubing scan of the defect severity string was performed before and after the field trial of one of the wells (Figure 8) which showed significant improvement and eliminated the previous failure point of worn-through tubing.

CONCULSIONS

The benefits of applying DLC to the sucker rod couplings have both been demonstrated in the lab and the field to improve the life of the tubing string. The low CoF and high hardness of the DLC coating when forced in deviated condition against tubing decreases the amount of adhesive wear between the two sliding surfaces, which in turn prevents the material loss resulting in tubing holes. A comparative, real-world tubing wear lab test showed how much wear improvement the DLC is provides over conventional spray metal and other low friction offered couplings. Installing DLC coated couplings downhole in deviated locations increased up to four times the amount of time between tubing failures. The results from the lab and the field prove that using an enhanced DLC coated coupling in a reciprocating, rod lift application will result in reduced tubing wear, reduced coupling surface wear, and longer production tubing life. The novelty of the DLC coated coupling relates to the reduced frictional and high hardness properties which both extend tubing life and reduce coupling wear.

REFERENCES

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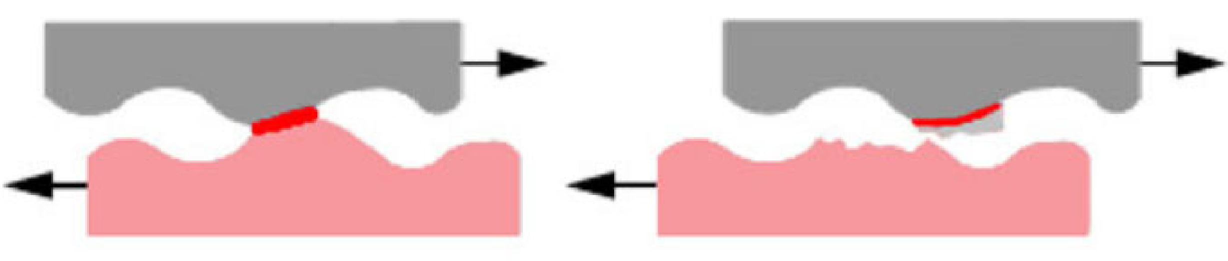

Figure 1: Adhesive wear during a sliding application

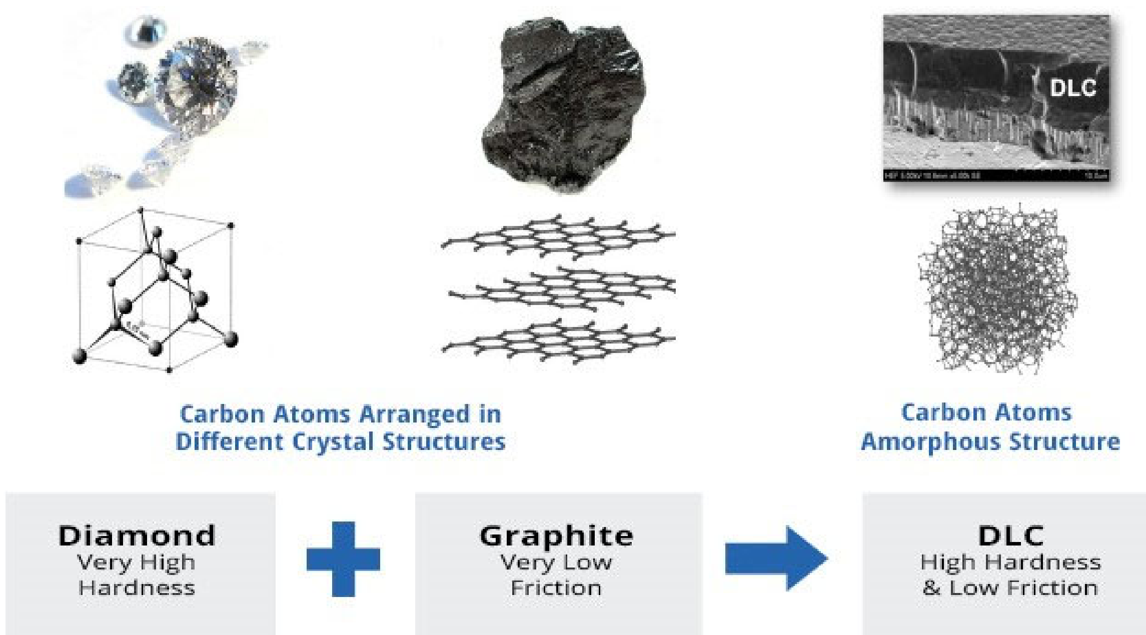

Figure 2: Different arrangement of carbon atoms~~.—~~. DLC amorphous structure combines high hardness of diamond and very low friction of graphite.

Figure 3: In-house Tubing Wear Testing Weldment Frame

Figure 4: Lubricity Testing Machine

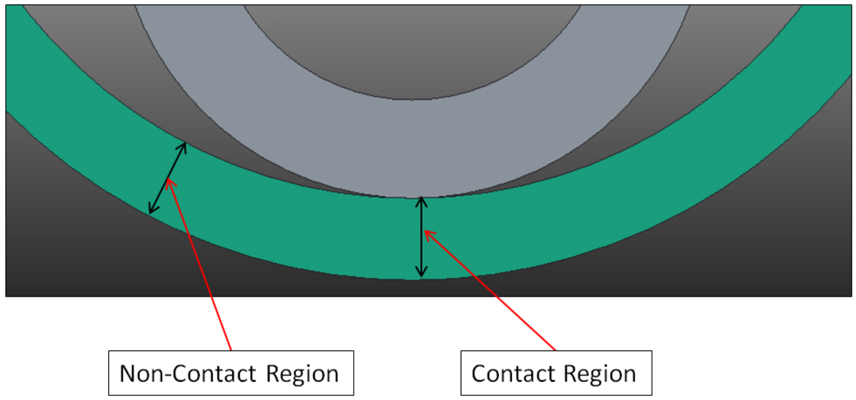

Figure 5: Tubing/Coupling Interface During Reciprocating Wear Test

Coupling	Cycles	Tubing Wear (in.)	Max Coupling Wear (in.)
API T Grade	3,000	0.018	0.0539
API Spray Metal	450,000	0.033	0.0028
CuNi	250,000	0.028	0.1430
DLC Coated	450,000	**0.005**	**0.0001**

Table 1: Reciprocating Wear Test Results, 74 lbs. Side Force

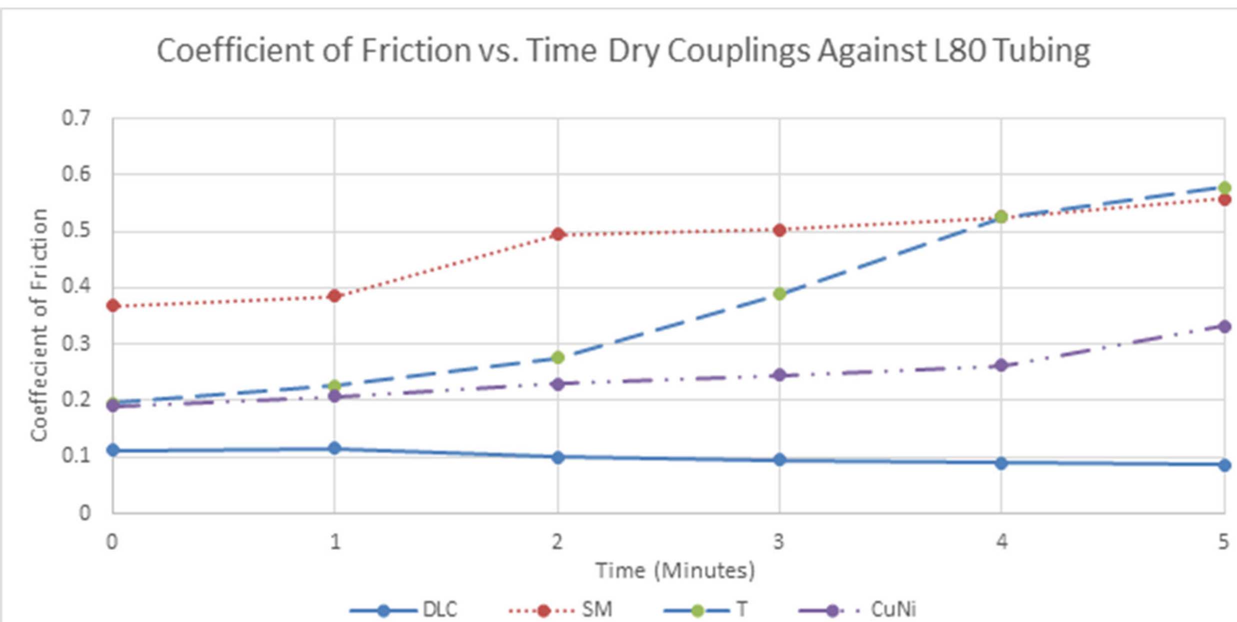

Figure 6: CoF vs. Time, Dry Coupling / Tubing Interface

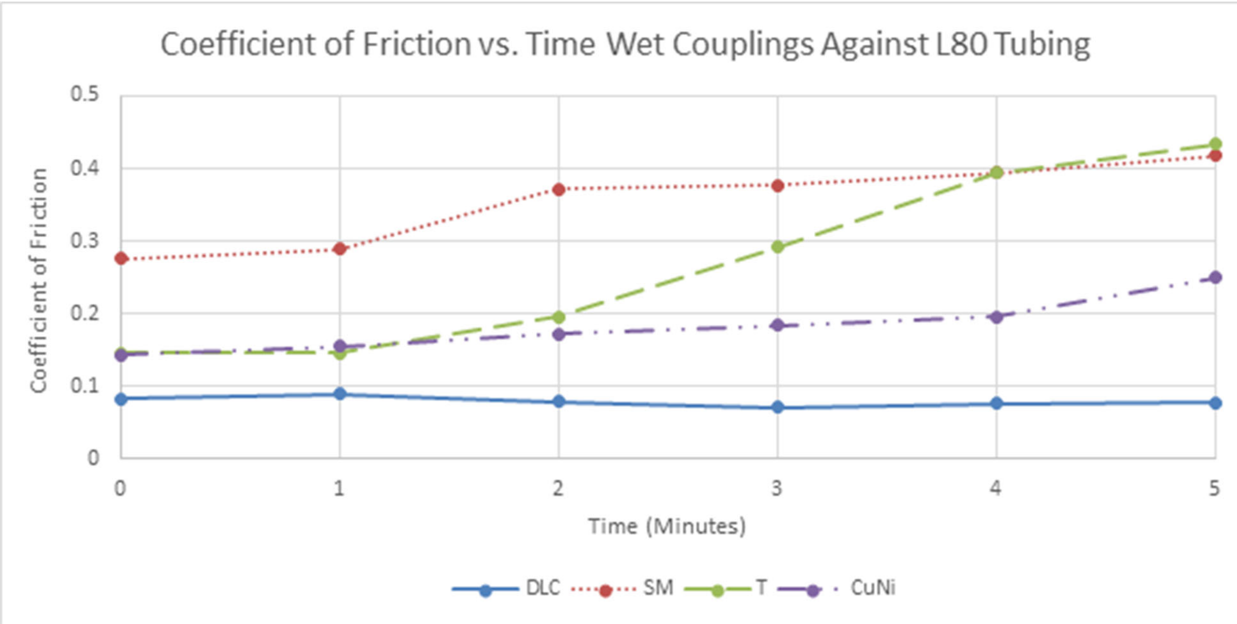

Figure 7: CoF vs. Time, Wet Coupling / Tubing Interface

	Well 1	Well 2	Well 3
Number of Couplings Installed	100	39	28
Size of coupling Installed	7/8"	7/8"	7/8"

Table 2: Field trial coupling configuration.

	Well 1	Well 2	Well 3
Base time between tubing failures (months)	4	6	6
Running time without failure with coating (months)	16	24	19
Factor of increase of time between workovers	4X	4X	3.2X

Table 3: Field trial results showing gained tubing life.

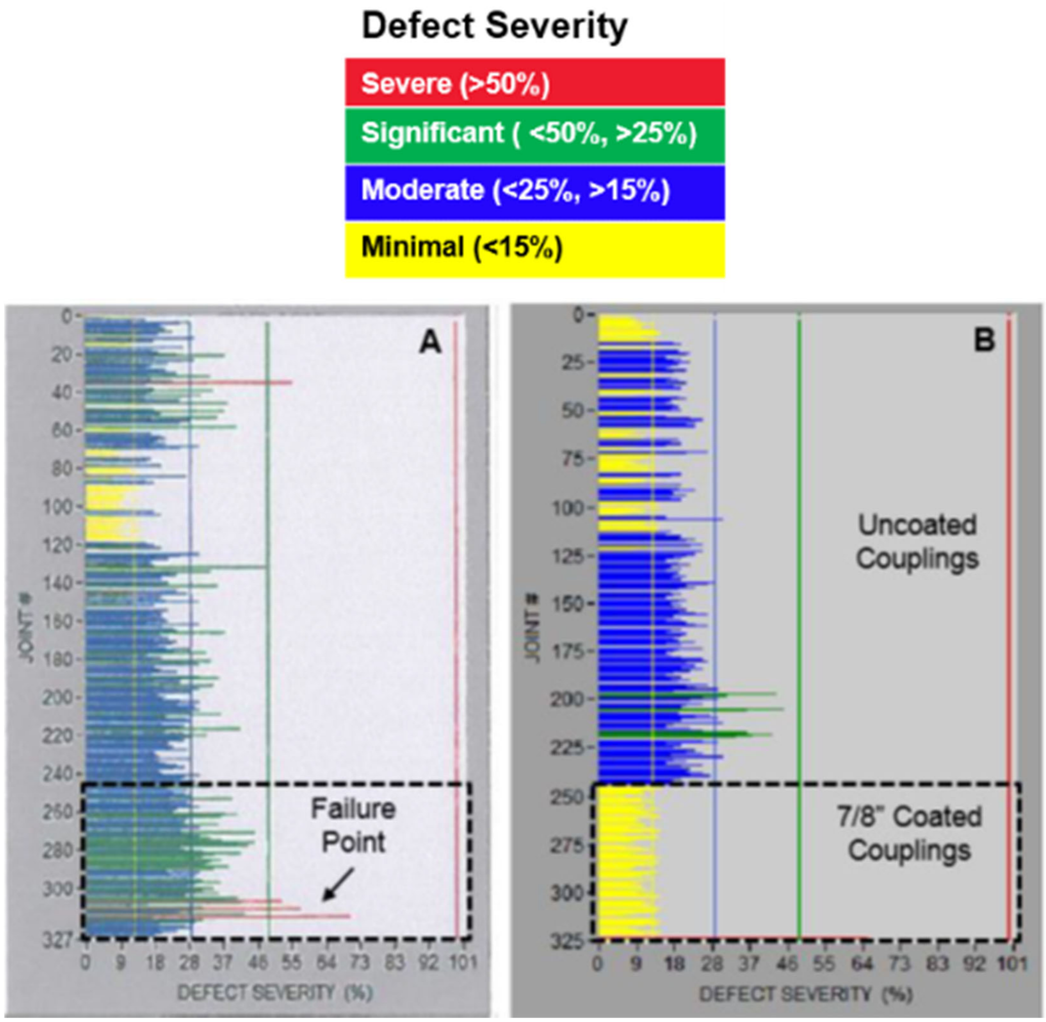

Figure 8: Pre-field Trial Scan (A) and End of Field Trial Scan (B)