STEEL SUCKER ROD FATIGUE TESTING – PHASE I UPDATE

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ABSTRACT

There are very few papers that present the actual fatigue data for various grades of sucker rods from a variety of manufactures. This paper will provide information on the testing being conducted by one sucker rod manufacturer and the performance of high strength API D grade rods versus non-API extra high strength rods for air fatigue in rotary bending tests. Additionally, information will be provided on the relevance of these results and on the next phases of fatigue testing that is being planned.

BACKGROUND

Sucker rod fatigue testing has had little formal fatigue performance results published. Hein and Hermanson[1] provided a discussion of published fatigue testing from Goodman and the extension accepted by the oil and gas production industry in the development of the Modified Goodman Diagram (MGD) that was adopted in API RP 11BR. These graphs are shown in Figures 1 & 2. Figure 3 provides an actual allowable MDG stress fatigue curve for API grade C sucker rods.

Additionally, a number of major parameters that would affect fatigue life were applied to sucker rods for the consideration of developing recommended fatigue life. These major parameters included environmental conditions, surface condition of the rods, steel quality/effect of inclusions, and the effect of cycle rate along with corrosion that might occur. These effects are shown in Figures 4, 5, 6 and 7.

Finally, the original paper summarized the very conservative nature of the MDG compared to the progress that had occurred of the past 50 to 60 years determining fatigue performance prediction methods. These are summarized in Figure 8 and recommended that a different consideration than the MDG be used that would increase allowable loads/stresses if the Gerber parabola was used. Even with this higher load range postulated, it was recommended that the expected fatigue life for modern day sucker rods should be in the range of 50 million cycles.

Since the SPE paper was published in 1993, there had been little data presented to actually determine the allowable load/stress range and/or the expected fatigue life for sucker rods. However, recently a number of companies have presented sucker rod fatigue testing programs and some limited results. Hein[2] provided testing that was conducted at Tulsa University on a program that investigated the effect of properly shot peening sucker rods. Table I, reproduced here in, provides the fatigue cycle results for rotary bend fatigue data conduced in air with samples being peened or unpeened. A variety of load ranges were applied showing the effect of fatigue life on applied load and the great improvement in expected life from Nor-Peening®. The graph of the fatigue life data from this testing is shown in Figure 9.

Fatigue life data of premium connections and a comparison of the base rod for both axial and torsional loading were presented at the 2012 SWPSC.[3,4] Additionally at the 2012 SWPSC a third party inspection service company provided fatigue data on shot peening sucker rods again affirming the increased benefit on fatigue life as well as potential improvement if this technique is used as part of the sucker rod inspection process.[5]

CURRENT TESTING PROGRAM

Rotary bend fatigue testing was conducted in air to establish the base line and best case performance expectation for a variety of different sucker rod grades. Testing originally was conducted with ¾" diameter sucker rods from a variety of manufacturers. These rods represented the high strength API Spec 11B, D grade rods and the manufacturer's special high strength non-API sucker rod grades. Originally, the samples were four feet long and bending fatigue was conducted at 400 rpm. Testing was repeated for at least three sample rods and the average fatigue life was recorded. Fig. 10 shows a picture of the smaller test machine.

Once testing started, it was found that the shorter length samples concentrated the applied load too close of the collet that held the rod in place in the test machine. A longer sample tester shown in Fig. 11 was then developed to allow eight foot long samples with diameter of the rods up to 1 – 1/8th inch, and cycle rates of 600 to 800 rpm could be applied. The longer length for the rod sample will allow the testing of the coupled connections being made up to see how a variety of connecting methods to hold the rod string together would perform versus the original parent material. All testing averaged the life of at least three rods for each specific grade tested.

The applied load assumed full cycle, reverse bending with the maximum load applied being 40% of the tensile strength of the sucker rods. This load is very conservative in that the normal applied load from the MGD is only 25% of tensile for the API grade rods. However, the applied load of 40$ of tensile is closer to the maximum recommended allowable MDG for the non-API, special high strength rods (typically ~35.7% of tensile or (1/2.8).

Figure 12 provides a graph of the performance of another type of non-API, special high strength rod using a grade 96. Fatigue life for various loads and actual cycles to failure showed the shot peened rod again had much higher fatigue life performance than the non-peened rod.

A comparison of fatigue life performance for the 15 different rods available from 4 different manufacturers is shown in Figure 13. These data showed the longer expected fatigue life for the two different grades of rods that were Nor-Peened®. Additionally, the cycles to failures varied from the three different manufactures of the API D grade and special high strength rods from only about 100,000 cycles to approximately 1,150,000 cycles versus the approximately 1.625 to 1.7 million cycles for the peened rods.

PHASE II PROPOSED TESTING PROGRAM

- Initiated air fatigue testing of welded, spoolable rods in bend fatigue test machine
- Started tension-tension (axial) loading of rods in MTS machine to determine if comparison can be obtained between bending fatigue and axial fatigue
- Partial results show axial – tension/tension has higher fatigue life (as expected) due to less damage than full reverse loading

CONCLUSIONS & RECOMMENDATIONS

1. Nor-Peening® proven effective on grades 96 & 97 special high strength rods extending air fatigue life.
2. Nor-Peened® fatigue life ~150% to ~1,500% greater than compared competitors at the same tensile load percentage.
3. Variation in internal versus external fatigue life results needs further investigation.
4. MTS air fatigue data and possible correlation will be useful to verify expected life.
5. Testing needs to continue including corrosion fatigue and connection testing.

REFERENCES

1. Hein, Jr., N.W. and Hermanson, D.E., *A New Look at Sucker Rod Fatigue Life,* SPE 26558, ATCE, Houston, Oct. 3 – 6, 1993, Richardson, TX.
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4. Fernandez, E., *Premium Technology – Beyond the Limits of Artificial Lift Systems – Field Experiences,* SWPSC, Lubbock, TX., 2012.
5. O'Neal, T., *Shot Peening Sucker Rods to Prolong Fatigue Life,* SWPSC, Lubbock, TX., 2012.

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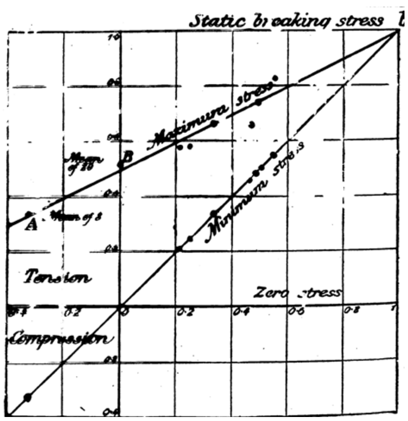

Fig 1. Original Goodman Fatigue Graph

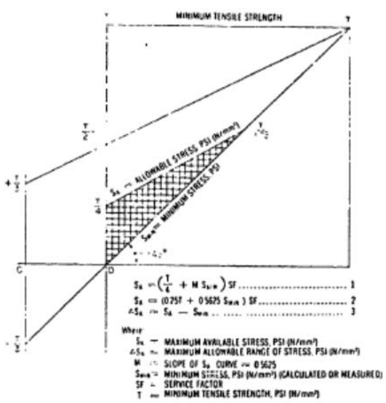

Fig 2. Modified Goodman Diagram

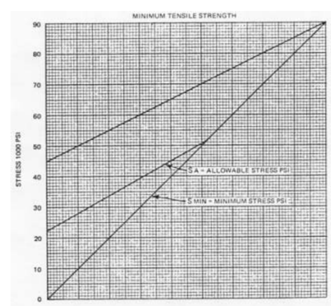

Fig 3. Allowable MGD C Grade

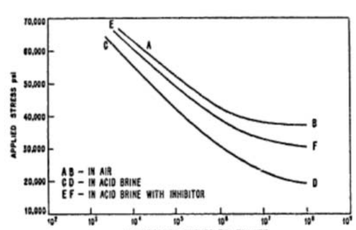

Fig 4. Effect of environment on fatigue

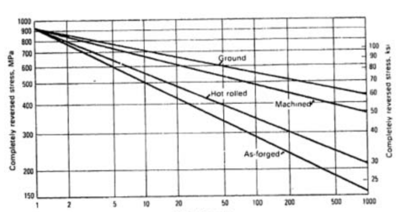

Fig 5. Effect of surface condition on fatigue

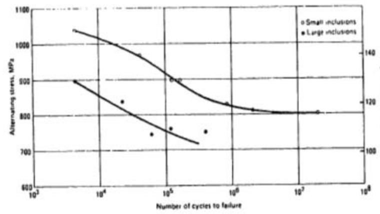

Fig 6. Effect of steel quality on fatigue

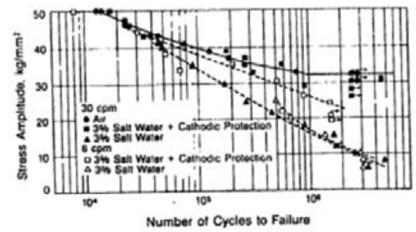

Fig 7. Effect cycle rate and environment on fatigue

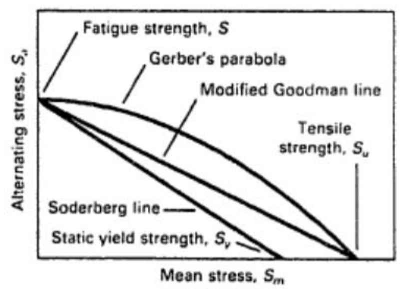

Fig 8. Comparison of various fatigue relationships

Table I. Fatigue cycles for non-API, Special high strength rod showing effect of Nor-Peening®

NON-SHOT PEENED TEST RESULTS				NOR-PEENED TEST RESULTS				Percent Increase
Force	Stress Amplitude	Number of Test	Average Life Cycles	Force	Stress Amplitude	Number of Test	Average Life Cycles	
90 lbs	89.64 ksi	2	27,515	90 lbs	89.64 ksi	2	62,946	129%
80 lbs	83.12 ksi	2	50,782	80 lbs	83.12 ksi	2	164,748	224%
70 lbs	76.60 ksi	3	114,787	70 lbs	76.60 ksi	3	498,713	334%
60 lbs	70.08 ksi	5	170,005	60 lbs	70.08 ksi	3	7,702,305	4,431%
50 lbs	63.56 ksi	6	139,482	50 lbs	63.56 ksi	1	21,696,977 (NO FAILURE)	INFINITE

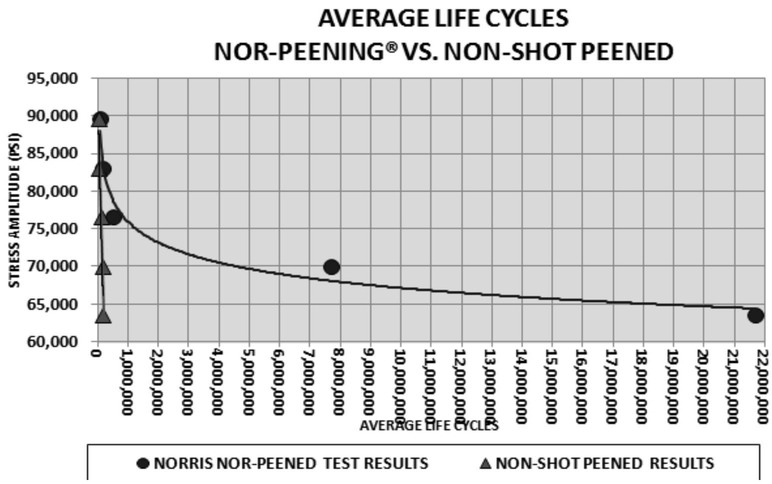

Fig 9. Graphical comparison of non-API special high strength rod and fatigue life


Fig 10. Small rotary bend fatigue tester

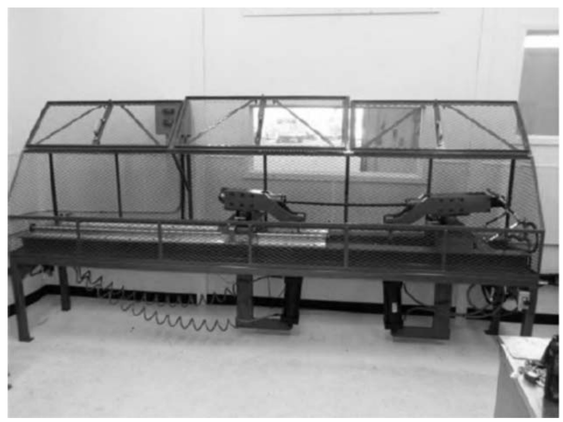
Fig 11. Larger rotary bend tester

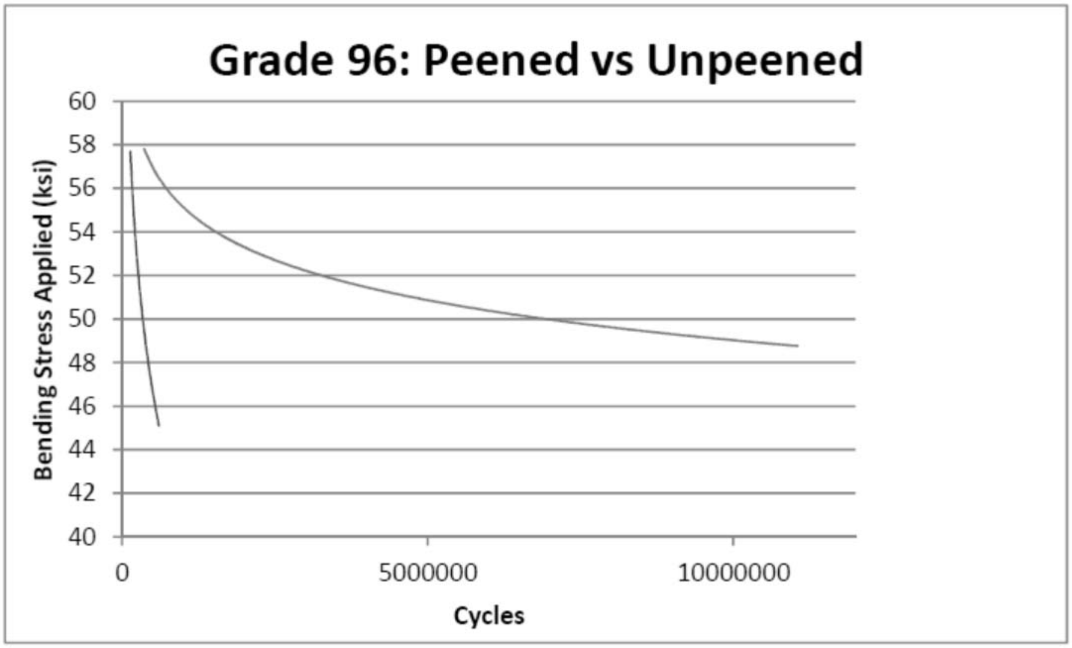

Fig12. Fatigue life curves for non-API, special high strength rod and surface peening.

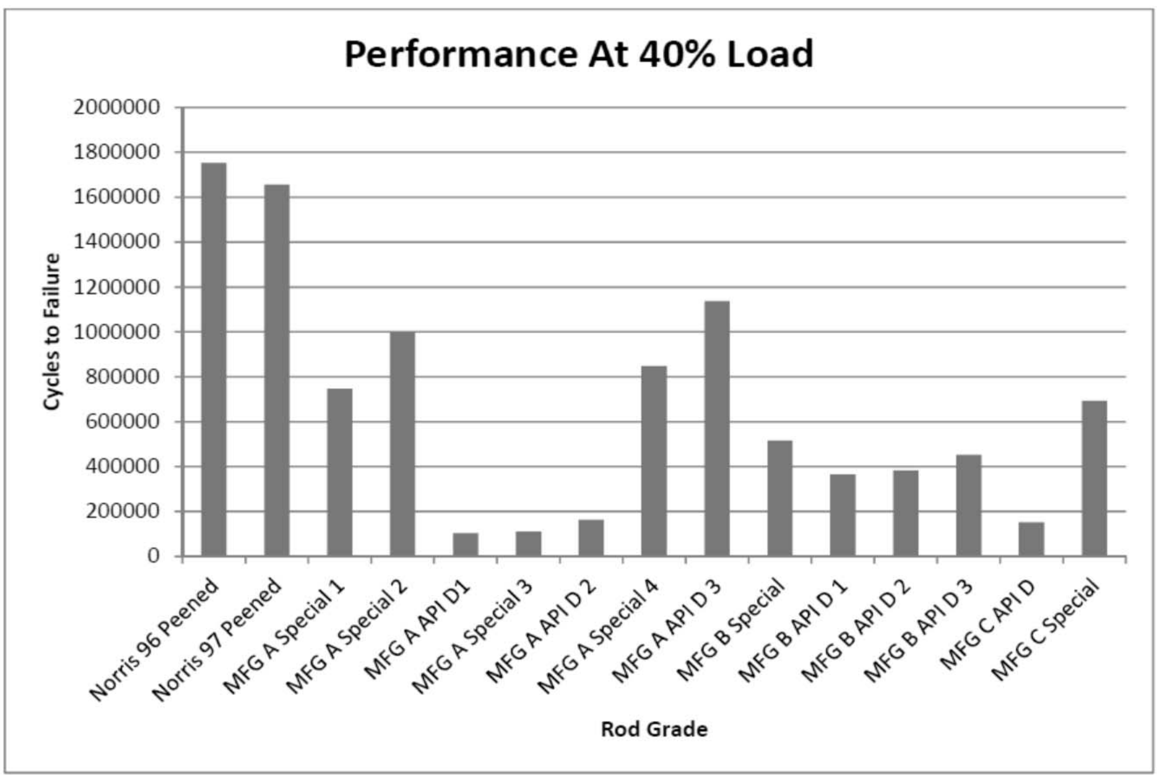

Fig 13. Generalized fatigue life test results for rotary bend, air fatigue with max load at 40% of actual tensile strength