IT'S ALL ABOUT THE END FITTING: ADVANCED TESTING AND DESIGN IMPROVES FIBERGLASS SUCKER ROD

Ryan Gernentz, Karol Hricisak, Mohamed F. Alzoubi
John Crane

ABSTRACT

The full potential and benefits of the fiberglass sucker rods (FSR) are not being realized. FSR manufacturers are required to meet the requirements for increased operating ranges and one-time pull loads of FSR. Increasing the operating load requires the redesign of the end fitting to ensure reliability. This paper outlines the standard design of an end fitting and how it interfaces with the pulltruded fiberglass rod. Test data used to validate the design is also included. The overall wedge design is explained in detail, demonstrating the interaction of forces acting on the rod/end fitting interface. The stress range diagram will be presented with emphasis on the critical areas of the end fitting design. The overall goal is to show how the fiberglass rod combined with a new end fitting is stronger than high strength steel of equivalent pin size.

INTRODUCTION

Fiberglass Sucker Rods (FSR) have not been widely accepted, despite being able to increase production rates and reduce energy consumption. Two reasons for limited use is the limited strength of the rod as measured by average working load and maximum one-time pull and the mode of failure where rod breaks that are difficult to fish from the well.

This paper presents a unique design approach to the end fitting geometry and investigates how the strength of a fiberglass sucker rod performs as a system and how the load of a rod string can be distributed differently, addressing the two primary issues associated with the adoption and use of FSRs. Additionally, design changes and testing results are presented. Researchers and scientists around the globe, such as studies conducted by Woldesenbet, et al. [1], have investigated the effect of fatigue cycles on the performance of these sucker rods.

During the process of improving a FSR design, an understanding of how the product performs as a system helps to identify the limiting factors of current designs. Considering each component of the FSR, an evaluation of the glass strands, the resin used to hold the glass strands, the epoxy connecting the rod to the end fitting and the end fitting geometry was conducted. The overall strength of the assembly is based upon the components, but also on the interface and boundary conditions between the materials. The characteristics of these interfaces can contribute significant load carrying capability to the overall assembly. This paper discusses the fiberglass rod system, components of the system, including the rod body, end fitting and connection pin. Utilizing technology and data from laboratory testing results in an improved design, higher performance while improving and streamlining the overall design process.

FSR COMPONENTS AND MANUFACTURING PROCESS

A FSR consists of three integral components: a fiberglass rod, end fittings and epoxy between the two. A fiberglass rod body accounts for the majority of the size (length) of FSR. It consists of axially aligned glass strands bonded by resin. The glass strand material used in the John Crane FSR has a per-strand rating of 450-550 ksi in tension. The resin is used hold the glass strands together forming the rod body. A fiberglass rod is then capped with an end fitting at each end. An API pin is machined on the opposite side of the end fitting body to join another FSR via couplings. The end fitting is typically machined from metal bar stock with an internal cavity to accept the end of the fiberglass rod body and epoxy bonding agent. Per American Petroleum Institute (API) Specification 11B, the "C grade" steel alloy used in the end fittings has a limiting tensile rating of 90-115 ksi. The epoxy adheres to the rod body, not the end fitting, and serves as a means for transferring load from the end fitting wedges to the rod body.

As a part of the FSR assembly process, the internal cavity of the end fitting is filled with epoxy. It is then driven onto the end of the rod body. During this step, the epoxy fills all voids within the end fitting not occupied by the fiberglass rod. The epoxy assumes the internal shape of the cavity and is then cured and hardened thru a heating and cooling process. Once cured and cooled a load is applied to the FSR in order to ‘set the wedges’. As a final step required by API, the setting load is 110 percent of the maximum allowable working load in order to verify the quality of the assembly and minimize the effects of cyclic loading during normal operation.

END FITTING

The overall geometry of the end fitting is prescribed by API specification with the exception the internal cavity. The geometry of the internal cavity is essential to the assembly and the primary contributor to the performance of the FSR. The purpose of the of the wedge is to provide an increase in diameter (upset) at the end of the fiberglass rod to prevent the end fitting from pulling off the rod body when the operating load of the rod string is applied. The epoxy used to form the wedge is intended to create a maximum adhesion with a fiberglass rod body. Adhesion is not desired between the end fitting and the epoxy as it causes premature epoxy failure due to shearing. The wedge transfers the axial loading of the rod string to a radial load (N1) to the body of the end fitting as seen in Figure 1. F1 and F2 are equal and opposite forces as a result of the relative friction coefficient between the metal wall of the end fitting and the epoxy.

The resulting load (N2) acts opposite to the radial load (N1) in a compressive direction onto the rod body, transversely with respect to the fiberglass strands. The amount and the direction of compressive load are directly dependent on the internal geometry (angles of the wedges) of the end fitting. As a function of the wedge angle, the shallow angle would result in the load causing swelling or splitting of the end fitting or splintering of the fiberglass rod. On the other hand, a large angle would result in the load shearing the epoxy or the epoxy-rod body bond. The objective of redesigning the end fitting is to improve the current design by modifying the internal geometry of the end fitting while employing already established materials that are currently in use for the following two reasons:

1. Material is well established and proven.
2. There is significant opportunity for performance improvement by managing the distribution of stress.

It was determined to optimize the current design by modifying the force generated by N_2 along epoxy-wedge distributing the stress in the rod more evenly and making the interface as strong as possible.

ESTABLISHING A BASELINE

The first step in developing an improved end fitting was to understand the performance of the current design. A simplified axisymmetric model using Finite Element Analysis (FEA) was utilized to assist in this process. The material properties of the three components that were used in building the FEA model were extracted from several literatures such as those used in Kumosa, et al. [2, 3]. The model demonstrates the internal deformation and loading mechanisms of the ‘end fitting-epoxy-fiberglass rod’ joint. Figure 2-Figure 4 show the model elements, element mesh density and the resultant Von-Mises stress respectively of the baseline model.

From the results of the baseline model shown in Figure 4, the load distribution as a function of the internal geometry is clearly identified. Taking into account the limitations of the FEA analysis, this model was to establish critical areas of design only. An iterative process combined with lab testing was employed to establish a valid simulation envelop due to model’s high sensitivity to assumed boundary conditions, material properties, and friction coefficients. A number of models were evaluated and the results within the linear elastic region were compared with the results of the tensile tests of the fiberglass rod. Standardized material testing of the fiberglass and the epoxy aided to fine tune the material properties used in the simulation model. The FEA results are highly dependent to the relative friction coefficients utilized within the model, in particular the epoxy-end fitting interface. If the joint is assumed frictionless the model results in low absolute tensile strength, but it would replicate the swelling of the end fitting. However, increasing the friction coefficient near the upper tolerances would result in the epoxy shearing prematurely, resulting in a low axial force .The final friction coefficient selected best matched the radial deformation and relative axial displacement between the components seen in lab testing. With the FEA model closely matching the lab results the confidence in the predicted stress plots is established. The derived baseline model can further be considered in future design decisions relevant to the end fitting internal geometry.

VIRTUAL PROTOTYPING

From the established baseline, conceptual designs were developed and analyzed using FEA to compare performance while varying the following key parameters:

1. Length of engagement (length of rod penetrating the end fitting)
2. Angles of the wedges
3. Epoxy thickness
4. Outside Diameter (OD) profiles
5. Stress concentration factors
6. Wedge Type (straight vs. asymptotic vs. hybrid)

Figure 5 shows total reaction force percentage vs. relative deflection between rod body and end fitting for various epoxy thicknesses.

These preliminary results suggest that varying epoxy thickness has minimal effect on the one-time pull load capacity of the end fitting. However results in Figure 6 show that the assembly is highly sensitive to variations of the wedge angles. The variation in the wedge angle affected both the slope of the linear region of the system as well as the peak load.

The remaining parameters were plotted to establish how the system reacted to the variations. The parameters with the highest response were selected to optimize the end fitting design. The best performing candidates were prototyped to be validated by lab testing. Figure 7 shows the results of validating the coefficient of friction against the lab results.

LAB TESTING

The John Crane lab has the capability to test steel or fiberglass rods up to 40ft in length with loads not to exceed 225kips. This tensile testing rig can perform one time pull to failure loading as well as cycle testing. There is a secondary test rig dedicated for cycle testing to failure while in a heated oil bath. The maximum rating on the cycle tester is 70 kips with a maximum oil bath temperature of 350°F. The initial lab testing consisted of loading the FSR assemblies until they parted while recording the load, elongation of each test, end fitting deformation and the failure mode. Each FSR concept underwent a number of lab tests to establish a consistency in results. Once the first round of lab testing was complete, the best characteristics were determined and utilized to proceed to the next revision of modeling. The FEA boundary conditions were again validated against the lab test results to assure good correlation. This iterative method of combining the virtual testing with actual testing was imperative to ensure that the FEA modeling represented physical performance.

Upon completion of the initial test matrix the variation in design parameters showed a close correlation to the various failure modes (rod break, end fitting deformation, epoxy failure, etc.). The test results were compiled and ranked based on the criteria listed below.

1. Standard deviation of Peak Load (2 kips -15 kips)
2. Peak Load (Variance 58 kips)
3. Failure mode (Pin Failure, Rod Body Break, End Fitting Swelling / Splitting, Epoxy Shear)
    a. Repeatability
    b. Predictability

However a number of the tests showed high ultimate load values, low standard deviations and preferred failure mode. Those candidates underwent additional iterations before arriving at designs selected for cycle testing. Up to this point, all design parameters were evaluated only by one time pull to failure tests due to simplicity and repeatability of the testing. Cyclic testing was performed as a final validation method against expected field operating conditions.

FINAL DESIGN

The final end fitting design consists of a four wedges with varying wedge angles and graduating lengths. This internal geometry was optimized using all available engagement length of the cavity. While maximizing the effective length of the cavity (rod engagement length), high stress regions were minimized to allow for the lowest possible stress per unit load.

Design goals were successfully achieved with a use of this iterative design process. The final design of the end fitting achieves considerably higher working loads, one time pull to failure loads with a predictable failure mode. John Crane's published literature shows a working load that is at least 25 percent higher than all other currently available fiberglass rod alternatives. Also, an increased ability to remove stuck pumps was achieved by an increase in the one-time pull load capacity of 30 percent. The failure mode of the rod pulled in tension no longer causes deformation to occur at the end fitting allowing the rod end to separate. Instead, the entire end fitting and epoxy connection is strengthened such that the pin can be the engineered point of failure allowing for easier retrieval of parted rods stings. The final allowable stress range diagram is provided in Figure 9.

CONCLUSION

The John Crane team was able to meet the objectives set for the new generation of the end fitting by employing the accelerated/iterative design process. This design process consisted of FEA modeling supported by lab test data. Lab testing assisted in both model setup and final verification of the performance. During this effort, the design team was able to establish correlation between geometry parameters (wedge angle, engagement length, and epoxy thickness) and end fitting performance (working load, one-time pull load, failure mode). The final design has the following improvements:

1. Working load that is at least 25 percent greater than all other currently available fiberglass rod alternatives.
2. Increased ability to remove stuck pumps achieved by an increase in the one-time pull load capacity of 30 percent.
3. The failure mode was also changed from end fitting swelling to a controlled pin failure higher than the breaking load of most high strength steel rods.

REFERENCES

1. Fyassu Woldesenbel "Finite Element Analysis of Composite Sucker Rods," Journal of Energy Resources Technology, Vol. 125, (Dec. 2003) pp. 299-303.
2. M. Kumosa, Y. Han and I. Kumosa, "Analysis of Composite Insulators with Crimped End-Fitting: Part I – Non Linear Finite Element Analysis Computation," Composites Science & Technology, Vol. 62, No. 9(2002) pp. 1191-1207.
3. M. Kumosa, H. Shankara Narayan, Q. Qiu & A. Bansal, "Brittle Fracture of Non-Ceramic Suspension Insulators with Epoxy Cone End-Fitting," Composites Science & Technology, Vol. 57 (1997) pp. 739-751.

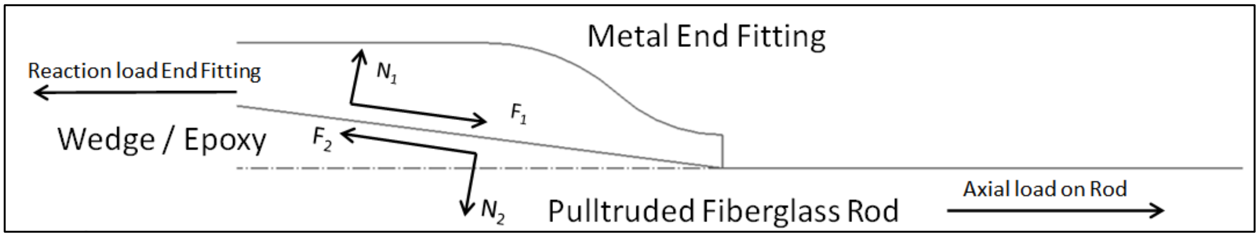

Figure 1- Simplified wedge free-body diagram

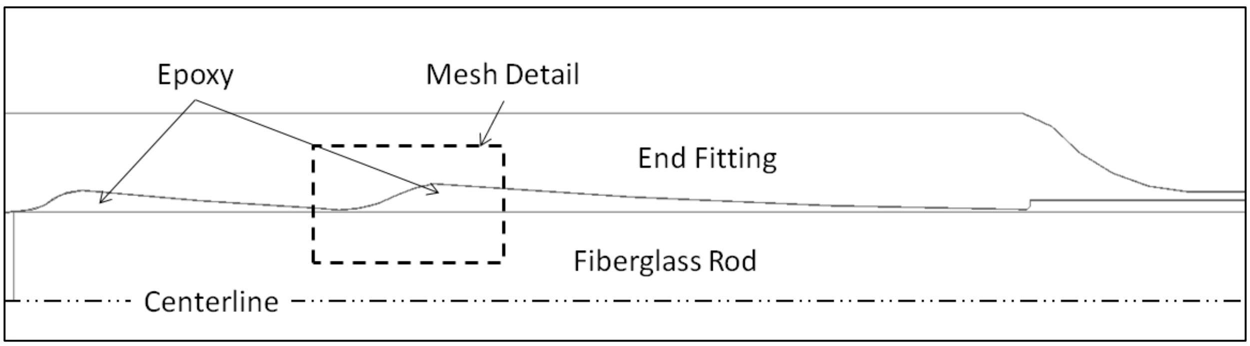

Figure 2- Baseline model of the axisymmetric sucker rod end fitting model used as a baseline

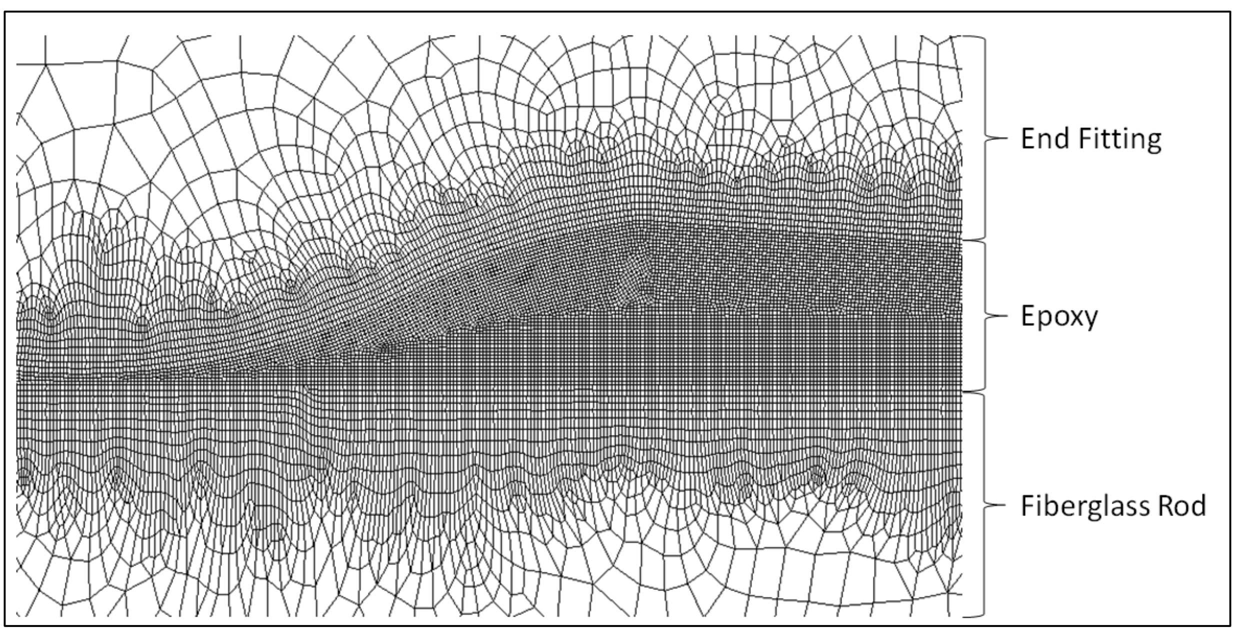

Figure 3- Mesh density detail of the baseline axisymmetric sucker rod end fitting model

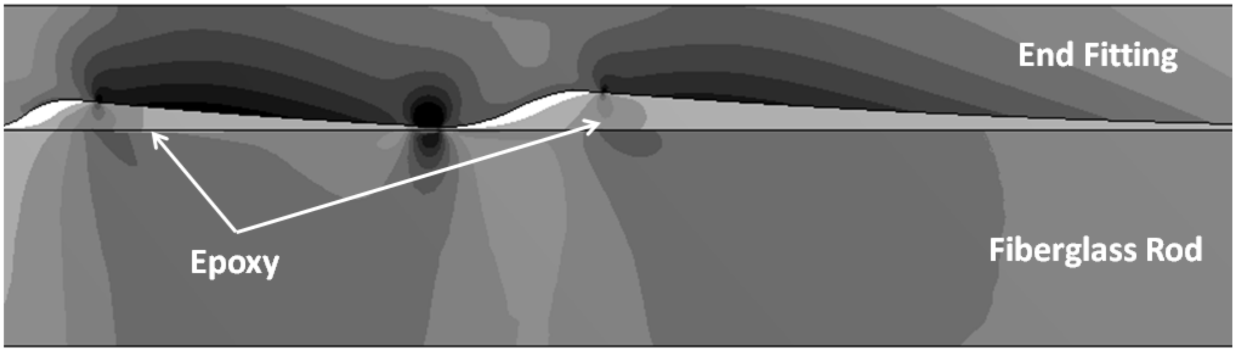

Figure 4- Von-Mises stress on the baseline axisymmetric sucker rod end fitting model

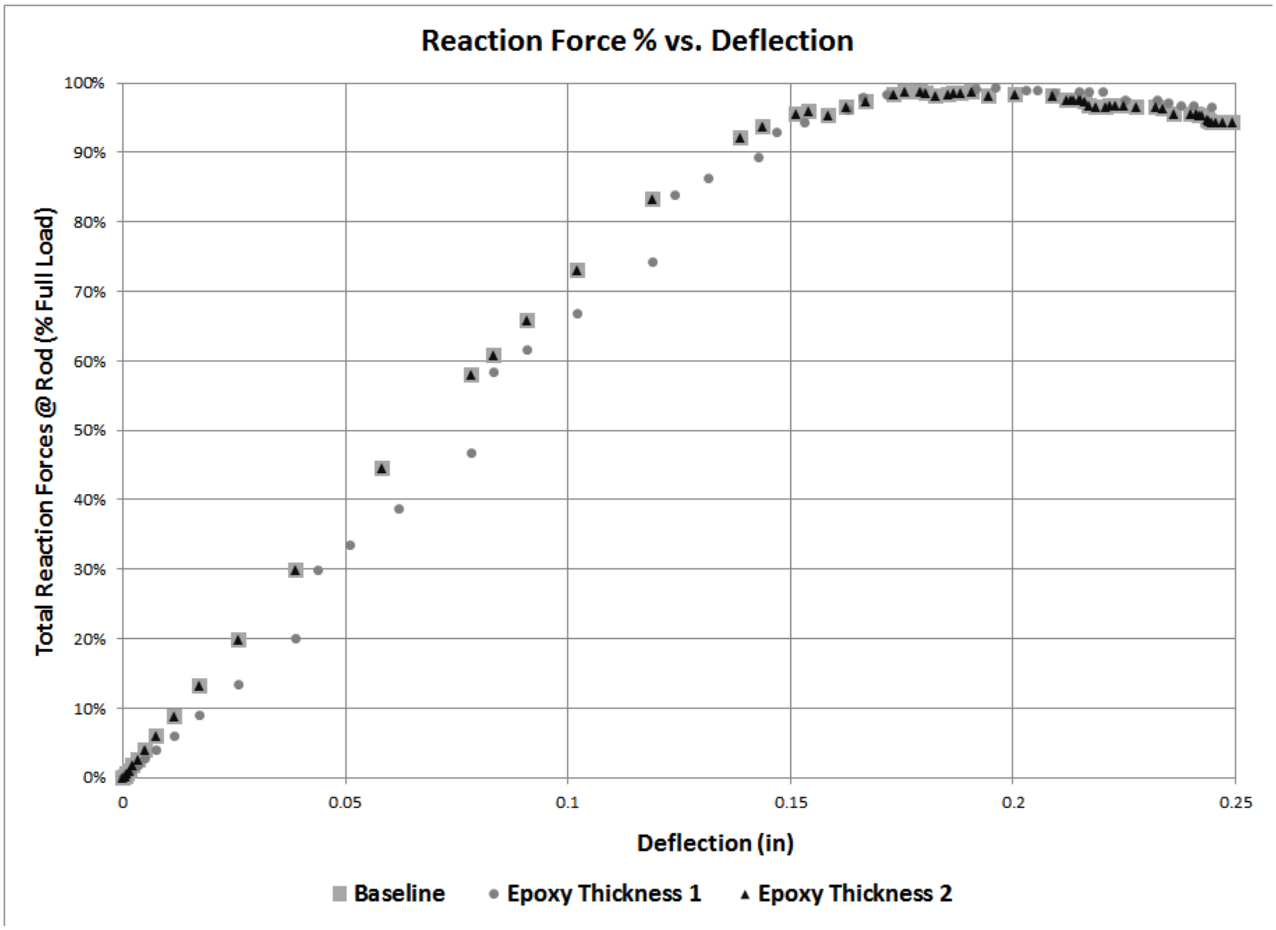

Figure 5- Results of varying epoxy thickness

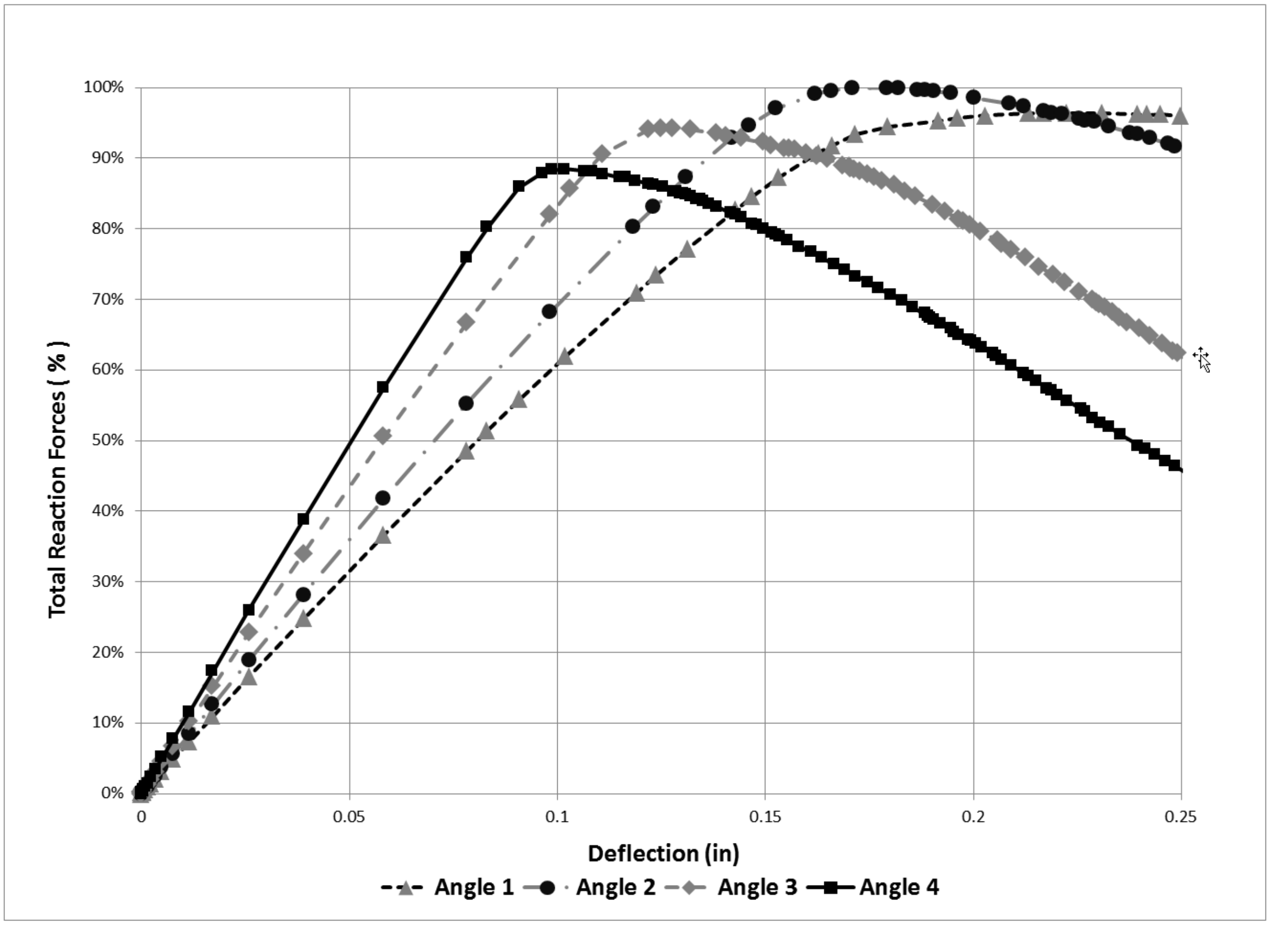

Figure 6- Effect of angle on reaction forces

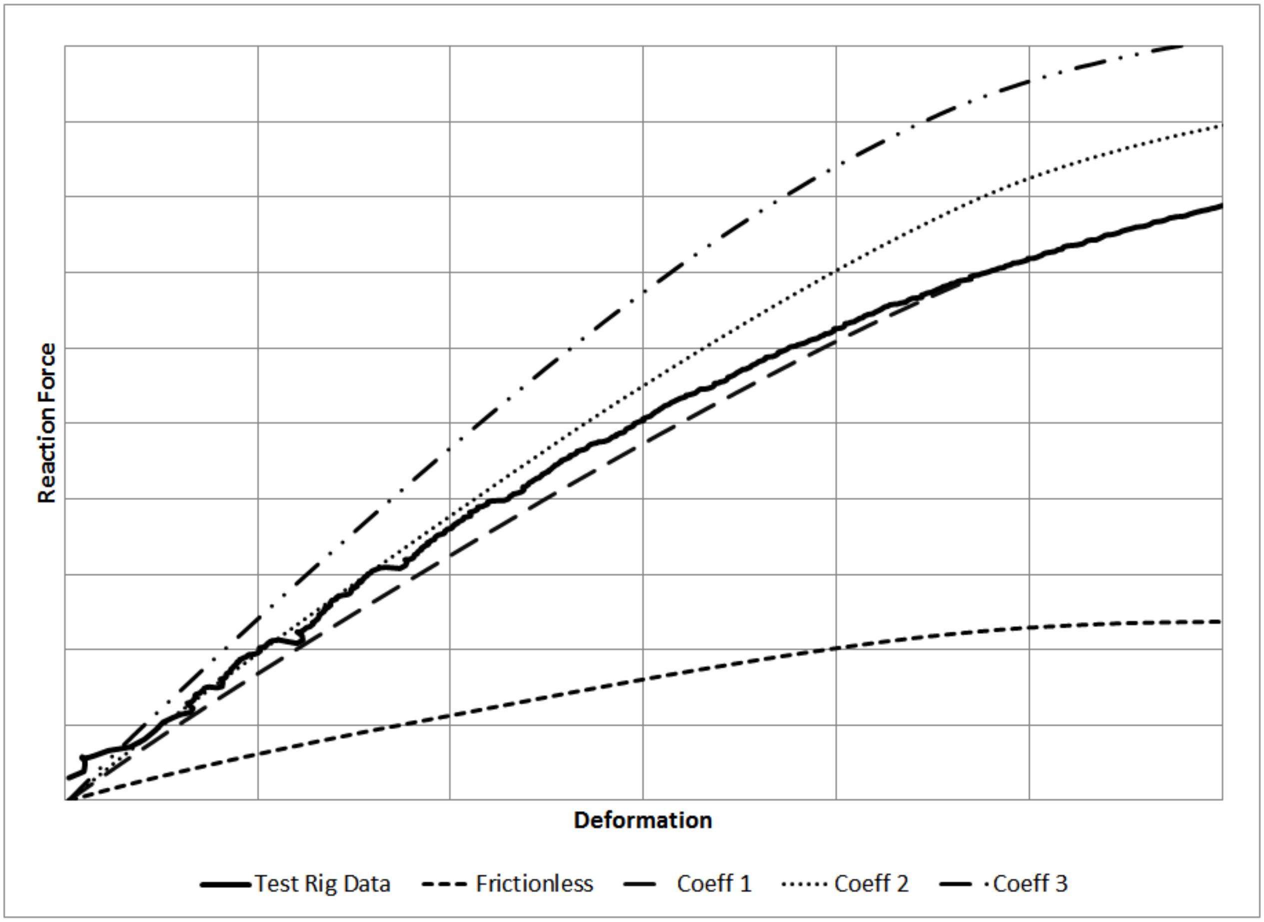

Figure 7- Correlation of FEA friction coefficient with lab data

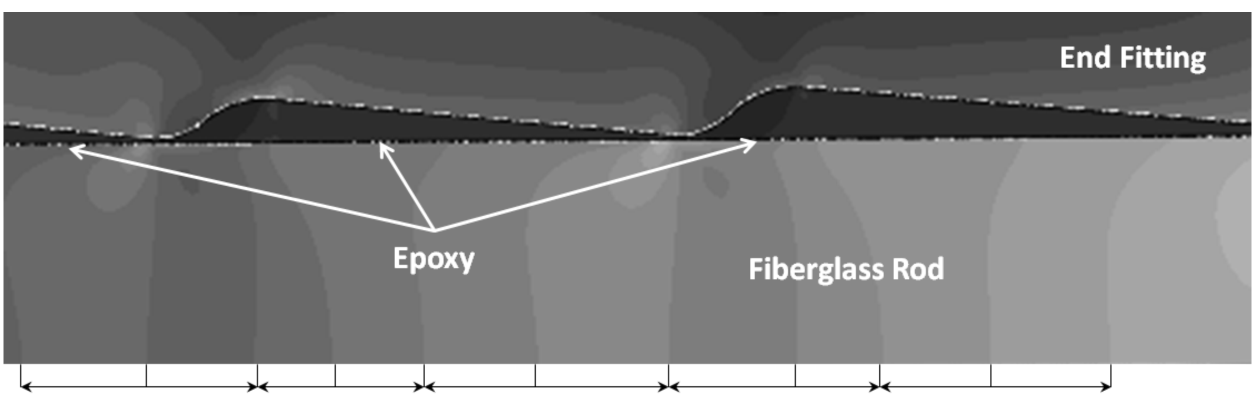

Figure 8- Final design with gradual distribution of stress

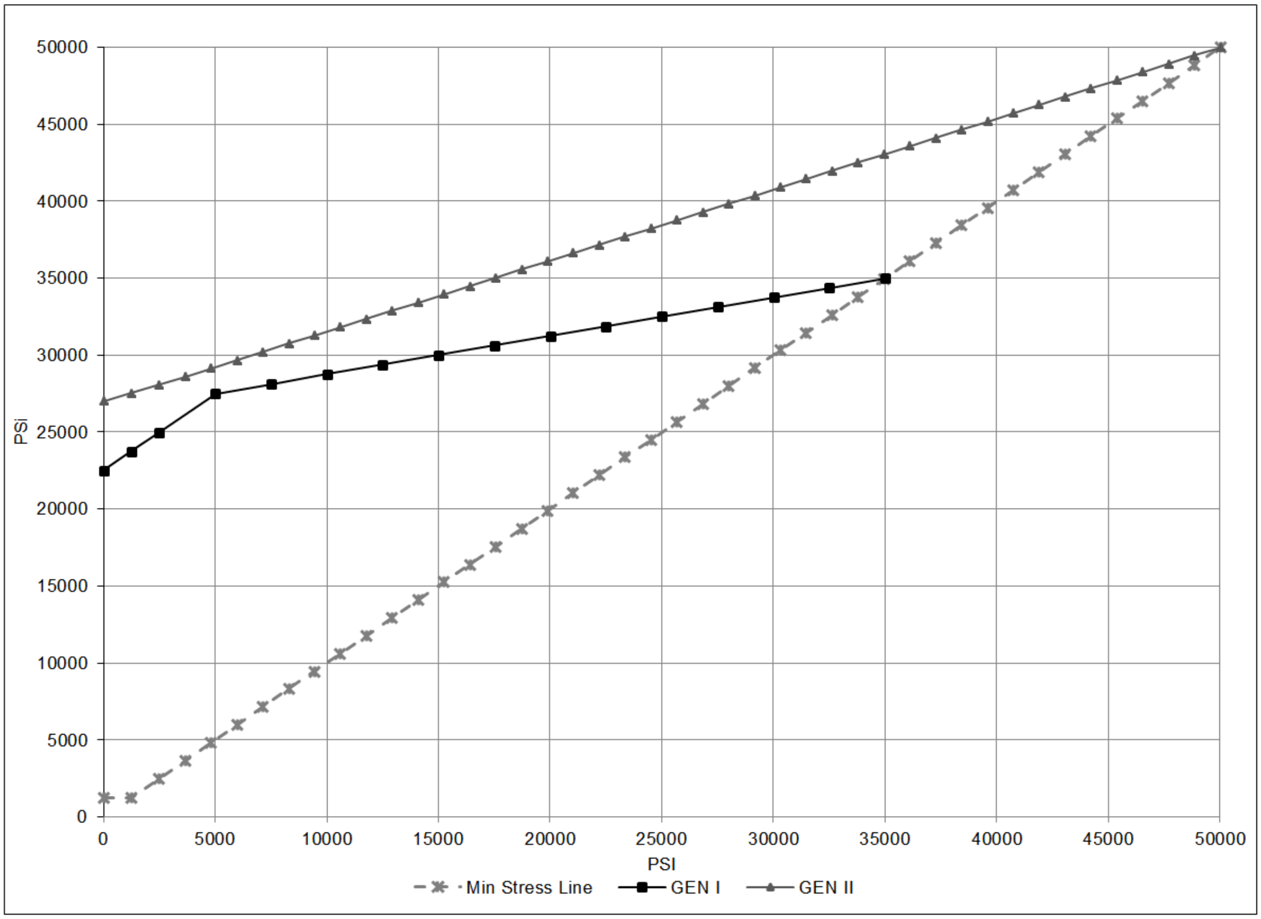

Figure 9- Stress range diagram