Modeling of Reinforced Elastomeric Hoses

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Abstract: *Reinforced hoses are used across industries, including hydraulic systems, fluid transport, and mooring systems. These systems consist of multiple layers of reinforcement, both woven and single fibers or cords, embedded in elastomeric matrices. This paper presents an example of reinforced hose simulation and discusses the challenges of embedding highly anisotropic reinforcements in a nonlinear rate-dependent elastomeric material. The discussion includes modeling the microscale interaction between individual reinforcements with a rubber matrix, particularly with respect to asymmetry between compression and tension, and small scale relaxation effects. The simulation results are compared with measurements of actual hose behavior.*

Keywords*: Elastomer, Hose, Reinforced Hose, Mooring Lines, Kevlar Reinforced, Nylon Reinforced, PolyUMod.*

1. Introduction

This project used Abaqus to simulate the deformation of a Kevlar and Nylon cord reinforced, elastomer mooring hose. The hose is used as a stretchable portion of a mooring line connecting a surface-following buoy to the ocean floor. An image of one such mooring hose is provided in Figure 1. The mooring lines are designed to stretch several hundred percent and are typically deployed with an initial tension in the hose to provide a more stable buoy position. (Irish, 2005; Paul, 2004, Paul, 2005)

The hoses have a complicated structure. Described from the center, moving radially outward, they have an inner, water-filled center, surrounded by an elastomer inner layer. Next are multiple layers of Nylon tire cord oriented at an angle designed to be initially in compression as the hose elongates, transitioning to tension as the hose lengthens. This transition from compression to tension develops from the rotation of the orientation of the cords from a circumferential to a more longitudinal direction. Continuing radially outward are more elastomers layers, which frequently contain embedded signal wires providing both power and signal transmission to sensors located lower in the mooring system. The next layers are Kevlar cord for protection from impact and shark bites. The final layer is a woven nylon fabric embedded in elastomer for abrasion resistance.

Given the complexity of the design, the hoses are constructed by hand, layering uncured strips of elastomer or elastomer with cord over a mandrel. The assembled hose is then cured in long autoclaves to fix and fuse the layers.

The combination of the multiple layers, all with different material nonlinearities and anisotropy, made design of these hoses difficult. Veryst Engineering was hired to produce a finite element model of the hose to include explicitly more material nonlinearities than was possible using the design tools previously used to construct these hoses.

Figure 1: Image of stretchable reinforced mooring line

2. Model Development and Comparison with Experiments

Figure 2 provides an overall view of the hose geometry. The ends of the hose were not modelled, as the end constructions are complicated by metal end flanges. The elastomer layers were modeled with an isotropic Bergstrom-Boyce material model with Mullins effect to account for the change in response after the first few loading cycles (Bergstrom, 2001). The model was selected from the Veryst Engineering PolyUMod library of Abaqus UMATs (Veryst Engineering, www.veryst.com). The cord reinforced layers was modeled as homogeneous using the anisotropic Bergstrom-Boyce model to account for the directional stiffness provided by the cords. At the time of the commencement of this project, the Abaqus Parallel Rheological Framework model was not available for use.

Figure 3 provides the correlation between the elastomer experimental stress/strain behavior and the Bergstrom-Boyce model. The elastomer in this case was subjected to two loading-unloading cycles in tension up to 100% true strain and at a constant strain rate. The cord material models were substantially more complex, as both the Nylon and Kevlar layers were highly anisotropic and demonstrated very different behavior in compression and tension.

The actual hose geometry was modeled as a 2D axisymmetric structure employing the Abaqus feature of “axisymmetric with twist” which permits analysis of axisymmetric structures that can rotate about the axis of symmetry (Abaqus Users Manual).

Veryst measured the stress/strain behavior of the corded materials both in multiple in-plane directions, at different strain rates, as well as in compression and tension. As expected, the materials were highly anisotropic and, given the elastomer, also rate-dependent.

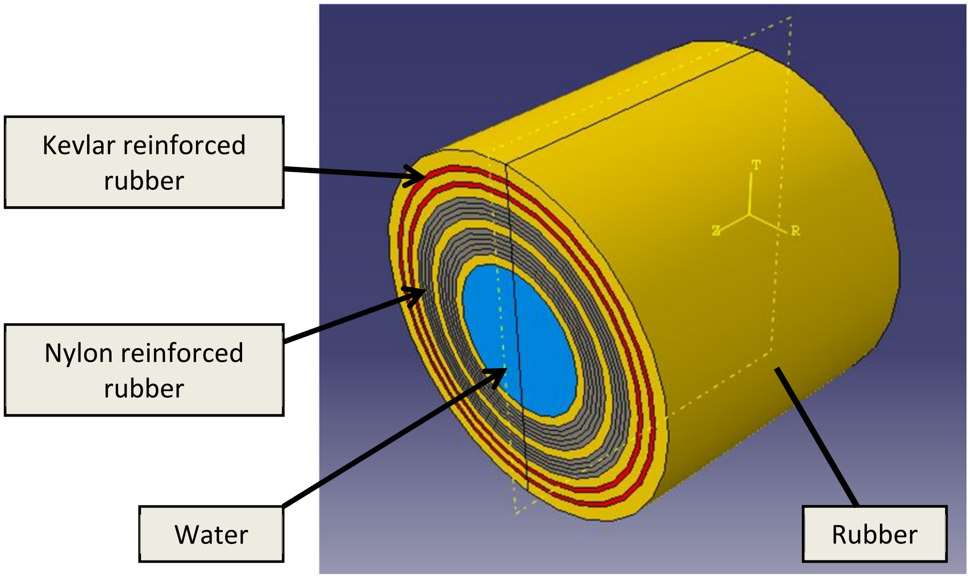

Figure 2: Overall hose geometry

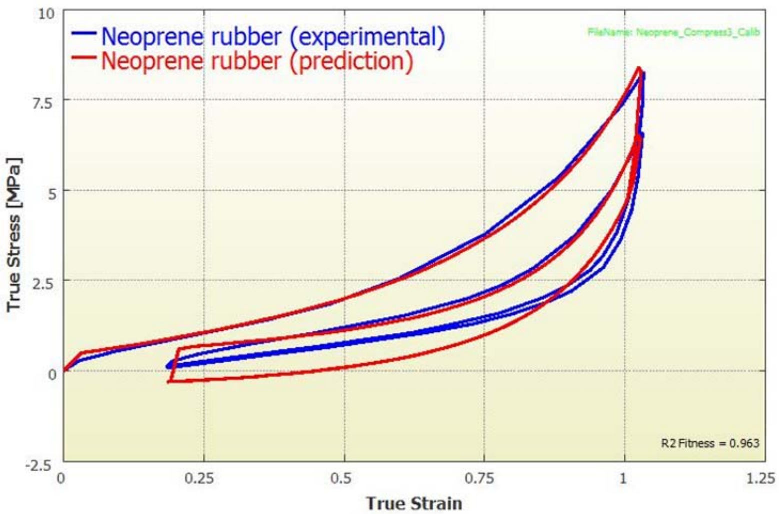

Figure 3: Comparison between elastomer experimental data and PolyUMod Bergstrom-Boyce model

Figure 4 through Figure 6 provide example behavior for the Nylon reinforced layers. Figure 4 provides the stress/strain response in the cord direction at two strain rates. Figure 5 provides similar data perpendicular to the cords, and Figure 6 provides data in compression.

Once the material nonlinearities were captured with appropriate material models, the simulation performed well relative to experimental data on the complete hose. The actual hose deflection data shown in Figure 7 indicates that the actual hose accumulated more damage than the model. This is not surprising, as one would expect the hand-assembled hose to undergo more microstructural rearrangement around the cords during stretching than the model would permit.

Figure 8 indicates the ability of the model to capture the force relaxation in the hose during a stepped stretching experiment. The Bergstrom-Boyce model represents the periods of relaxation well. This behavior was not modeled in earlier hose design efforts, as the material models were not sufficiently complex to capture this rate-dependent behavior.

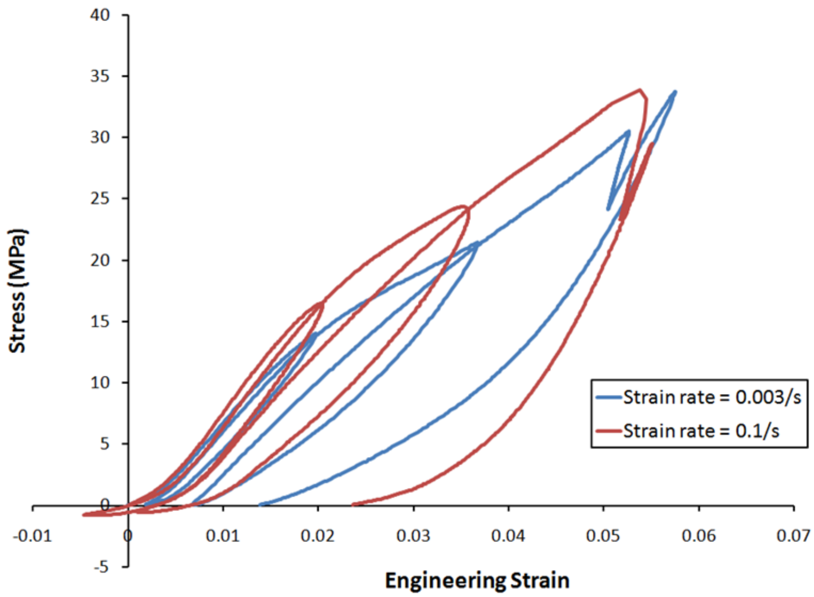

Figure 4: Material behavior of Nylon reinforced layer in direction of cords

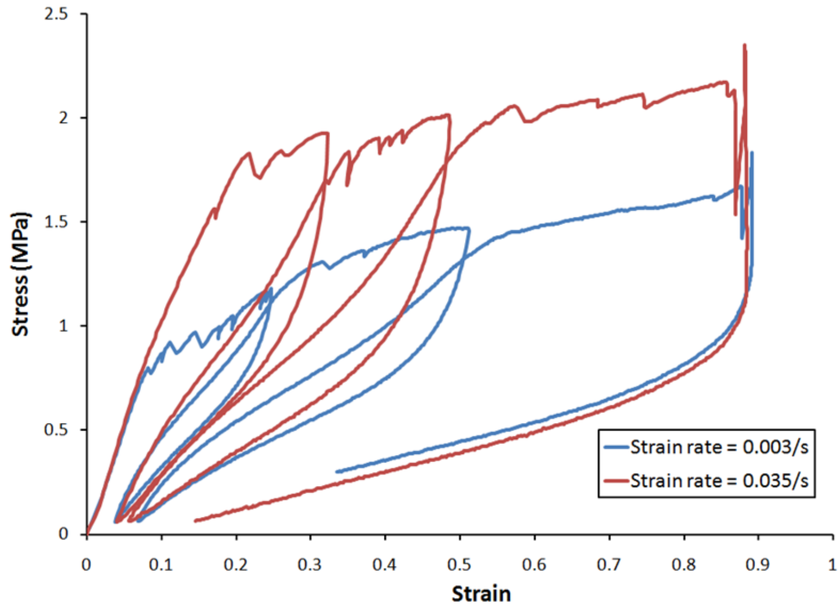

Figure 5: Material behavior of Nylon reinforced layer perpendicular to cords

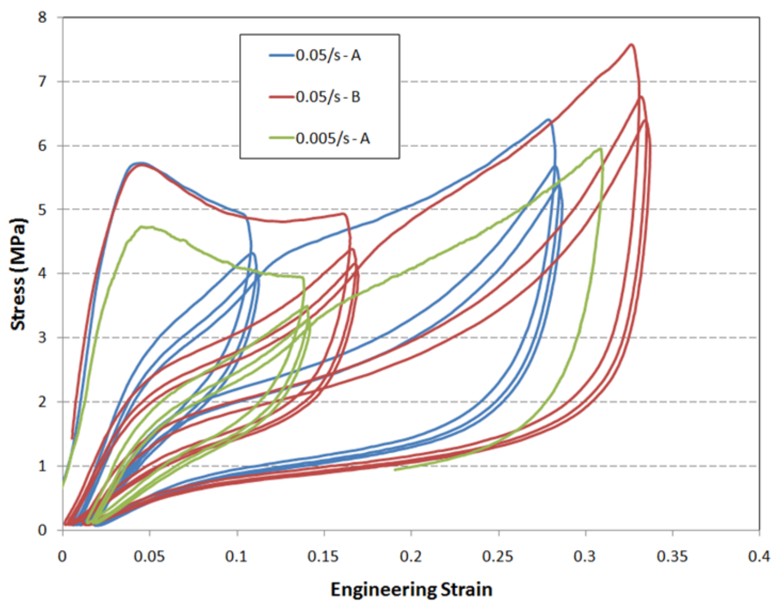

Figure 6: Compressive behavior of Nylon reinforced layer in direction of cords

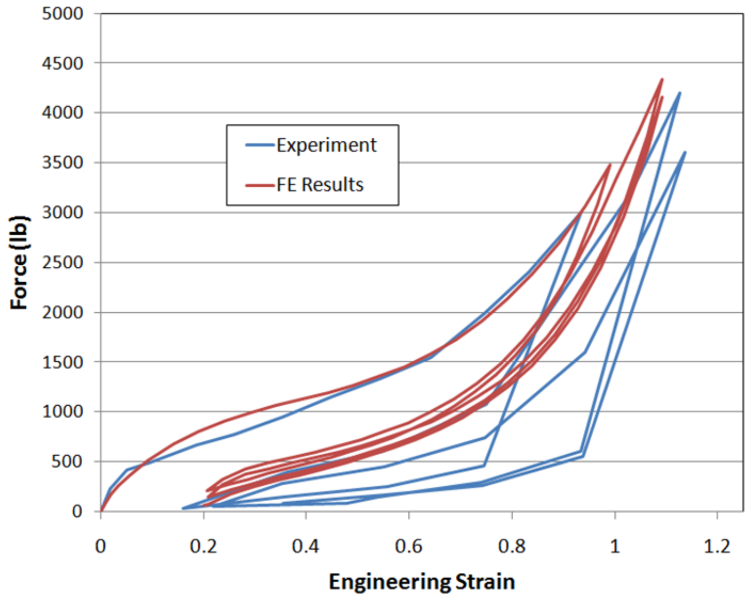

Figure 7: Comparison of hose axial force/deflection data with simulation prediction

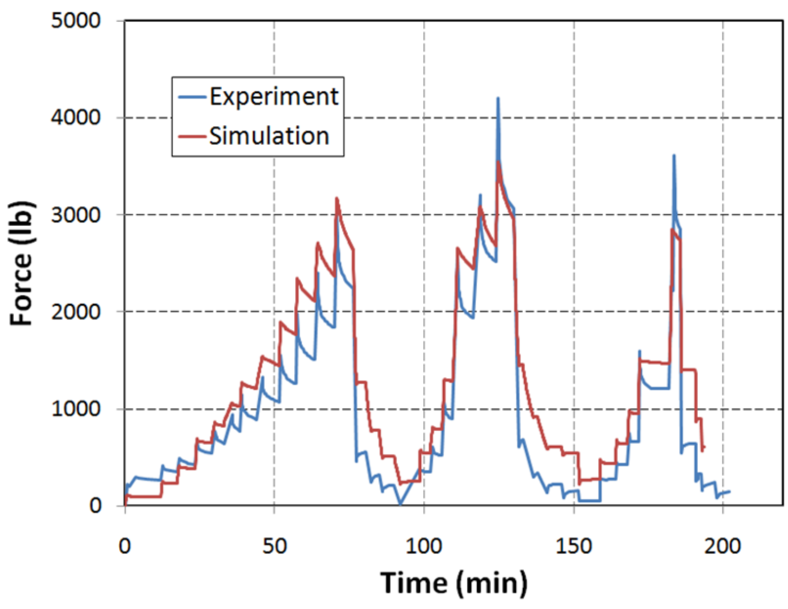

Figure 8: Prediction of force as a function of time for stepped hose stretching

3. Conclusions

It is possible to capture the highly anisotropic and nonlinear behavior reinforced hoses using appropriate material models. The axisymmetric with twist option within Abaqus provides a computationally efficient means of capturing certain material anisotropies without requiring the complexity of a full three dimensional model.

The two dimensional idealization however does not permit important deformation modes, such as buckling, ovalization of the cross section, or dynamic analysis. Ultimately a full three dimensional model is needed to accommodate all potential deformation modes within the hose.

The simulation also failed to capture certain important aspects of the hose deformation. The center of the hose is filled with water which provides hydrostatic stiffening in extension. During points of stretching the water pressure is negative, which our model does not represent. Also, as previously mentioned, the material models are not adequately capturing the material damage within the hose.

Despite these limitations, we were able to model the deformation behavior of the reinforced hose with an accuracy that considered not possible by our client. Obvious next steps to improve the uses of these simulations for design include parameterization of the geometry to explore design alternatives, implementation of a full three dimensional model, and obtaining more experimental data for both calibration and validation of the simulations.

4. References

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5. Acknowledgements

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