Finite Element Modelling and Simulation of Rubber Component in Predicting Hyperelastic material model

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Abstract – *The aim of this paper is to model the rubber component for parameter identification of different Hyperelastic models under different load conditions. Mainly three Hyperelastic models- Neo-Hooke, Mooney-Rivlin and Yeoh models are used. Simulated results are compared with the test data for calculation of error. Among three Hyperelastic models, Yeoh model seems to be best model, because of its ability to match test load- displacement data with simulated data. As rubber component is main component in the rubber bushing using at mounting places of differential and vehicle suspension, it plays an important role in performance of the vehicle. FE simulations are carried out to for comparison of Hyperelastic models to predict the behavior rubber bushing. The crack issue in the rubber bushing under load condition is to be resolved by structural optimization of rubber bushing such that, the parameter for rubber are identified by minimizing the errors between the test data and simulated data.*

Key Words: Rubber Bushing, Static analysis, Hyperelastic models, structural optimization.

1. INTRODUCTION

Rubber component in the rubber bushing is the important component used in vehicle suspension system in order improve the vehicle performance. Because of its ability to experience large deformation under small loads and retaining its initial configuration without considerable permanent deformation after load is removed[1].

The behaviour of rubber material is expressed in Strain Energy Function 'W' (SEF) in terms of strain invariants and principle stretches. The SEF in three Hyperelastic models considered in this paper is expressed in terms of strain invariants. SEF is the energy stored in material per unit of reference volume (volume in the initial configuration) as a function of strain at that point in material[2].

$$W= f (I_1,I_2,I_3) \qquad (1)$$

Where I_1, I_2 and I_3 are three strain invariants of left Cauchy deformation tensor and W is Strain Energy Function. Generally, I_3=1 for incompressible hyperelastic materials. Therefore, W depends only on invariants I_2 and I_2 as

$$W= W (I_1-3,I_2-3) \qquad (2)$$

The suitable SEF selection depends on its applications, its variables and available data for parameter identification of hyperelastic models[3].

The main qualities of efficient hyperelastic models are described by Chagnon et al.[4] as follows.

- The ability to exactly reproduce the entire 'S' shaped response of rubber component under loading conditions.
- If the model operates well in uniaxial direction, then it must also operate well with simple shear and equibiaxial extension.
- In order to decrease the number of experimental tests, the number of fitting material parameters should be small.

2. Hyperelastic Material Models in Abaqus

There are two types of hyperelastic material models are available in Abaqus and defined by different Strain Energy Function. One is the phenomenological models and other one is physically motivated models. A brief review about the hyperelastic models available in Abaqus is explained below.

2.1. Mooney-Rivlin model

This model is two parameters phenomenological model that works well for moderately large stains in uniaxial elongation and shear deformation[5,6]. But, it cannot capture the upturn (S-curvature) of the force-extension relation in uniaxial test and the force-shear displacement relation in shear test. For a compressible rubber, model has a form

$$W= C_{10}(I_1-3) + C_{01} (I_2-3) +1/D_1(J_{el}-1)^2 \qquad (3)$$

According to Bing Xu et al.[7] Mooney-Rivlin model fits well with the test data for the strain rate less than 100% for uniaxial, simple shear and equibiaxial extension. This model accommodates constant shear modulus for the given test data under moderately less strain rate.

2.2. Neo-Hookean model

This model is a special case of Mooney-Rivlin form with C_{01}= 0 and this model can be used when material data available is insufficient. It is simple to use and can make good approximation at relatively small strains. But, it too cannot capture the upturn of force- displacement curve.

$$W= C_{10}(I_1-3) +1/D_1(J_{el}-1)^2 \qquad (4)$$

According to Bing Xu et al.[7] this model fits well with the test data for the strain rate 30%-40% under uniaxial tension and up to 90% under pure shear approximately for the given rubber material behavior.

2.3. Yeoh model

This model was proposed by Yeoh in 1963. This model is phenomenological model in the form of third-order polynomial based only on first invariant I_1. Further strain invariants increase to capture the infinitesimal points. It can capture the desired upturn of force- displacement curve. It has good fit over a large strain range and can simulate various modes of deformation with limited data. This leads to reduced requirements for material testing[8]. The Yeoh model is also called the reduced polynomial model and for compressible rubber can be given as

$$W= C_{10}(I_1-3)^i +1/D_1(J_{el}-1)^{2i} \quad (5)$$

Where, exponent(i)= 1 to 3

According to Bing Xu et al.[7] this model fits well with large strain rate ranges from 200%- 300%.

3. Finite Element Model Setup

For accurate results within a given time, accurate model setup is important. There are different ways of model setup such as, considering only the rubber component for the simulations, or considering the geometric asymmetries of FE model setup. The sectional view and top view of rubber bushing is showed in figure 1 and 2.

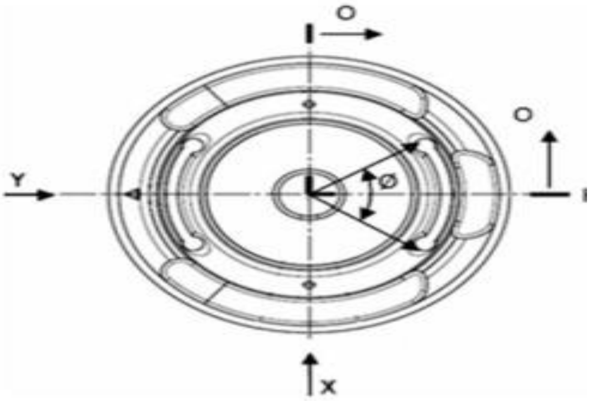

Figure 1: Top view of rubber bushing with void in the rubber component.

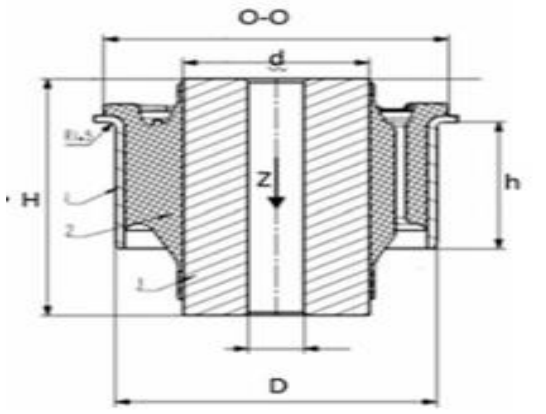

Figure 2: Sectional view of rubber bushing with void in the rubber component

Rubber bushing used in this paper consists of rubber component which is hyperelastic in nature covered with inner and outer steel tube. This bushing is modeled using C3D4H element for rubber component as its behavior is highly non-linear and C3D10 element type for inner and outer steel tube. The mesh size of the rubber component is maintained between 1.7mm to 2mm after convergence study on this model. The FE model is showed in figure 3 as,

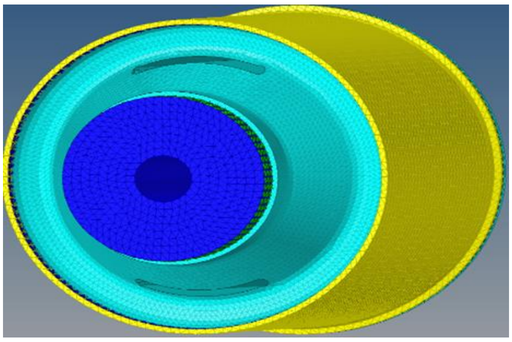

Figure 3: Finite Element model of rubber bushing with void along radial direction.

The outer steel tube of rubber bushing is fixed in all the direction (translational and rotational) and load is applied along inner steel tube in order to capture the stiffness and the stress distribution along the rubber component.

3.1 Convergence Study

Convergence study becomes a very important role before starting an analysis on the rubber bushing in order to know the type of element to be used for the rubber component and several considerations. Some of the main considerations in this study is element size, element type and type of loading. In this study load conditions are axial, radial solid and radial void. The nonlinear behavior occurs when one surface of rubber component comes in contact with other rubber surface between void space showed in figure 4.

4. Results and Discussions

The results presented were obtained from the static analysis on the rubber bushing. The material identification is done for three hyperelastic models under radial void load condition. The test data for the radial load case is showed in figure 4 in terms of force-displacement curve, where the plot is linear until one surface of the rubber component comes in contact with the other surface of the rubber component.

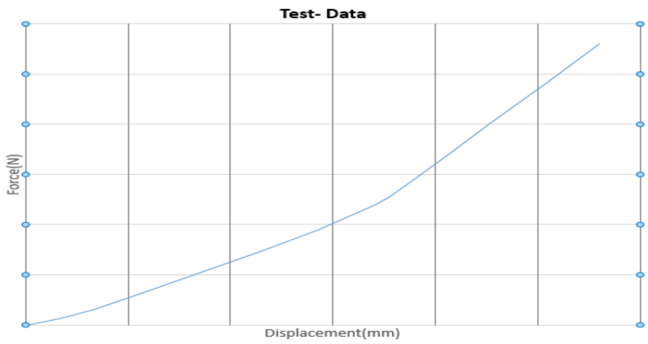

Figure 4: Stiffness Characteristics for test model under Radial Void Load Condition.

The parameter identification starts using Neo-Hookean model. The incompressiblity constant remains constant for all the models so that the bulk modulus of rubber componen remains constant. In order to determine the parameters, tuning is to be done. Tuning of parameters starts with Neo-Hookean model as the number of parameters required is less. From the figure 5, as the shear constant C10 increases, the stiffness also increases and after some point no changes occures as the number of parameters required is less. But after the simulation found that this model wont fit well with the test plot as the starin rate is high enough that Neo-Hookean model becomes inadequate.

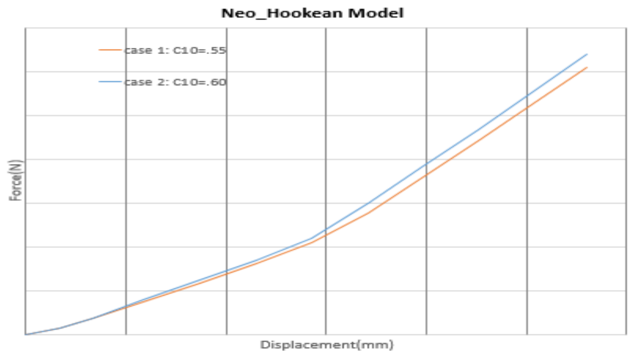

Figure 5: Parameter tuning for Neo-Hookean Model

Figure 6: Parameter tuning for Mooney-Rivlin Model

When Neo-Hookean Model becomes inadequate at certain strain range, Mooney-Rivlin model overcomes the problem occurs in basic model. But this model also fails to captured upturns after certain strain rate. Tuning of M-R model is showed in figure 6, as increase inn material constant, the stiffness of rubber component also increases.

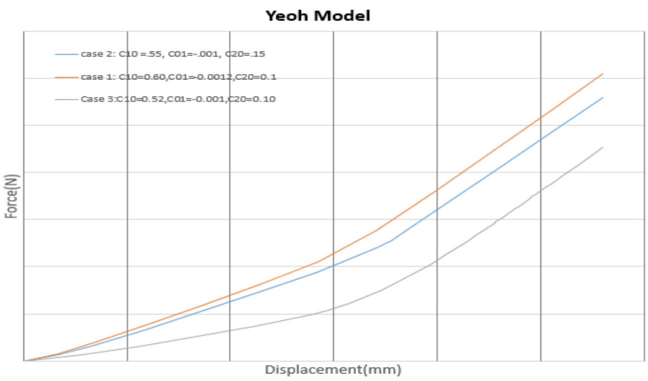

Figure 7: Parameter tuning for Yeoh Model

After a certain tuning, both Neo-Hookean and Mooney-Rivlin model becomes inadequate as it fails to capture upturns in force-displacement curve.

Yeoh model overcomes the problem of these models as it can capture the upturns accurately for the strain rate ranges between 200%-300%. From the figure 7 shows, parameter identification can be done accurately for high strain rate. When simulated data compared with the test data, it is found that Yeoh model fits closely with the test data with minimum percentage of error than the other models.

5. CONCLUSION

In this work, static analysis is done for rubber bushing under radial void load conditions in Abaqus for parameter identification and curve fitting for the given rubber component behaviour. Trial and error method is used for tuning the parameters. Taguchi Design Method can be employed if the rubber component faces crack issues at the critical locations. Among the number of models available in literature and implemented into commercial FE codes, Yeoh model was found to be the most suitable choice. For both deformation types such as simple shear and equibiaxial extension, the Yeoh model gives a stable analytical description of the material stress–strain response and a good agreement between numerical and experimental data, even at large values of strains.

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