High Fidelity Numerical Simulation of Non-Pneumatic Tire

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Abstract

This study is focused on, developing a high fidelity three dimensional (3D) finite element model of solid resilient tire for the static numerical simulation. To develop the model and describe the mechanical behavior of filled vulcanized rubber in the tire a suitable hyper-elastic material model is required. The best fitted hyper-elastic material model is obtained by using curve fitting approach. Numerical and laboratory experimental data are compared together to validate the developed model. The validation results show that the minimum values of the three measures (MAPE, MAD, and MSD) of accuracy obtained from best fitted numerical model with experimental model deviation values are very smaller and less than permissible limits (5%). Further, stress distribution in tire reinforcements are investigated using numerical model. Moreover, this study can be further extended to investigate the dynamic behavior of the solid tire.

Keywords: High Fidelity Static Simulation, Hyper-Elastic Material Models, Non – Linear Finite Element Simulation, Solid Tires.

1. Introduction

Solid tires more popular in heavy duty vehicles due to its ability to operate in harsh environments with bearing excessive loads. In the solid tire, base section, cushion section and tread section are the main three rubber sections. Moreover, few bead bundles (reinforcements) are embedded into the base layer as the structural reinforcements. These three rubber sections are made by using three different rubber compounds and properties are different to each other. The reinforcements with base can define as foundation of the tire. It gives better contact with tire and rim while aids to sustain under heavy loads. Arise heat is mainly dissipated through the cushion. Tread section controls the rolling resistance, traction, tire service life and its durability.

Mostly, the analysis of these tires are often done in industry using laboratory experimental methods. These methods are time consuming, costly and usually do not help to explain the mechanical behavior and tire attributes properly.

In the literature, the majority of FE studies on the tires have been conducted for pneumatic tires (Marais, 2018; Hofstetter *et al.*, 2006; Cho *et al.*, 2004; Lin, 2004). For solid tires, Suripa (2008), developed a general FE model to study distribution of strain energy density and deflection of a solid tire under different loading conditions. Moreover, Phromjan (2018), developed 3D FE tire model to analyze the tire behavior on static conditions. Here, tread section was modeled using tetrahedral elements while the other sections of the tire were modeled using hexahedron elements. Dechwayukul *et al.* (2010), proposed an experimental method to evaluate tire service life, life time of the tire at different loading conditions and speeds of selected industrial solid tires. Further, Rukkur *et al.* (2013), conducted a laboratory experimental study to improve and reduce heat buildup at the tread layer of a solid

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industrial tire. Moreover, to acquire more realistic tire analysis results it is necessity to having a detailed tire model which includes all tire elements (Cho *et al.*, 2004; Cho *et al.*, 2006). Considering these factors, the main focus of this study is to develop high fidelity Finite Element (FE) model for a solid resilient tire to analyze its static conditions with numerical simulation.

2. Methodology

This study is focused on learning the importance of driving simulator tire static model and a mathematical representation of solid tires in three dimensions (3D). Figure 1 shows the flow diagram of the methodology of this study which is used to develop a suitable numerical simulation model for solid tires.

The 3D hexahedron (brick) element type has been used to model all sections in the solid tire. To develop the FE model, the required best fitted constitutive model/s and material properties of the rubber and other reinforcements of the tire are gathered through conducting relevant laboratory experiments. Here, the Yeoh hyper-elastic material model is selected to describe the mechanical behavior of the filled rubber. Moreover, the properly validated FE model is then used to analyze the static behavior of an actual solid tire under different load conditions.

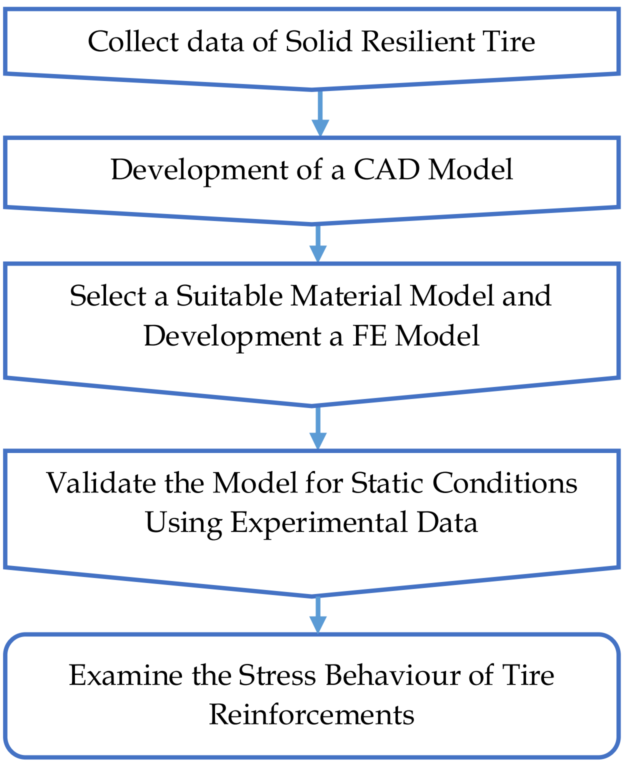


Figure 1: Flow Chart of the Methodology

3. Validation of the FE Model

Figure 2 and Figure 3 present, that the numerical simulation results of the tire vertical and horizontal deflections are in good agreement with the physical experiments conducted in this study. Statistical analysis has been used to compare and select the best fit FE model with physical experimental data. Table 1 shows the minimum values of the three measures (MAPE, MAD, and MSD) of accuracy obtained from best fitted numerical model with experimental model. Since, all three measures values are very smaller and less than the permissible limits (5%), it can be concluded that the model is on acceptable level of the validation process.

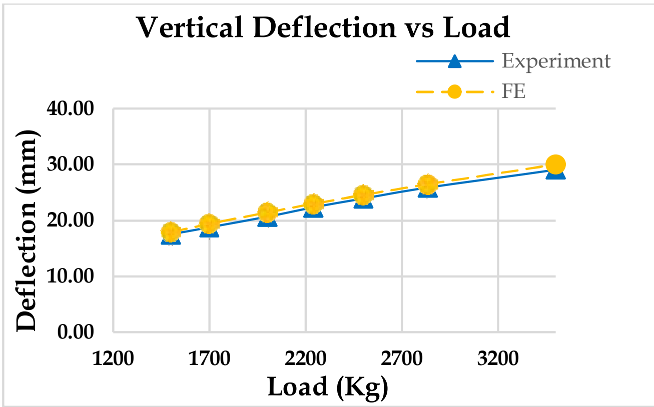


Figure 2: Tire Vertical Deflections

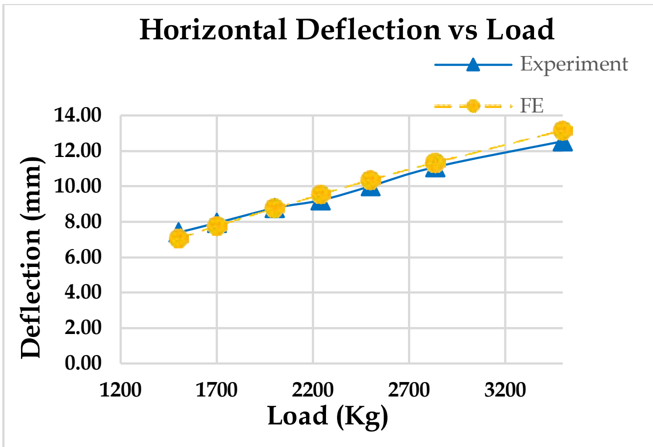


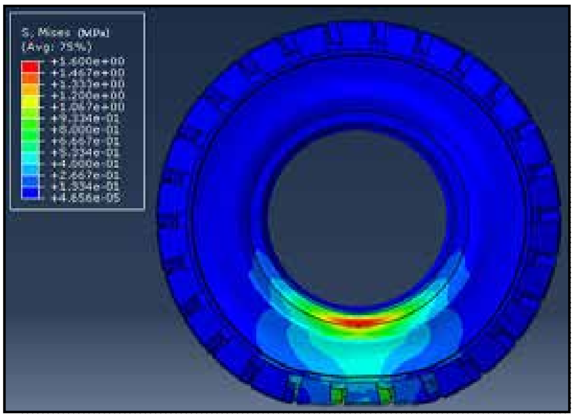
Figure 3: Tire Horizontal Deflections

Table 1: Measures of Accuracy

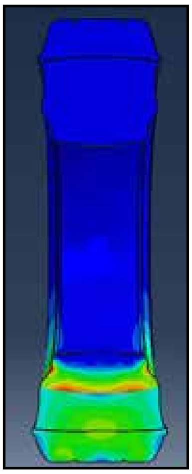
ERROR	MAPE (Mean Absolute Percentage Error)	MAD (Mean Absolute Deviation)	MSD (Mean Squared Deviation)
Vertical	2.91	0.66	0.46
Horizontal	3.00	0.29	0.12

4. Results and Discussion

Figure 4 shows the solid tire 3D FE model and Max Von Mises stress distribution of the developed 3D FE model using *ABAQUS CAE* application. Based on the results the high stresses accumulate in the region of base. This may leads to occur the issues on gripping contacts with tire rim when it reaches to its maximum bearing load capacity. Figure 5 presents the numerical simulation view of stress distribution in reinforcements. In addition, Figure 6 represents, that the stress in reinforcements increase when the applied load on the tire increase.



(a)



(b)

Figure 4: Max Von Mises Stress Distribution in Rubber Components of Deformed Tire Model (Load: 2240 kg): (a) Tire Side View, (b) Tire Profile View

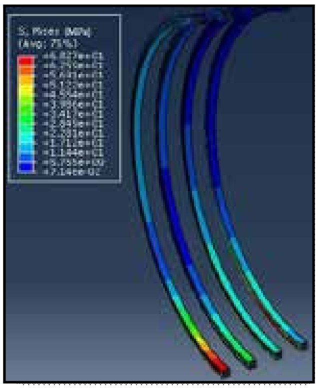


Figure 5: Max Von Mises Stress distribution in reinforcements of deformed tire model (load: 2240 kg)

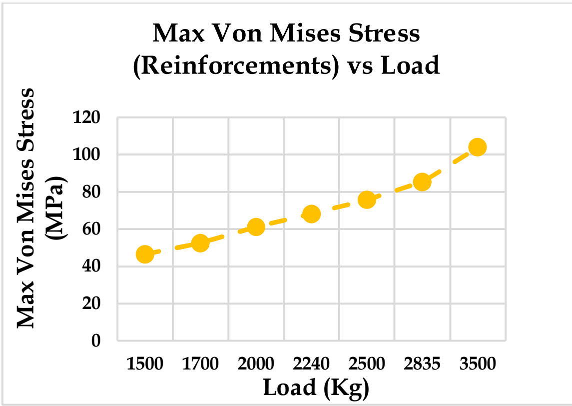


Figure 6: Numerical Values of Max Von Mises Stress Distribution in Reinforcements

5. Conclusion

The study presents the usage of modeling and static analyzing techniques of FE method on solid resilient tire. In the study the validated model is used to analyze the vertical and horizontal deflections of solid tire under different loads. In addition, Max Von Mises stress in reinforcements are obtained through the model. Here, localized high stresses are mainly distributed in base section and reinforcements. In addition, asymmetrical stress distribution in the reinforcements are observed. Further, such observations can be effectively identified using FE simulation and it can be used to optimize the tire design.

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