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Numerical evaluation of the temperature field of steady-state rolling tires

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ABSTRACT

Rubber is the main component of pneumatic tires. The tire heating is caused by the hysteresis effects due to the deformation of the rubber during operation. Tire temperatures can depend on many factors, including tire geometry, inflation pressure, vehicle load and speed, road type and temperature and environmental conditions. The focus of this study is to develop a finite element approach to computationally evaluate the temperature field of a steady-state rolling tire. For simplicity, the tire is assumed to be composed of rubber and body-ply. The nonlinear mechanical behavior of the rubber is characterized by a Mooney–Rivlin model while the body-ply is assumed to be linear elastic material. The coupled effects of the inflation pressure and vehicle loading are investigated. The influences of body-ply stiffness are studied as well. The simulation results show that loading is the main factor to determine the temperature field. The stiffer body-ply causes less deformation of rubber and consequently decreases the temperature.

1. Introduction

Rubber is the major element of pneumatic tires. Rubber is a viscoelastic material and as such it shows hysteresis during cyclic loading, i.e., less energy is given back during unloading than it was received during loading, the missing energy being dissipated as heat. The effect is more pronounced when the loading/unloading is done quickly, as in a high speed rolling tire. The reliable prediction of the temperature distribution due to the heat generated by the hysteresis of rubber is crucial in order to accurately estimate the material damage in the tire and vehicle fuel consumption due to tire hysteresis losses. Another main component of tires is the body-ply embedded in the rubber which prevents excessive deformation of the tire. The body-ply maintains the shape of the inflated tire. Its stiffness has definitely strong influence on the tire heating.

Tire heating and temperature distribution have been studied for several decades because of the complexity of the problem. Experimental methods required to determine the tire temperature fields are costly and time consuming. Furthermore, it is not practical to experimentally determine the temperature distribution throughout the tire section. As such the imperative need for better understanding of tire heating phenomena strongly motivates the development of computational methods to rapidly and confidently analyze the tire temperature field. Due to its accuracy and geometrical flexibility, the finite element method (FEM) has been widely used in conjunction with experimental methods for predicting the temperature distribution within tires [1–10]. Most of the models solved the coupled thermo-mechanical problem in an iterative manner, including three common important modules: deformation, dissipation, and thermal modules. The model can either be coupled or uncoupled with respect to temperature. A coupled model calculates the heat transfer from the deformation and dissipation

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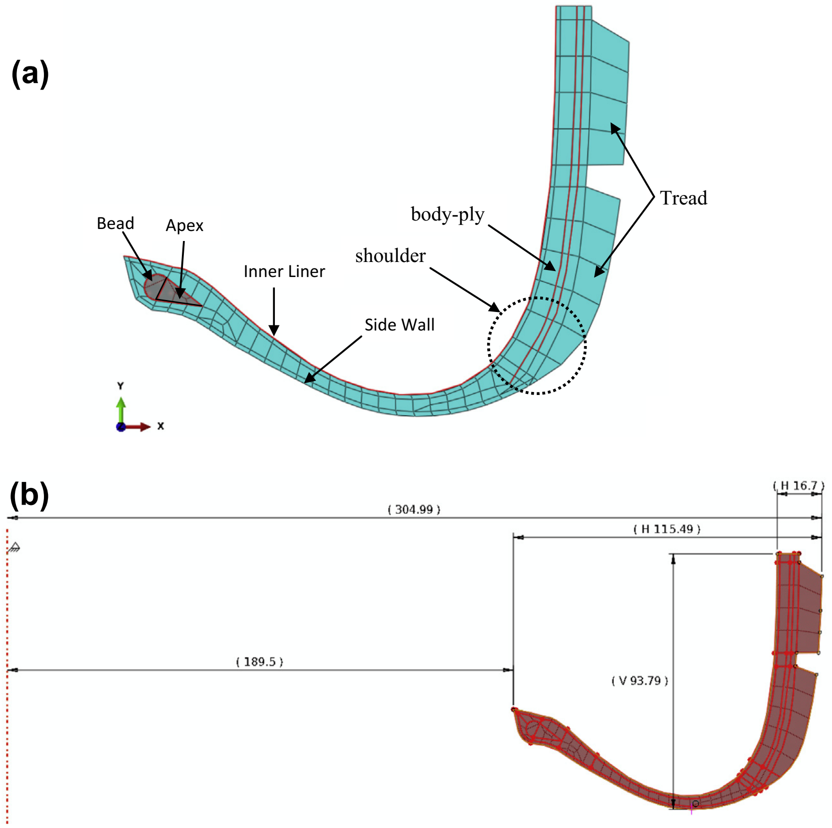

Fig. 1. The axi-symmetric cross-section of an inflated tire (185/60 R15): (a) components of tire. The area within dashed circle refers to the shoulder; (b) Tire size, unit (mm).

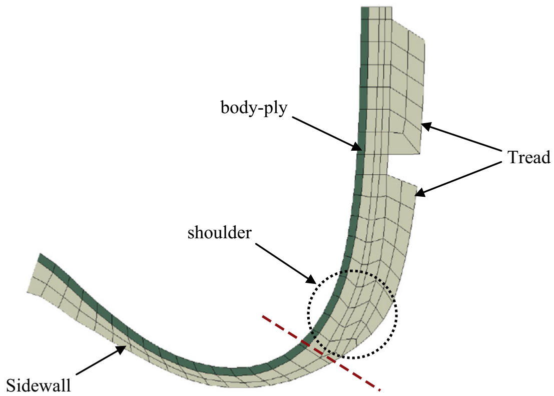

Fig. 2. The axi-symmetric cross-section of tire (185/60 R15) geometry and meshing used in this study. For simplicity, the tire is assumed to be composed of body-ply, tread, and sidewall. The red dashed line is the demarcation between the tread and sidewall. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

modules. The new temperatures from the thermal module are used to update the material properties in the deformation and dissipation modules. The model is run until the temperatures converge. In an uncoupled model the material properties are assumed to be independent of temperature [1]. Past research has often used the three module thermo-mechanical model in various ways to predict tire temperature distributions. Differences between previous works include the material models used in the deformation module, the calculation of the energy dissipation rate from the dissipation module, and the inputs and boundary conditions of the thermal module.

In the deformation module, different material models were used to calculate the stress and strain for different tire loading conditions, such as Mooney–Rivlin model [2], Yeoh model [3], etc. The results can be validated by comparing the modeling