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Finite Element Modelling of Tire Pavement Interaction on Micromechanical Pavement Surface

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Abstract - This study presents finite element (FE) modelling of tire pavement interaction based on a micromechanical pavement surface. The FE model of the pavement surface is created using CT scan images of an actual pavement specimen to accurately represent the micromechanical surface morphology of the pavement. The micromechanical FE model of the pavement consists of aggregate, binder, and air voids. Using the micromechanical pavement model, tire pavement interaction simulations are performed using ABAQUS by setting binder and rubber as viscoelastic materials and aggregate as an elastic material. Moreover, the FE model includes layers of asphalt, base course, and subgrade to mimic a real pavement. The interaction between tire and the pavement surface is modelled via the surface-to-surface contact.

***Keywords*:** Tire pavement contact, pavement surface texture, viscoelastic, asphalt pavement

1. Introduction

The accurate and efficient modelling of tire pavement interaction is considered a challenging task, arising from the complex dynamics that characterize the interaction between tire and pavement. The complexity is evident in the non-linear characteristics of the materials, intricate contact interactions, significant deformation of the tread, and irregularities in the pavement surface. Numerical modelling, specifically FE modelling, has been recognized for its successful modelling of complex problems such as tire pavement interaction. Modelling tires for the FE simulations has evolved through four stages: static load, uniformly moving load step, 2D tire model [1], and 3D tire model [2]. However, the first three models inadequately capture the intricate tire structure and non-linear tire pavement interactions. With increased computational speed and FE software development, 3D tire modelling is widely employed for comprehensive simulation and analysis.

Pavement texture modelling involves different methods. Past studies characterized pavement as flat or textured. Although more expensive, textured surfaces are more realistic for assessing pavement macrotexture effects on tire pavement interactions. In one study, FE texture reconstruction was employed to evaluate how macrotexture affects skid resistance and braking distance [3]. In another study, researchers investigated the measurement of pavement texture and interior structure using laser scanning and X-ray computed tomography [4]. While others utilized grayscale CT scan images for FE simulation and reconstitution of distinct pavement kinds under varied mix patterns, other research used detailed texture data to create a pavement surface model [5]. A FE model examined skid resistance by utilizing grooved surface pavement [6]. Another study examined the structural behavior of layered inelastic pavement using a FE based model that simulates the interaction between the tire and the pavement [7]. Many techniques approximate the pavement model as a rigid flat plate, disregarding pavement surface characteristics and pavement viscoelasticity. On the other hand, the models that considered pavement surface roughness simplified the accurate representation of pavement microtexture and modelled pavement as a single material. Furthermore, some research that used complex constitutive models for pavement materials oversimplified tire loading by expressing it as a uniformly distributed pressure over a specific area, which does not adequately reflect the distribution of tire load. [8].

The primary objective of this study is to utilize FE modelling at the microscale level to analyse the interaction between tire and pavement. The model specifically represents the pavement as a material with distinct phases, including air voids, aggregate, and binder. And it considers the viscoelastic properties of the material. The FE model of the pavement surface accurately represents the physical composition of the pavement, facilitating a more sophisticated analysis of the interaction. Furthermore, it considers the precise representation of the tire, where the rubber material is described by viscoelasticity.

2. Methodology

For FE modelling, the micromechanical pavement surface is generated using a CT scan of an actual pavement specimen composed of aggregate, binder, and air voids, as illustrated in Figure 1. In this study, aggregate and binder are modelled as elastic and viscoelastic materials, respectively. Pavement is discretized using four node tetrahedral elements (C3D4).

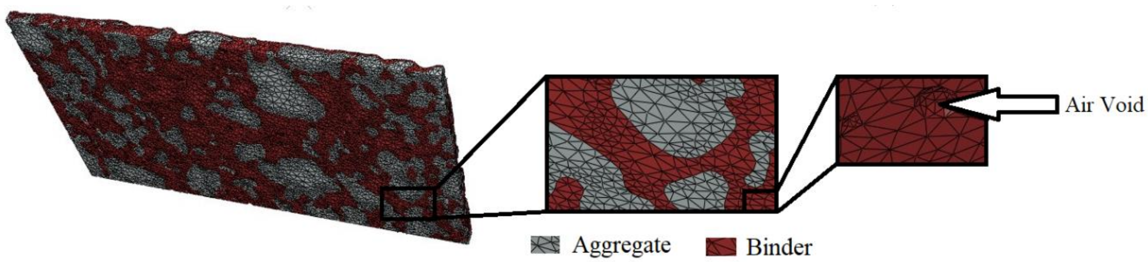

Fig. 1: FE mesh model for asphalt

The viscoelastic properties of rubber are described using a generalized Maxwell model. The tire model is constructed according to the procedures outlined in the ABAQUS manual [9], as shown in Figure 2a, which details the technique for tire modelling. Initially, a 2D axisymmetric tire is created where tire structural components are embedded in the rubber body. Subsequently, this 2D model is rotated about its axis, resulting in a half (partial) 3D tire, and then it is reflected to form a full 3D tire. The resulting tire rubber element type is an eight-node linear brick element (C3D8).

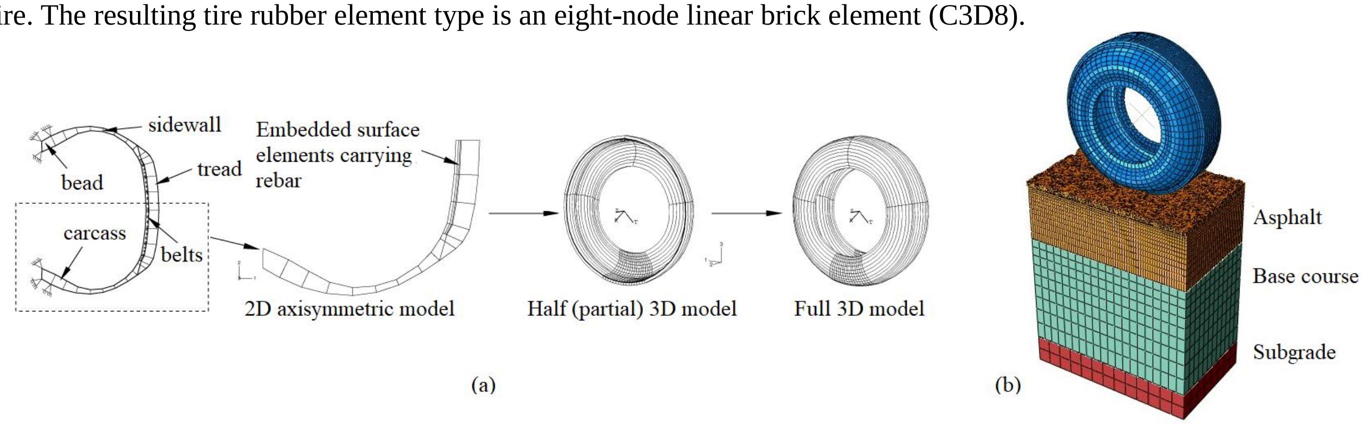

Fig. 2: (a) Tire modelling steps [9] (b) Tire pavement interaction model

An additional layer of asphalt, characterized as a viscoelastic material, is added beneath the micromechanical asphalt surface. In addition, extra layers consisting of base course and subgrade have been added with C3D8 elements for asphalt and base coarse and eight-node linear one-way infinite element (CIN3D8) elements for subgrade to imitate infinite-depth features, as shown in Figure 2b. The base coarse and subgrade layers are modelled as elastic materials. Table 1 provides a summary of material properties.

The "tie constraint" algorithm is used to connect the pavement layers. The general contact method, employing the surface-to-surface contact algorithm, is used to model the contact between the tire rubber and the pavement surface. The 3D tire is first inflated by applying internal pressure. Once inflated, it contacts the pavement and is subjected to a vertical load.

Table 1: Summary of material properties.

Material	Type of material	Modulus of elasticity (MPa)	Density (kg/m3)	Poisson’s ratio
Rubber	Viscoelastic	-	1200	0.45
Aggregate	Elastic	40000	2000	0.32
Binder/ Asphalt Layer	Viscoelastic	-	2300	0.35
Base course	Elastic	400	2400	0.15
Subgrade	Elastic	150	2350	0.33

3. Results and discussion

Using the described model, it is possible to obtain different outcomes, such as the deformation, contact stresses, and Von Mises stresses of both the tire and the pavement. In Figure 3, the pavement deformation spreads to the layers beneath it, with the most significant deformation occurring exactly where the largest stresses are located, as shown in Figure 4.

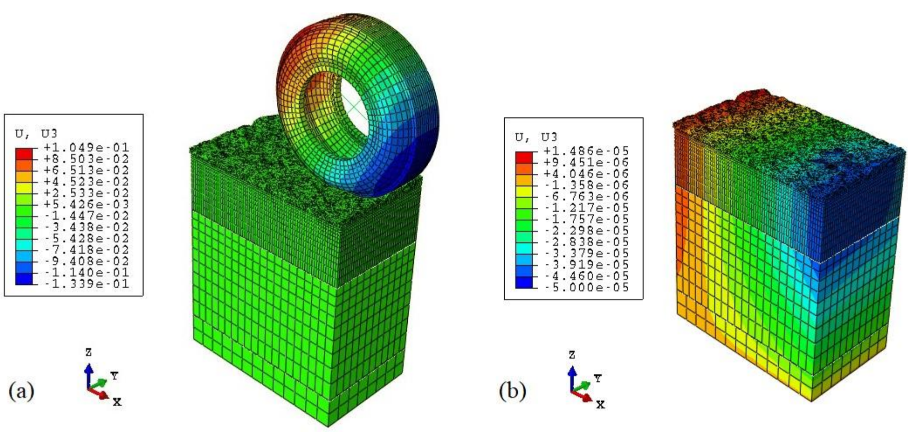

Fig. 3: (a) Deformation in pavement and tire (b) deformation in pavement

The deformation direction indicates that there is compression occurring beneath the tire and tension in the area further away from the tire. This is consistent with observation in the field that when a weight is exerted on pavement, it tends to exhibit an upward concave shape. Examining the contour plot of pavement deformation assists in determining the precise depth at which the highest level of deformation takes place.

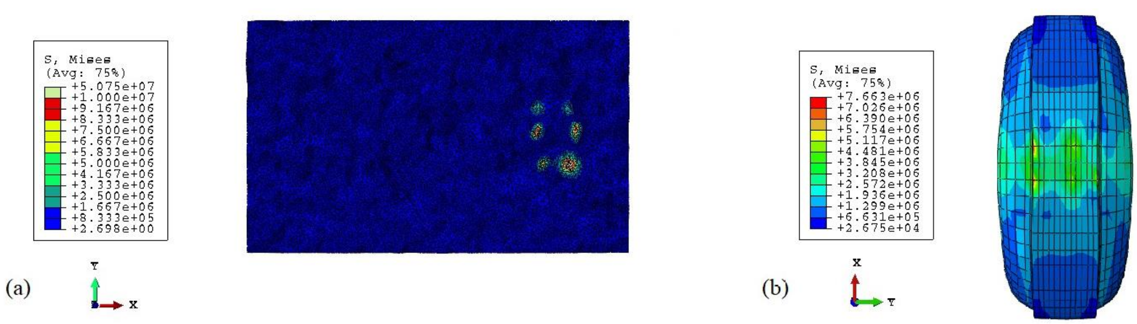

Fig. 4: (a) Von Mises stress at asphalt surface (b) Von Mises stress in tire

Figure 4 illustrates Von Mises stresses for both the tire and pavement. The locations with greater surface roughness clearly exhibit the greatest stress levels. These graphs can be used to determine the relationship between inflation pressure, tire load, and Von Mises stress, which subsequently affects skid resistance. Furthermore, this model can yield various outcomes, such as contact stress, strains, energy loss resulting from hysteresis, and rolling resistance. It can be utilized to simulate the impact of using different materials and various tire operating conditions.

The tire model was validated using vertical static load deflection tests that were performed in the lab [10]. Aspect ratio values of footprints were measured and compared with FE values. Nevertheless, it is recommended to do a vertical static load test on a real asphalt pavement structure to validate the footprint results on a rough asphalt pavement.

4. Conclusion

This work describes the realistic FE modelling of the interaction between tire and pavement, specifically focusing on the micromechanical aspects of the pavement. The FE modelling presented sheds light on the interactions between tire and pavement by providing predictions for deformation and stresses in both tire and pavement. Practical observations of pavement behavior under load are consistent with the observed pavement deformation, which indicates compression beneath tire and tension farther away. The model makes it possible to pinpoint the exact depth at which the greatest deformation occurs, which has beneficial implications for pavement repair and design. Furthermore, the results imply that regions with higher surface roughness undergo higher stress levels. The model is a useful tool for researching the impacts of various materials, and tire operating conditions on pavement performance because of its adaptability in forecasting contact stress, stresses, energy loss due to hysteresis, and rolling resistance.

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