JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2017; X (X): 1–8

Available online at www.sciencedirect.com

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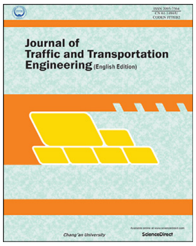

Original Research Paper

Analysis of asphalt mix surface-tread rubber interaction by using finite element method

Q4 Q1 *Srirangam Santosh Kumar* [a], *Kumar Anupam* [b,*], *Cor Kasbergen* [b], *Athanasios (Tom) Scarpas* [b]

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HIGHLIGHTS

- Developing three-dimensional FE model to evaluate hysteretic friction.
- Revealing the micromechanical pavement surface morphology.
- Simulating different loading pressures, sliding velocities, and surfaces.
- Showing the result that hysteretic friction inversely varies with the sliding speed.

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Surface texture
Hysteretic friction
Micromechanical analysis
Finite element
Contact

Q2

ABSTRACT

The surface texture of the pavement plays a very important role in driving the frictional properties at the tire rubber-pavement interface. Particularly, the hysteretic friction due to viscoelastic deformations of rubber depends mainly on the pavement surface texture. In the present paper, the effect of micromechanical pavement surface morphology on rubber block friction was brought in by comparing the friction results for three different asphalt mix morphological surfaces, named stone mastic asphalt (SMA), ultra-thin surfacing (UTS) and porous asphalt (PA). The asphalt surface morphologies of these mixes were captured by using an X-ray tomographer, from which the resulting images micromechanical finite element (FE) meshes for SMA, UTS and PA pavements were developed by means of the SimpleWare software. These asphalt meshes were combined with the contact algorithm for the micromechanical analysis of the contact problem of rough surfaces.

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2017.07.004

Please cite this article in press as: Kumar, S.S., et al., Analysis of asphalt mix surface-tread rubber interaction by using finite element method, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.07.004

1. Introduction

Tire rubber is an elastomeric material which undergoes large deformation. The contact between a rubber block and a hard, randomly rough, pavement surface is an important subject of practical application interest. Rubber friction in many cases is directly related to the internal friction of the rubber, i.e., it is a bulk property of the rubber (Grosch, 1963). When a rubber is indented onto a rough pavement surface by applying a constant pressure, the real contact area will increase with the contact time (Persson et al., 2004). In addition, if the rubber slides on a hard, rough substrate, the surface asperities of the substrate exert oscillating forces on the rubber surface leading to energy ‘‘dissipation’’ via the internal friction of the rubber (Persson and Volokitin, 2002). The force required to slide the rubber depends on the area of real contact, indentation pressure and the indentation time (Persson et al., 2004). The influence of asphalt mix characteristics on pavement surface morphology and ultimately on rubber-pavement interaction under different applied pressure and sliding speed conditions is the topic of the present research.

According to the past research studies, hysteresis was found to account for the larger part of the total friction force. Hence, in the present study, rubber friction due to the hysteresis loss is considered as the main cause of friction development. The effect of pavement macrotexture surface morphology on rubber block friction was brought in by comparing the friction results for three different asphalt mix morphological surfaces. The disparity of friction with stiffness conditions of pavement was determined by conducting the simulation analyses for non-deformable and deformable pavement surface conditions. The rubber and asphalt binder were modeled as viscoelastic (VE) materials and the formulation was given in the large deformation framework. The commercial FE package, ABAQUE/Explicit (Hibbit, Karlson & Sorensen, Inc., 2010), was used for the present analyses.

2. Description of model

In this study, the essential parameters required to simulate the interaction between tire tread block and real pavement surface morphology in macro scale are presented. The simulation of rubber-pavement surface morphology is performed under different loading pressures, sliding velocities and pavement morphological conditions described as follows.

(a) Tread rubber non-deformable pavement macrotexture interaction for SMA, UTS, and PA pavements. Such an analysis, supplements the past research studies (Klüppel and Heinrich, 1999, 2008; Persson et al., 2004) which were based on the non-deformable pavement surface conditions by simulating the rubber friction on real non-deformable asphalt pavement macrotexture conditions

(b) Tread rubber deformable pavement macrotexture interaction for UTS pavement. Such analysis emphasizes the error committed by the aforementioned analytical approaches in the determination of the friction by ignoring the deformability of the pavement surface.

2.1. Study parameters

In the present analyses, three-dimensional (3D) FE models of rubber block sliding on micromechanical pavement surface models were utilized to study the effect of pavement macrotexture morphology on rubber friction. First, 3D FE meshes of real SMA, UTS and PA pavement macrotexture morphologies were built by using X-ray tomography scans. The analysis was carried out by simulating the interaction between rubber block and pavement macrotexture under different sliding velocity and normal pressure conditions. Four sliding velocities 5, 10, 15 and 25 m/s and three pressures conditions, 200, 400 and 700 kPa were considered for this purpose. The rubber block was modeled as a viscoelastic material. In the first stage of FE simulations, the pavement surfaces were modeled as non-deformable. In the next stage of simulations, the asphalt binder was modeled as a viscoelastic (VE) material and the aggregate was modeled as a linear elastic material for all three pavements to identify the effect of pavement stiffness characteristics on rubber-pavement interaction.

2.2. Constitutive model for the viscoelastic material

In this section, the VE constitutive modelings of rubber and asphalt binder and the developments of macrotexture morphology and FE meshes for SMA, UTS, and PA are presented. Optimum dimensions of pavement surface and rubber block were selected in order to capture the effect of pavement morphology on the frictional behavior of the different material and mechanical properties. In the model, the pavement has a size of 240 mm × 40 mm × 8 mm while the rubber block has a size of 20 mm × 20 mm × 5 mm. Thermal effects have been neglected. The main assumption of the analysis is that rubber hysteretic friction is the main factor of rubber friction and the result from the internal energy dissipation of the rubber.

In the analyses, the material behaviors of the rubber and asphalt binder were characterized by means of the generalized viscoelastic model as shown in Fig. 1.

The model consists of an elastic spring in parallel with a number of Maxwell elements depending on the material representation. The Maxwell element consists of a spring and dashpot in series. The Maxwell element allows the force of the elastic spring to vary with loading rate because the viscous forces increase with the rate of deformation. In order to employ the generalized viscoelastic model, it is essential to implement viscoelastic constitutive equation into the ABAQUS numerical solving system. This can be done by calling a user-defined explicit subroutine VUMAT. ABAQUS/Explicit uses the VUMAT subroutine feature to calculate the tangent moduli of the rubber and asphalt binder.

In the model, total stress in the VE material at any time is as follow

$$\sigma = \sigma_\infty + \sum_{i=1}^{m} [\sigma_v]_i \tag{1}$$

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