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EFFECTS OF TRAFFIC LOAD, TEMPERATURE AND MATERIAL PROPERTIES ON RUTTING IN FLEXIBLE PAVEMENTS

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Abstract

Rutting (permanent deformation) is one of the most common and serious kinds of damage to flexible pavement, particularly in countries with high summer temperatures. Rutting also occurs when there is a lot of traffic and the use of poor materials. Pavement engineering is greatly influenced by the use of materials such as asphalt and cement in modern times. To study the effect of load, high temperature, and materials properties on rutting damage of flexible pavement this paper is the best approach to all these concerned issues related to rutting. Abaqus ver.6.12.1 has been used to simulate flexible pavement under different loading and thermal conditions. Three models have been developed in this paper, the first model simulated against traffic loading only, the second model shows combined traffic and thermal loading while the third model is related to the change of materials property in terms of Young's modulus (E).

Keywords: Flexible Pavements, FEM, Rutting, Traffic loads, Temperature

I. Introduction

The effect of traffic loading and combined thermal loading conditions have been studied theoretically with the application of the ABAQUS finite element program to observe the induced behaviour of high temperature on rutting damage of flexible pavement. And it has been obtained that both thermal and traffic loading conditions have a substantial impact on rutting damage of flexible pavement, with greater temperatures resulting in rut depths of 2.29, 3.1, and 4.3 times for the Asphalt layer, base layer, and subgrade layer, respectively [VIII]. As the applied pressure is increased, the rut depth and plastic strain values increase [I]. The base layer reduced rutting damage by about (58%) but the subgrade layer only reduced rutting damage by 10% in flexible pavement, which is less important than the base layer [IX]. It was observed that lowering the temperature reduced the predicted rut depth. The percentage decreases were 68.5%, 80.4%, and 38%, respectively, as the temperature dropped from 40°C to 25°C, 40°C to 5°C, and 25°C to 5°C [VII]. According to this finite element study, increasing the temperature from 10 to 50°C causes a 740% rise in rutting depth and a 673% increase in plastic strain [II]. The fine finite element mesh employed in this study provides more accurate stress and strain values at each point. Near the applied load, where greater deformations occur, the stress has higher values. The stress parameter generated from finite element analysis in each layer is used in local empirical models to determine rut depth. Although the stress level in the levelling course and the base course both reduced by 14% and 27% respectively, the rut depth in those layers increased by 12% and 28%, respectively, due to material characteristics changes [III]. According to one study potential technical approach for reducing vertical displacement in all pavement, types is incremental changes to the subgrade elastic modulus [XII]. The surface deformation is reduced by 73.48% in the reclaimed base layer model and a stabilized base layer containing 5% lime silica fume improves surface deformation effects to a minimum [V]. Rut depth was calculated using ABAQUS simulation at various temperatures for both static and cyclic loads. The rutting caused by the static load is 4.5 times more than the rutting caused by cyclic load at 60°C. At -30°C, however, the rutting caused by the static load is 32.5 times that caused by the cyclic load. Given a reference temperature of 30°C, rutting under static loading at 45°C is 1.5 times greater, 2.3 times higher at 50°C, and 3.8 times higher at 60°C than at the reference temperature. When cyclic loading is applied, rutting is observed to be 2.7 times higher at 45°C, 4.4 times higher at 50°C, and 8.6 times higher at 60°C than at 30°C [X]. The permanent deformation rises as the number of loading cycles increases [XIII]. It was investigated flexible pavement rutting using an elastic-visco-plastic constitutive relation for asphalt concrete in their work. According to this study, the tire type and traffic speed have a considerable impact on pavement rutting. As a consequence, it was discovered that a drop in traffic speed causes an increase in pavement load time, which leads to an increase in pavement rut depth [VI]. Rutting in the pavement is a concern for at least three reasons: a- Water can collect in the rut and penetrate the pavement, causing structural damage; b- A rut can cause the driver to lose control of the steering, which is a serious safety concern; and c-Ruts will hold water, making the road surface moist and perhaps causing car hydroplaning, which is another safety concern [XI]. As stresses and strains are used more and more to predict pavement distresses and, as a result, the relative state of the various layers in the pavement structure, non-linear material behavior is becoming more significant. In pavement analysis, linear elastic approximations of unbound material behavior are no longer appropriate. For an accurate assessment of true pavement reaction, the stress state dependency of granular materials, as well as strain-based subgrade soil models, must be taken into account [XII]. The most essential factor in pavement design is the material's elastic modulus. A resilient modulus (MR) test was used to assess the elastic performance of several high-rigidity materials. The soil mechanical response (MR) is the result of cyclic dynamic load application [XIV]. Jan Ritter defined, It was found that thinner asphalt layers reduce the strength of the pavement structure and promote crack development in the asphalt foundation layers. The addition of polymer or other additives to asphalt mixes improves the pavement's durability and reduces rutting [XV].

II. Finite Element Modeling

The best method to model a pavement is the finite element approach. Element type (C3D8R) has been used in this research to study the effect of traffic, temperature and materials property on the rutting of flexible pavement. The finite element model including asphalt layer (12 cm) thickness; granular base layer (15 cm) thickness; sub-base layer (13 cm) thickness and subgrade layer (15 cm). For the whole 3-Dimensional section of flexible pavement, acceptable sizes in longitudinal and transverse directions (3000 mm 6000 mm) have been used to minimize the effect of inaccuracy due to the edge. Meshing is done for each section by parts which are shown in Figure1, the purpose of meshing is to make the problem solvable and increase the accuracy of results. In the interaction module tie surface to surface, the connection is used to connect various surfaces which are shown in Figure2. and fixed boundary condition is used for subgrade to prevent vertical movement. The ABAQUS finite element model was used to simulate traffic loading using a standard axle load of 18 kip (18 kN) and contact pressure of (0.6 MPa) as shown in Figure 3. The input material characterization for flexible pavement layers is shown in Table 1.

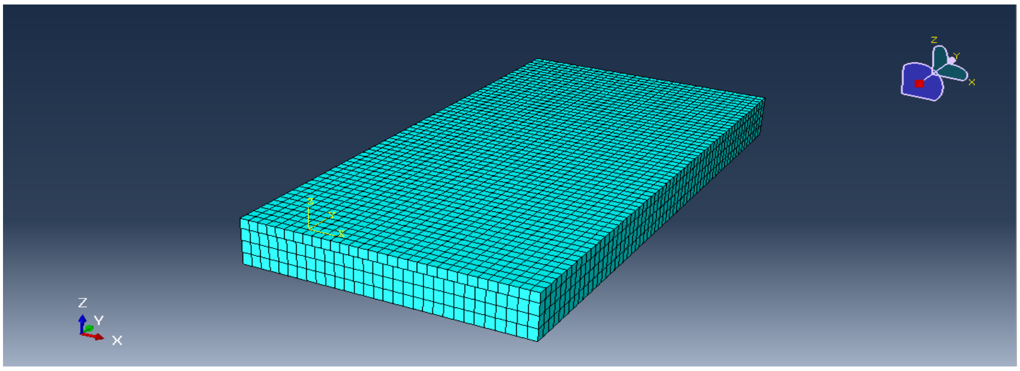

Fig.1: Mesh model of Flexible Pavement

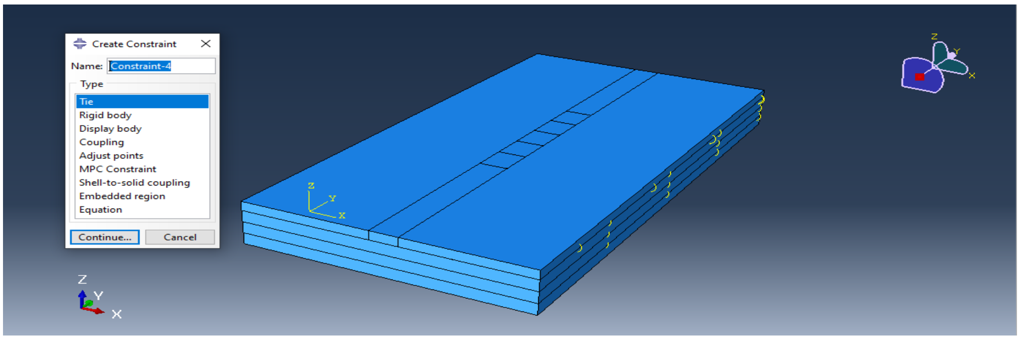

Fig. 2: Interaction model

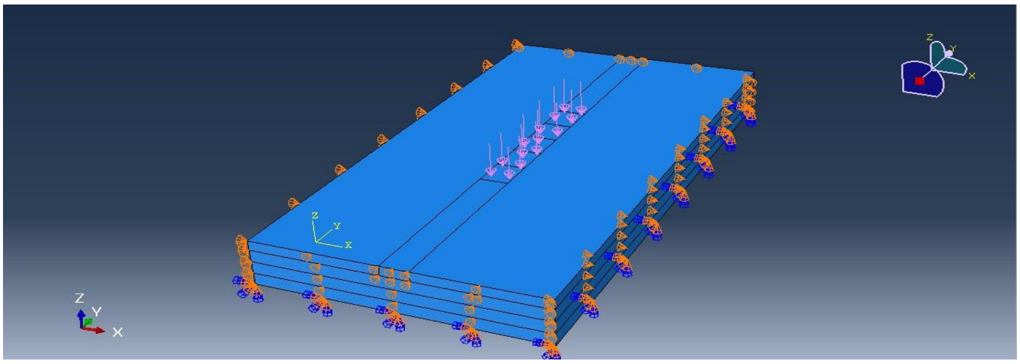

Fig.3: Loading model

Table 1: Inputs of Flexible Pavement Layers Properties

Layers	E (MPa)	Poisson ratio	Density (kg/m^3)
Asphalt [1]	7500	0.35	2240
Base Course [1]	38.5	0.2	2280
Sub-base [7]	400	0.35	2160
Subgrade [1]	211.53	0.4	1870

III. Results and Discussions

Standard tire pressure (600KPa) with an increment of 100KPa in different steps has been applied on the pavement section and rutting in each layer i.e. Asphalt, Base Course, Subbase Course, and Subgrade has been calculated against each tire pressure individually. Results show that 47.1% of rutting occurs in the Asphalt layer, 43.87% rutting occurs in Base Course, 5.95% rutting occurs in the Sub-base Course while 3.08% rutting occurs in the Subgrade layer which is shown in below Table 2.

Table 2: Values of Rut Depth of different layers for different Tire Pressure

Tire Pressure (KPa)	Rut Depth (mm)				Cumulative Rutting (mm)
	Asphalt	Base Course	Sub-base Course	Subgrade	
600	1.85	1.65	0.23	0.12	3.85
700	2.16	2.15	0.27	0.14	4.72
800	2.46	2.27	0.31	0.16	5.2
900	2.77	2.58	0.35	0.18	5.88

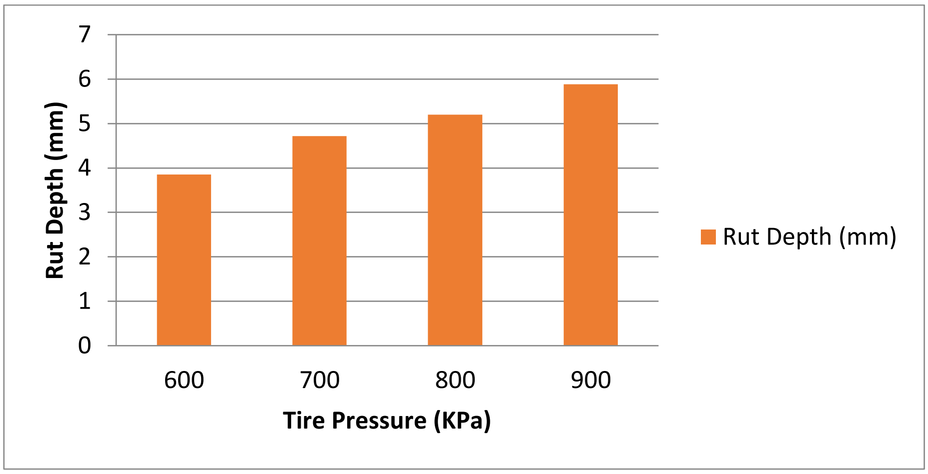

Fig.4. Rut Depth at Flexible Pavement under the effect of Traffic Loading

Combined traffic and thermal loading have been applied on the flexible pavement model and the obtained results demonstrated that; there is a significant effect of both thermal and traffic loading conditions on rutting damage of flexible pavement and higher temperatures will provide high rut depth by 2.23, 2.98, 3.1 and 4.1 times for Asphalt layer, base layer, Sub-base layer, and subgrade layer respectively. Similarly in this case rutting depth in the flexible pavement is about 3 times greater than the previous result. As shown in the following Table 3.

Table 3: Values of Rut Depth of different layers for different Tire Pressure with an increase of local Temperature up to 45° C

Tire Pressure (KPa)	Rut Depth (mm)				
	Asphalt	Base Course	Sub-base Course	Subgrade	Cumulative Rutting (mm)
600	4.2	4.92	0.73	0.52	10.37
700	4.82	5.86	0.84	0.59	12.11
800	5.48	6.78	1.3	0.67	14.23
900	6.2	7.76	1.1	0.75	15.81

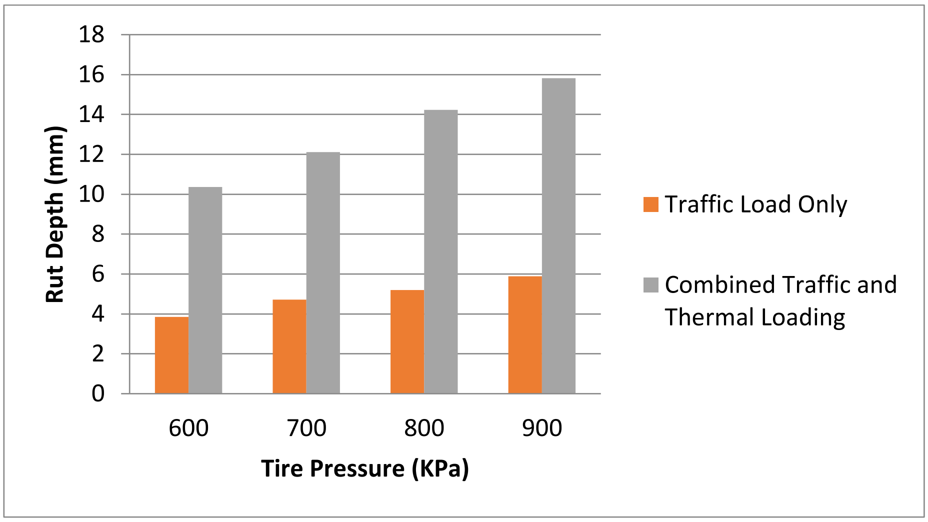

Fig.5. Rut Depth at Flexible Pavement Layers under the Combined Effect of Traffic and Thermal Loading

Material property in term of young's modulus has been analyzed with 5% and 10% increment for different layers of flexible pavement, while the tire pressure (700KPa) and the temperature has taken constantly. The results show that rutting decreases with the improvement of material property. Rut depth decreases 4.66% with the first increment (E_1) and 9.32% decreases with the second increment (E_2). Results are shown below:

Table 4: Materials property (E) with 5% increment

Layers	**E (MPa)**	**E_1 (MPa) (5%)**	**E_2 (MPa) (10%)**
Asphalt	7500	7875	8250
Base Course	38.5	40.42	42.35
Sub-base Course	400	420	440
Subgrade	211.53	222.11	232.69

Table 5: Rut Depth with varying (E)

Material Property (MPa)	Rutting (mm)				Cumulative Rutting (mm)
	Asphalt	Base Course	Sub-base Course	Subgrade	
E	2.16	2.15	0.27	0.14	4.72
E_1	2.06	2.05	0.26	0.13	4.5
E_2	1.96	1.95	0.25	0.12	4.28

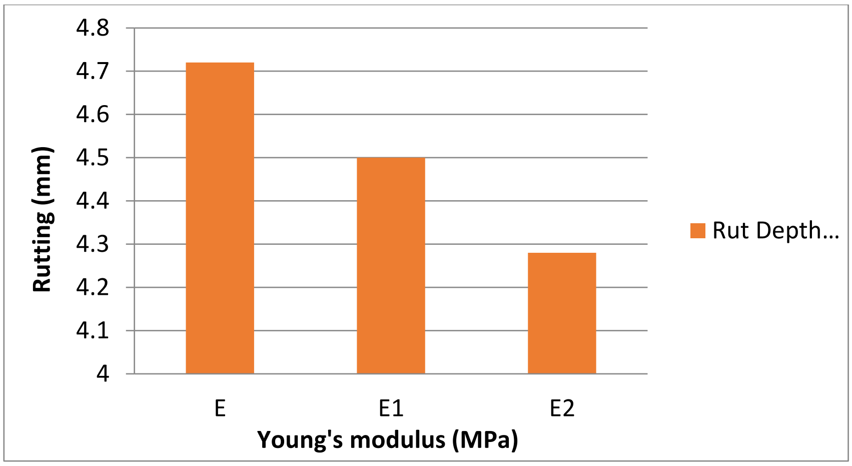

Figure 6. Rut Depth concerning Material Properties

IV. Conclusions

In this study, the main concluding remarks that have been achieved from the results may be summarized as follows:

- Rut depth increases with an increase in tire pressure
- Results show that 47.1% of rutting occurs in the Asphalt layer, 43.87% rutting occurs in Base Course, 5.95% rutting occurs in Sub-base Course while 3.08% rutting occurs in the Subgrade layer.
- Combined traffic and thermal loading cause high rut depth by 2.23, 2.98, 3.1, and 4.1 times for Asphalt layer, base layer, Sub-base layer, and subgrade layer respectively than traffic loading condition only.
- With the increase in the material property i.e. young's modulus rut depth decreases.

Conflict of Interest:

There is no relevant conflict of interest regarding this paper.

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