IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 1 Ver. IV (Jan. - Feb. 2018), PP 57-63
www.iosrjournals.org

Effects of Truck Tire Pressure on Fatigue and Rutting of Flexible Pavements

Abdullah I. Al-Mansour*, Abduraof H. Al-Qaili**
**professor of transportation, Civil Engineering Department, College of Engineering, King Saud University, Riyadh, KSA*
*** graduate student, Civil Engineering Department, College of Engineering, King Saud University, Riyadh, KSA*

Abstract: *In the past, damage resulted from load application to highway pavements focused primarily onthe magnitude and frequency of axle loads. In recent years, the effect of increased truck tire pressure on flexible pavements responses has become a subject of great concern. The tire inflation pressure of trucks causes severe deterioration to the pavement and thus reduce its life. This paper aims to evaluate the effects of tire inflation pressure on the pavement response and failure life of pavement. The research uses the ELSYM5 software and pavement materials conditions to estimate the tensile strains occurring under the asphalt concrete (AC) layer and the compressive strains above the subgrade surface. The calculated strain is then utilized to estimate the number of load repetitions to failure due to fatigue cracking and rutting using the asphalt institute (AI) method.*
Keywords: *Fatigue life, Rutting life, Tensile strain, Compressive strain, Flexible pavement, ELSYM5, Tire inflation pressure.*

Date of Submission: 06-02-2018 Date of acceptance: 26-02-2018

I. Introduction:

Structuralfailure of flexible pavements has more spreadin many roads as a result of the drastic changes in truck axle loads as well as tire pressures. Important findings of a recent study have concluded that tire pressure has more significant effect on rutting tendency ofsurface asphalt layer than wheel loads [1]. In the past, damage resulted from load application to highwaypavements focused primarily on the magnitude andfrequency of axle loads. In recent years, the effect ofincreased truck tire pressure on flexible pavementsresponses has become a subject of great concern.Analytical studyto investigate the effects of truck tirepressure on pavement responses found that tirepressure was significantly related to tensile strain; $\varepsilon_t$at the bottom of the asphalt layer and stresses near thepavement surface for both the thick and thinpavements [2]. However, tire pressure effects on verticalcompressive strain; $\varepsilon_c$at the top of the subgrade wereminor, especially in a thick pavement. The increasedrutting, decreased fatigue life and acceleratedserviceability loss of the pavement have beenattributed to the effect of increased truck tire pressure as well as increased axle loads[3,4].

Existing practice assumes the tire pressure to be uniform over the contact area. The size of contact areais then calculated depending on the contact pressure. The contact pressure is greater than tire pressurefor low-pressure tires, because the wall oftires is in compression and the sum of vertical forcesdue to wall and tire pressure must be equal to the forcedue to contact pressure. On the other hand, the contactpressure is smaller than tirepressure for high pressuretire, since the wall of tires is in tension [5]. A computer program called TireView wasdeveloped that provides estimates of tire contact areaas a function of tire type, tire load, and tire inflationpressure and predicts the stress distribution at the tire pavementinterface based on polynomial interpolationsof measured tire contact stresses [6]. In pavement analysis tire pressure on the surface of the pavementproduces, two strains which are believed to be critical for design purposes. These are: the horizontal tensile strain ε_t at the bottomof the asphalt layer and the vertical compressive strain $\varepsilon_c$at the top of the subgrade layer. If the horizontal tensile strainε_t is excessive cracking of the surface layer will occur, and thepavement distresses due to fatigue. If the vertical compressivestrain $\varepsilon_c$is excessive, permanent deformation occurs on thesurface of the pavement structure from overloading the subgrade and the pavement distresses due to rutting[8, 9].

II. Problem Statement:

Tire inflation pressure of trucks can cause excessive damage to pavement structure, such as cracking, rutting, potholes, etc. The deteriorationof pavements can, in turn, results in reducing pavement service life and increased accident potential. To reduce this effect, it is important to enforce the legal tire pressure to keep the pavement in good conditions as long as possible. Without active enforcement, the amount of tire pressure will increase leading to rapid deterioration of pavement.

III. Objective:

The primary objective of this study is to estimate and analyze theeffects of tire pressure onpavement responses and to determine the number of load repetitions to pavement failure. This will provide a meansto:

1.Investigate the flexible pavement performance due to variation of tire pressure.
2.Predict the design life of the flexible pavement at different tire pressure levels.
3.Perform sensitivity analysis of the variation in tire pressure levels.

IV. Pavement Failure Criteria

In pavement analysis, loads on pavement surface produces two strains.These are the horizontaltensile strain, ε_t, at the bottom of the asphalt layer andthe vertical compressive strain, ε_c, at the top of thesubgrade layer. The two strains are believed to be critical for design purposes. The two critical strains are determined using computer program ELSYM5. Damage analysis was performed for both fatigue cracking and permanent deformation asfollows:

Fatigue failure:

The relationship between fatigue failure of asphaltconcrete and tensile strain ε_t, atthe bottom of asphaltlayer is represented by the number of repetitions as suggested by Asphalt Institutein the followingform:

$$N_f = 0.0796\ (1/\varepsilon_t)^{3.291}(1/E_1)^{0.854}$$

Where:

N_f: Number of load repetitions to prevent fatigue cracking
ε_t; Tensile strain at the bottom of asphalt layer.
E_1; Elastic modulus of asphalt layer.

Rutting failure:

The relationship between rutting failure and compressive strain at the top of subgrade is represented by the number of load applications as suggested by Asphalt Institute in the following form:

$$N_r = 1.365 \times 10^{-9}(\frac{1}{\varepsilon_c})^{4.477}$$

Where:

N_r :Number of load repetitions to limit Rutting
ε_c :Vertical compressive strain at the top of Subgrade

V. Methods of Analysis

Two typical pavement cross sections are considered foranalysis. The first represents, in general, a strongsection used in major roads, while the second sectionrepresents a weak section used in minor (agriculture) roads. Theses typical sections were selected based on the Saudi Arabia Specifications ofRoads. Flexible pavement is typically taken as a multi-layeredelastic system in the analysis of pavement response.Materials in each layer are characterized by a modulusof elasticity (E) and a Poisson’s ratio (μ). The structuralproperties of the investigated pavement sections areshown in table 1.

Loading conditions evaluated included two axleconfigurations, and four tire pressure levels. The two axle configurations were a dual tired single axle and a dual tired tandem axle. Tire loads used were 14,350 lb per tire for a dual tired single axle whereas for a dual tired tandem is 11,050 lb per tire. Tire pressures of 80, 100, 120 and 130 psi were used. The dual tire isapproximated by two circular plates (with variableradius according to axle load and tire pressure) andspaced at 13.6in. center to center. The tandem axlesare represented by two axles spaced 48-in. center to center. The geometry of axle's configuration along with the locations for the determination of maximumstrains are illustrated in Fig.1. A circular tire

Table 1. The structural properties of the investigated pavementcross sections

Section	layer	Thick. (in)	E(psi)	μ
Section (1)	surface	2	600,000	0.35
	Asphalt base	4	600,000	0.35
	Granular base	12	15,000	0.40
	Subgrade	--	10,000	0.45
Section (2)	surface	2	600,000	0.35
	Granular base	12	15,000	0.40
	Subgrade	--	10,000	0.45

A circular tire imprint is assumed and the radius of contact is calculated as follow:

$$a = \sqrt{P/\pi\,\rho_t}$$

Where:
a :Radius of contact
P:Wheel load
ρ_t: Contact pressure.

Evaluation points were determined depending on failure criteria and axleconfiguration. In asphalt concrete pavements, the failure criteria were fatigue and rutting, therefore strains at the bottom of the asphalt concrete and top ofsubgrade were used to determine the load repetitions to failure for fatigue andrutting respectively. Strains directly under a tire, under the tire edge, between the dual tires and between the axles were calculated for the dual tandem axle configuration. For the single axle configuration, the strains under a tire, under the tire edge, and between the tires were determined. Only the largest strain found for each loading condition was used in determining the load repetitions to failure. Other strains were not considered.

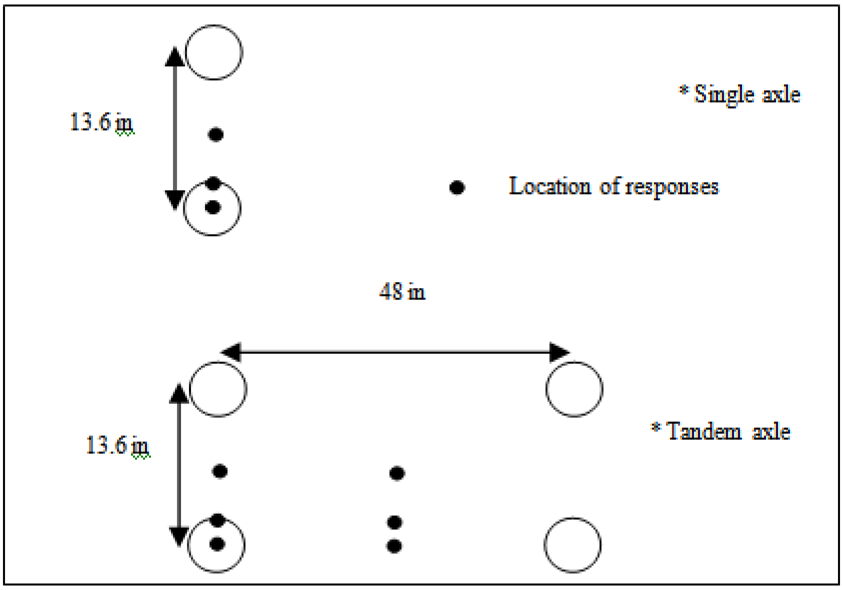

Fig. 1. Geometry of axles configuration

Determination of strains:

Determination of horizontal tensile strain at the bottom of asphalt concrete and vertical compressive strains at the top of subgrade were determined using the ELSYM5 computer softwareprogram developed by the Federal Highway Administration. ELSYM5 useselastic layer theory to calculate the stresses and strains at specified points inmulti-layer pavement systems. Input variables were material properties, loadingcondition, and points of evaluation.

Number ofload repetitions to failure:

For each pavement section and loading condition, the strains at the selected points ofinterest were calculated using the ELSYM5 program. Using the strain calculatedby ELSYM5 and the Asphalt Institute failure formulas, the number of loadrepetitions to failure for each combination of pavement section and loading condition was determined.

VI. Results

The results of the conducted analysis are discussed in the following sections:

Effect of tire Pressure on pavement responses:

It can be seen from Figure 2 that the relationship between horizontal strain at the bottom of the asphalt surface and tire pressure levels is nearly linear for the single axle,while it isobviously nonlinear with tandem axle in strong section.The figure shows that the effect of tire pressure was more evidentin the range of 90–110 psifor both single and tandem axels. Also, the horizontal strain at bottom asphalt surface increased significantly with increasingtirepressure.There is about 100% increase in horizontal strains with single axle where is 75% with dual axle due to increasing tirepressure from 80 to 130 psi.

Figure 3 show the variation in the horizontal strains with tire pressure for the weak section. The relationship is nearly nonlinear forsingleaxle and linear for tandem axle. The result detects 22% increase in horizontalstrains with single axle whereas 50% with tandem axle due to increasein tirepressure from 80 to 130 psi. Figure 4 and 5 show the relationship between compressive strain above the subgradeandtire pressure levels.The effect of the tire pressure is not very significanton the compressive strain above the subgrade compared to the horizontal strain at the bottom of the asphalt surface.

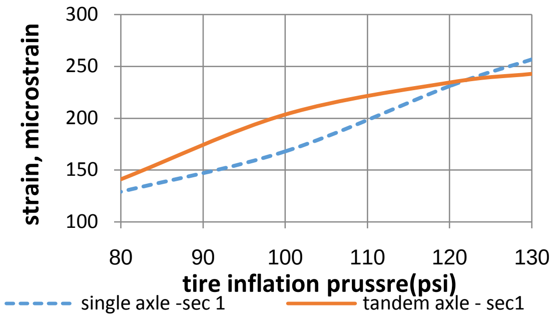

Fig. 2. Horizontal strain at the bottom of the asphalt surface with tire pressure for strong section.

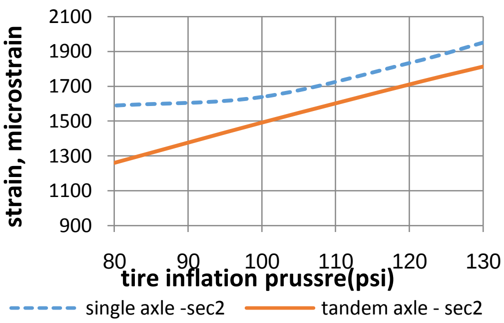

Fig. 3.horizontal strain at the bottom of the asphalt surface with tire pressure for weak section.

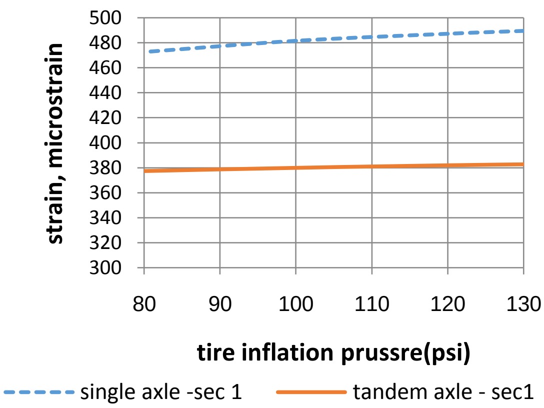

Fig. 4. Compressive strain above the subgrade with tire pressure levelsfor strong section

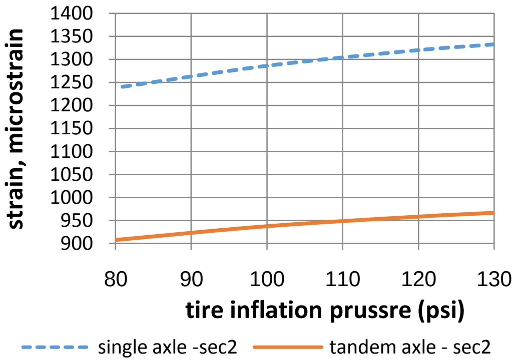

Fig. 5. Compressive strain above the subgrade with tire pressure levels for weak section.

Effect of tire pressure on fatigue life:

Figs. 6 and 7 explain the trends of the predicted number of loadrepetitions to failure Nf(fatiguelife) for the strong section and weak section, respectively. It is shown that fatigue life Nfgenerallydecreased with increased tire pressure levels, and themagnitude of the reductions were highest in the range of 80 – 120 psi. Fig. 6.Shows that the number of repetitions to failure Nffor the tandem axle on the strong section decreased from $4\times10^{6}$to 1×10^{6}due to increase in tire pressure from 80 to 120 psi. The number of load repetitionsto failure for single axle reduced from $6\times10^{6}$to 1×10^{6}as a result of increasing tire pressure from 80 to 120 psi.The corresponding reductionof the number of load repetitionsto failurefor the single axle and tandem axle forthe weak section were 34 and 63%, respectively The effects of tire pressure levels onthe number of load repetitionsto failure is more for the strong section than for the weak section.

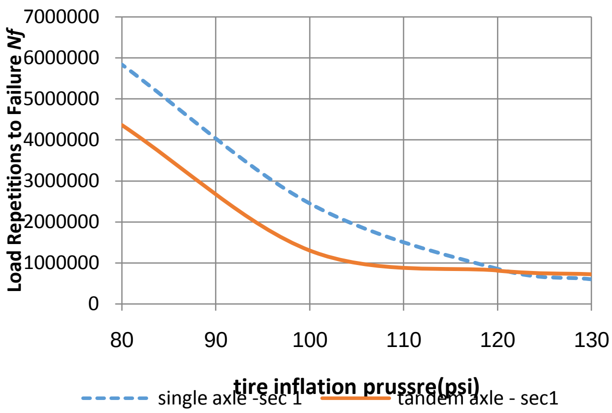

Fig. 6. Estimated number of loadrepetitions to failure Nfforvarying tire pressure levelsfor the strong section.

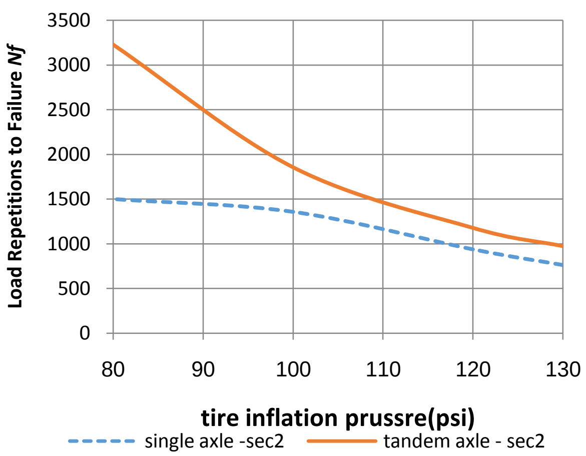

Fig. 7. Estimated number of load repetitions to failure Nfforvarying tire pressure levelsfor the weak section.

Effect of tire pressure levels on rutting life:

The number of load repetitions due to rutting is related to the compressive strain above the subgrade. Figs.8 and 9 shows that the tire pressure levelsdo not have significant effect on the number of load repetition determined from the rutting model. The rutting life increasedas a result of decreasing tire pressure from 80 – 130 psi by about 3 and 10 % for single axle and tandem axle, respectively on strong pavement section. The rutting life increased by about 32and 21 % for the single axle and the tandem axle, respectively on weak section with the decrease in tire pressure from 130 – 80 psi. the number of load repetitions due to rutting is related to the compressive strain above the subgrade.

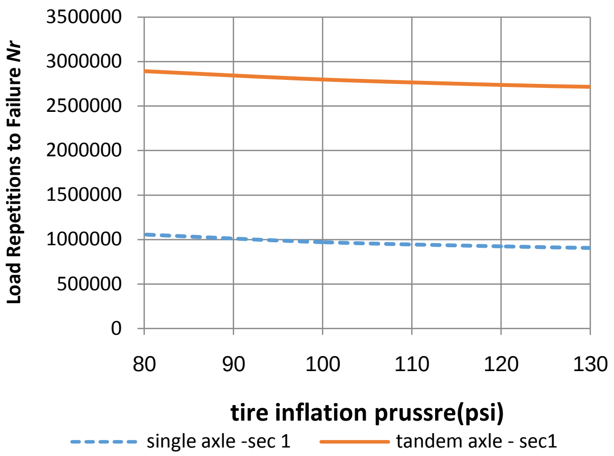

Fig. 8. Estimated Load Repetitions to Failure Nr for Varying tire inflation pressure in strong section

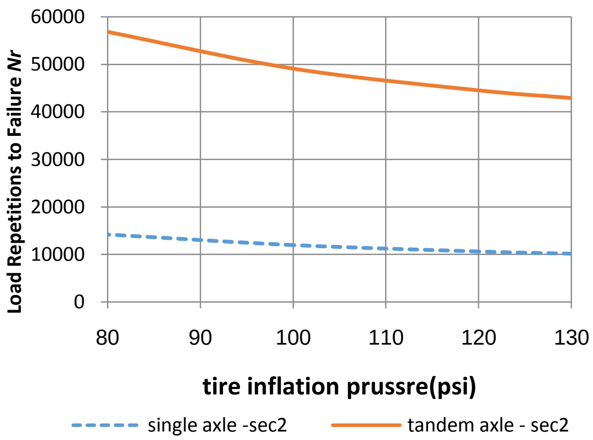

Fig. 9. Estimated Load Repetitions to Failure Nr for Varying tire inflation pressure in weak section

VII. Conclusion:

This preliminary study indicated that reducing tire pressure will reduce pavementstrains and extend pavement service life. Tire pressure affect both fatigue and rutting failure. Based on the methodologyand analysis of results for this study, the followingconclusions are drawn:

- Horizontal strain at the bottom of the asphalt layer and compressive strain above the subgrade increase with increase intire pressure. The effects of tire pressure on the horizontal strain at the bottom of the asphalt layer is much more than on the compressive strain above the subgrade.
- The magnitude of the tire pressure effects on the horizontal strain at the bottom of the asphalt layer and compressive strain above the subgrade was mainly noticed in the range of 80 – 120 psi.
- An increase in tire pressure from 80 – 120 psi will result in decrees inthe number of repetitions to failure Nf for the tandem axle by about75% and 84 % for the single axel on a strong pavement section. The corresponding reductionof the number of load repetitionsto failurefor the single axle and tandem axle for the weak section were 34 and 63%, respectively.This indicates that the effect of tire pressure on the strong section was more than on the weak section.

- The weak pavement section was more affected than strong section with increased tire pressure with changing the configuration from single to tandem axle.
- The pavement design life is generally governed by fatiguefailure with respect tire pressure.
- Tire pressure has no significant effects on rutting life compared to fatigue life, which is highly sensitive to pressure levels.

Acknowledgment:

This paper is a result of a research conducted at the civil Engineering Department of King Saud University.

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Abdullah I. Al-Mansour "Effects of Truck Tire Pressure on Fatigue and Rutting of Flexible Pavements.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 15, no. 1, 2018, pp. 57-63