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Research article

MODEL PREDITION OF TENSILE STRESS AND STRAIN ON MIX STIFFNESS MODULUS TO DETERMINE FATIGUE ON PAVEMENT FAILURE

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Abstract

Fatigues in pavement are one major causes of pavement failure, these are challenges from accumulative load repetition subjecting the pavement to stress and strain, pavement under this condition are bound to experience failure , moreover pavement structure experience failure, there should be designed parameters that should provide factor of safety to prevent rutting poses a serious safety danger to motorists. Pooling of water in the ruts definitely result to hydroplaning, making vehicle steering, and braking hard. The water may as well result into loss of asphalt stiffness due to degradation and stripping, these conditions are some of the causes of pavement failure, most roads without thorough design experience constants failure from load repetition subjecting the pavement to stress, mix stiffness of material in some designed are not considered, this subject the pavement to serious stress resulting to fast failure before the design period, there is need to determine the rate of stress and strain including the stiffness of modulus in pavement failure, an approach from mathematical model were found imperative to predict this parameters subjecting pavement deformation. The models were derived through an expressed mathematical governing equation, mathematical expressions were derived, thus generate models under two conditions the derived model will definitely be a useful tools to predict stress and strain including mix stiffness of material and fatigue in pavement failure.

Keywords: model predition, tensile stress, mathematical model, material

1. Introduction

Many factors contribute to the degradation of asphalt pavements. When high quality materials are used, distresses are typically due to traffic loading, resulting in rutting or fatigue cracking. Environmental conditions such as temperature and water can have a significant effect on the performance of asphalt concrete pavements as well. The presence of water (or moisture) often results in premature failure of asphalt pavements in the form of isolated distress caused by debonding of the asphalt film from the aggregate surface or early rutting/fatigue cracking due to reduced mix strength. Moisture sensitivity has long been recognized as an important mix design consideration. (Paul, 2005). Probably the most damaging and often hidden effect of moisture damage is associated with reduced pavement strength. Tensile strength plays an important role in the performance of a mixture under fatigue, rutting and moisture susceptibility. The damage due to moisture is controlled by the specific limits of the tensile strength ratios (TSR) or the percent loss in tensile strength of the mix. Probably the most damaging and often hidden effect of moisture damage is associated with reduced pavement strength. Tensile strength plays an important role in the performance of a mixture under fatigue, rutting and moisture susceptibility. The damage due to moisture is controlled by the specific limits of the tensile strength ratios (TSR) or the percent loss in tensile strength of the mix Wayne 2003. A significant number of studies have been conducted to develop a comfortable, safe and economical pavement system. However, a major problem still involving premature distresses and pavement failures. In recent years this difficult problem has been further aggravated by substantial increase in loads transmitted by modern heavy trucks (Lee et al. 1990).

There are three different approaches for considering vehicular and traffic characteristics, which affects pavement design. Fixed traffic Thickness of pavement is governed by single load and number of load repetitions is not considered. The heaviest wheel load anticipated is used for design purpose. This is an old method and is rarely used today for pavement design. Fixed vehicle: In the _fixed vehicle procedure, the thickness is governed by the number of repetitions of a standard axle load. If the axle loads is not a standard one, then it must be converted to an equivalent axle load by number of repetitions of given axle load and its equivalent axle load factor? Variable track and vehicle: In this approach, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load. The loads can be divided in to a number of groups and the stresses, strains, and defections under each load group can be determined separately; and used for design purposes. The track and loading factors to be considered include axle loads, load repetitions, and tyre contact area.(Flexible Design, 2006). In most studies the investigate are done to examine the deformation and stiffness properties of different asphalt mixes used in Norway (Lerfald 2004 Nunns et al 199).

In order to design a long lasting pavement, it is very important to estimate the actual field conditions in design phase of asphalt concrete pavements. For example, better structural performance depends on a good projection of future traffic and accurate representation of field conditions, i.e., temperature. Traffic loads are represented by cyclic loads in the performance testing of asphalt mixtures, and the resilient modulus is used to describe the stress-strain behavior of asphalt concrete under cyclic traffic loading. As the number of load applications increases, the plastic strains due to load repetition decreases (Huang, 1993). Because the applied load is usually small compared to the strength of the specimen, the same specimen may be used for the same test under different loading and temperatures

(Katicha W.S., 2003 Canser 2010). It has been selected by most engineers as a method to measure the resilient modulus of asphalt mixes (Brown et al., 1989 Canser2010). It is one of the most commonly used models to predict the stiffness modulus of bitumen as a function of time of loading, the penetration index, and the temperature at which the penetration of the bitumen is 800 (Suhaibani et al., 1997). Standard monograph were prepared to determining the stiffness modulus of the bituminous mixtures (Bonnaure et al., 1977). Witczak and Fonseca (1995) propose an empirical model to predict the complex modulus of an asphalt mixture. The proposed model for complex modulus master curve was generated based on a large amount of data consisting of 1429 points from 149 separate asphalt mixtures.

2. Theoretical background

The answer of a pavement structure to traffic loading should be mechanistically modelled by computing stresses and strains within its layers. If too much, stresses cause pavement fatigue cracking and/or surface rutting. This may result in both structural and functional failure, thus causing a safety hazard to motorists. These failure distresses are minimised among others by use of effective balanced pavement designs. Pavement stress-strain analysis is an ideal tool for analytical modelling of pavement behaviour and thus, constitutes an integral part of pavement design and performance evaluation. It is the fundamental basis for the mechanistic design theory. With the ever increasing truck tyre loading and inflation pressures, a better understanding of the Pavement stress-strain behaviour is an enhancement in the development of more constitutive design models centred on pavement-traffic load response and distress minimisation. Wide use of thin asphalt surfacings (≤50mm) in most part of developing nations are considered economical, this implies that there should be more extensive studies to understanding the traffic load response of these layers. This study is to predict the stress and strain on mix stiffness modulus of material reflecting to pavement damage, in most conditions simplified linear elastic analysis of the stress-strain behaviour of an "Asphalt are imperative in such condition. To determine the cause of this failure the following parameters are considered, these include Surfacing Layer" under static traffic loading. The top asphalt layer are normally investigated, to determine the effects and variation of the required parameters: this study will also streamline some conditions were simplified linear elastic analysis of the stress-strain behaviour of an "Asphalt Surfacing Layer" under static traffic loading is analysed on there modulus The top asphalt layer was modelled by Investigating the effects of the variation of the following parameters: load repletion subject pavement to stress and such condition if not thoroughly designed according to specification will always fail before the designed period .

Furthermore, the performance of pavements are determined by the designed parameters so that the pavement can last designed period. Moreso there other conditions considered to develop pavement failure, surface ruts may occur in the asphalt-surfacing layer under the action of heavy vehicle loading, particularly in areas of extreme high temperatures. Principally, the surface rutting in the asphalt layer is mainly caused by shear deformation (Long F, 1999) coupled with high-localised vertical Compressive stresses in the top zone. Asphalt-mix densification due to traffic loading is another contributing factor. Pavement uplift (shoving) may also occur along the sides of the rut. In many Instances, ruts are only noticeable during and/or after rainfall, when the wheel tracks are filled with water.

Most existing models do not adequately predict the permanent deformation response of asphalt concrete nor directly relate traffic load repetitions to asphalt surface rutting. Long F (1999) has however, reported an on-going research into the development of more constitutive asphalt-surface rut models based on the SHRP mix-design procedures. The tensile strength is primarily a function of the binder properties. The amount of asphalt binder in a mixture and its stiffness influence the tensile strength. Tensile strength also depends on the absorption capacity of the aggregates used. At given asphalt content, the film thickness of asphalt on the surface of aggregates and particle to particle contact influences including the adhesion or tensile strength of a mixture. Various studies have repeatedly proved that the tensile strength increases with decreasing air voids. The tensile strength of a mixture is strongly influenced by the consistency of the asphalt cement, which can influence rutting. Thus, tensile strength plays an important role as a design and evaluation tool for Superpave mixtures.

2. Governing Equation

$$\frac{\partial Nf}{\partial t} = K_1 C \left(\frac{1}{\varepsilon}\right) \frac{\partial Nf}{\partial Z} + \left(\frac{1}{\varepsilon}\right) \frac{\partial Nf}{\partial Z} \qquad \text{………………………..} \quad (1)$$

Asphalt road performance is usually assessed using fatigue cracking and rutting models. Fatigue cracking and rutting are primarily caused by stresses and strains due to cumulative repetitive and/or high traffic loading. Other factors such as material mix-design, temperature, moisture, ageing, oxidation, etc directly or indirectly contribute to pavement distress. The governing equation were developed to predict the mix stiffness strength characteristics of materials that are subjected to stress under the influence of load repetition, long time accumulative of this load repetition through stress develop to fatigue of the pavement, the governing equation were generated through this parameters to ensure that the characteristics of the material are thoroughly evaluated thus predicting the stiffness modulus.

Let $Nf_{(z,t)} = Z_{(z)}\, T_{(t)}$ be the solution

$$ZT^1 = K_1 C \frac{1}{\varepsilon} Z^1 T + \frac{1}{\varepsilon} Z^1 T \qquad \text{………………………..} \quad (2)$$

Dividing by ZT

$$\frac{T^1}{T} = K_1 C \frac{1}{\varepsilon}\frac{Z^1}{Z} + \frac{1}{\varepsilon}\frac{Z^1}{Z} \qquad \text{………………………..} \quad (3)$$

From (2)

$$\frac{T^1}{T} = -\lambda^2 \qquad \text{………………………..} \quad (4)$$

$$T + \lambda^2 T = 0 \qquad \text{………………………..} \quad (5)$$

$$K_1 C \frac{1}{\varepsilon}\frac{Z^1}{Z} + \frac{1}{\varepsilon}\frac{Z^1}{Z} = -\lambda^2 \qquad \ldots\ldots\ldots\ldots \quad (6)$$

$$K_1 C \frac{1}{\varepsilon}\frac{Z^1}{Z} + \frac{1}{\varepsilon}\frac{Z^1}{Z} + \lambda^2 = 0 \qquad \ldots\ldots\ldots\ldots \quad (7)$$

$$Z^1 - \frac{1}{\varepsilon} Z^1 - \frac{1}{K_1 C \frac{1}{\varepsilon}} + \lambda^2 = 0 \qquad \ldots\ldots\ldots\ldots \quad (8)$$

$$Z^1 - Z^1 - \beta Z = 0 \qquad \ldots\ldots\ldots\ldots \quad (9)$$

Where $\beta = \frac{1}{K_1 C \frac{1}{\varepsilon}} + \lambda^2$ ………………………. (10)

Equation (2) to (10) were subject to variable discretizing the parameters in the system

Separating it according to variables that establish relationship between each other, parameter in these condition express their various functions, these condition are in accordance with the characteristics determinant of the stiffness modulus of the materials under the influence load repetition . "Fatigue Cracking" is the progressive cracking of the asphalt surfacing or stabilized base layers due to cumulative repeated traffic loading. This occurs as a result of tensile stresses and strains in the bottom zone and propagates upward to the top. On the pavement surface, it finally manifests as alligator cracks along the wheel tracks. Fatigue cracking in asphalt layers is considered a major structural distress and is predominantly caused by traffic loading. In addition, ingress of rainwater through the cracks can lead to serious structural failure of the underlying layers particularly granular and unbound materials including the subgrade. The cracks are measured in square meters of the surface area.

Suppose $Z = \ell^{M_z}$ in (9)

$$ZM^2 - M\ell^{M_z} + \beta\ell^{M_z} = 0 \qquad \ldots\ldots\ldots\ldots \quad (11)$$

$$XM^2\ell^{M_z} + M\ell^{M_z} - \beta\ell^{M_z} = 0 \qquad \ldots\ldots\ldots\ldots \quad (12)$$

$$\left(ZM^2 - M - \beta\right)\ell^{M_z} = 0 \qquad \ldots\ldots\ldots\ldots \quad (13)$$

But $\ell^{M_z} \neq 0$

$$ZM^2 - M + \beta = 0 \qquad \ldots\ldots\ldots\ldots \quad (14)$$

Applying quadratic expression, we have

$$M_{1,2} = \frac{-1 \pm \sqrt{1+4\beta z}}{2z} \qquad \ldots\ldots\ldots\ldots \quad (15)$$

$$M_1 = \frac{-1 + \sqrt{1+4\beta z}}{2z} \qquad \ldots\ldots\ldots\ldots \quad (16)$$

$$M_2 = \frac{-1 - \sqrt{1+4\beta z}}{2z} \qquad \ldots\ldots\ldots\ldots \quad (17)$$

Therefore, $Z_{(Z)} = C_1 \ell^{M_{1z}} + C_2 \ell^{M_{2z}}$ ……………………….. (18)

$= C_1 CosM_{1Z} + C_2 SinM_{2Z}$ ……………………….. (19)

Solving from equation (3) gives

$$T_{(t)} = \ell^{\frac{-\lambda^2}{}t}$$ ……………………….. (20)

The express model in (20) streamline the rate of mix stiffness modulus of materials , this condition are reflected from the rate of accumulative load repetition, this expression determine the stiffness modulus of the material with respect to time of tensile stress and strain of the material through of fatigue on pavement failure. Subject to this relation, pavement developed fatigue at a very short time before the designed period.
Hence the solution of the equation can be expressed as

$Nf = C_1 \; and \; C_2$

$$Nf_{(Zt,t)} = \left(C_1 \, CosM_{1Z} + C_2 \, Sin \, M_{2Z}\right)\ell^{-\lambda^2 t}$$ ……………………….. (21)

The expression in (21) is the final developed mode to predict the mix modulus of material that reflect the failure of pavement, under the influence of stress and strain from load repetition, the issue of load repletion subject the pavement to stress. With the ever increasing truck tyre loading and inflation pressures, a better understanding of the pavement stress-strain behaviour is an enhancement in the development of more constitutive design models centered on pavement-traffic load response and distress minimisation. wide use of thin asphalt surfacing (≤50mm) in most developing nation are considered economical, this implies that further studies should be thoroughly carried out to predict the stress and strain influence on mix stiffness modulus of material from load repletion. More so there is needed to understanding the traffic load response of these layers. These parameters were subsequently correlated to the pavement service life in terms of the number of load repetitions to initiation of fatigue cracking (relative fatigue life). The stress-strain distributions and the three-dimensional stress state in relation to the asphalt surfacing layer thickness are also presented. This is under the influence of accumulative load repetition constantly subjecting the pavement to stress.

4. Conclusion

In observation of the present traffic rule, study's presently emphasis focused on high traffic loading which is considered as a major factor responsible for most pavement damage world-wide. The 1997 South African traffic statistics revealed that 35% of the 90 000 weighed heavy trucks were overloaded (De Beer et al, 1999). In most developing nation like Zambian weighbridge stations (Kafue) it was confirm on physically visit in 1998, 6 of the 25 weighed trucks between 08.00hrs to 16.00hrs were on average 12.5% overloaded above the 80kN legal axle-load limit. Thus, on average, one in every five trucks on the Zambian road could be overloaded. According to the "fourth power law", 12.5% overload results in about 60% more pavement damage compared to an 80kN legal axle load. Therefore is an imperative to take seriously look into the current standard design loads if modern pavements to sustain these extreme high loads. Traffic laws and regulations also need to be effectively enforced to minimize pavement damage. Nigeria is not left behind, constant repetition of load from different truck accumulate stress and strain consequently develop fatigue on pavement, More so most material characteristic strength are substandard in design material, in fact most roads are not designed developing pavement failure thus life span of the pavement cannot be determined. Subject to this ugly scourge, high rate of pavement failure are of high increase in Nigeria roads. The developed model will definitely predict mix stiffness modulus of the material and determine fatigue on pavement failure.

Thus, the tensile strength is one of the critical parameters to be always taken into consideration for performance evaluation. The evaluation of the fatigue life of a mixture is based on the flexural stiffness measurements. Tensile strain at the bottom of the asphalt concrete layer in a pavement is an important parameter in the measurement of fatigue life of a mixture. The bottom of asphalt concrete layer has the greatest tensile stress and strain. Cracks are initiated at the bottom of this layer and later propagate due to the repeated stressing in tension of asphalt concrete pavements caused by bending beneath the wheel loads. Ultimately, the cracks appear on the surface in the wheel paths which we characterize as fatigue cracking.

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