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Distress Effective Temperature For Asphalt Pavement Performance Evaluation

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Abstract

As the asphalt pavement mix is placed at a given project location, it will be simultaneously subjected to the local environmental conditions and traffic loading. Due to the viscoselastic nature of the asphalt pavement mix, its behavior is highly dependent on both temperature and rate of loading. The loading rate of the asphalt pavement mix depends on the speed of the traffic running on the road. The loading rate varies from short under freeway traffic to long under urban traffic. Low temperature coupled with a short loading rate is the best condition for an asphalt pavement mixture while high temperature coupled with a long loading rate represents the worst condition. This research purpose is to evaluate the asphalt pavement mix stiffness under fatigue and permanent deformation effective temperature at fast and slow loading rates using dynamic modulus analysis. With this approach, it is more convenient to describe the viscous component (loss modulus) as a function of the elastic component (storage modulus). There are four categories of mixes. Which are FLV, FHV, CLV and CHV. Among all, FHV shows stability in terms of stiffness at all levels of condition. It is valuable to give general guidance on the magnitude of the dynamic modulus range at the distress effective temperature of road traffic under tropical environments especially for pavement performance evaluation.

Keywords: Effective temperature, performance evaluation, dynamic modulus, asphalt pavement, stiffness, viscoelastic

Introduction

It is necessary for people who have interest in the pavement performance to understand pavement behavior especially under local environmental conditions. Repeated axle loading, the environment, and materials are some factors that affect pavement behavior. The test method for pavement behavior covers procedures for preparing and testing asphalt mixtures to determine the dynamic modulus and phase angle at a single effective temperature T_{eff} and the design loading frequency (Bonaquist, Christensen, & Stump, 2003). The dynamic modulus values that are

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measured at one T_{eff} and one design frequency are used as performance criteria for fatigue and permanent deformation resistance for asphalt pavement mixture. This method was designed for the Superpave mix sample using the Simple Performance Test (SPT). The primary difference in the SPT is the temperature for measuring the dynamic modulus. For fatigue, tests were performed at intermediate temperatures while high temperature was applied for the permanent deformation tests. The frequency of 10Hz can simulate for highway speed and 0.1Hz for creep intersection traffic (Bonaquist et al., 2003). In the United States, the T_{eff} for fatigue ranges from 12°C to 20°C and the T_{eff} for permanent deformation ranges from 25°C to 55°C (Ann Myers & John, 2005). Since Malaysia is in a tropical region, there has been a great difference in its temperature range. Pavement temperatures in peninsular Malaysia rarely fall below 30ºC in daylight hours, and usually lie within the range 35ºC to 55ºC.

The effective temperature measurement is one of the sustainability elements that exist in the pavement design process. The definition of sustainability in the pavement design is the process of identifying the functional requirements of a pavement, gathering relevant information (e.g., subgrade, traffic, weather), and then selecting and specifying materials and the pavement structural composition (Zhang & Mohsen, 2018). This sustainable element in pavement design is briefly discussed throughout this paper.

Literature Review

A better understanding of the fatigue behavior of asphalt mixtures is required to improve asphalt mixture design and asphalt pavement mix performance. Accurate prediction and evaluation of fatigue is a difficult task not simply because of the complex nature of fatigue phenomena, but also because fatigue testing is expensive and time-consuming (Kim & Little, 2005). The current testing method reported in National Cooperative Highway Research Project (NCHRP) 465, “Simple Performance Test for Superpave Mix Design” (2002), has proved that it is suitable for fatigue analysis to use the dynamic modulus Simple Performance

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Test (SPT). Accordingly, the dynamic modulus values at one effective temperature (T_{eff}) and one design frequency selection are typically used (Witczak, Kaloush, Pellinen, El-Basyouny, & Von Quintus, 2002). These parameters refer to performance criteria for fatigue cracking resistance of the asphalt pavement mixture to be used in conjunction with the Superpave Volumetric Mix Design Method. The fatigue effective temperature was mostly at medium temperature. This is further proven by Shenoy and Romero (2002) in the pavement distresses in WesTrack sections and found that E^* in the intermediate temperature range relates to fatigue cracking. The data are from the Federal Highway Administration (FHWA) project, in an attempt to introduce to practitioners the use of SPT for the first time in 2005. The data were collected at a permanent deformation effective temperature from 15 states in the United States. The samples were tested at five different groups of mixes. The mixes were the combination from two different nominal aggregate sizes and five different types of asphalt.

In a tropical environment, fatigue failure usually occurs at mid temperature and permanent deformation certainly occurs at high temperature. Alongside, the asphalt pavement material is sensitive to changes in temperature. At fatigue effective temperature (T_{eff}) is mostly stiffer than at permanent deformation T_{eff} resulting in much greater dynamic modulus being measured. However, it all depends on the nature of the surfacing material and sometimes these situations can be different. The ranking has been distinguished at two loading frequencies, which are 0.1Hz and 10Hz. At 0.1Hz represents the situation at creep intersection traffic and 10Hz represents traffic on highways. Past research suggests simulations of pavement loads using confining pressures greater than 207kPa (Bonaquist, 2008; Geng, Ren, Wang, & Gao, 2011; Witczak et al., 2002). The simulations of pavement loads in this research were using confining pressures of 250 kPa. This is to represent the most critical conditions of overloaded vehicles passing on the road. For asphalt pavement, the dynamic modulus value more than 2500 Mpa is specified as good performance (Hasim, Abd Hameed, Hye, Abdul Malek, & Mustafa, 1994).

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Methodology

The materials used are granite aggregate and two types of asphalt which are 80/100 Pen and 60/70 Pen. Based on the Superpave asphalt specification, penetration grade 60/70 of asphalt meets the physical property requirements of high temperature as well as low temperature in tropical countries (Hsu, Yang, & Wang, 2013; Nuttapom, Kunnawee, & Hussain, 2013). The four mixture categories are CLV, CHV, FLV, and FHV. The CLV and CHV mixture used 12.5mm nominal aggregate size. The FLV and FHV mixture used 9.5mm nominal aggregate size. For clearer view, the design matrices are shown in **Table 1**. The source of aggregate is from Kajang Rock Quarry. There are four stockpiles of aggregate consisting of two coarse and two fine materials. Representative samples for each stockpile were obtained, and washed sieve analysis was performed for each stockpile.

Table 1: Design Matrix

Nominal Aggregate Size	**Asphalt Grade**	**Mixture Category**	**Abbreviation**
12.5mm (C)	80/100 (LV)	Course-Low Viscous	CLV
	60/70 (HV)	Course-High Viscous	CHV
9.5mm (F)	80/100 (LV)	Fine-Low Viscous	FLV
	60/70 (HV)	Fine-High Viscous	FHV

A primary performance parameter for fatigue depends more on structural design and subgrade support than mix design (Brown, Kandhal, & Zhang, 2004). However, a better understanding of the behavior of asphalt pavement mix stiffness under fatigue T_{eff} is required to improve the mix design performance. In addition, fatigue damage occurs more frequently when the asphalt pavement layer is experiencing moderate to high temperatures (15ºC to 40ºC) (Harvey, Deacon, Tsai, & Monismith, 1995). The dynamic modulus range may represent fatigue failure that can occur at fatigue $T_{eff.}$. **Equation (1)** is the permanent deformation

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T_{eff} as reported in the NHCRP 465 (Witczak et al., 2002).

$$T_{eff}\,(FC) = 0.8\,(MAPT) - 2.7 \tag{1}$$

where:

T_{eff} *(FC)* = effective temperature in °C for fatigue cracking

MAPT = mean annual pavement temperature in °C at one third of the depth of the pavement layer

The surface temperature for pavement in Malaysia rarely exceeds 60°C. The mean annual pavement temperature at one third of the depth of the pavement layer (*MAPT*) is typically 35°C to 45°C (Adebayo & Muhammad, 2010; Smith & Jones, 1980). The author adopts 45°C in the fatigue T_{eff} in order to visualize the extreme temperature on the roadways in Malaysia.

taken:

MAPT = 35°C to 45°C

then:

$$T_{eff}\,(FC) = 0.8\,(45) - 2.7$$
$$= 33.3$$
$$\approx 33°C$$

Hence, the calculated fatigue T_{eff} is 33°C.

A key performance parameter in permanent deformation is depending largely on mix design (Brown et al., 2004; Nuttapom et al., 2013; Qiang, Fujian, Guofen, & Hongchang, 2013). High temperatures in the upper 100mm of the asphalt layer contribute to permanent deformation. It is because temperatures above 30ºC near the surface of the asphalt pavement are important for predicting permanent deformation. Obviously, more frequently permanent deformation happened because of higher surface temperatures due to higher air temperature, and less

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rainfall (Ongel & Harvey, 2004). **Equation (2)** is the permanent deformation T_{eff} as reported in the NHCRP 465 (Witczak et al., 2002).

$$T_{eff}\ (PD) = 30.8 - 0.12Z_{cr} + 0.92(MAAT + K_{\alpha}\ .\ {}_{\sigma}MAAT) \qquad (2)$$

where:

$T_{eff}(PD)$	= effective temperature in °C for permanent deformation
Z_{cr}	= critical depth in mm of the mix layer in question
$MAAT$	= mean annual air temperature in °C
$K\alpha$	= value computed from the normal probability table related to designer selected level of reliability
$\sigma MAAT$	= standard deviation of the mean annual air temperature

The critical depth was taken as 40mm and this depth is the relevant depth of thick pavement (Smith & Jones, 1980). The mean annual air temperature for Malaysia was taken as 28°C (Jabatan Kerja Raya, 2008). While a level of reliability (K_{α}) was estimated at 2.055 (Huang, 2002). The annual mean surface air temperature (${}_{\sigma}MAAT$) is 0.6 and changes by early, middle and late 21st century. From 2011 to 2030 the scenarios are the same by early, middle and late 21st century (Valentin, Veronika, Vladimir, Tatyana, & Igor, 2010).

taken:

Z_{cr}	= 40mm
$MAAT$	= 28°C
K_{α}	= 2.055 at 98% reliability
${}_{\sigma}MAAT$	= 0.6

then:

$$T_{eff}\ (PD) = 30.8 - 0.12\ (40) + 0.92\ [28 + (2.055 \times 0.6)]$$
$$= 52.9$$
$$\approx 53°C$$

Hence, the calculated permanent deformation T_{eff} is 53°C.

Results and Discussions

The mix ranking analysis helps to identify the necessary changes in mix properties

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that will improve its resistance to fatigue and permanent deformation at the highway and intersection. Some mix properties which do not achieve satisfactory criteria at fatigue T_{eff} or permanent deformation T_{eff} can be easily modified during production. This will also lead to substantial improvement in the response of the asphalt pavement mix. The critical condition in this case refers to the 250kPa confined specimens. The confinement of the specimens is to simulate heavy loaded vehicles running on the road. Accordingly, the dynamic modulus value in fatigue T_{eff} decreases as the confinement level increases, while, the dynamic modulus value in permanent deformation T_{eff} increases as the confinement level increases.

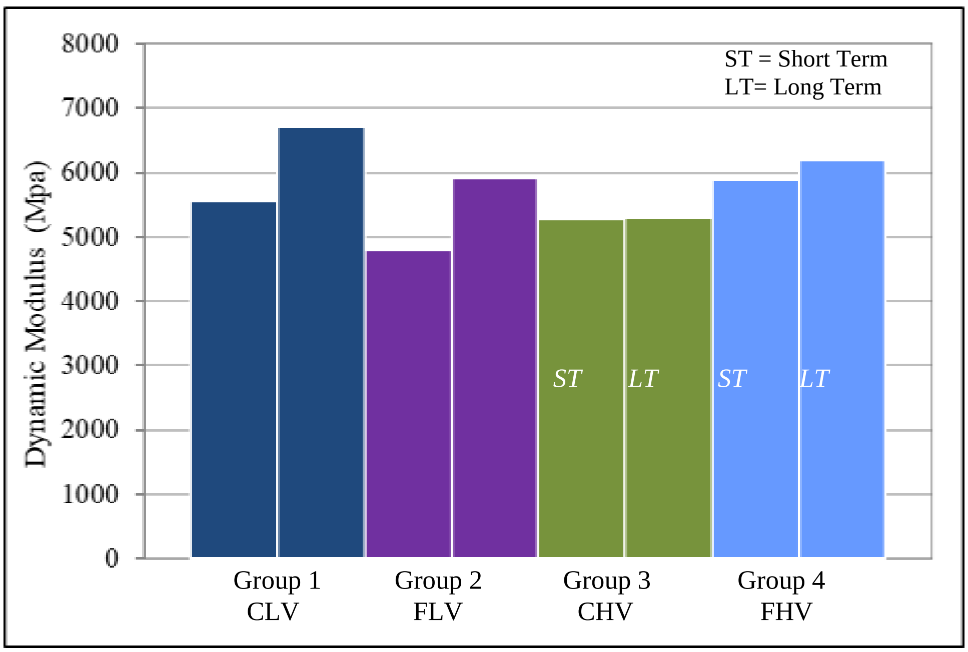

Figure 1: Mix Ranking at Fatigue T_{eff} (10Hz)

A distinct pattern in fatigue effective temperature (T_{eff}) has high dynamic modulus values showing that these mixes were stable. However, the interpretation of good performance does not rely on the high dynamic values only. Dynamic modulus represents both the viscous and elastic components of mixture stiffness. As the asphalt pavement ages, the dynamic modulus value increases. This shows

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that the specimen loses its viscous component (loss modulus) and increases its elastic component (storage modulus). High elastic component means the specimen becomes more brittle as it is aged and thus indicates that the specimen is more susceptible to fatigue. **Figure 1** shows mix ranking at fatigue T_{eff} of 10Hz. It seems that the CLV mix is possibly prone to fatigue failure because when the mix ages, the elastic component is higher. It gives guidance that the CLV mix is probably not the best choice for long-term performance.

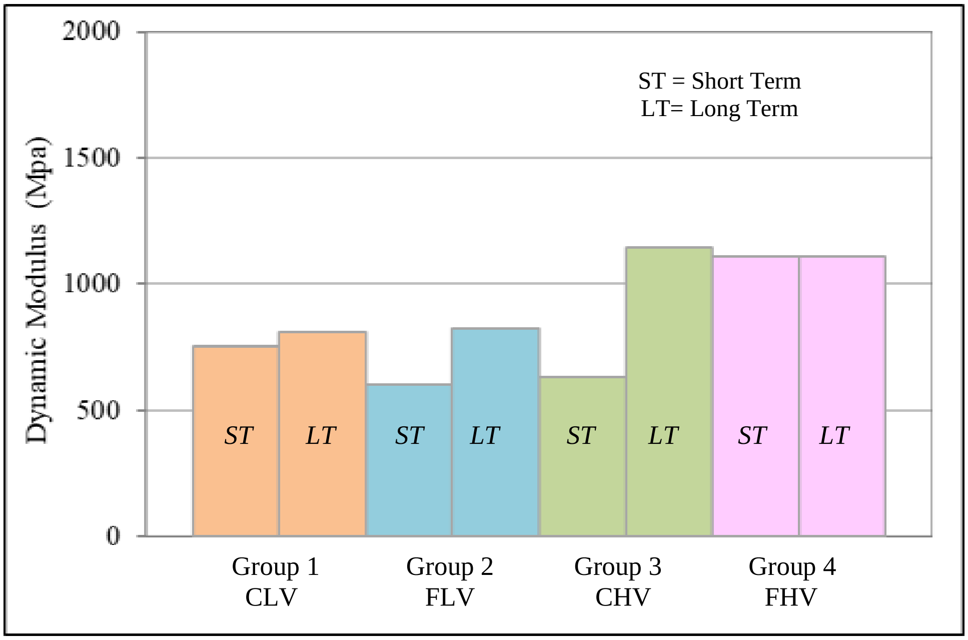

Figure 2: Mix Ranking at Permanent Deformation T_{eff} (10Hz)

Figure 2 demonstrates the mix ranking at 10Hz of permanent deformation effective temperature (T_{eff}). An obvious pattern in permanent deformation T_{eff} has very low dynamic modulus values. However, low dynamic modulus is common as temperature increases. From the column chart, very low dynamic modulus as it ages for CLV group. It appears that the CLV mix is not able to resist deformation when it ages because the specimen loses its elastic component (storage modulus) and increases its viscous component (loss modulus), where the viscous component is too apparent. This means that the specimen has bad bonding between asphalt and aggregate when they aged. It gives guidance that the CLV mix will not be

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able to perform for long-term operation on the highway.

Conclusions and Recommendations

Frequency curves limits for dynamic modulus and phase angle to control thermal cracking, fatigue, and permanent deformation. A range frequency limit for phase angle peak may serve as control for thermal cracking, fatigue, and deformation since phase angle value represents the amount of viscous and the elastic component of the mixture's stiffness. These maximum and minimum limits could also be used in an asphalt-aggregate mixture specification for application in the field. The research had shown the potential of using dynamic modulus to identify those mixtures that would exhibit fatigue and permanent deformation. Generally, fatigue starts two years after construction. This means, the long-term condition, best describes the performance towards fatigue resistance. Permanent deformation begins right away after construction. Therefore, the short-term condition best describes the performance towards permanent deformation resistance. This tends to confirm that the fine mixes exhibited less fatigue cracking and permanent deformation. In conclusion, a maximum limit of dynamic modulus, or storage modulus at the fast loading rate could serve as a limit to control fatigue because this value represents the mixture's elastic behavior of which is susceptible to fatigue. Similarly, a minimum limit of dynamic modulus, or loss modulus at a long loading rate could serve as a lower limit to control permanent deformation because this value represents the mixture's viscous behavior, which relates to permanent deformation.

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