



## STIFFNESS MODULUS PROPERTIES OF HOT MIX ASPHALT CONTAINING WASTE ENGINE OIL

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### ABSTRACT

This study presents the effect of waste engine oil (WEO) on the mechanical properties of hot mix asphalt mixtures. It was added into mixture at 0%, 3%, 5%, 7%, 10% and 15% by weight of binder. The mechanical properties of the mixes were evaluated by conducting indirect tensile stiffness modulus (ITSM) at temperatures of 25°C and 40°C. The results indicated that modified mixes exhibited lower stiffness modulus with the increasing amount of WEO as well as testing temperature. The increasing amount of WEO was found to have a good linear correlation to the decreasing of stiffness modulus. The finding showed that the WEO has the significant role as a softening agent which affected the stiffness modulus even at low percentage.

**Keywords:** stiffness modulus, waste engine oil, modified mixture, hot mix asphalt.

### INTRODUCTION

Nowadays, there are many vehicles used all over the world due to the economic growth and modernisation. It includes Malaysia as one of the developing countries. According to the motorcar registration statistics released by the Malaysian Road Transport Department, about 11 million motorcars were registered in Malaysia until 31st December 2013 [1]. After a specific time or mileage usage, the motorcars need to be serviced in order to ensure good conditions and performance. One of the compulsory changing is the engine oil. In a single motorcar oil change, about 4 to 5 liters of WEO can be produced. The improper disposal of this WEO can lead to water and soil pollution [2]. The effect can be seen by eutrophication process. The thin layer of oil appears on the surface of river or lake can block the sunlight, the photosynthesis and also disrupting the oxygen supply to the aquatic life [2-3]. These processes lead to the excessive growth of micro-organism, phytoplankton and algae that use the WEO as a food source. Lake or river quality was deteriorating and also disrupted the intrinsic equilibrium of the aquatic ecosystem.

In the asphalt pavement construction, WEO can be used as potential binder replacement due to the resemblance of their chemical constituent [4]. WEO prominently affects the properties of asphalt binder. Villanueva *et al.* [5] found the penetration value of bitumen increased with the increasing amount of WEO. In terms of aged binder, it was found that the viscosity of aged bitumen was reduced [6], permanent deformation is slightly decreased with respect to the original bitumen [8-9] and increased mix compatibility [9]. This characteristics encourage the exploration WEO as the alternative rejuvenator to renewable or restore the properties of aged bitumen [10]. Additionally, Borhan *et al.* [11] conducted the laboratory evaluation of low cost cold asphalt which modified with 0, 20, 25 and 30% of used cylinder WEO by weight of binder content. As the amount of used cylinder

WEO increased, the creep stiffness decreased. The WEO weakens the bonding between the binder and aggregate within the cold mix. The addition of WEO to the cold asphalt mixture made asphalt pavement become susceptible against permanent deformation. The stiffness also was reduced about 28% compared to the control mixtures (without WEO) at the temperature of 40°C. This is due to the lower viscosity offered by the waste engine WEO deteriorating the mastic bonding. Literature review has shown that limited investigation on the effects of WEO in hot mix asphalt (HMA). Hence, the aim of this paper was to investigate the effect of low range percentage of waste engine WEO to mechanical properties of the pavement mixture in terms of stiffness modulus.

### MATERIALS AND METHODS

The bitumen of penetration grade 80/100 supplied by Kemaman Bitumen Company was used as a base binder. The aggregate was obtained from Hanson Quarry Batu Pahat, Johor. Meanwhile, the WEO was collected from a workshop in Batu Pahat, Johor. In this experiment, the amount of WEO was added at 0%, 3%, 5%, 7%, 10%, and 15% of the weight of bitumen. The WEO and bitumen were mixed using a high shear mixer at 600 RPM for 15 minutes in order to ensure WEO spread uniformly in the bitumen. Then, the modified binder was mixed with aggregate for further testing. The specimens were prepared at 4% air void using Superpave specification at 7% optimum bitumen content (OBC).

### Indirect tensile stiffness modulus (ITSM) test

Stiffness modulus is an important mechanical characteristic of the road base and base-course layers. This test describes a material stiffness that most closely simulates the behavior of material under a moving wheel [12]. Basically, the term stiffness refers to stress divided by corresponding strain [13]. The stiffness can be easily measured by Indirect Tensile Stiffness Modulus Test



(ITSM) by using Universal Testing Machine (UTM-5P). The test conducted was in accordance to BS DD 213 Method for the determination of the indirect tensile stiffness modulus of bituminous mixtures which is a non-destructive test [14]. The test was conducted by applying five pulse loads with a suitable waveform. This repeated load generates movement (strain) along the vertical plane of cylindrical specimen. The load was applied for a period of 0.1 seconds and rest period (load is released) of 0.9 seconds. Therefore, the stiffness modulus,  $S_m$  can be determined using the equation below:

$$S_m = \frac{P(\nu + 0.27)}{Dt} \quad (1)$$

Where;

- $S_m$  = indirect tensile stiffness modulus (MPa),
- $P$  = applied load (N),
- $\nu$  = Poisson's ratio - 0.35 for temperature 25°C,
- $D$  = mean amplitude of horizontal deformation obtained from 5 applied of the load pulse (mm) and
- $t$  = mean thickness of the test specimen (mm)

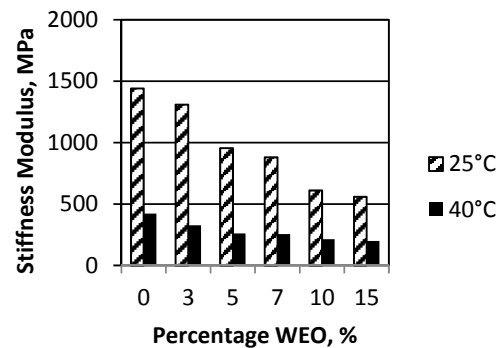
The test temperature is at 25°C which indicates the mixture's resistance to fatigue, whereas the  $S_m$  at 40°C indicates the mixture's resistance to rutting [15]. All of the specimens were conditioned in the chamber at a set temperature for 2 hours before testing. Each sample was tested 3 times with a different angle that is 0, 45 and 90 degree. Then, the average of these angles was computed as the stiffness modulus for the sample [12].

## RESULTS AND DISCUSSIONS

### Indirect tensile stiffness modulus (ITSM) results

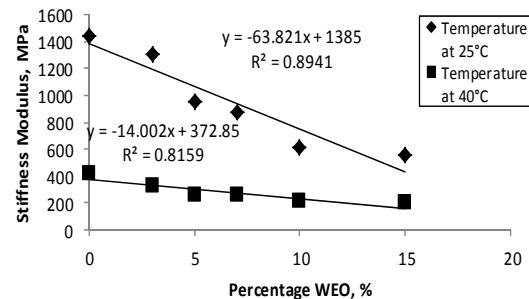
Figure-1 shows the ITSM results for temperature of 25 °C and 40 °C. The results showed that the stiffness modulus apparently decreases with the increasing temperature as well as the WEO percentage. The modified mixture showed a decrease of stiffness modulus with mean value of 1310 MPa (3% WEO), 955 MPa (5% WEO), 880 MPa (7%WEO), 611 MPa (10% WEO) and 559 MPa (15% WEO) as compared to control, 1442 MPa at the emperature of 25 °C. Meanwhile, the graph of 40 °C temperature showed that there has been a gradual decline of the stiffness modulus with a mean value of 421 MPa (0% WEO), 327 MPa (3% WEO), 261 MPa (5% WEO), 255 MPa (7% WEO), 213 MPa (10% WEO) and 200 MPa (15% WEO). This is due to the softening of the bituminous binder as the temperature and WEO percentage increased. These results are consistent with Borhan *et al.* [11] and suggested that higher WEO content caused the mixture to be unable to bond strongly with the aggregate. The WEO mainly functioned as softening agent to the asphalt binder which reduced the viscosity and increased the rutting susceptibility [8]. As a result, the

strain is increased under applied load, and thus it will lower the stiffness modulus of the modified mixture [16].



**Figure-1.** Comparison of stiffness modulus of different percentages WEO at 25 °C and 40 °C.

In order to correlate between the stiffness modulus and WEO percentage, linear regression was used and the equations were obtained. The accuracy of the equations was verified by the coefficient of correlation ( $R^2$ ). According to Figure-2, it was observed that there are good correlations between the results.  $R^2$  shows the significance of the contribution of WEO content to the stiffness modulus value. In general, the increasing of WEO amount tends to result the decreasing of stiffness modulus



**Figure-2.** Relationship of stiffness modulus and percentage WEO.

## CONCLUSIONS

In conclusion, WEO modification has weakened the performance of the mixture compared to the control mixture (0% WEO). The presence of the WEO has decreased the stiffness modulus of the mixture. The result of this study indicates that WEO has a significant role to soften the mixture and it suggests that the application of the WEO need to be restricted when blending directly with base bitumen. Therefore, the usage of WEO in HMA is not suitable at the moment. However, the WEO can potentially be applied in RAP due to its rejuvenating characteristics which can revive the aged binder. It is expected that the presence of RAP which contributed the



high stiffness in pavement mixture can be compensated by the addition of WEO.

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