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Rutting Evaluation of Aged Binder Containing Waste Engine Oil

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Abstract: The stiffness of aged binder is highly contributed to the workability problem. Rejuvenating agent such as waste engine oil (WEO) is one of the sustainable modifiers that can be used to improve and attain the desired performance of the aged binder. However, concern arises on the consistency of the engine oil properties due to its unknown history usage. This study focused on the rutting properties evaluation of the partial aged binder integrating with engine oil (new and waste sources) using Dynamic Shear Rheometer (DSR). The findings showed that, the addition of WEO affects the rutting performance under ageing condition. From the isochronal curve, the complex modulus, G* of the rejuvenated binder was found lower than the aged binder at un-aged condition. However, after ageing process, the stiffness of the rejuvenated binder was increased and the phase angle, δ decreased obviously compared to virgin binder. The critical temperature of the binder was not differing substantially particularly under ageing. Meanwhile, the ageing index rutting factor (AIRF) clearly summarised that the rejuvenated binder with WEO with higher mass loss more susceptible to ageing.

Introduction

The construction of road infrastructure is a continuous process that required substantial demand of non-renewable materials i.e. bitumen. Additionally, fast depletion of natural materials also has impelled the asphalt industries to find another alternative source to construct sustainable and economical road without disregarding the quality. Due to this factor, the use of reclaimed asphalt pavement (RAP) has gained high interest in road construction. During the pavement service life, the asphalt binder has a potential to become aged or hardened due to the exposure to ultraviolet (UV) radiation and oxygen. Unmodified of RAP can produce stiffer asphalt bitumen [1] that can cause a workability problem [2]. The hardening effect of this aged binder can be offset by using a soft binder or rejuvenating agents. The criteria selection of rejuvenator is that, it must be able to coat sufficiently the fresh and RAP material, disperse easily in old binder and produce a uniform batch to achieve the desired level [3]. From the previous study, one of the waste materials that are able to be used as rejuvenator is waste engine oil [3,4]. However, the unknown history of the waste engine oil and the ability of the modifier to achieve the desired criteria have become the main concern among practitioners and justification is needed. At high temperature, rutting is the predominant damage on the pavement surface. Hence, this paper focuses on the rutting evaluation of partial aged binder (extract and recovered from field samples) containing waste engine oil and then compared with the binder containing new oil (un-used).

Materials and methods

The bitumen of penetration grade 80/100 supplied by Kemaman Bitumen Company was used as a virgin binder. The RAP source was obtained from surface layer milled from section 137.183 to

137.673 in Johor Route State J5, Johor, Malaysia. The RAP materials were then extracted in accordance to ASTM D2172-11(Standard Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures) using centrifuge apparatus and Methylene Chloride as the solvent. The solution then evaporated using vacuum rotary evaporator to separate the binder and the solvent. The product of bitumen extracted from RAP materials is termed as aged binder (AB). The proportion of RAP used in this study is 50% from total mass of binder as recommended by the previous researcher [6]. In addition, virgin binder is also considered to contribute to the softening effect of the aged binder. For the purpose of comparison, two types of engine oil were used i.e. waste oil (WO-used oil) and new oil (NO-un-used oil), which are from the same brand. The basic properties of the engine oil are given in Table 1. The oil was blended with the binder at the minimum amount that can produce the penetration value as the virgin binder [4] at the temperature of 150°C with 600 rpm. The penetration of the virgin binder was obtained at 88.10 dmm and 15% of engine oil (by weight of the binder) was required to achieve the similar range of penetration value. The sample was then subjected to short term ageing and stimulated using rolling thin film oven (RTFO) procedure. The samples were tested using the Dynamic Shear Rheometer (DSR) for getting the bitumen rheological properties at temperature range of 46 - 82°C. However, the presence of aged binder has increased the testing temperature. Table 2 gives the designation and detailed constituents of the tested binder.

Table 1: Basic properties of used and un-used engine oil

Properties	Sources	
	Waste Oil	**New Oil**
Viscosity (cP), 60°C	33.25	N/A
Flash Point,°C	193	228
Fire Point, °C	210	N/A
Loss on heating, °C	4.45	0.42
Oil type	Synthetic	Synthetic
Viscosity Grade based on Society of Automotive Engineers (SAE)	10W/40	10W/40
Millage usage, km	5000 – 7000	N/A

Table 2: Designation and constituents of binder

Designation	Constituents
Binder A	Virgin binder
Binder B	Virgin binder + aged binder
Binder C	Virgin binder + aged binder + waste oil
Binder D	Virgin binder + aged binder + new oil

Results and discussion

Effect on Isochronal Curve. The isochronal curves is the variation of complex shear modulus, G* and phase angle, δ with temperature at a selected frequency [7]. Figure 1 shows the corresponding relationship of G* and δ for un-aged and short term aged conditions (after RTFO) at the oscillation speed of frequency 10 rad/s (approximately 1.592 Hz). This is to simulate the traffic at the speed of 75-90 km/h [7,8]. Waste engine oil appears to reduce the stiffness of the partial aged binder under un-aged condition. Binder D (new oil) produced higher stiffness than binder C (waste oil). Other researcher [10] also found that the complex modulus of the rejuvenated binder is lower than the aged binder. This proved that WEO soften the aged binder. However, the complex shear modulus, G* and lower phase angle particularly for binder C were more pronounced after ageing in RTFO as indicated by upward shift of the line. This could be due to the higher rate loss of volatile component of the waste oil that could cause binder hardening [3]. This is supported by the previous study which also found that the aged binder with waste engine oil exhibited higher loss in mass that exceed the allowable limit of 1% [2].

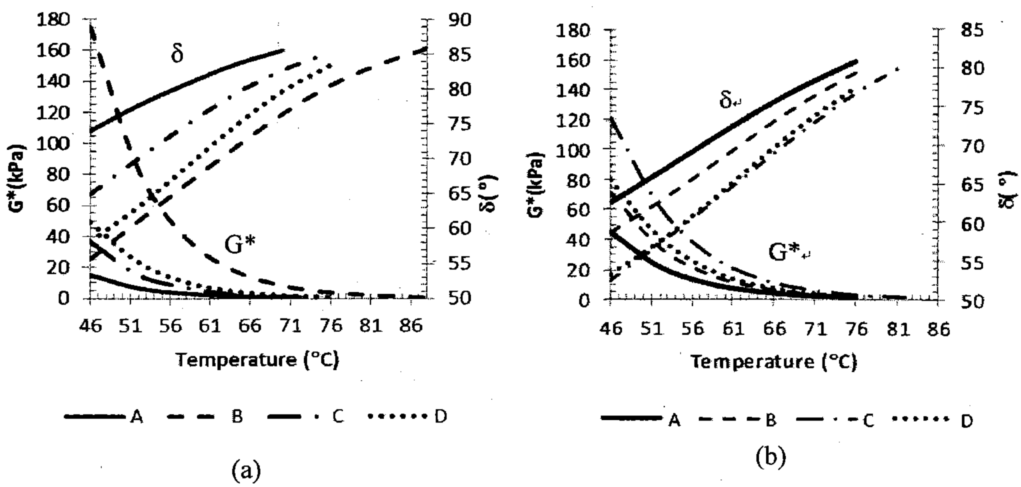

Figure 1: Complex shear modulus as function of temperature (a) un-aged condition (b) short term aged condition

Effect on Rutting Resistance

There are two rheological parameter developed in Strategic Highway Research Program (SHRP) test series, i.e. G*/sin δ or "rutting factor" and G*.sin δ or "fatigue resistance". However, this study discusses only on the property subjected to rutting factor. Figure 2 shows the result of rutting resistance for un-aged and short term ageing condition obtained from DSR test. HAAKE software was set for a number of repetitions to obtain an average value. For this study, 10 cycles was used and the test temperature range between 46 and 88°C. The rutting factor was automatically calculated and also checks if the compliance is fulfilled. The compliance of rutting factor, G*/sin (δ) equal to 1 kPa for un-aged (refer dashed line in Figure 2(a) and 2.2 kPa for aged binders after RTFO (refer dashed line in Figure 2(b). For un-aged condition, binder B exhibited the highest rutting resistance. This could be due to the presence of the aged binder from RAP. However, with the addition of WEO, the rutting resistance was reduced. Surprisingly, after exposed to short term ageing condition, binder C containing waste engine oil exhibited highest rutting resistance, indicating the addition of waste engine oil has the positive effect on rutting resistance.

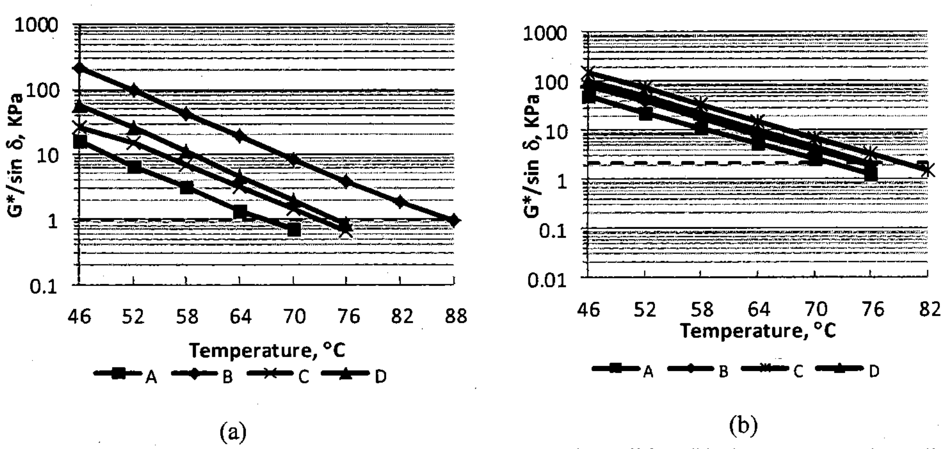

Figure 2: Phase angle as function of temperature (a) un-aged condition (b) short term aged condition

Failure Temperature

Failure temperature is the additional indicator in rutting evaluation [11]. The higher failure temperature values is the desired attributes which demonstrates that the binders are less susceptible to permanent deformation at high temperature [12]. This information provided the useful reference to the contractor for pavement construction process and understanding of the material behaviour under temperature effects. Table 3 shows the failure temperature of the binders. Binder B showed the highest failure temperature meanwhile binder A has the lowest under un-aged condition. Similar to rutting resistance results, highest stiffness of binder B showed significantly higher failure temperatures than others. After the RTFO ageing process at 163°C for 85 minutes, binder C exhibited the highest failure temperature and binder A maintains the lowest among all. Binder B and D does not vary significantly indicated new oil does not affected the binder properties under ageing conditions.

Table 3: Failure temperature of binder

Binder type	Failure temperature (°C)	
	G*/sin δ = 1.0 kPa (Un-aged)	G*/sin δ = 2.2 kPa (RTFO)
A	67.39	71.97
B	84.78	75.17
C	73.66	79.77
D	75.18	75.69

Ageing Index Rutting Factor

The ageing index rutting factor is an alternative options to clearly express the effects of ageing of binder [13]. Ageing index rutting factor can be defined as the ratio of rutting factor of aged binder to the original binder as illustrated in Equation 1. Generally, higher value of AIRF describes the binder is more susceptible to ageing [10,11]. Table 4 shows the AIRF value at the reference temperature of 64°C [16]. The binder C (with waste engine oil) exhibits lower resistance to oxidation compared to binder with new oil (binder D). This finding is due to high increased for G*/sin δ as induced by ageing [14]. The lowest AIRF denotes by binder B indicates that aged binder is less susceptible to temperature after ageing due to increased complex shear modulus [13].

$$AIRF = \frac{G*/\sin(\delta)aged}{G*/\sin(\delta)un\text{-}aged} \tag{1}$$

Table 4: Ageing index rutting factor at the temperature of 64°C

Binder type	Ageing index rutting factor
A	3.822
B	0.442
C	5.010
D	2.187

Conclusion

Based on the result, it can be concluded that waste engine oil can performed well compared to the new engine oil as rejuvenator for aged binder. Waste engine oil in the partial aged binder that denotes as C produced the higher value of stiffness and failure temperature after ageing. These characteristics are desired for rutting resistance as it improves high temperature performance. However, the concern is that it tends to become brittle that could lead to cracking problem.

Moreover, from the AIRF value, the binders containing waste engine oil are susceptible to ageing. These binders are recommended for further investigation using advanced asphalt binder testing, Fourier Transform Infrared Spectroscopy (FTIR) to give the insight view of the chemical changes in the rejuvenated binder.

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