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RHEOLOGICAL AND ENVIRONMENTAL EVALUATION OF RECLAIMED ASPHALT INCORPORATING A WAX ADDITIVE

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ABSTRACT

This study evaluates the rheological properties and environmental impact of reclaimed asphalt binder with wax additive named RH-WMA. The virgin binder was blended with a high percentage of reclaimed asphalt binder obtained from three road sources. The rheological properties were assessed from the viscosity test results and rheological master curve. The results showed that the addition of RH-WMA enables reduction in production temperature. The rheological master curve indicates that the source of reclaimed asphalt affects the rheological behavior. The addition of reclaimed asphalt binder showed improvements in rheological properties at high temperature. However, the addition of RH-WMA improved the low temperature performance of reclaimed binder.

The environmental evaluation suggests that RH-WMA could potentially reduce the fuel requirement and Greenhouse Gas emissions. The integration of reclaimed asphalt and wax warm mix additive can be an alternative material for sustainable road construction.

Keywords: Greenhouse Gas Emissions, Reclaimed Asphalt Binder, Viscosity, Rheology, Wax Additive

I. INTRODUCTION

Waste materials produced from construction and maintenance works continuously threatened the environment and public health. Related industries have tried to minimize the environmental effects by developing new technology to recycle the waste material. In the asphalt industry, recycling of secondary material such as aggregate and binder contributes to the decrement of the environmental load, public health and construction cost.

Past research reported that utilizing recycle asphalt for pavement construction could potentially reduce the global warming, energy consumption, water consumption, life cycle cost and hazardous waste by 20, 16, 11, 21 and 11%, respectively [1]. A hybrid life cycle assessment on asphalt mixtures showed a significant reduction in energy consumption and greenhouse gas emissions with the increasing amount of reclaimed asphalt (RA) pavement added into the mixture [2]. However, increased stiffness of binder due to the increment of RA content requires very high production temperature. The use of warm mix asphalt (WMA) technology to reduce the production temperature has been recently researched particularly with a high amount of RA. WMA additive can reduce the production temperatures between 10 and 38°C lower than traditional HMA temperatures [3]. This will in turn reduce fuel usage as well as emissions directly related to the fuel usage. The discharge of gaseous pollutants (CO, NOx, and SO_2) and greenhouse gasses (CO_2) will be lowered. In addition, it will result in a reduction of hazardous air pollutants release into the atmosphere and provide a safer working environment for the workers. Based on the World Bank estimation, for each 10°C drop in the mixture manufacturing temperature, it reduces fuel oil consumption by 1 liter and CO_2 emission by 1 kg per ton [4]. Consequently, utilizing RA and WMA additive will support the effort to develop sustainable pavement production.

The extent of viscosity reduction depends on the types of WMA additive. Wax type of additive showed significant viscosity reduction when incorporated into RA due to the melting point of the wax ([5, 6]. The reduction in viscosity decreases the aging of RA binder because the mixture can be produced at a lower temperature. Wax additives such as Sasobit have been commercially used in WMA and incorporated to various percentages of RA. Mixture performance incorporating Sasobit and RA showed that the WMA additive produced a more uniform mixture [7]. Sengoz [8] compared the strength of reclaimed asphalt with WMA (RA-WMA) produced from different types of WMA additive and concluded that wax additive exhibits the highest strength. On the other hand, mixtures performance containing RA also affects the composition in RA. According to Al-Qadi [9], the source of RA, type of aggregate, type of binder, additives, the level of damage and methods of storing; all affect mixture performance. Another research reported that the rheological properties of recovered RA blends at intermediate to high temperature performance influenced by the RA source, content, aging and test temperature affects the rheological properties[10]. This indicates that to utilize the RA for road construction and maintenance, it needs proper evaluation.

Based on the reported benefits of utilizing RA and WMA, and factors that influence the mixture performance, it is necessary to investigate the rheological properties of RA with wax additive. Environmental evaluation will provide an indication of the sustainability of the materials. This paper presents the rheological and environmental evaluation of RA incorporating a wax additive named RH-WMA.

II. MATERIALS AND METHODS

2.1 Materials

A PG64 asphalt binder supplied by a local company in Malaysia was used as a base binder. Performance grading, as suggested by the Strategic Highway Research Program (SHRP), was used to evaluate the asphalt binder properties. Table 1 shows the basic rheological properties of the virgin base binder.

Table 1: Properties of virgin PG64 binder

Properties	Value
Viscosity at 135^{o}C [Pa.s]	0.432
G*/sin δ at 64^{o}C [kPa]	1.529
Failure temperature [^{o}C]	67
Penetration [dmm]	87
Softening point [^{o}C]	46
Flash point [^{o}C]	331
Ductility	>100
Specific heat capacity [J/kg/°C]	920

A wax WMA additive named RH-WMA, developed in China, was used as an additive. RH-WMA is made of polyethylene wax based additive and produced from cross-linked polyethylene. The optimum amount of RH-WMA added to the virgin binder was 3%.

The RA was obtained by milling process from three local roads at difference state in Malaysia. These roads have been trafficked about 5-7 years. In this paper, the roads named as R1, R2 and R3. The RA aggregate and binder was separated using solvents, and the extracted binder were further recovered via rotary evaporator. The amount of RA binder incorporated with virgin binder was 50%. Table 3 shows the rheological properties of the recovered binder.

2.2 Methods

2.2.1 Sample Preparation

The RAP binder was blended manually with PG64 virgin binder at 140 °C for 5 minutes under controlled temperature. For blending the RAP binder with RH, the temperature increases to 160 °C with 10 minutes blending duration. The blending temperatures of RH-WMA were based on the manufacturer recommendation, while the blending temperature of RA binder is based on previous research [11].

2.2.2 Viscosity Test

Viscosity test was performed to measure the flow of binder that enables sufficient fluidity during asphalt production in the mixing plants. The rheological properties of the reclaimed asphalt binder at very high temperature were evaluated using rotational viscometer. The viscosity test was carried out at temperatures ranging from 120 to 170ºC at 10ºC increment using spindle number 21 in accordance with the Asphalt Institute procedure [12].

2.2.3 Frequency Sweeps

Evaluation of rheological properties of the binder from low to high temperature was conducted using the Dynamic Shear Rheometer (DSR). The test was performed in an oscillatory type testing mode via 8 mm diameter plates with a 2 mm testing gap and 25mm with 1 mm thickness. The appropriate size of the plate was determined based on the stiffness of the specimen. For determining the linear viscoelastic region, amplitude sweeps were carried out at 10 and 40°C on 8mm and 25mm plate, respectively. From the amplitude sweep test,

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the strain of 0.1 % was employed for performing the frequency sweeps from 0.1 to 10Hz at temperatures ranging from 5 to 65 °C.

2.3 Aggregate Gradation and Mix Design

Granite and RA aggregate were graded and blended in accordance with the Malaysian Public Works Department (PWD) specifications for AC14 Marshall mix design [13]. The mix specification was adopted from previous research by Hamzah et al. [14] and shown in Table. 2. The granite aggregate specific heat capacity at ambient temperature was 790J/kg/°C.

Table 2: Mixture properties of AC14 based on PWD specification; source: [14]

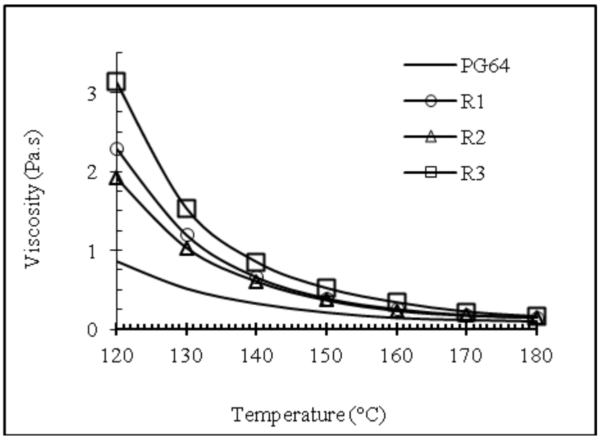
Properties of Mixture	Value	Prescribed ranges by PWD
Optimum binder content [%]	5.0	4-6
Air void [%]	3.90	3-5
VFA [%]	75.60	70-80
VMA[%]	15.37	-
Density	2.38	-
Stability[kN]	20.64	More than 8.00

[a] Void filled with asphalt; [b] Void mineral aggregate

III. RESULTS AND DISCUSSION

3.1 Effects of Reclaimed Asphalt Binder on Viscosity

The relationship between viscosity and temperature of RA binder are illustrated in Figs. 1 and 2. In general, the viscosities of the RA binders are different. As indicated in Table 3, the R3 is the stiffest binder followed by R1 and R2. This trend is an agreement with the viscosity result. The stiffest binder has a higher viscosity and therefore, requires a higher production or mixing temperature. The addition of RH-WMA decrease the viscosity and mixing temperature (Fig. 2). For example, the viscosity of R3 reduces from 3.14 to 1.89 Pa.s. Addition of RH-WMA decreases the mixing temperature by about 39.8%. At 120°C, the addition of RH-WMA reduces the viscosity of R1, R2 and R3 by 31.3, 35.6 and 39.8 %. There is less reduction in viscosity as the temperature increase. The decrement of viscosity is influenced by the source and stiffness of RA binder. The corresponding mixing temperature based on the viscosity is presented in Table 3. In this study, the mixing temperature obtained from the graph of viscosity for RA binder with RH-WMA viscosity are further reduced to 20°C.



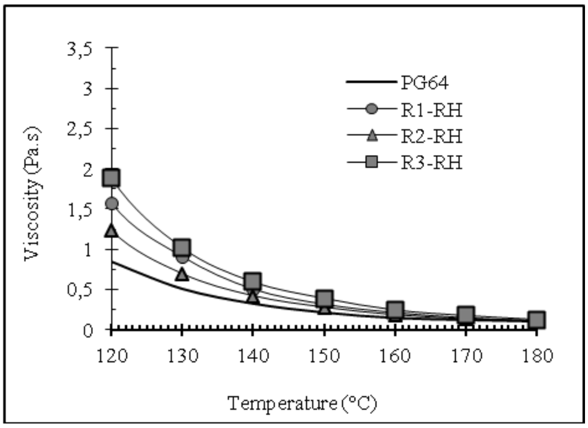


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Figure 1: Viscosity of base binder and reclaimed asphalt binder

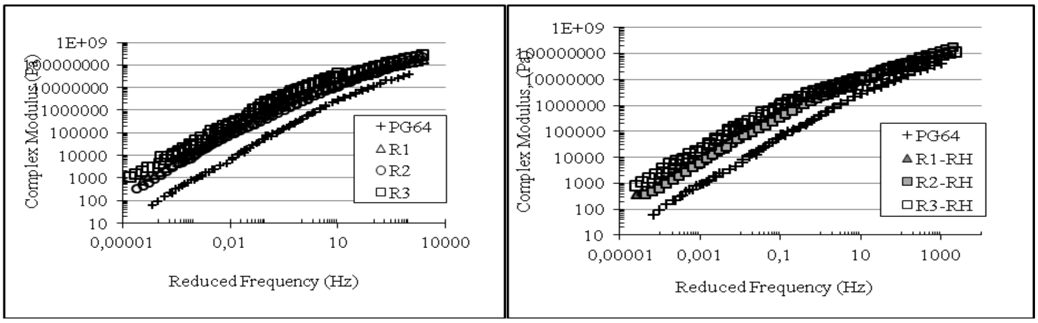
Figure 2: Viscosity of base binder and reclaimed asphalt binder with RH-WMA

Table 3: Rheological properties and mixing temperature of reclaimed asphalt binder blends

Binder Designation	Penetration at 25°C[dmm]	Viscosity at 135°C [Pa.s]	Mixing temperature [°C]
R1	24	0.912	170
R2	32	0.761	168
R3	22	1.112	176
R1-RH	38	0.686	146
R2-RH	43	0.541	142
R3-RH	30	0.762	152

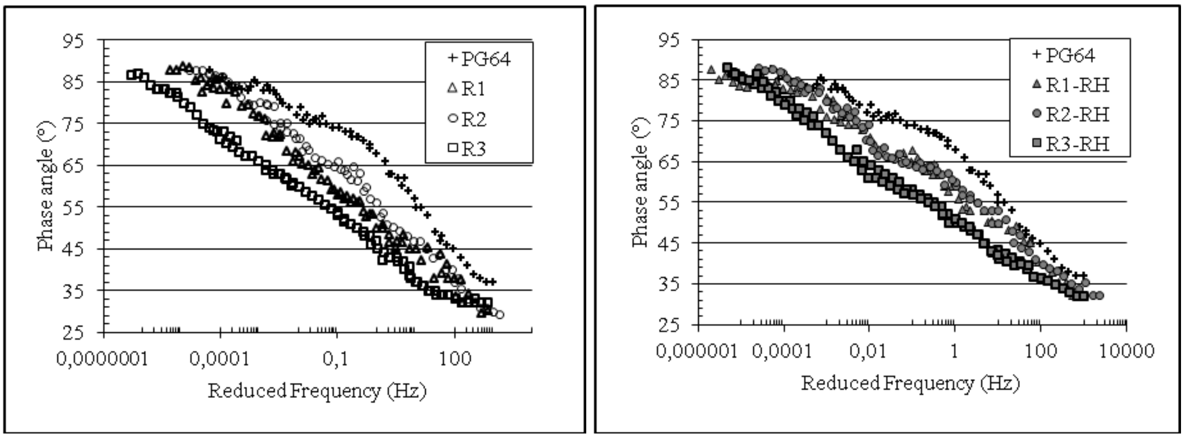
3.2 Rheological Master Curve

A master curve was produced at a reference temperature of 25°C to describe the rheological behaviour of the binders over a wider range of frequencies. Figs. 3 and 4 present the rheological master curve of complex modulus and phase angle. As shown in Fig. 3, the complex modulus increases with frequency. At lower frequency, there are notable differences among the RA, and it get closer to each other as the frequency increase. Lower frequency represents the binder behaviour at high temperature. At high temperature, the stiffest binder (R3) can better resist rutting compared to R1 and R2. The binders performance at a higher frequency or low temperature are almost similar as indicated by the overlapping curve. The addition of RH-WMA slightly reduced the G* and shown in Fig. 3b. Similar trends of the curve are observed at low frequencies. However, when the frequency increases the curves starts to overlap at G* above 2.E+07. This shows that the source of RA behaves differently due to variations in the RA material composition. The master curve of phase angle shown in Fig. 4 describes the elastic behaviour of the RA binder. The binder from R3 exhibits the lowest phase angle, followed by R1 and R2. The addition of RH-WMA slightly increases the phase angle. The overlap of phase angle master curve of R1-RH and R2-RH illustrates that these binders may have similar elastic behaviour. On the other hand, the differences among the RA binder are more significant in the phase angle master curve plots. The phase angle is more sensitive to the material composition and molecular interaction. Based on the phase angle, none of the binders exceeded the threshold for thermal cracking that is 1.E+09. Therefore, the use of 50% RA are acceptable based on the rheological master curve.



a) Reclaimed asphalt binder **b) Reclaimed asphalt binder with RH-WMA**

Figure. 3: Master curve of complex modulus at 25°C reference temperature



a) Reclaimed asphalt binder **b) Reclaimed asphalt binder with RH-WMA**

Figure. 4: Master curve of phase angle at 25°C reference temperature

3.3 Environmental Evaluation based on GHG Emissions

Environmental evaluation is necessary to help the policymaker or engineers to estimate the environmental load for different RA source. The environmental evaluation is measured based on the fuel requirement and Greenhouse Gas(GHG) emissions by adopting the approach proposed by previous researcher [13]. The analysis is carried out by calculating the amount of fuel to heat up the aggregate and binder from ambient temperature up to mixing temperature as specified in Table 3. The average ambient temperature of 33°C is selected to represent the aggregate temperature at the quarry. This environmental evaluation is an indirect measurement and calculated using the formula shown in Eq. (1):

$$Q = \sum_{i=n}^{j=n+1} mc\Delta\theta \qquad (1)$$

where, Q is the sum of required heat energy[J], m is the mass of materials[kg], c is the specific heat capacity coefficient [J/kg/°C], $\Delta\theta$ is the difference between the ambient and mixing temperature [°C], and i and j indicate the different types of material. The mix density and other volumetric properties of the mixtures were calculated based on the information given in Table 2. Environmental analysis conducted based on the total material required for a construction of 10-km dual carriageway road with 3 lanes per direction and 5cm thick wearing course. The type of fuel used in the calculation is diesel. For calculation, the required heat energy is converted to the required fuel and GHG emissions using conversion factor [15,16]. The results of the analysis are summarised in Table 4. From the analysis, addition of 50% RA increases the fuel requirement and GHG emissions regardless of RA source. There is more increment of fuel requirement and GHG emissions for the stiffer binders. Nevertheless, the addition of RH-WMA reduces the fuel requirement and GHG emissions for R1, R2 and R3 by 11.9, 15.3 and 6.8 % respectively, in comparison with the virgin base binder. The amount of fuel requirement and GHG emissions decrement for each sources of RA due to the addition of RH-WMA for R1, R2 and R3 are 18.9, 20.7 and 18.1% respectively. Incorporation of RH-WMA reduces the environmental load. Therefore, the integration of RA and RH-WMA can be considered as an alternative for sustainable road construction.

Table 4: Analysis of fuel requirement and GHG emissions

Mixture	Q_T	Fuel requirement[a] [ton]	GHG emissions[b]	Increase/decrease in fuel requirement [%]	Increase/decrease in GHG emission [%]
PG64	3.07	67	214425		
R1	3.34	73	232898	+8.6	+8.6
R2	3.28	72	229187	+6.9	+6.9
R3	3.50	76	244078	+13.9	+13.9
R1-RH	2.71	59	188910	-11.9	-11.9
R2-RH	2.60	57	181697	-15.3	-15.3
R3-RH	2.86	62	199794	-6.8	-6.8

TJ: terra joule; Q_T: required energy to heat the aggregate and asphalt binder; [a]: type of fuel is diesel and conversion factor is based, on DTI [15]; [b]: the direct GHG emission calculated based on the scope 1 in the GHG protocol in DEFRA [16].

IV. CONCLUSIONS

Rheological properties and environmental impact of binder containing 50% reclaimed asphalt from three sources of roads and incorporated with RH-WMA were evaluated. The rheological properties evaluation based on viscosity and DSR conclude that the source of reclaimed asphalt binder affects the viscosity. Meanwhile, the addition of RH-WMA reduces the viscosity and production temperature. The frequencies dependency of the reclaimed asphalt binder was assessed by the rheological master curve of complex modulus and phase angle. The binder modification showed improvement in high temperature rheological properties. The addition of RH-WMA slightly enhances the low temperature performance of reclaimed asphalt binders. The master curve plots showed variation amongst the modified binder due to the different source of reclaimed asphalt. Environmental evaluation based on the fuel requirement and GHG emissions indicate that the environmental load increases due to the addition of reclaimed asphalt. Nevertheless, the addition of RH-WMA shows a potential reduction of fuel requirement and GHG emissions. Therefore, the incorporation of reclaimed asphalt and RH-WMA can be an alternative for sustainable pavement construction.

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