Recycled Asphalt Pavement with Warm Mix Additive for Sustainable Road Construction

Meor Othman Hamzah, Lillian Gungat, Nur Izzi Md. Yusoff, Jan Valentin

Abstract**—**The recent hike in raw materials costs and the quest for preservation of the environment has prompted asphalt industries to adopt greener road construction technology. This paper presents a study on such technology by means of asphalt recycling and use of warm mix asphalt (WMA) additive. It evaluates the effects of a WMA named RH-WMA on binder rheological properties and asphalt mixture performance. The recycled asphalt, obtained from local roads, was processed, fractionated, and incorporated with virgin aggregate and binder. For binder testing, the recycled asphalt was extracted and blended with virgin binder. The binder and mixtures specimen containing 30 % and 50 % recycled asphalt contents were mixed with 3 % RH-WMA. The rheological properties of the binder were evaluated based on fundamental, viscosity, and frequency sweep tests. Indirect tensile strength and resilient modulus tests were carried out to assess the mixture's performances. The rheological properties and strength performance results showed that the addition of RH-WMA slightly reduced the binder and mixtures stiffness. The percentage of recycled asphalt increased the stiffness of binder and mixture, and thus improves the resistance to rutting. Therefore, the integration of recycled asphalt and RH-WMA can be an alternative material for road sustainable construction for countries in the tropics.

Keywords**—**Recycled asphalt, warm mix additive, rheological, mixture performance.

I. Introduction

THE increasing costs of raw materials and demand for environmental friendly paving material in road construction have challenged the asphalt industry. To offset the rising cost of asphalt binder, many studies have been conducted on the potential use of high recycled asphalt (RA) for sustainable road construction [1]. The incorporation of higher amount of RA showed significant reduction in energy consumption and greenhouse gasses emissions [2]. However, the higher amount of RA needs higher production temperature, which will further age the RA binder. Innovative material that able to decelerate further aging of the RA, such as warm mix additives (WMA), has been studied widely [3]. The ability of WMA additives to decrease the binder viscosity that leads to a lower production temperature is dependent on the type of additive. There are three common classifications of WMA additive namely organic, chemical and foam additives. RH-WMA is a new warm mix additive which is designed to reduce the viscosity of the asphalt binder at high temperature, while strengthening the asphalt crystalline structure at low temperature [4]. In addition, the integration of the WMA additive into the RA improves the mixtures performance due to better workability and blending [5]-[7]. The aged RA binder coated the RA aggregate produces a stiffer mixture and therefore increases the resilient modulus [8], [9]. Sengoz [10] investigated the stiffness of the RA-WMA mixture produced from a different penetration grade and various percentages of RA incorporating organic, chemical, and foaming WMA additives based on the Marshall Quotient (MQ). In general, the MQ values indicate the stiffness increased linearly with RA percentage. A study [5] on the RA with Sasobit shows that the addition of the RA slightly increases the resistance to rutting in comparison to the similar grade of binder without the WMA additive. According to [11], the improvement of resistance to rutting could be due to good particle arrangement obtained through the improved workability. The rutting behavior of RA-WMA at 40 ºC and 60 ºC for various percentages of RA content were studied by [12] and it was found that that 15 % and 30 % RA content failed to resist rutting compared to 50 % and 60 % RA. This finding suggests that high RAP content can be an alternative material for roads in the tropical region where the rutting is known to be the major reason for road failures.

Based on the positive findings on RA-WMA, a research on RA incorporating RH-WMA was carried out in Malaysia. Pavement conditions at various locations differ, depending on the environmental conditions and traffic load. Therefore, the properties of the RA pavement will also vary. The variability of RA leads to further investigation on pavement recycling with the WMA additive for local roads. This study aims to evaluate the effects of RH-WMA on recycled asphalt pavement in Malaysia.

II. Materials and Methods

A. Materials

The main materials used in this study were PG 64 asphalt binder, recycled asphalt (RA) pavement, granite aggregate, pavement modifier (PMD) as a filler and RH-WMA. RH-WMA is a wax-based additive developed by the Research Institute of China Highway Ministry of Transport [4]. The RA was collected from two roads, namely the Public Works Department (PWD) and the North-South Expressway (NSE)

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road, by the milling process. Both RA has been trafficked for five to seven years. The RA was further processed in the laboratory through heating, crushing, and fractionation. The fractionated RA was blended with virgin aggregate at 30 % and 50 % of RA content by following the PWD gradation specification. Fig. 1 shows the gradation of the recovered RA aggregate containing virgin aggregate. A designation was adopted for easy reference, for which the first number denotes the RA content, followed by the source of the RA. For instance, 30NSE means 30 % RA content from the North-South Expressway road.

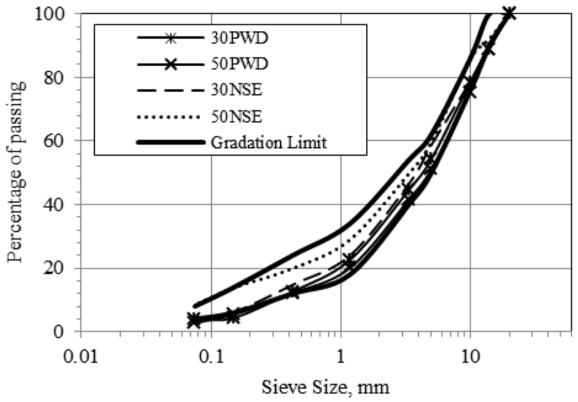


Fig. 1 Gradation of recovered RA aggregate with virgin aggregate

B. Sample Preparations

The sample preparation involves the blending of RH-WMA with the extracted RA binder and mixing the selected percentage of RA with virgin materials and RH-WMA. The RH-WMA supplied by the local distributor was blended with virgin binder at 145 °C for 15 minutes using laboratory mechanical mixer. Meanwhile, the modified binders containing 30 % and 50 % RA were blended at 160 °C. The amount of RH-WMA was 3 % by weight of the asphalt binder. For preparation of the mixture, the RH-WMA was added in dry and wet condition. The wet addition applied to virgin binder and followed the procedure as describe earlier. Since the RA was also containing the aged binder, the RH-WMA was added in dry conditions to the batched samples at room temperature. The mixtures were designed for heavy traffic and compacted using a gyratory compactor. The mixing temperature was determined based on viscosity and mixability. Therefore, the selected compaction temperature for conventional binder, WMA and RA with RH-WMA were 150 °C, 125 °C and 130 °C, respectively. The mixing properties are tabulated in Table I.

C. Tests

Fundamental tests such as penetration test and viscosity test were carried to determine the engineering properties of the materials. Rheological properties using dynamic shear rheometer (DSR) were investigated by performing frequency sweep at temperature of 5 °C to 65 °C at 10 °C increments. Mixtures specimen were tested for standard laboratory using indirect tensile strength and indirect tensile modulus tests. All samples were prepared with 4 % air void and conditioned for a minimum of four hours at testing temperature prior to testing.

TABLE I
THE DESCRIPTION OF MIXING PROPERTIES

Type of Mixtures	Optimum binder (%)	Compaction Temperature (°C)
PG64	5.2	150
PG64+RH-WMA	4.9	125
30PWD/30NSE	5.6	130
50PWD/50NSE	5.7	130
30PWD+ RH-WMA/30NSE+ RH-WMA	5.4	130
50PWD+ RH-WMA/50NSE+ RH-WMA	5.5	130

III. RESULTS AND DISCUSSION

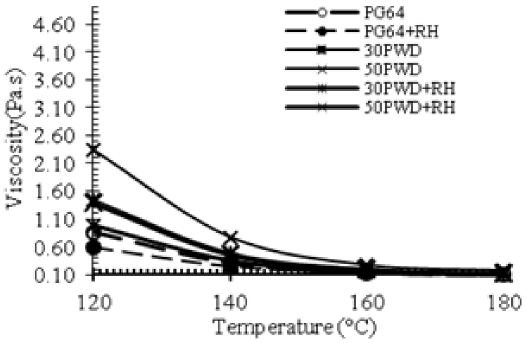
A. Effects of Warm Mix Additive on the Rheological Properties

The results of the basic engineering properties of the modified binder are shown in Table II. The addition of RH-WMA increases the penetration grade, while the percentage of RA incorporated with the virgin binder reduces the penetration grade. This indicates that the binder becomes stiffer when more percentage of RA used. Stiffer binder is the main concern in recycling asphalt, as this will cause fatigue cracking. The addition, the RH-WMA slightly reduces the stiffness of the RA binder. Furthermore, RH-WMA has the ability to reduce the viscosity, as shown in Figs. 2 (a) and (b). As the temperature increases, the viscosity reduces and significant changes in viscosity are observed at lower temperature. The viscosity describes the handling characteristics of a mixture. At 135 °C lower viscosity is desirable for better workability. The addition of RH-WMA causes a reduction of viscosity at lower temperature and therefore reduces the production temperature. There is more viscosity reduction at the higher percentage of RA. This will benefit the asphalt industry in terms of environmental, energy and cost considerations.

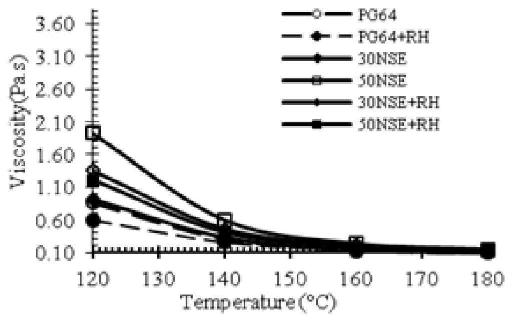
TABLE II
ENGINEERING PROPERTIES OF MODIFIED BINDERS

Binder	Penetration		Viscosity at 135°C (Pa.s)	
	0%RH	3%RH	0%RH	3%RH
PG64	86	92	0.425	0.300
30PWD	39	53	0.670	0.480
50PWD	23	36	1.082	0.640
30NSE	44	54	0.640	0.460
50NSE	30	35	0.900	0.580

Figs. 3 (a) and (b) present the master curve that describes the rheological properties of a binder in the linear viscoelastic region with references to their complex modulus (G*) and phase angle (δ). Complex modulus relates the stiffness and resistance to deformation, while phase angle indicates the viscoelastic balance of rheological behavior. Since both the source of RA has a similar trend of master curve, only the master curves of RA from the PWD road are shown in those figures. The observations from the master curve diagram confirm the result obtained from the conventional tests that RA hardened the binder and RH-WMA decreases the stiffness. At low frequency, binders containing RA are stiffer than the control, which is good for improving rutting. On the other end, at high frequency all curves do not reach the complex modulus value of 1GPa. The 1GPa is known as the glassy modulus that is set as the limiting value at high frequency to avoid low temperature cracking [13]. The addition of RH-WMA into the RA slightly softens the binder and therefore improves binder hardening in the long term. This indicates that the RA binders are able to resist low temperature cracking. The phase angle master curve shows that at low frequency all binders become viscous, reaching the value of 90 °C. While at high frequency, there are significant differences in elasticity. The 50PWD shows the highest complex modulus with most elastic properties, followed by 50PWD+RH, 30PWD, 30PWD+RH, PG64 and PG64+RH.



(a)



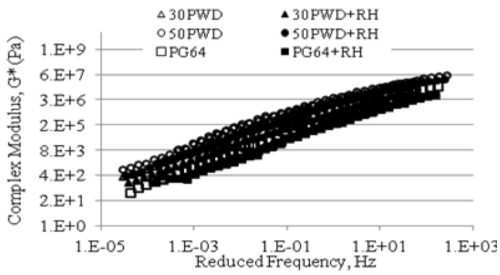
(b)

Fig. 2 Effect of RH-WMA on the binder viscosity. (a) RA from PWD road and (b) RA from NSE road

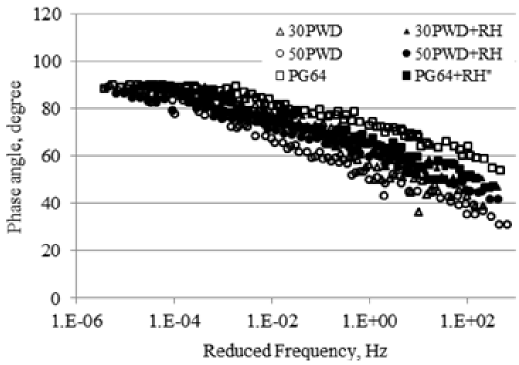
B. *Strength Performance*

The strength performance related to tensile properties in pavement engineering is associated with cracking problems. The result of indirect tensile strength (ITS) test and indirect tensile modulus are used to indicate the strength performance of the RA-WMA mixtures. Figs. 4 and 5 show the ITS and resilient modulus of the mixtures containing high RA with and without RH-WMA. In general, the addition of RH-WMA reduces the ITS, while the increase of RA content slightly increases the ITS. The RA obtained from the PWD road has higher ITS compared to RA from NSE. On the other hand, the RA obtained from the PWD has higher ITS compared to the RA from NSE. This is influenced by the environmental and traffic conditions. The PWD road is located within the state region which is used to link different towns in the state. Whereas, the NSE is the main trunk road connecting states in the country.

The resilient modulus result shows consistent trend with the ITS result. Both the ITS and resilient modulus indicate that 50PWD produces the highest strength.



(a)



(b)

Fig. 3 (a) Master curve of complex modulus, (b) Master curve of phase angle

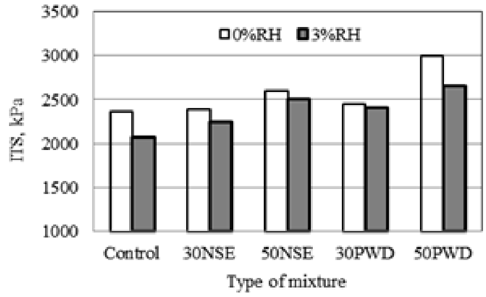


Fig. 4 Effects of RH-WMA on the indirect tensile strength

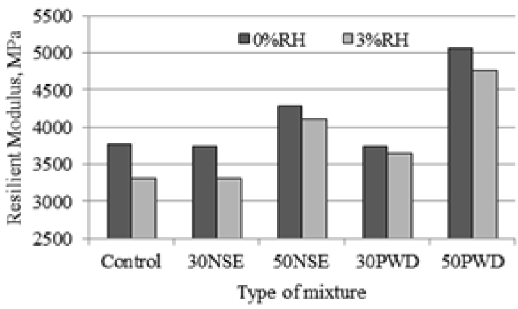


Fig. 5 Effect of RH-WMA on the resilient modulus

C. Relationship of Rheological Properties and Mixtures Performance

Modification of binder slightly changes the rheological properties and it also affects the mixture performance. Hafeez [14] found that the master curve of the binder and mixtures have similar trends; therefore, the master curve of the binder can be used to predict the performance of asphalt mixtures. The master curve shows that the addition of RH-WMA slightly reduces the stiffness of the binder. This finding is in agreement with the ITS and resilient modulus results, whereby RH-WMA slightly reduces the strength of the RA mixtures. The penetration test and master curve diagram indicates that the 50PWD is stiffest and therefore produces the stiffest binder. The results of the mixtures on the stiffest 50PWD binder are also consistent with penetration and master curve. Mixture with high stiffness is desirable to overcome the rutting problem in tropical climate regions.

IV. CONCLUSIONS

From the test results on the materials used in this study it can be concluded that the addition of RH-WMA to recycled asphalt slightly affects the rheological properties with improved long term ageing. The strength performances of RA mixtures slightly decrease with the addition of the RH-WMA. Higher percentage of RA improves binder stiffness and elasticity, and therefore produces higher strength of mixtures. The integration of RA with RH-WMA produces a stiffer mixture than the control which has the potential to improve rutting in tropical regions.

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