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Warm Mix and Reclaimed Asphalt Pavement: A Greener Road Approach

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Abstract**—**Utilization of a high percentage of reclaimed asphalt pavement (RAP) requires higher production temperatures and consumes more energy. High production temperature expedites the aging of bitumen in RAP, which could affect the mixture performance. Warm mix asphalt (WMA) additive enables reduced production temperatures as a result of viscosity reduction. This paper evaluates the integration of a high percentage of RAP with a WMA additive known as RH-WMA. The optimum dosage of RH-WMA was determined from basic properties tests. A total of 0%, 30% and 50% RAP contents from two roads sources were modified with RH-WMA. The modified RAP bitumen were examined for viscosity, stiffness, rutting resistance and greenhouse gas emissions. The addition of RH-WMA improved the flow of bitumen by reducing the viscosity, and thus, decreased the construction temperature. The stiffness of the RAP modified bitumen reduced with the incorporation of RH-WMA. The positive improvement in rutting resistance was observed on bitumen with the addition of RAP and RH-WMA in comparison with control. It was estimated that the addition of RH-WMA could potentially reduce fuel usage and GHG emissions by 22 %. Hence, the synergy of RAP and WMA technology can be an alternative in green road construction.

Keywords**—**Reclaimed asphalt pavement, WMA additive, viscosity, stiffness, emissions.

I. INTRODUCTION

THE increasing demand for infrastructure construction has led to more energy consumption in the asphalt industry and consequently affects the environment. In addition, the price of bitumen for the past 10 years showed an increase of crude oil price up the year 2014, and subsequently, increases in road construction costs [1]. The recycling of milled pavement can reduce construction costs, as 70% of road construction costs are from the raw materials [2]. Nevertheless, most countries are reluctant to use RAP more than the threshold value (25-30%) due to lack of guidelines [3]. Recent guidelines on the mix design of high RAP content have been documented to foster recycling in order to sustain the demands for civil infrastructure [4].

High RAP content is stiffer than virgin bitumen because it contains oxidized bitumen [5]. When high RAP content is incorporated into hot mix asphalt (HMA), it produces asphalt mixtures with high stiffness that might have problems in the field [6]. A stiffer bitumen also requires a higher production temperature to melt the binder to ensure uniform blending with virgin bitumen. This is necessary to achieve the desired viscosity of bitumen to completely coat the aggregate, exhibits good workability during laying and compaction as well as durability while in service. WMA technology has the ability to reduce the production temperature as a result of viscosity reduction. The integration of WMA technology with recycling approach for a greener road construction allows higher percentage of RAP usage with improved blending and workability at lower production temperature [3]. The benefits of lower production temperature of RAP with WMA additive (RAP-WMA) includes minimizing further aging of RAP, is more workable with lesser emissions during production, and paving, shorter construction duration and cost savings.

The laboratory performance of RAP-WMA in previous studies reported significant improvement in moisture sensitivity due to the stronger bonding of the aged asphalt and aggregates particles [7]. Other research findings suggested that incorporation of a high percentage of RAP into WMA mixtures can be an alternative for increasing the moisture resistance [8]. Apart from moisture improvement, the addition of high RAP content also showed better rutting resistance compared with conventional asphalt mixture [9]. The structural response due to traffic loading of high RAP-WMA mixtures on the National Center for Asphalt Technology (NCAT) test track using embedded instrumentation to record the strain and temperature characteristics was evaluated. The section with high RAP has the lowest strain that indicates that these materials may carry loads more efficiently [10]. Further laboratory research to confirm the field findings indicated that the use of WMA technologies increased rut depth, while the addition of high RAP improved resistance to rutting [11].

The types of WMA additives affect the rheological and mixtures performance. Wax based additive is able to reduce the viscosity of a bitumen, and thus, lowers the production temperature. RH-WMA is a newly developed wax based additive and composed of polyethylene. It can lessen the viscosity of bitumen at high temperature, while strengthening the bitumen crystalline structure at low temperature. The studies in the past have highlighted the improved mixture performance of RAP-WMA. Nevertheless, not many studies reported on the rheological properties of RAP-WMA bitumen blend. This paper investigates the synergy of a WMA additive containing high RAP for a greener road construction approach.

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The rheological properties evaluations were carried out based on viscosity and dynamic shear rheometer (DSR) tests.

II. Materials and Methods

A. Materials

Conventional PG64 bitumen, which is commonly used for road construction in Malaysia, was used in this study. The bitumen was supplied by SHELL Malaysia Ltd.

A WMA additive named RH-WMA supplied by a local distributor was added to virgin bitumen at various percentages. In the initial study, 1%, 2%, 3% and 4% RH-WMA content by the mass of asphalt bitumen were blended with virgin bitumen. Basic properties test such as penetration and viscosity were carried out to determine the optimum RH-WMA to be incorporated with the reclaimed bitumen.

RAP was obtained by milling process from two road sources under the jurisdiction of Jabatan Kerja Raya (JKR) and Projek Lebuh Raya Utara Selatan (PLUS). The bitumen from the RAP was extracted by using trichloroethylene solvent, followed by recovery using a rotary evaporator. Extracted bitumen was tested for penetration and the penetration of JKR and PLUS were 11 and 19 dmm, respectively. Then, the recovered bitumen was mixed with the virgin bitumen at 140°C in the proportion of 30% and 50% by mass of bitumen. For consistency, the term reclaimed bitumen will be used instead of recovered bitumen. A designation was adopted to simplify the identification of the bitumen blend. The designation and penetration of the blended RAP are shown in Tables I and II.

TABLE I
Designation of Bitumen Blends

Source	Reclaimed bitumen content (%)	WMA additive	Designation
JKR	30		30JKR
	50		50JKR
	30	RH-WMA	30JKR+RH
	50	RH-WMA	50JKR+RH
PLUS	30		30PLUS
	50		50PLUS
	30	RH-WMA	30PLUS+RH
	50	RH-WMA	50PLUS+RH

TABLE II
Penetration of Bitumen

Penetration of Bitumen	Penetration, dmm
Control	86
Control+RH	95
30JKR	42
50JKR	24
30JKR+RH	53
50JKR+RH	40
30PLUS	49
50PLUS	34
30PLUS+RH	63
50PLUS+RH	48

B. Sample Preparation

The required amount of conventional bitumen and RH-WMA was blended using a laboratory mechanical mixer at 145°C for 15 minutes to obtain a homogenous blend. As recommended by the RH-WMA manufacturer, virgin bitumen containing reclaimed bitumen was blended with RH-WMA at 160°C.

C. Tests

The viscosity of bitumen represents its handling characteristics during the production of mixtures and construction of a road. The viscosity was determined using a Brookfield rotational viscometer (RV). Viscosity readings of bitumen were taken from 110°C to 170°C at 10°C interval using spindle number 21.

The rheological properties of the reclaimed bitumen and bitumen blends with RH-WMA were investigated using the DSR machine for temperature sweep and multiple stress creep and recovery (MSCR) in accordance with AASHTO T315 procedures [12]. Temperatures sweeps were performed at 46 to 82 °C at 6 °C increments for the unaged sample using a 25 mm diameter plate. The applied loading frequency was 1.59 Hertz, which simulates the shear stress on pavement when traffic speed is approximately 90 km/hr. The MSCR test was used to characterize the rutting behavior based on the non-recoverable creep compliance (J_{nr}). Two shear stresses (0.1 kPa and 3.2 kPa), were applied to the short-term aged sample at the high temperature performance grade of the control bitumen.

III. Results and Discussion

A. Determination of Optimum RH-WMA Content

The optimum RH-WMA dosage to be incorporated into conventional bitumen containing high percentage of reclaimed bitumen is determined based on penetration and viscosity tests. The two tests were selected because it indicates the physical hardness and handling characteristics of a bitumen. The penetration and viscosity of bitumen containing 1%, 2%, 3% and 4% RH-WMA are shown in Figs. 1 and 2, respectively. The amount of RH-WMA addition increases linearly with the penetration. Noticeable change in penetration starts at 2% and 3% RH-WMA that increases about 4.6% and 10.4%, respectively. The penetration at 4% RH-WMA is slightly high and indicates that the bitumen is much softer than the control bitumen. Meanwhile, the bitumen viscosity decreases with the addition of RH-WMA. Considerable reduction in viscosity is observed at 1%, 2% and 3% RH-WMA content. At higher percentage of RH-WMA, the decrease in viscosity is almost similar with 3% RH-WMA. Based on the results of penetration and viscosity tests, the 3% RH-WMA content is selected as optimum content to be mixed with the reclaimed bitumen.

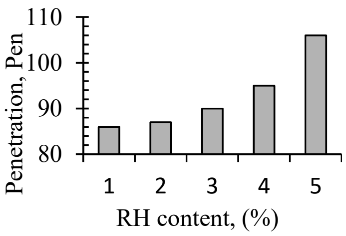

Fig. 1 Penetration of RH modified bitumen

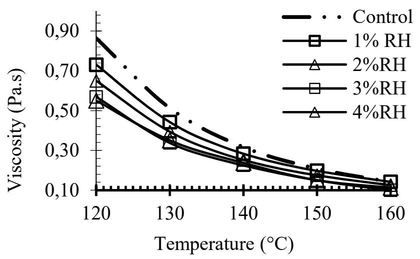

Fig. 2 Viscosity of RH-WMA modified bitumen

B. Effects of RH-WMA on Viscosity

The handling characteristics of a bitumen can be indicated by its ability to flow at a certain temperature to enable sufficient coating and bonding of the aggregates. The viscosities of reclaimed bitumen containing an optimum percentage of RH-WMA and without RH-WMA are shown in Figs. 3 and 4. The decrease in viscosity at a lower temperature (110°C to 120°C) is more significant, as compared to the corresponding reduction at higher temperature. This is due to the lower melting point of the wax additive. The penetration of a bitumen affects the viscosity reduction, whereby a hard bitumen indicates remarkable viscosity reduction at a lower temperature.

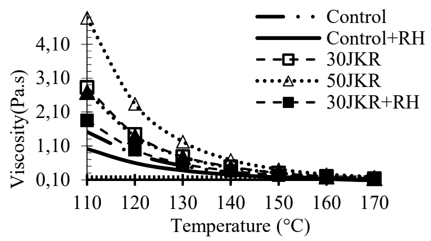

Fig. 3 Relationship between temperature and viscosity of JKR RAP modified bitumen

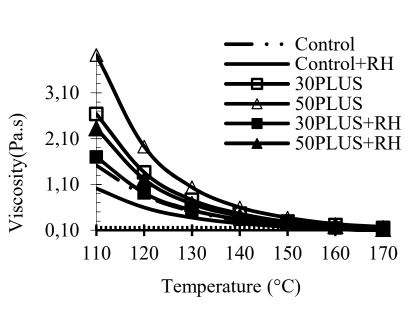

Fig. 4 Relationship between temperature and viscosity of PLUS RAP modified bitumen

At a higher temperature, the effects of temperature difference due to the addition of reclaimed bitumen and RH-WMA is less. The relative difference of bitumen temperature at an equal viscosity of 0.17 Pa.s with the control is shown in Table III. Both sources of RAP shows an almost similar value and the amount of RAP incorporated influenced the relative difference in temperature.

For determination of construction temperature, the addition of RH-WMA additive can further reduce the construction temperature by 15°C lower than the values recommended by the Asphalt Institute. The construction temperatures of the reclaimed bitumen modified with and without RH-WMA are identical and tabulated in Table III. Reclaimed bitumen requires higher construction temperature due to its higher stiffness as the result of aging. Higher construction temperature has the potential to produce more fumes in comparison to the HMA. The addition of RH-WMA into 30 and 50% reclaimed bitumen content decreases the construction temperature by 15.7% and 15.8%, respectively. With the reduction in construction temperature, there will be less energy consumption and better working environment in the field. Accordingly, it will benefit the asphalt production plant and road contractors.

TABLE III
CONSTRUCTION TEMPERATURES OF CONTROL AND MODIFIED BITUMEN OF BITUMEN

Source of RAP	Temperature at viscosity of 0.17, Pa.s	Relative of difference temperature with control, %	Proposed Construction Temperature, °C
Control	155	-	160
Control+RH	150	0.8	130
30JKR	165	1.6	162
50JKR	170	2.3	168
30JKR+RH	158	0.5	140
50JKR+RH	165	1.6	145
30PLUS	162	1.1	162
50PLUS	170	2.3	168
30PLUS+RH	157	0.3	140
50PLUS+RH	165	1.6	145

C. Effects of RH-WMA Addition on the Stiffness of Reclaimed Bitumen

Complex modulus (G*) and phase angle (δ) in the temperature sweep test were used to determine the performance grade (PG) of bitumen at high temperature. The Strategic Highway Research Program (SHRP) stipulated that the PG indicate the stiffness and the critical value for PG determination for the unaged bitumen is 1.0 kPa. The effects of RH-WMA addition on the PG are shown in Figs. 5 and 6 and Table IV. Figs. 5 and 6 presents the stiffness-temperatures relationship of the modified reclaimed bitumen. Bitumen stiffness increases linearly with reclaimed bitumen content. The incorporation of RH-WMA into control and reclaimed bitumen reduces the high temperature PG except for 30JKR. This means that the RH-WMA softens the bitumen and decreases the failure temperature.

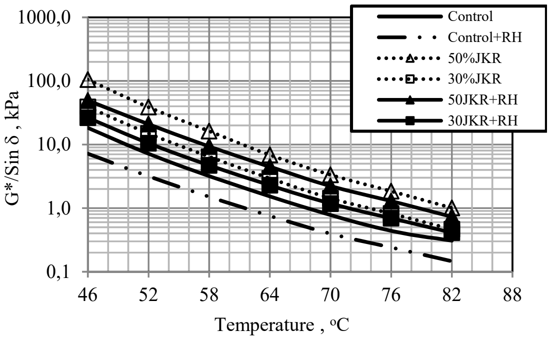

Fig. 5 Stiffness-temperature relationship of JKR RAP modified bitumen

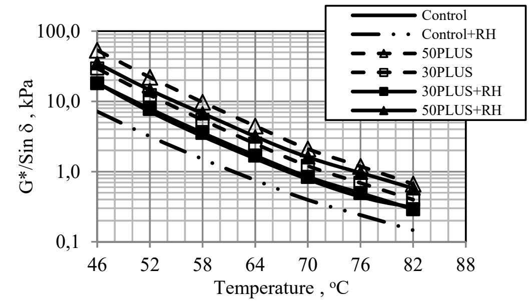

Fig. 6 Stiffness-temperature relationship of PLUS RAP modified bitumen

TABLE IV
PERFORMANCE GRADE OF MODIFIED RECLAIMED BITUMEN

Bitumen	PG		Failure Temperature, °C	
	RH-WMA		RH-WMA	
	0%	3%	0%	3%
Control	64	58	67	61
30JKR	70	70	74	73
50JKR	82	76	83	79
30PLUS	70	64	72	69
50PLUS	76	70	78	76

D. Evaluation of Rutting Resistance

The inadequacy of the parameter G*/sin δ to characterize the rutting resistance of modified bitumen has been highlighted in many studies [13]. Hence, the Federal Highway Administration (FHWA) in the United States has suggested the use of the MSCR test to evaluate the resistance of bitumen to rutting at high temperatures [13]. The non-recoverable creep compliance (J_{nr}) and the average percentage of recovery are two essential parameters for rutting characterization using MSCR test. J_{nr} indicates the rutting resistance, while the latter represents the elastic behavior. Lower J_{nr} implicates more contribution of bitumen to the rutting resistance while higher J_{nr} suggests that the bitumen has higher rutting potential [14].

Figs. 7-10 present the reclaimed modified bitumen behavior related to rutting. In general, reclaimed bitumen without RH-WMA are better at resisting rutting despite the stress level. The J_{nr} is highly influenced by the stiffness of the bitumen as indicated by the penetration. For instance, at 0.1 kPa stress level the J_{nr} of the control binder, 30PLUS and 50PLUS are 0.008, 0.003 and 0.0007 with penetration of 86, 49 and 34, respectively. There is a linear relationship between the penetration and the J_{nr}. Fundamentally, a harder bitumen will produce a better resistance to rutting. On the other hand, the addition of RH-WMA slightly increases the J_{nr} that implies reduced bitumen resistance to rutting if compared with the reclaimed bitumen without RH-WMA. However, reclaimed bitumen are better than the conventional asphalt at resisting rutting. At higher stress level (3.2 kPa), the increase of J_{nr} indicates that traffic loading can reduce the materials resistance to rutting. In general, the percentage of average recovery result shows that the addition of RAP and RH-WMA increases the elasticity of bitumen at 0.1 kPa and 3.2 kPa stress level.

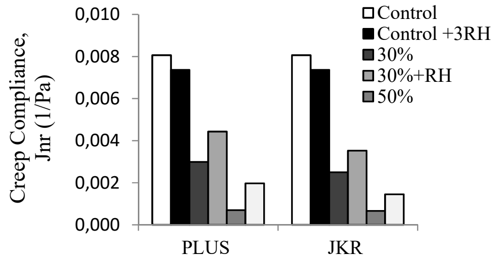

Fig. 7 Non-Recoverable creep compliance of RAP modified bitumen at 0.1 kPa stress level

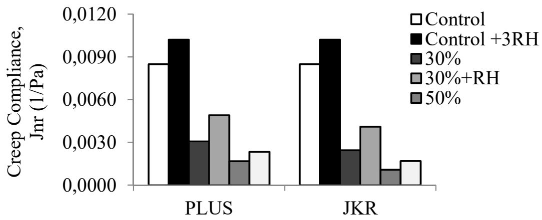

Fig. 8 Non-Recoverable creep compliance of RAP modified bitumen at 3.2 kPa stress level

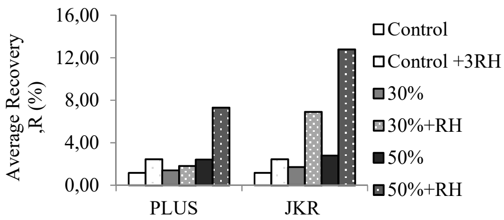

Fig. 9 Recoverable strain at 0.1 kPa stress level

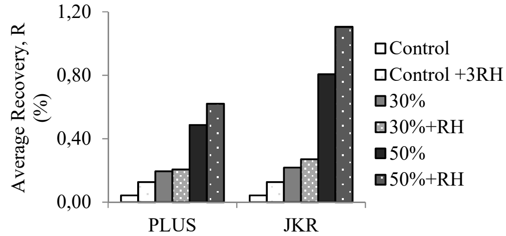

Fig. 10 Recoverable strain at 3.2 kPa stress level

E. Estimation of Greenhouse Gas Emission

Environmental implications on the greenhouse gas (GHG) emissions of reclaimed bitumen are estimated by adopting the method proposed by DEFRA and Hamzah [15], [16]. The environmental effects were estimated based on the required amount of fuel required to heat up the aggregate from ambient temperature (33°C) to the target mixing temperature using (1).

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

where Q is the sum of heat energy (J), m is the mass of material (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 different materials types. Table V presents the results of the environmental estimation. The decrease in fuel consumption and GHG emissions for the reclaimed modified bitumen are similar for both RAP sources. The reduction in fuel consumption denotes positive cost savings and benefits the asphalt mixture mixing plant. The GHG emissions reduce by 22% due to the addition of RH-WMA into the RAP. This will contribute to greener road construction as it will produce lesser fumes.

TABLE V
FUEL REQUIREMENT AND GHG EMISSIONS OF RECLAIMED MODIFIED BITUMEN

Mixture	Q_T (TJ)	Fuel (Ton)	Decrement in	
			Fuel usage (%)	GHG emission (%)
Control	3.370	74		
Control + RH	2.548	56	33.9	33.8
30JKR/30PLUS	3.426	75		
50JKR/50PLUS	3.595	78		
30JKR+RH /30PLUS+RH	2.819	61	22.0	22.5
50JKR+RH/ 50PLUS+RH	2.955	64	22.6	22.5

Calculation based on: 10 km dual carriageway, 3 lanes per direction, 5 cm thick wearing course and 5% optimum bitumen content.
Q_T: Required energy to heat up the aggregate and asphalt bitumen; Type of fuel: Diesel; Specific heat capacity of bitumen (PG64): 920 J/kg/°C;
Specific heat capacity of granite aggregate: 790 J/kg/°C

IV. CONCLUSION

The addition of RH-WMA at 3% improved the viscosity and lowered the production temperatures of conventional bitumen incorporating high percentage reclaimed bitumen. The reduction in production temperature will minimize the aging of reclaimed bitumen. Reclaimed bitumen modification with RH-WMA reduces the stiffness and performance grade at high temperature. The addition of reclaimed bitumen into the control bitumen improves the mixtures resistance to rutting. Hence, the by considering the reduction in viscosity due to the addition of RAP-WMA and the effects of bitumen stiffness due to reclaimed bitumen, RAP-WMA can be a possible solution to the rutting problem, especially in hot climate regions. Other than the improvement of bitumen performance, the reclaimed modified bitumen has the potential to reduce the fuel usage and GHG emissions by 22% with the addition of RH-WMA. Hence, the integration of RAP and WMA technology can be an alternative for green road construction

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