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Design and properties of high reclaimed asphalt pavement with RH-WMA

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Abstract. Economic and environmental benefits gain from the recycling of old pavement promotes the use of reclaimed asphalt pavement (RAP) in the road construction and rehabilitation. However, high production temperature due to RAP stiffness becomes the main concern in the production of RAP. Reduced production temperature with the addition of warm mix asphalt (WMA) may compensate for aging of RAP binder, nevertheless the stiffness of RAP binder is depending on how much it ages and needs localised investigation for a bulk production of RAP. This research investigates the mix design and properties of high RAP content incorporating a WMA additive for a bulk RAP production in Malaysia. Milled RAP obtained from local roads were incorporated with a WMA named RH-WMA. Prior to addition of RAP into mixtures, the milled RAP were processed and characterized as a quality control of RAP from various sources. Mix design of mixture that contains RAP and 3% RH-WMA were performed using the Response Surface Method. Subsequently, the specimens were evaluated for its chemical and mechanical properties. The analysis on mix design showed that compaction temperature and bitumen content were significant factors. Reasonable reduction of optimum binder content and energy consumption were observed with the additions of RH-WMA. Tests on mechanical properties demonstrate increased on stiffness with the addition of RAP and hence reduced the fatigue resistance. However, the addition of RH-WMA on specimens that subjected to combined effects of moisture and aging showed improvement on fatigue resistance. Hence, with proper quality control of RAP material, the incorporation of RH-WMA into RAP indicated potential as an alternative material for green road construction.

1. Introduction

In recent years, awareness on environmental impact particularly on emissions has been growing. The environmental regulation and the need for green construction technology have fostered innovations and renewed interested for old technology in pavement construction. Green construction such as recycling and low energy consumption materials can contribute to achieve the global environment goal. Recycling of used pavement has started since the mid 1970's due to the significant increase in asphalt prices as a result of Arab oil embargo [1]. During resurfacing, rehabilitation and maintenance operations, old asphalt pavement materials are normally removed. The removed and processed materials are defined as reclaimed asphalt pavement (RAP). Asphalt mixture incorporating RAP will produce a comparable performance with conventional hot mix asphalt (HMA) when treated properly



[2]. However, the increasing amount of RAP content requires high production temperatures during production and road construction and thus causes health threat to the asphalt paving workers.

Recycling of HMA can be categorized into cold planning, hot recycling, hot in-place recycling, cold in-place recycling and full depth reclamation. The most commonly implemented method of recycling is hot recycling due to its proven cost effectiveness and environmentally friendly in comparison to other techniques. In the hot recycling process, the old road surfacing is milled, processed and combined with a new/virgin binder, aggregate and/or recycling agent in the asphalt plant. Milling removes one or more layers of an existing pavement surface.

When using RAP in road construction, it should fulfil the requirement as for virgin materials and its performance must be at least equal or better than conventional HMA. The properties of asphalt mixtures with high RAP content or more than 30% RAP content can be improved by modifying the mixture such as using a softer binder grade, incorporating a WMA additive, utilizing rejuvenators, and adding anti-stripping agents [3-4]. WMA additives are widely used in European countries due to its ability to decrease the production temperature. In general, WMA additive reduces production temperature by lowering the temperature to 30-50°C lesser than conventional HMA [5]. The synergy of RAP and WMA aids in the recycling of high RAP content because of the reduced production or mixing temperature. However, the RAP materials need to be characterized properly to ensure the quality of the resultant mixture performance. The RAP needs to be processed and screened into multiple sizes before it is blended with a virgin binder. There are various methods available for processing the RAP aggregates. For high RAP content, fractionation approach is the most suitable for a better quality control of the mixture.

When RAP is mix with virgin materials, the addition of RAP changes the volumetric and mechanistic properties of the resultant mixtures and hence affected the optimum binder content (OBC) [6-7]. Typically, the determination of OBC of mixture containing RAP is similar to the conventional mixture except for the consideration of the RAP binder. In other study, the fabrication of WMA at various compaction temperatures can affect its volumetric and strength properties [8-9]. Hence, the author proposed a simultaneous evaluation of binder content, compaction temperature and WMA additive content for determining the OBC using Response Surface Method (RSM).

Some concerns when utilizing high RAP content are the low temperature and fatigue cracking performance because the stiffness of the asphalt mixture can dramatically increase with the inclusion of RAP [9]. The incorporation of RAP increases the mixture's stiffness and may improve the mixture performance at high service temperatures. Nonetheless, the mixture properties should be monitored to avoid fatigue failure. Previous research findings indicated that the addition of WMA additives reduced stiffening effects and hence produce better resistance to thermal cracking and also improved mixture resistance to fatigue resistance and moisture [10-13]. Nevertheless, the RAP properties are differ as it is influence by level of RAP aging and variability of RAP aggregate gradation. Hence, this study investigates the local RAP in terms of mix design with relate to the effects of RAP content and compaction temperature. Besides that, the effects of RH-WMA on the chemical and mechanical properties are also investigated.

2. Experimental Design

2.1. Materials

The PG64 binder which equivalent to 80/100 pen and commonly used for local road construction in Malaysia was supplied by SHELL Sdn. Bhd for this research. The granite aggregate was supplied by Kuad Kuari Sdn. Bhd and fulfilled the Jabatan Kerja Raya (JKR) Malaysia aggregate gradation specification for AC14. RAP was obtained by milling process from two local roads along North-South Expressway which located at KM 75.4 and KM138. North-South Expressway is the main road networks in Peninsular Malaysia. In this study, 30%, 40% and 50% RAP content based on RAP aggregate were incorporated into virgin materials. A wax WMA additive named RH-WMA was incorporated into the RAP and virgin material to decrease the production temperature. A designation shown in Table 1 was adopted to simplify the identification of the mixture blend. In the following

sections, number will be used together with the designation to indicate the RAP content. For example, 30RA1 denotes 30% RAP from RA1 was incorporated in the mixture.

Table 1. Designation of mixture blend.

Source of RAP	Additive (%)	Designation
-	0	PG64
-	3	PG64-RH
RA1	0	RA1
	3	RA1-RH
RA2	0	RA2
	3	RA2-RH

2.2. Specimen preparation and testing

The specimen preparation involves processing of RAP, characterization, preparation of RH-WMA with binder and determination of RH-WMA percentage. Various percentage of RH-WMA (1%, 2%, 3%, 4% and 5%) were added into binder by the total mass of binder and evaluated for its physical and rheological properties. The initial content of RH-WMA was selected based on the review of previous study for the organic WMA additive. The RH-WMA was blended with virgin binder at 145°C for 15 minutes using a mechanical mixer. Then, an optimum RH-WMA content was selected to be mixed with RAP. Subsequently, chemical tests were performed on extracted RAP binder blended with virgin binder and RH-WMA.

For mixing the RH-WMA with the RAP, the addition was done by dry mixing whereby required amount of RH-WMA was added into the RAP based on the calculated RAP binder. Mixing was done in accordance to the standard lab procedures and all specimens were compacted using the gyratory machine at 100 gyrations to simulate the high traffic. Optimization using RSM was adopted for the mix design. There were three main parameters included which were the compaction temperature, binder content and RAP content. The responses or inputs for the optimization were the conventional Marshall mix design parameters, energy consumption and cost. Optimization of RAP-WMA mixtures production based on the method suggested by Derringer was performed to propose the optimum binder content and compaction temperature [14]. Energy consumption was calculated by adopting the method proposed by DEFRA and Hamzah as shown in Equation (1) [15-16].

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

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 temperatures (°C), and i and j indicate different materials types. All specimens were fabricated at 10°C higher than the compaction temperature. Cost of RAP-WMA production was calculated based on the data provided by quarries.

Subsequently, specimens were fabricated based on design mix and examined for cracking potential by performing indirect tensile and fatigue tests. Specimens for the fatigue test were conditioned to simulate the effects moisture and long term aging. All specimens for both tests were kept in the incubator at 15°C for 4 hours prior to testing. The indirect tensile strength and fatigue tests were conducted in accordance with ASTM D7369 and BS EN 12697-24 procedures.

3. Results and discussion

3.1. Processing and characterization of RAP

Prior to incorporating the RAP into the virgin materials, it needs to be processed. The processing of RAP includes heating, crushing and fractionation. For heating the RAP, the temperature and duration are the most important factors in order to avoid further aging of aged binder in the RAP. Based on review, the appropriate temperature for heating high RAP percentage is 110°C to 135°C [4]. The milled RAP used in this research were taken directly from the road maintenance site. Therefore, the moisture content in the RAP was determined to ensure that it does not affect the mixture performance. The changes in moisture content of the two sources of RAP after heated in the oven at 110°C is shown in Figure 1.

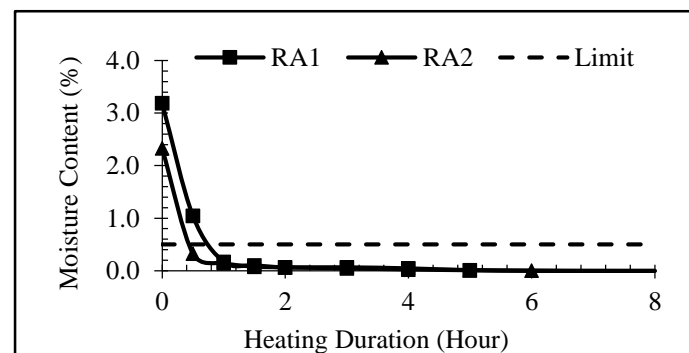


Figure 1. Heating duration of RAP.

All RAP has moisture content that less than 0.5% after one hour of heating. According to Xiao et al., there is no significant influence of the aggregates moisture content in WMA mixtures for values up to 0.5% [17]. Hence, one hour and 30 minutes was chosen to dry the RAP and enable the large RAP lump to be crushed manually. Aggregate gradation of recovered RAP aggregate by ignition method from an average of 5 samples was analysed. The coefficient of variance (COV) is less than 15% for all sources of RAP and considered acceptable. For mixture preparation, RAP from various sources were fractionated or separated into sizes according to AC14. In order to get the acceptable blending within AC14 gradation, a few trials of aggregate blending gradation consists of recovered aggregate and virgin aggregate were conducted.

The physical properties and binder content of reclaimed asphalt is shown in Table 2. The penetration result shows that the recovered RAP binders are stiffer. The RAP binder from RA2 is stiffer than the RAP binder from RA1. When in service, binder progressively ages and becomes stiffer due to various mechanisms. Aging of binder during construction and service are associated with oxidation, volatilization, polymerization, air voids in the HMA and position within the road construction [18,9]. Hence, the variations in physical properties of the RAP binder from the different sources are related to the mentioned factors.

Table 2. Physical properties and binder content in RAP.

RAP Source	Physical Properties		RAP Binder Content (%)
	Penetration (dmm)	Softening Point (°C)	
RA1	19	70	5.1
RA2	9	72	4.7

3.2. Effects of RH-WMA on chemical properties

The addition of RAP changes the chemical properties in the binder due to the aging. The Fourier Transform Infrared (FTIR) test was used to identify and quantify the chemical functional group of the binder as the results of the binder modification and effect of aging. The functional group is characterized based on absorbance related to C=O stretching (1700cm^{-1}), C=C stretching (1598cm^{-1}) and S=O stretching (1030cm^{-1}). FTIR output for RAP from RA1 is shown in Figure 2.

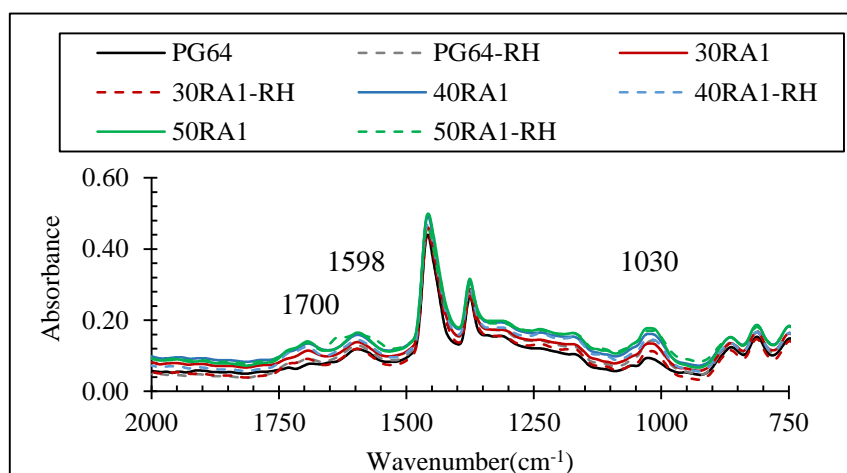


Figure 2. Effects of RAP binder on FTIR.

In general, the binder modified with RAP exhibits higher absorbance for all selected spectral band. Similar trend is observed for RAP from RA2. Since RAP binders in the recycled binder are highly oxidized, RAP binders contain high amount of Sulfoxide and Carbonyl. The Sulfoxide and Carbonyl are related to the spectral band at 1030cm^{-1} and 1700cm^{-1} . It can be seen the absorbance increased with RAP binder content. For instance, 50RA1 has higher absorbance than 30RA1. With the addition of RH-WMA additive, the absorbance slightly reduced. This indicates the RH-WMA potential to reduce the oxidation as the results of aging.

3.3. Mix Design of RAP mixture

Mix design of control mixture was carried out in accordance with the job mix formula in JKR specification. The optimum binder content are 5.2% for the control (PG64) and 4.9 % with RH-WMA. For the mix design of RAP mixture, experimental design approach using RSM was adopted in order to reduce the cost, labour and time in mix design. The mix design involves three main tasks that are the aggregate gradation, trial mixing and determination of optimum binder content using RSM. In the mix design of RAP, simultaneous effects of compaction temperature, RAP content and binder content were evaluated by using RSM. The minimum temperature and binder content to enable the properly coating of aggregate were determined prior experimental design in the RSM. Specimen fabrication, experiment and analysis were performed based on the compaction temperature, RAP content and binder content. Analysis of variance on the selected responses according to JKR specification for mix design indicated that the compaction temperature and binder content are the two significant factors affecting the responses. The RAP content does not significantly affect the responses.

Subsequently, optimization on responses were carried out which is according to the JKR design parameter in JKR/SPJ/2008-S4, energy consumption and cost. In line with the steps provided by the Design Expert software, the desired goal of each factor and responses were set. All factors (RAP content, compaction temperature and binder content) were chosen as 'within the range' which refers to JKR specification, while the responses (cost and energy) were selected as minimum. Similarly, the

volumetric and strength properties were set according to the JKR specification. The Design Expert software optimized each parameters based on the desired goal. During the optimization, the effects of responses can be illustrated. For examples, Figure 3 demonstrates the relationship between the energy consumption, cost, RAP content and temperature for production of 1 Ton RAP-WMA for RA1.

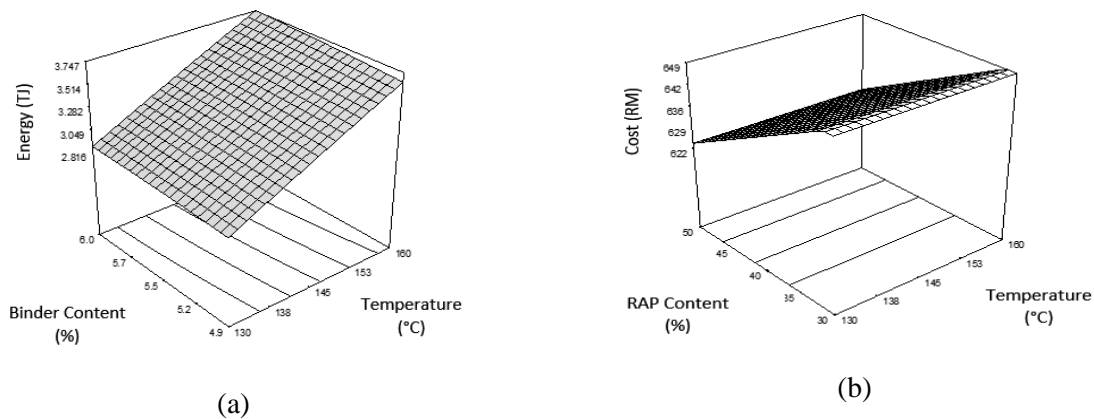


Figure 3. Relationship between energy consumption, cost, RAP content and temperature for production of 1 Ton RAP-WMA.

As seen in Figure 3, both binder content and mixing temperature increase linearly with energy usage. It appears that mixing temperature at 40% RAP has a significant effect on the energy usage which is indicated by the slope of the graph. Steeper slope relates to the more significant changes in energy usage due to increment in mixing temperature. In terms of cost, increase in RAP content reduces the cost linearly. For example, increasing RAP content from 30% to 50% saves 3.7% production cost when temperature and binder content are constant. Similar pattern is observed for 30% and 50% RAP contents. Overall desirability was calculated to proposed best solution based on the optimized parameters. Based on the optimized parameters, specimens were fabricated in the laboratory at 140°C mixing temperature using the optimized RAP content to verify the optimal condition. The average differences of the experimental and optimized parameters for air voids, bulk specific gravity of mixture (G_{mb}), voids filled with asphalt (VFA) and stability are 10.3%, 0.4%, 2.7% and 5.4 % respectively. Some differences between the optimized and experimental are due to the variation in RAP. The differences are considered acceptable and RAP-WMA mixtures containing 50%, 40% and 30% RAP were fabricated at the suggested condition. Table 3 shows the optimum binder content in mix design using the RSM.

Table 3. Optimum binder content.

RAP (%)	Optimum Binder Content			
	RA1	RA1-RH	RA2	RA2-RH
30	5.6	5.4	5.9	5.7
40	5.7	5.5	5.8	5.6
50	5.7	5.5	5.8	5.6

3.4. Effects of RH-WMA on mechanical properties

In this study, the ITS was conducted to indicate the mixtures' stiffness. As shown in Figure 4, RAP increases the stiffness. At higher RAP content, the increase of ITS produces a stiffer mixture. Previous research reported similar finding on the increased ITS with the addition of RAP but on the

porous asphalt. [19]. The stiffness of RAP is affected by the source of RAP and the ITS is consistent with the penetration of RAP binder presented in Table 2.

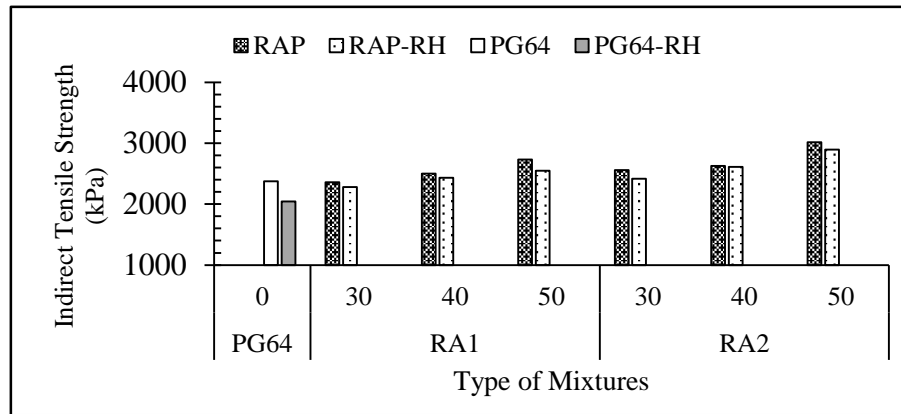


Figure 4. ITS of mixture with RAP.

Table 4. Regression coefficient.

Type of Mixture	Regression Coefficient		R ²
	K	n	
PG64	5.00E+08	-2.005	0.9468
PG64-RH	1.00E+08	-1.844	0.9682
RA1	2.00E+07	-1.337	0.9856
RA1-RH	7.00E+07	-1.376	0.8777
RA2	2.00E+06	-0.789	0.9149
RA2-RH	6.00E+06	-0.934	0.9851

The fatigue failure is determined based on the number of cycles that cause fracture to the asphalt specimen. Prior to the determination of fatigue failure, the initial strain and maximum tensile at the center of the specimen are calculated. Figure 5 exhibits the fatigue curve for various RAP mixture. The gradient of the slope (n) can be calculated based on the power relationship. In general, a higher value of n results in a higher fatigue life. The regression parameters obtained from the fatigue relationship with their R² values are shown in Table 4. Based on Figure 5 and Table 4, RA2-RH results in comparable fatigue resistance with control. This shows that RH-WMA improve the fatigue resistance in RAP mixture.

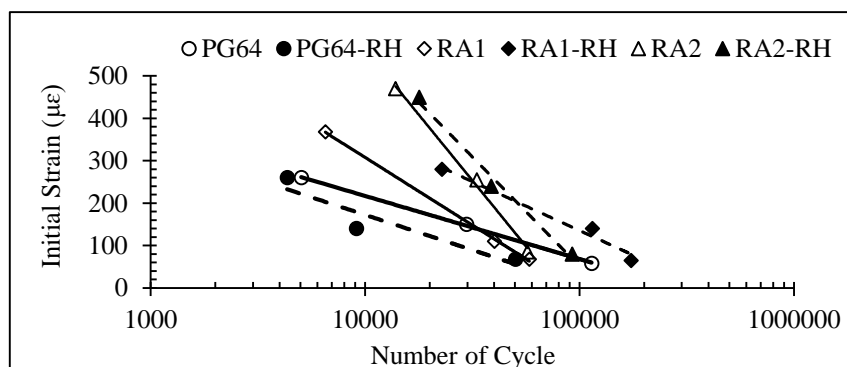


Figure 5. Fatigue curve for mixture with RAP.

In the diametral fatigue test, the applied stress causes horizontal deformation and tensile stress at the center was monitored. The high tensile strain at the bottom of the HMA layer creates cracks that propagate upwards to the pavement surface. The tensile properties of asphalt are essential because of the problem associated with cracking. Specimens subjected to moisture and aging exhibit higher tensile strains indicating the damaging effects of moisture and aging that have weakened the specimen. Moisture and aging are two main components that can significantly increase the potential for fatigue cracking to develop in an asphalt mixture [20]. The variation of fatigue resistance in RAP affected by the binder oxidation and aging, increased binder stiffness and variability of aggregate gradation [21]. In general, the addition of RAP reduces the mixture resistance to fatigue and sometimes the stiffness of the asphalt mixture can dramatically increase with the inclusion of high RAP [9]. When using high RAP content, the fatigue resistance can be reduced due to the addition of aged binder that stiffened the asphalt mixtures.

4. Conclusions

The research findings indicated that proper mix design and localised study on RAP from various sources are necessary due to variation in RAP properties. RAP characterization showed that the RAP met the general quality control characterization. In mix design of 30%, 40% and 50% RAP content, it was found out that temperature and binder content were significant factors. Increased in temperature lead to higher energy consumption which generates negative impact to environment. On the other hand, the addition of high RAP content in RAP-WMA mixtures showed some cost reduction. The lowest compaction temperature of 130°C and 50% RAP content showed the highest cost reduction at lowest energy consumption. In terms of mechanical properties, higher RAP content produced higher stiffness but less resistance to fatigue. However, the addition of RH-WMA in RAP mixture also reduced the stiffness and hence demonstrated better resistance to fatigue compared to RAP mixture only. These findings suggested the potential of recycling the local RAP in bulk production for more than 30%. As a conclusion, study of RAP from local road indicated the possibility for the plant recycling with RH-WMA because it reduced the production temperature, saved cost and produced comparable properties.

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