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THE EFFECT OF INCORPORATING RECLAIMED ASPHALT PAVEMENT ON THE PERFORMANCE OF HOT MIX ASPHALT MIXTURES

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Abstract

In pavement industries, incorporating appropriate amount of reclaimed asphalt pavement (RAP) in the fresh mixtures is one of the approaches to attain sustainable principle in construction. Usage RAP materials have been practiced since 1970s, however, pavements made with RAP will reach the end of service life and need to be recycled again. Only a few studies done on the second recycle of RAP (R^2AP). Therefore, this paper aimed to investigate the effect of incorporating RAP and R^2AP in the asphalt mixture. RAP was collected from in-service road which was exposed to the environment and traffic for seven years. While, the second cycle of RAP (R^2AP) was obtained through the laboratory aging process. 20, 40, and 60 % of RAP and R^2AP were mixed with fresh dense graded aggregates to form Asphaltic Concrete with 14 mm nominal maximum aggregate size (AC 14). Resilient modulus test was performed to evaluate the performance on rutting resistance. Tensile strength was also evaluated at 25 °C as an indicator for fatigue resistance. 60 % of RAP and 40 % of R^2AP are observed to the best optimum amount to be added in the fresh mixture in order to improve both fatigue and rutting resistance.

Keywords: RAP, R^2AP, long term oven aging, Resilient modulus, HMA

Abstrak

Dalam industri turapan jalan raya, campuran turapan tebus guna (RAP) yang bersesuaian di dalam campuran segar merupakan salah satu kaedah untuk mencapai prinsip pembinaan mampan. Penggunaan RAP bermula sejak tahun 1970an lagi, tetapi jangka hayat turapan yang mengandungi RAP akan berakhir dan turapan perlu dikitar semula sekali lagi. Kajian terhadap penggunaan RAP kali kedua (R^2AP) adalah sangat terhad. Oleh itu, kajian ini dijalankan untuk menyiasat kesan campuran RAP dan R^2AP di dalam campuran asphalt. RAP diperolehi daripada jalan raya yang telah dibuka pada trafik dan terdedah pada persekitaran selama tujuh tahun. Sementara turapan tebus guna untuk kali kedua (R^2AP) dihasilkan melalui proses penuaan di makmal. 20, 40 dan 60% RAP dan R^2AP dicampurkan dengan aggregate baru bergred padat untuk membentuk Asfaltik Konkrit dengan saiz nominal maksimum 14 mm (AC 14). Ujian modulus kebingkasan di jalankan untuk menilai prestasi campuran terhadap keupayaan rintangan aluran. Ujian kekuatan tegangan pada suhu 25 °C juga turut dijalankan untuk menunjukkan keupayaan ritangan terhadap kelelahan. 60 % RAP and 40 % R^2AP dilihat jumlah optimum yang boleh dicampurkan ke dalam campuran segar untuk meningkatkan keupayaan rintangan terhadap kelelahan dan aluran.

Kata kunci: RAP, R^2AP, penuaan ketuhar jangka panjang, Moduli keanjalan, HMA

1.0 INTRODUCTION

1.1 Background

Sustainability in construction is a practice that minimizes the use of virgin materials, energy consumption and waste production at the same time provides the best infrastructure to the public. Material recycling is one of the best approaches that support sustainability principle. In pavement construction, cost of construction can be reduced by incorporating reclaimed asphalt pavement (RAP) in fresh mixtures [1]. Usage of RAP in road construction was first reported in 1915 [2]. However, actual developments on the usage of RAP materials had been started since 1970s. Later, with the implementation of Kyoto Protocol in 2005, recycle received major attention and extensive application including the road construction [3].

RAP materials were generated from old or damaged pavement [4]. They are produced by cold or warm milling. Cold milling would pulverize the aggregate while warm milling would damage the binder. Pulverizing the aggregate means some of the gradation value was lost. RAP materials are collected either directly from the milling machine or from the disposal area. Figure 1 shows how RAP was disposed just after the milling process.

Figure 1 RAP stockpiles

Generally, previous researchers reported that there were advantages and disadvantages of incorporating RAP in the mixture. RAP increases rutting resistance and tensile strength; however, it also decreases the fatigue resistance of the mixture [5-7]. These results occur due to oxidation process and environmental exposure of RAP during its service life that made the binder stiffer. It was also stated that binder becomes stiffer at low temperature and the mixtures tended to crack at lower temperature [8-10].

Thus, there are various claims regarding the appropriate amount of RAP that can be added in a fresh mixture. Most of them agreed that the amount of RAP should be not more than 50 %. For example, Miró et al. recommended only 30 % of RAP [11]. While, Su et al. and Widyatmoko claimed that RAP quantity should be not be more than 40 and 50 % [12, 13]. Only Oliveira et al. proved that 100 % of RAP can perform as good as fresh mixture [14]. Meanwhile, Kandhal and Foo reported that when 15 % RAP is added to a mixture, no change in binder grade is necessary. However, addition of 15 % and 25 % RAP, the virgin binder grade must be reduced by one performance grade (PG) increment. When above 25 % RAP is incorporated into the mixture, a blending chart is required to determine suitable binder grade that should be used in the mixture [15].

However, pavements made with RAP will reach the end of service life and need to be recycled again. Only a few studies done on the second recycle of RAP (R^2AP). Chen et al. found that 40 % R^2AP did not alter the mixture. If the percentage of R^2AP is higher, there were significant change on the mixture properties and performance [16]. On the other hand, Su et al. found out that there are no distinct differences in bending strength among virgin, modified, RAP and R^2AP [17].

1.2 Objective and Scope

The study aimed to investigate the effect of incorporating RAP and R^2AP in the asphalt mixture. RAP was collected from the milling process of in-service road. While, the second cycle of RAP (R^2AP) was obtained through the laboratory aging process. Indirect tensile resilient modulus test was performed as an initial indicator of the mixture's performance on rutting resistance. The indirect tensile strength (ITS) test indicated the fatigue resistance of the mixtures.

2.0 EXPERIMENTAL DESIGN

The experimental design of this research is illustrated in Figure 2. This study consists of two phases where the first phase was selection of materials. This comprised selection of aggregates, type of binder, RAP and optimum binder content for the mixtures. Then, indirect tensile resilient modulus and indirect tensile strength test were conducted to complete the first phase. In the second phase, the mixtures were artificially aged in the oven before they were mixed with the fresh materials. Similarly, resilient modulus and tensile strength values were used to evaluate the performance of the mixtures in this phase. The results of each test were compared to evaluate the effect of incorporating RAP in the mixture.

2.1 Materials

Granite aggregates used in this study were supplied by MRP Quarry, Ulu Choh, Johor. It was collected from one source in order to control the quality and properties throughout the study. Binder grade 60-70 PEN was used as the binder for the mixtures. Both aggregates and binder properties were evaluated for compliance of Standard Specification for Road Work [18]. Table 1 and 2 provide the physical properties of the binder and aggregates used in this study. Marshall mixture design procedure was used to design HMA mix. The sample was compacted using a Marshall compactor by applying 75 blows on each side of the sample. A minimum of three samples was produced to evaluate the reproducibility of the results. Selected percentages of RAP and R^2AP were mixed with fresh dense graded aggregates to form Asphaltic Concrete with 14 mm nominal maximum aggregate size (AC 14). Since the AC 14 was designed as fine dense graded mixture, the bulk specific gravity was determined using saturated surface dry method [19]. Figure 3 shows the gradation of the combined aggregates used for all the mixes.

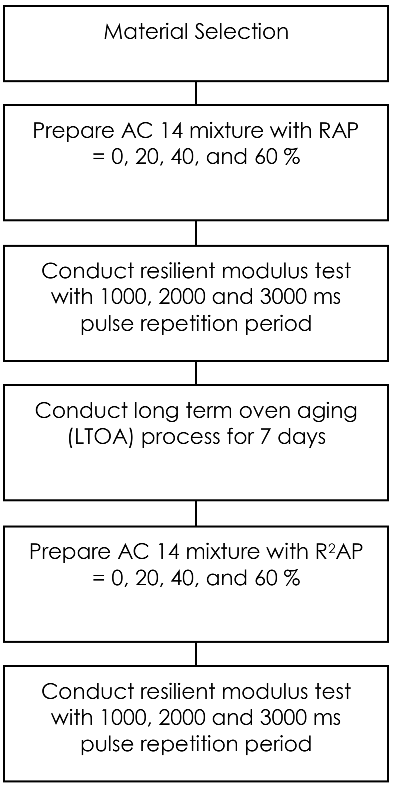

Figure 2 Flow chart of experimental design

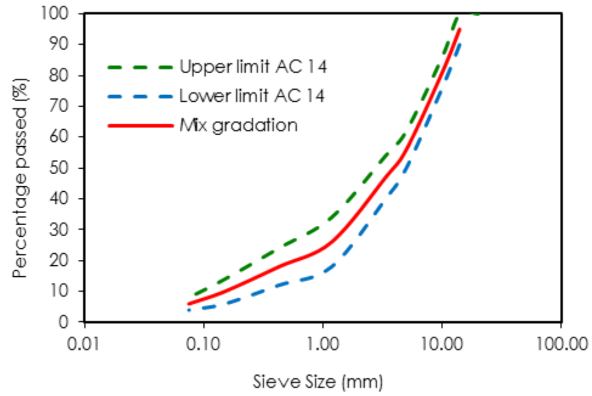

Figure 3 AC 14 aggregate gradation

RAP materials were collected from the millings of the HMA surface layer from Jalan Batu Pahat – Muar (J5) which connects the town of Batu Pahat and town of Muar in Johor. The road was exposed to the environment and traffic for seven years. Figure 4 shows the collection RAP obtained from cold milling process.

Figure 4 Cold milling process

Table 1 Properties of bitumen

Binder Test	Results	Standard
Penetration (PEN)	68	ASTM D5
Softening point (°C)	49	ASTM D36

Table 2 Physical properties of the aggregates

Aggregate property Test	**Results**	**Criteria**	**Standard**
Flakiness (%)	10	<20	BS 812
Elongation (%)	13	<20	BS 812
Los Angeles (%)	24	<45	AASHTO T96
Soundness (%)	1.1	<12	ASTM C88
Aggregate Impact value (%)	17	<30	BS 812
Aggregate Crushing Value (%)	22	<30	BS 812
Ten percent fines (kN)	170	>100 kN	BS 812
Water Absorption (%)	0.5	2	MS 30

2.2 Mixture Aging Procedure

R^2AP materials were obtained through long term oven aging (LTOA) process. After the mixture incorporating the best percentage of RAP was identified (first phase recycle), it was aged for the second time by LTOA process. This process produced R^2AP materials (second phase recycle). According to AASHTO R30 [20], LTOA simulated an aging of HMA for 5 to 7 years of in-service pavement. Through the simulation process, the performance of the mixture can be estimated within the pavement service life. Compacted samples were aged in the force draft oven at 85 °C for seven days. This process was used to emphasize the effect of aging for local environment and materials. Figure 5 shows the oven used for the aging process.

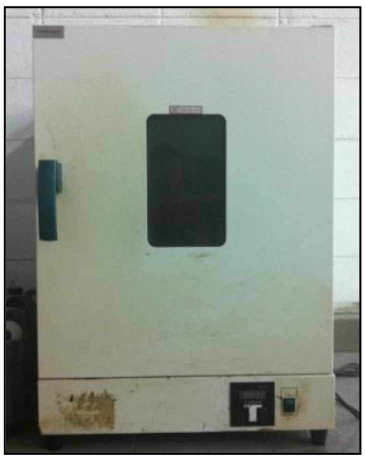

Figure 5 Forced draft oven

2.3 Indirect Tensile Resilient Modulus Test

HMA stress-strain relationship, as characterized by elastic or resilient modulus, is an important characteristic in pavement material analysis. Indirect Tensile Test used to determine the elastic or resilient modulus. This non-destructive test is the measurement of dynamic stresses of pavement and the corresponding strain as presented in Equation 1.

$$M_R = \frac{\sigma_d}{\varepsilon_r} \qquad \text{(Equation 1)}$$

Where M_R is the resilient modulus; σ_d is the maximum applied load (stress); and ε_r is the strain of the specimen. In this study, all aged and unaged samples were tested for resilient modulus by using Universal Testing Machine (IPC UTM-5) as shown in Figure 6. Each sample was tested at 25 °C and 40 °C. In accordance with ASTM D 4123-82 [21], the samples were conditioned at the selected test temperature for 4 hours before they were tested. Resilient modulus test was done on aged and unaged samples using repeated load of fixed magnitude and cycle duration to a cylindrical test sample. A haversine load with 1000 N peak force was applied with three pulse width of 100 ms along with a rest period of 900 ms.

Figure 6 Universal Testing Machine (IPC UTM-5)

All samples were tested at three different pulse repetition periods (1000, 2000 and 3000 ms); 1000 ms indicates high traffic volume while 2000 and 3000 ms indicate medium and low traffic volume. Hence, the sample received one load cycle per second. After 5 pulses, the resilient modulus can be calculated using the horizontal deformation and an assumed Poisson's ratio. The test procedure then repeated by orientating the sample at approximately 90 degrees (90 °). All test data were calculated and recorded by specific computer software.

2.4 Indirect Tensile Strength (ITS) Test

Indirect tensile strength (ITS) test was conducted in accordance with ASTM D 6931[22]. Samples were tested using universal compression machine with ITS loading fixture as shown in Figure 7.

Figure 7 Universal compression machine

Before the test, samples were placed in the plastic bag before they were conditioned in a 25 °C of water for 2 hours. The test was then conducted by applying vertical compressive load on the cylindrical sample until it reached the maximum load. A 50 mm/min loading rate was applied on all samples in this test. Tensile strength of each sample was determined by the following equation 2

$$S_t = \frac{2000P}{\pi t D} \qquad \text{(Equation 2)}$$

Where S_t is the ITS (kPa); *P* is the maximum load (N); *t* is the sample height (mm); *D* is the sample diameter (mm). ITS result was then reported based on the average of 3 samples for each type of mixture.

3.0 RESULTS AND DISCUSSION

3.1 Resilient Modulus Test Result

Figure 8(a) and Figure 8(b) illustrate the resilient modulus value of AC 14 incorporating various percentages of RAP at 25 and 40 °C. The test was performed on samples with 3 different RAP amount and one control sample. The graph was plotted based on the results of 3 samples.

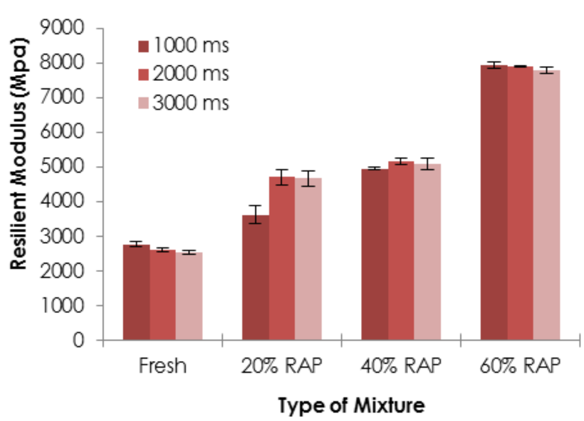

Figure 8(a) Resilient modulus of mixture incorporating various percentages of RAP at (a) 25°C; (b) 40°C

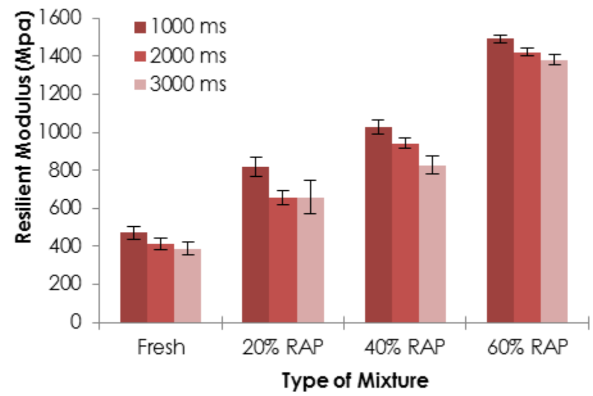

Figure 8(b) Resilient modulus of mixture incorporating various percentages of RAP at (a) 25°C; (b) 40°C

It can be seen that as the temperature decreases, the resilient modulus of all type of sample decreases by more than 80 %. It is well known that temperature significantly influence the resilient modulus of asphalt mixtures. It was stated that binder becomes brittle at low temperature and the mixtures tended to crack at lower temperature [7-9].

Generally, as the RAP amount increases, the resilient modulus value also increases. Figure 8 (a) clearly shows that at all three repetition period of 1000, 2000 and 3000 ms the mixture with the most resistant to fatigue is 60% RAP, with average resilient modulus value of 8000 MPa, followed by 40 % RAP, 20 % RAP and Fresh mixture. Figure 8 (b) shows the resilient modulus value of the samples tested at 40 °C. 60 % RAP is also found to be the highest resilient modulus value with an average 1400 MPa for all three repetition periods. It is then followed by 40 % RAP, 20 % RAP and Fresh mixture. It indicates that 60 % RAP mixture is the best mixture that can provide highest rutting resistant. This result proves that it is possible to incorporate more than 50 % of RAP in fresh mixture for the first phase recycle. It is slightly higher from findings from previous studies by Miró et al., Su et al. and Widyatmoko. [5-7].

60 % RAP mixtures were aged in the laboratory oven at 85 °C for seven days. This process was done to simulate the long term aging of pavement. Then, aged samples were mixed with several percentages of fresh aggregate again (second phase recycle).

Figure 9 (a) and (b) present the resilient modulus value of AC 14 incorporating various percentages of R^2AP at 25 and 40 °C. At 25 °C, sample with 40 % R^2AP attained the highest resilient modulus value with 8500 MPa followed by 60 % R^2AP, 20 % R^2AP and fresh mixture. Similar trend occurred at 40 °C where 40 % R^2AP is observed to be the highest resilient modulus with 1350 MPa, followed by 60 % R^2AP, 20 % R^2AP and fresh mixture.

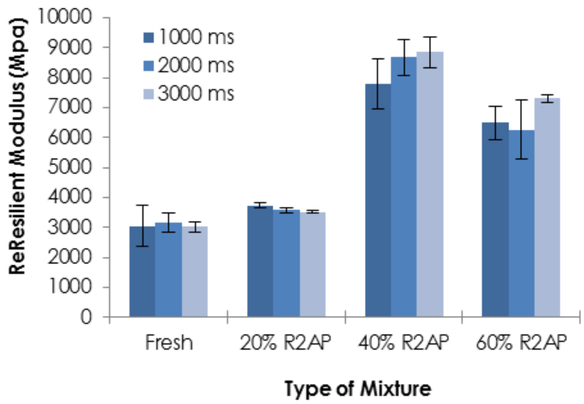

Figure 9(a) Resilient modulus of mixture incorporating various percentages of R²AP at (a) 25°C; (b) 40°C

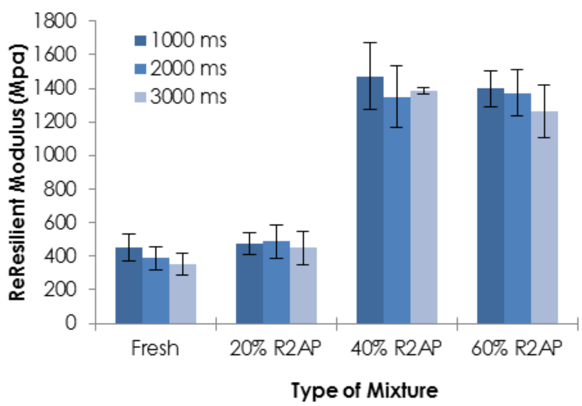

Figure 9(b) Resilient modulus of mixture incorporating various percentages of R²AP at (a) 25°C; (b) 40°C

This result shows that usage of RAP for the second time may reduce the ability to resist rutting. Only 40 % R²AP is found to be the best appropriate amount to be added in the fresh mixtures instead of 60 % for RAP. This finding is found to be similar to the claim made by Chen et al. [15].

3.2 Indirect Tensile Strength (ITS) Test Result

Figure 10 presents the strength from the indirect tensile strength (ITS) test of the mixture with various percentages of RAP. The graph was plotted based on the average of 3 samples for each type of mixture. Mixtures with RAP exhibit higher tensile strength than the fresh mixture. As the amount of RAP increases the tensile strength increases. 60 % RAP presents the highest tensile strength with 1900 kPa. This result can be attributed to the aged and stiffed binder in RAP due to the aging process. This test result is consistent with the study conducted by Shu et al. [7].

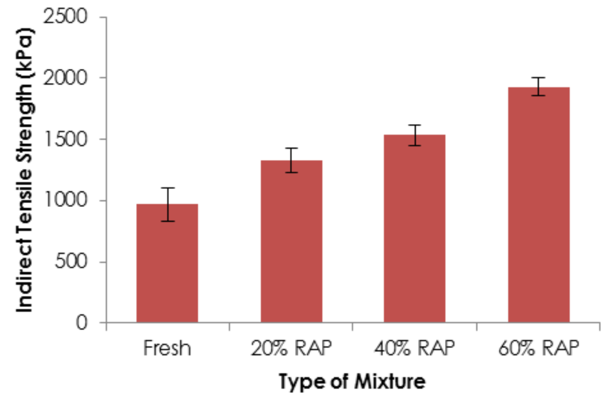

Figure 10 Indirect tensile strength of mixture incorporating various percentages of RAP

60 % RAP mixtures were then artificially aged in the laboratory oven at 85 °C for seven days to produce R²AP.Figure 11 presents the tensile strength from the ITS test of the mixture with various percentage of R²AP. It can be observed that similar trend as the first phase occurred for the second phase of this study. 40 % of R²AP shows the highest tensile strength with 1800 kPa. Tensile strength of 60 % R²AP is slightly lower than 40 % R²AP. High amount of stiffed binder in 60 % R²AP mixture caused the mixture tended to crack earlier than 40 % R²AP.

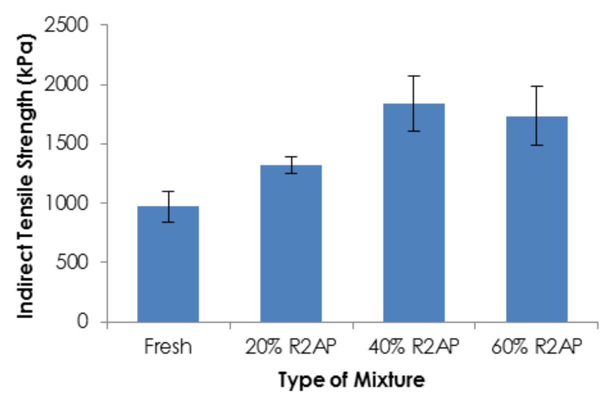

Figure 11 Indirect tensile strength of mixture incorporating various percentages of R²AP

4.0 CONCLUSION

This research was conducted to investigate the effect of incorporating RAP and R²AP in the hot mix asphalt mixture using indirect tensile resilient modulus test and indirect tensile strength (ITS) test. The results of this study proved that incorporating RAP or R^2AP in the fresh mixture could improve the fatigue and rutting resistance. The following conclusion can be drawn:

- For the first phase recycle, 60 % of RAP is found the be the best possible amount to be added in the fresh mixture which can increase the resilient modulus and tensile strength values of the mixture at 25 °C and 40°C.
- For the second phase recycle, only 40 % of R^2AP is observed to the best approprite amount to be added in the fresh mixture in order to improve both rutting and fatigue resistance.
- Reuse of RAP twice might reduce the ability to resist fatigue and rutting.

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