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Repeatability of reclaimed asphalt pavement as related to properties of bitumen

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Abstract. Abstract— Material recycling is one of the best solution that support sustainability aspect and at the same time reduce the construction and material cost. One of the common method in bituminous recycling is using reclaimed asphalt pavement (RAP). Although usage of RAP in the pavement has been established, properties of bitumen after repeated recycling process is unclear. Bitumen was extracted from recommended recycled mixtures that had undergone through repeated recycling process. In this study, bitumen was assessed in three different ageing stages namely 0 Cycle, 1st Cycle and 2nd Cycle. 0 Cycle is the sample which extracted from fresh mixture (represents 100% fresh materials). 1st and 2nd Cycles represent the number of recycling process. Penetration, softening point and viscosity test were used to evaluate the properties of extracted bitumen. From the tests, the results indicate that repeated recycling process generally increased hardness of the bitumen. This result was proven with the reduction in penetration value and increased in softening point temperature. Furthermore, it was also discovered that multiple recycling stages reduced the mixture workability, which was demonstrated by the increment of viscosity value. Hence, recycling process without any rejuvenator is applicable up to certain levels only.

1. Introduction

Reclaimed asphalt pavement (RAP) is waste materials obtained from a milling process of pavement surface. It may consist of wearing course, binder course or both layers. Implementation of RAP as a pavement is considered successful by fulfilling three key elements which are cost effective, environmentally responsible, and well performance. RAP has different quality compared to virgin materials, but, incorporating it in the fresh mixtures generally could reduce the materials cost [1].

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Pavements made with RAP will reach the end of service life. The same problem will occur during the second phase of rehabilitation on how to deal with the milled RAP (R2AP) for the second time. Most of existing research on RAP typically concentrates on evaluating the performance of mixture incorporating RAP while performance and properties of R2AP is very limited and still debatable.

In real field practice, it is suggested that the 70% RAP content is allowed to be mixed in drum mix plant and only up to 50% RAP in batch plant [2]. Several researchers have conducted studies on the proportion of RAP and virgin materials. Yang and Lee [3] reported that when incorporating RAP less than 25%, this recycled mixture exhibit similar performance levels to conventional mixture (100% fresh materials). Apart from that, most of the previous researchers agreed that less than 40% RAP in the mixtures is acceptable [4-7]. Besides, Taiwan Public Construction Commission only allows 40% RAP in the recycled mixture [8]. Poulikakos et al. [9] also proved that recycled mixture with 40% RAP could perform as good as conventional mixture if proper design and handling is practiced. Other research found that, recycled mixtures up to 60% RAP could perform similar to conventional mixture. However, proper characterization and handling of RAP stockpiles are crucial steps to avoid excessive mix heterogeneity [10]. From existing accessible literature, only few studies conducted on the second recycle of RAP (R2AP). Chen et al. [11] claimed that up to 40% R2AP did not alter the mixture properties and performance.

However, RAP has different quality compared with fresh materials. In order to have a better quality of recycled mixture with minimum usage of new resources, the study on the suitable amount of RAP in the recycled mixture is very important.

Physical, rheological and chemical are some of the important binder properties that need to be evaluated on aged pavement. Ageing was greatly altered the rheological and chemical properties of bituminous mixtures [12-16]. Aged and RAP binders were physically hardened as a result of ageing. Ageing of binder basically increased the molecular weight, consequently changed the properties of bitumen. Longer ageing time also influenced the viscosity of binder [17-19]. However, some research discovered that, this finding only applicable on pure binder but not for modified binder. Yu et al. [20] and Wu et al. [21] found that softening point of polymer modified binder tend to decreased after long term ageing process. Possible reason of this trend is that the polymer molecules are degraded in size, and as a result, the bitumen-polymer interactions may be reduced dramatically, which induce the reduction of the softening point [22].

This study focused on investigating the effect of repeated recycling process on the properties of the binder.

2. Experimental Design

The experimental design of this research is illustrated in Fig. 1. This study consists of two phases where the first phase was preparation of recycled mixture and the second phase was properties evaluation of the aged bitumen. The first phase comprised selection of bitumen, determination of optimum bitumen and RAP contents for the mixtures. In the second phase, the mixtures were extracted and recovered through distillation process before the aged bitumen were tested.

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. Bitumen 60-70 PEN and 80-100 PEN were used as the binder for the mixtures. Both aggregates and binder properties were evaluated for compliance of Standard Specification for Road Work [23]. Table 1 shows the properties of bitumen used in this study.

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Table 1. Properties of pure (fresh) bitumen

Properties		80-100 PEN (B1)	60-70 PEN (B2)
Penetration (PEN)		87	68
Softening Point (°C)		38.3	46.3
Viscosity (cP)	at 135 °C	237	400
	at 165 °C	127	135

RAP material was 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. Fig. 2 shows the collection RAP obtained from cold milling process. Sieve analysis and bitumen test were carried to identify the properties of the RAP material. Fig. 3 illustrates the gradation of RAP aggregate based on ACW 20 gradation and Table 2 shows the recovered RAP bitumen properties and of RAP aggregate.

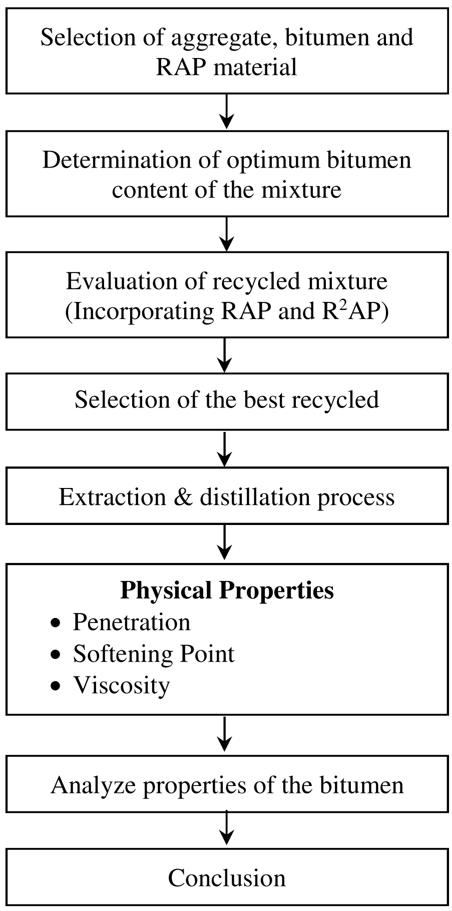

Figure 1. Experimental Design

Figure 2. Cold milling process

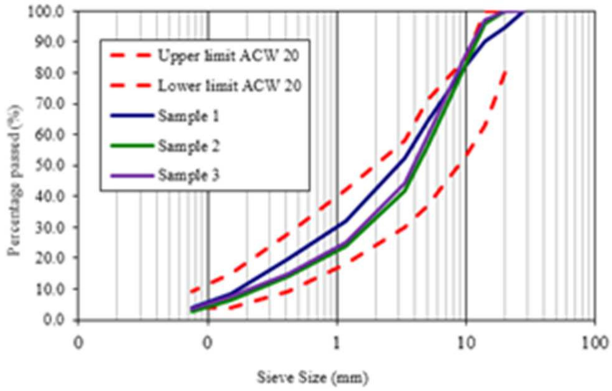

Figure 3. Sieve analysis of RAP aggregate at ACW 20 gradation

Table 2. Properties of RAP bitumen

Bitumen content in RAP		**6.1 %**
Penetration		10 PEN
Softening point		61.5 °C
Viscosity	at 135 °C	5539 cP
	at 165 °C	1467 cP

2.2. Methods

2.2.1. Phase I: Preparation of recycled mixture
There were several steps taken before recycled mixtures were prepared. The steps includes determination of optimum bitumen content, evaluation of first recycled mixtures, artificial ageing process and evaluation of second recycled mixtures. The details process and results can be referred to Idham & Hainin [24], Idham et al. [25] and Idham [26]. Based on the references, recommended RAP and R2AP contents shown in Table 3.

Table 3. Recommended amount of recycles materials at each cycle

Type of fresh bitumen	Amount of recycle materials (%)	
	1st cycle	2nd cycle
80-100 PEN	40	40
60-70 PEN	60	40

2.2.2. Phase II: Evaluation of aged bitumen properties

In Phase II, properties of aged bitumen under repeated recycling stage were evaluated. Aged bitumen was obtained from recommended recycled mixture in the first phase. Recycled mixtures were recovered through extraction and distillation process.

Extraction is a process to remove binder or bitumen from the bituminous mixture. It is commonly conducted to verify the amount of bitumen content in the respective mixture. The extraction procedure was conducted in accordance to ASTM D2172. Prior to the process, compacted mixture was heated to loosen it up. Then, the loose sample was weighed before a solvent was added to disintegrate bitumen and aggregates. About 1.5 litre of methylene chloride solvent was used to extract each sample. Filter paper was then placed on top extractor bowl before funnel-clamp was screwed on until it tight. An empty and clean container was placed under the discharged pipe to collect extracted solution from the sample. Once completed, discharged solution was collected and used in distillation process. Fig. 4 shows the extraction apparatus and Fig. 5 shows the solvent before and after the process.

Figure 4. Extraction apparatus

During extraction process, bitumen was disintegrated from the aggregates and dissolved in the solvent (also known as extracted solution), which is shown in Fig. 5 (b)). In order to evaluate the properties of the bitumen, distillation process was conducted to recover the bitumen from the extracted solution. This test was conducted in accordance to BS EN 12697-1. The recovery apparatus comprised of water bath with a heater element up to 100 °C, flasks of 250 mm³ capacities, a pressure gauge, and a vacuum reservoir. Fig. 6 illustrates a recovery apparatus used in this study.

The test was conducted by immersing the both flasks filled with 20 gram of extracted solution to approximately half its depth in the boiling water, and distilling off the solvent. Pressure was maintained less than 60 kPa until the end of the test. The test was repeated until the amount of recovered bitumen was sufficient to conduct all binder property tests.

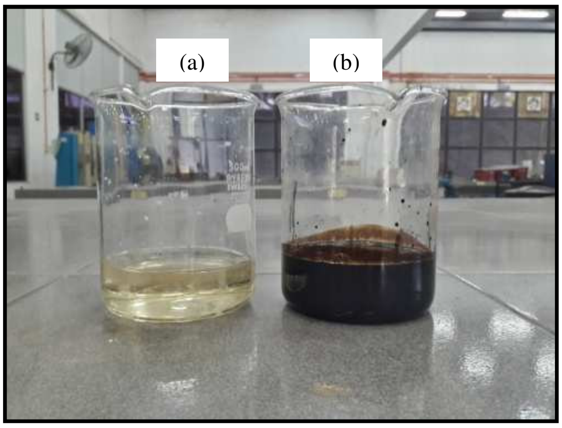

Figure 5. Solvent (methylene chloride); (a) fresh; (b) with extracted bitumen

Figure 6. Typical arrangement for distillation (binder recovery) apparatus

Bitumen was assessed in three different ageing stages namely 0 Cycle (Extracted Fresh), 1st Cycle and 2nd Cycle. 0 Cycle (Extracted Fresh) is a sample which extracted from fresh mixture (represents 100% fresh materials).1st and 2nd cycle mixtures represent recommended recycled mixtures which contains RAP and R^{2}AP material, respectively. Additionally, properties of RAP bitumen obtained from the field (Milled RAP) and fresh bitumen were also marked as references. Fresh bitumen is defined as undisturbed bitumen which was directly tested after it had been collected from the supplier.

Penetration, softening point and viscosity were used to measure consistency and hardness of aged bitumen in this study. Penetration test is a physical test that measurement the hardness of bitumen. The test measurement based on the depth of a standard needle penetrates the material under known conditions of time, loading, and temperature. It was conducted in accordance with the procedure specified in MS 124. In this study, the depth of the needle penetrated in the bitumen under 100 g loads in 5 seconds was measured. The bitumen temperature is maintained at 25 °C. The final result was averaged from three readings.

Softening point test is also known as the ring-and-ball test. It was used to measure the susceptibility of bitumen temperature changes by determining the temperature at which the bitumen adequately softened. Temperature at which the steel balls sank through the softened bitumen and touched the bottom plate was recorded. The test was performed in accordance to ASTM D36.

Viscosity is a resistance to flow of fluid. It was used to measure the torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in specific bitumen weight at a constant temperature. It also used to estimate mixing and compaction temperatures for use in hot mix asphalt mix design [27]. The test was conducted in accordance to ASTM D4402. In this study, viscosities were measured at 135 and 165 °C by using spindle number 27. The rotational speed was turned on at 20 RPM and the viscosity value was recorded once the consistent reading was attained.

3. Results

Fig.7 shows the significant reduction in penetration values of the recycled mixtures blended with 80-100 PEN (B1) and 60-70 PEN (B2) bitumen. As expected, very significant drop was observed between fresh and 0 Cycle. It is about 53% reduction for B1 and 31% reduction for B2 after the bitumen experiencing short term ageing. Incorporating RAP and R^2AP have further reduced the penetration. For B1, 0 Cycle penetration was recorded at 41 PEN, followed by 28 PEN in the 1st Cycle and 23 PEN in the 2nd Cycle. However, penetrations of all recovered bitumen are still higher than the Milled RAP penetration value.

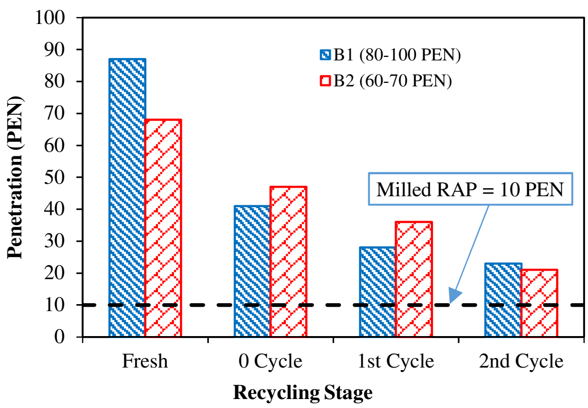

Figure 7. Penetration value based on recycling stages

Softening point test was also conducted to determine the temperature at which the bitumen become soft. Fig. 8 plots that temperature is increases with the increases of recycling stages. This finding is identical to the penetration result in Fig. 7, where softening point is getting higher if lower penetration is observed. From the graph, softening point of mixture blended with B1 at 1st and 2nd Cycles are still below the Milled RAP temperature. On the other hand, mixture blended with B2 at 2nd Cycle has attained 73.9 °C, which is 20% higher than the Milled RAP temperature.

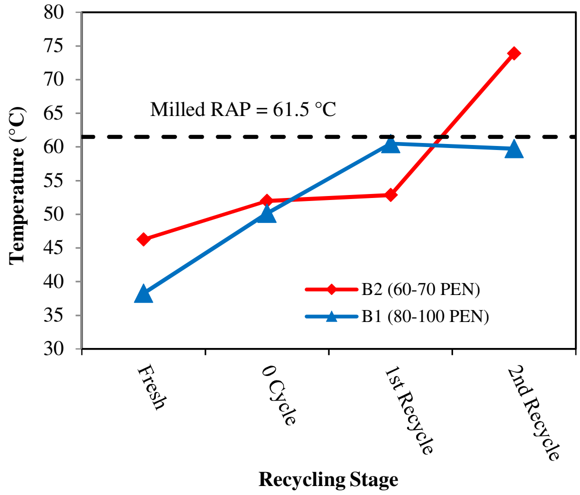

Figure 8. Softening point at different recycling stages

Similar trend was discovered in viscosity graph where viscosity increases with respect to the number of recycling stage. Figure 9 plots the viscosity at multiple recycling stages. 2nd cycle aged bitumen blended with B2 depicts the highest viscosity with 1667 cP which exceeds the Milled RAP value. In term of recyclability of the bitumen, regression line demonstrates that viscosity of aged bitumen blended with B2 intersects with Milled RAP value before 2nd Cycle.

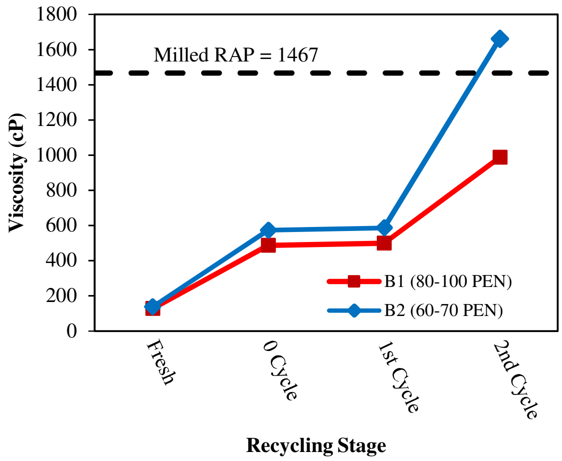

Figure 9. Viscosity of bitumen at different recycling stages

Repeated recycling indirectly caused the bitumen to get aged. Thus, these results are consistent with the previous studies [12-16] where ageing would change the bituminous mixture properties due to the increment of the nolecular weight.

4. Conclusion

The experimental results of this study explain the effect of incorporating recycled material on the properties of bitumen. Recycled materials consist of RAP and R2AP materials. At the same time, by incorporating these materials, effect of repeated recycling process could be investigated. Based on the results, incorporating recycled materials significantly reduced the penetration value and increased the softening point and viscosity value compared to the control B1 and B2 bitumen.

These results also indicate that repeated recycling process generally increased hardness of the bitumen. This result was proven with the reduction in penetration value and increment in softening point temperature with respect to the number of recycling. Furthermore, it was also discovered that repeated recycling reduced the mixture workability, which was demonstrated by the increment of viscosity value.

By using Milled RAP as a reference value, extrapolation of the results show that recycling process without any rejuvenator is applicable up to certain stages only.

5. Acknowledgement

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