The Influence of PelletRAP^{TM} Rejuvenator on the Mechanical Properties of Reclaimed Asphalt Pavement

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Abstract. In the last decade, the use of reclaimed asphalt pavement (RAP) resulted from asphalt milling process has been widely increased for economic and environmental reasons. However, RAP mixtures have undesired characteristics, such as higher stiffness and low flexibility. In this case, the rejuvenators should be used for restoring the properties of RAP which were lost during service life. In the present research, the mechanical properties of 100% RAP incorporating various percentages of PelletRAP^{TM} rejuvenator were evaluated via stability, flow, stiffness, indirect tensile strength (ITS), moisture damage and Cantabro loss measurements. The results showed that the rejuvenated mixtures containing 4% of PelletRAP^{TM} exhibited better performance in terms of stability, cracking and moisture damage resistance, as well as durability, compared with virgin mixtures. Thus, it can be concluded that 100% RAP can be renovated and re-used in the pavement if it is mixed with an appropriate prescription of PelletRAP^{TM}. The proposed of incorporating PelletRAP^{TM} with RAP is beneficial in the improvement of sustainability and cost-efficiency of the asphalt mixtures industry.

1. Introduction

Demand for the virgin asphalt and aggregates has increased with infrastructure expansion. The literature reported that over 110 million tonnes of asphalt binder are used annually [1, 2]. Additionally, many countries have a problem with obtaining of virgin materials, especially petroleum asphalt. Therefore, one alternative to achieve sustainability and to reduce the consumption of virgin materials in pavement design is the use of RAP removed from the resurfacing and rehabilitation of pavement. Additionally, utilisation of RAP can also reduce the disposal of landfill and energy-consuming as well as achieving economic and environmental benefits. However, the inclusion of a high percentage of RAP into the asphalt mixture produces poor performance in term of cohesion and adhesion properties [3] in addition to the issues associated with the fatigue life and low temperature cracking resistance. This is due to the short and long term ageing during the lifespan, which increase the viscosity and brittleness property [4]. Nevertheless, the properties of aged asphalt in the RAP can be renovated using rejuvenators [5]. Rejuvenators are materials that contain a high amount of maltene fractions, which can compensate the stiffness of aged asphalt in mixtures, soften and enhance the rheological properties of aged asphalt [6, 7]. Selection of a rejuvenator depends on the degree to which the characteristics of aged asphalt are enhanced, and the RAP binder ageing process is reversed [2]. Indeed, the durability of rejuvenated mixtures is an issue since the use of some rejuvenators can increase the rutting damage [7]. The literature also reported that some of rejuvenating agents accelerate of ageing of rejuvenated asphalt [8], leading to decrease the durability of pavement. Therefore, the integration of more than one rejuvenator additive into the aged asphalt has increased in recent years. The aim is to reduce the negative impact of some rejuvenating agents. For examples, Al-Saffar et al. [5] explored the possibility of using hybrid rejuvenator composed of maltene and waste engine oil (WEO)) to rejuvenate an aged asphalt. The results showed that the hybrid rejuvenator noticeably improved the rheological properties of aged asphalt. The stripping resistance test disclosed the equivalent characteristics of the rejuvenated asphalt comparing with virgin asphalt. Jahanbakhsh [9] investigated the mechanical performance of asphalt mixture containing high percentages of RAP, crumb-rubber and WEO. The finding reported that the results of rejuvenated mixtures were better than or equal to that of virgin mixture. Abreu et al. [10] analysed the mechanical attributes of hot mix asphalt (HMA) containing 50 % RAP and two types of additives. It was found that 7.5% of used motor oil (UMO) and 4.0% of high-density polyethylene (HDPE) could be used for rejuvenating the mechanical properties of HMA containing 50% RAP. Based on foregoing, the rejuvenator possibility of PelletRAPTM, which is commercial rejuvenator composed of six types of additives, was used in this research. The main objective of this study is to improve the sustainability and reduce the cost of asphalt mixtures production. The mechanical properties of 100% RAP mixture incorporating various amounts of PelletRAP^{TM} were evaluated via Marshall properties, ITS, moisture damage and Cantabro loss tests.

2. Materials and experiments

2.1. RAP (aged asphalt) and virgin asphalt

The sample of RAP was obtained from the milling process located on the north direction of highway Yong Peng to Pagoh, its optimum asphalt content (OAC) was 5.1% with the gradation of AC14. It was obtained via extraction method using methylene chloride solvent according to the ASTM D2172 [11]. 60-70 penetration grade obtained from Kemaman Bitumen Company (KBC) Malaysia, was used as a virgin asphalt. Table 1 lists the gradation of the aggregates used in the mixtures, whereas Table 2 lists the properties of RAP (aged asphalt) and virgin asphalt.

Table 1: Gradation limits of aggregates for AC14

Sieve size (mm)	Gradation	Passing (%)	Retained (%)	Mass retained (gm)
20	100-100	100	0	0
14	100-90	95	5	60
10	86-76	81	14	168
5	62-50	56	25	300
3.35	54-40	47	9	108
1.18	34-18	26	21	252
0.425	24-12	18	8	96
0.15	14-6	10	8	96
0.075	8-4	6	4	48
Pan	-	0	4	48
lime	-	0	2	24
Total				1200

Table 2: The properties of virgin and aged asphalts

Properties	virgin	aged	Standard method
Penetration (dmm.) at 25 °C	64	18.5	ASTM D5 [12]
Softening Point (°C)	51.5	73	ASTM D36 [13]
Ductility (cm)	116	9	ASTM D113 [14]
Viscosity @ 135 °C (mPa.s)	650	3500	ASTM D4402 [15]
Viscosity @ 165 °C (mPa.s)	200	700	ASTM D4402 [15]

2.2. PelletRAP™

It is a commercial rejuvenator, composed of 45 -65% (asphalt), 25-30% (ground tire rubber), 2-5% (Bitunite), 2-4% (Portland cement), < 1 of metal oxide and emulsion. This material (shown in Figure 1) is considered as one of the economical (cost effective) and environmentally friendly solutions (that utilised to restore and enhance the workability of highly oxidised asphalt for re-use in the pavement)**.**

Figure 1. PelletRAP™ rejuvenator

2.3. Preparation of samples

First of all, the virgin asphalt (VA) mixture was designed using the Marshall mix-design procedure. The samples were placed in a pre-heated mould and compacted at 75 blow/face using a Marshall compactor. The mixing and compacting temperatures (168°C and 156°C, respectively) for mixtures were determined based on the results obtained from the viscosity test results at both 135°C and 165°C, respectively. Three replicate samples (101.6 mm diameter and 63.5 mm average height) and asphalt content from 4-6% at 0.5% increment were prepared for each percentage. The optimum asphalt content (OAC) value was determined from the values of stability, flow, void in total mix (VTM), voids filled with asphalt (VFA) and density. Later, the values were verified and compared with Marshall mix requirements in accordance with JKR standard [16]. For comparison purposes, the RAP and rejuvenated samples were prepared based on the OAC, mixing and compaction temperatures of VA. This suggestion is in agreement with another research accomplished by Xia et al. [17]. The rejuvenated mixtures were prepared by adding various percentages of PelletRAP™ (2, 3, 4 and 5% by weight of total mixture) into the RAP and blending them for 2 minutes using electrical mixer machine. Then, the optimum rejuvenator content was determined based on the mechanical tests. All results were compared with VA and 100 % RAP mixtures. The mixtures were composed of 6 mixtures as shown in Table 3.

Table 3: Types of the selected mixtures

Type of mixture	Asphalt mixture details
VA	Virgin asphalt mixture (reference)
R100-0X	100 % RAP mixture
R100-2X	100% RAP+2% of PelletRAP™
R100-3X	100% RAP+3% of PelletRAP™
R100-4X	100% RAP+4% of PelletRAP™
R100-5X	100% RAP+5% of PelletRAP™

3. Tests

Marshall stability and flow results were carried out on the virgin, RAP and rejuvenated asphalt mixtures based on ASTM D6927 [16]. Then, the stiffness value was determined from the correlation between stability and flow. After that, the indirect tensile strength (ITS) and tensile strength ratio (TSR) were examined based on ASTM D4867 [18]. Finally, Cantabro loss test of was conducted in accordance with Texas Department of Transportation (TxDOT) Tex-245-F [19] to assess the mixture's resistance to disintegration caused by traffic load [20]. (See Figure 2).

Figure 2. Stability, ITS and Cantabro loss machines

4. Results

4.1. Marshall properties
The results of Marshall properties are shown in Figures 3-5. It can be seen that stability increased with the addition of rejuvenator and recorded 2278.8 kg at 4% PelletRAP™ (see Figure 3). However, this value declined when the percentage of PelletRAP™ exceeds 4%. The increment in stability values may be attributed to improving the adhesion among the asphalt mixture constituents as a result of adding the rejuvenator. Meanwhile, Figure 4 shows that the flow value increased when PelletRAP™ was added to RAP. However, all values were between 2-4 mm, which meet the minimum requirement of ASTM standard. The exception was R100-5X, which recorded a flow value of 4.04 mm. The result of the flow test reflects the resistance of the RAP mixtures to permanent deformation. The highest flow indicates the lowest deformation rate. On the other hand, stiffness was determined based on the correlation between flow and stability. Figure 5 shows that the highest stiffness value was achieved by R100-0X (1009.6 kg/mm), whereas the lowest stiffness was recorded by VA (460 kg/mm). This result is very close to stiffness value obtained from R100-5X (463.8 kg/mm). The results of flow, and stiffness are in agreement with the results presented by Nejad et al. [21] and Jahanbakhsh et al. [9] who reported that the rejuvenators can decrease the stiffness and increase the flow. However, most of the rejuvenators reduce the Marshall stability of mixture. On contrary, the PelletRAP™ showed a different trend where the stability increased by adding PelletRAP™. This is due to its several notable features compared to the other rejuvenators.

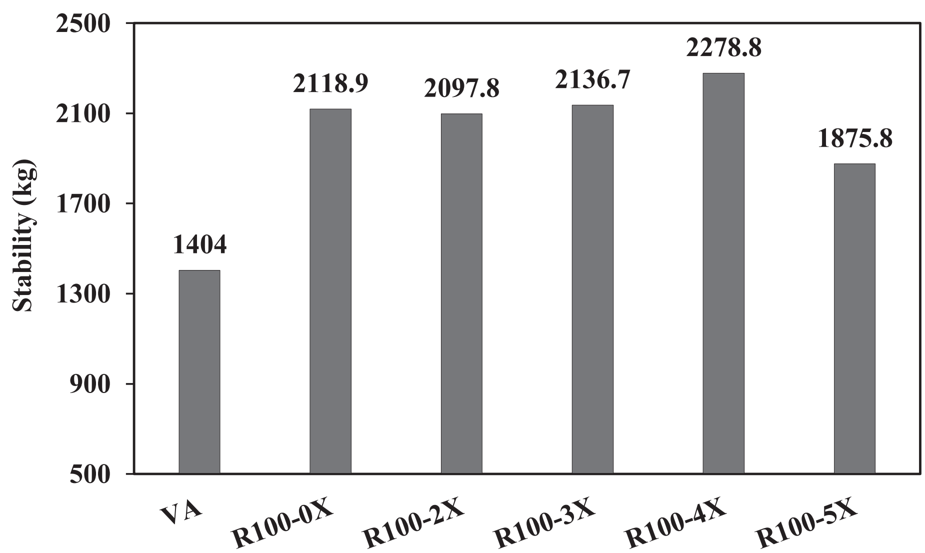

Figure 3. Stability values of asphalt mixtures

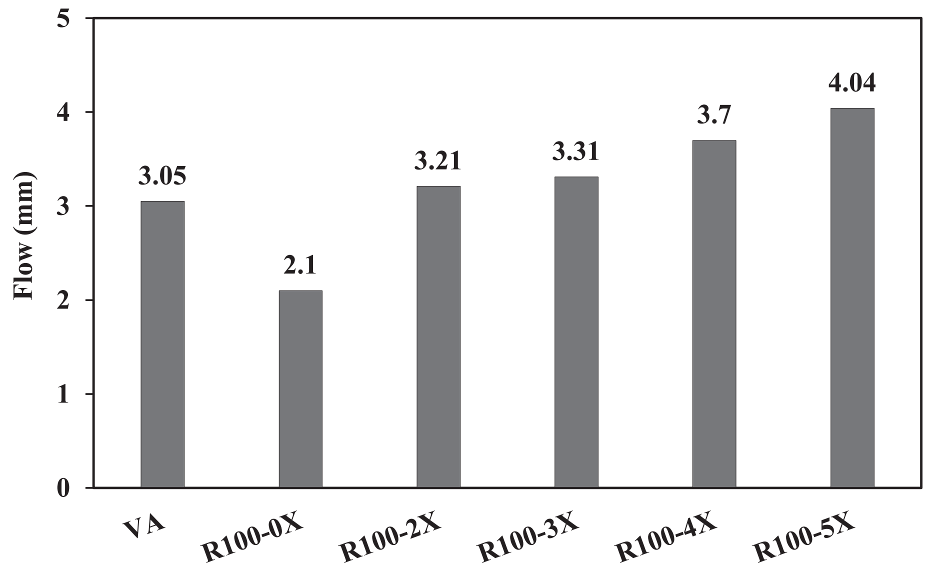

Figure 4. Flow values of asphalt mixtures

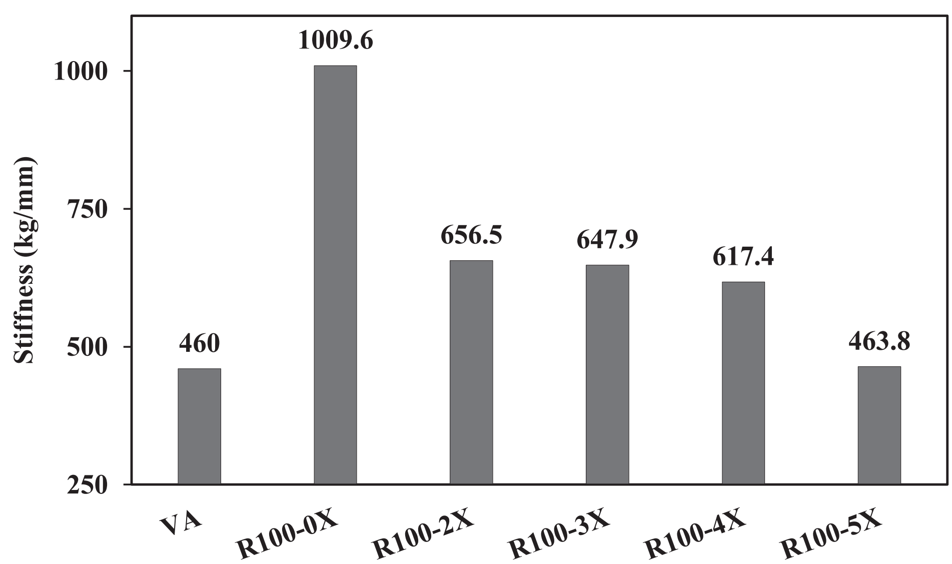

Figure 5. Stiffness values of asphalt mixtures

4.2. Moisture damage

Figure 6 portrays the ITS results of RAP and rejuvenated mixtures at both 25 and 60 °C. The results demonstrate that ITS at 25 °C values increase by adding PelletRAP™ and showed the highest value at 4%. This means that 4% of PelletRAP™ gave a positive effect on the cracking resistance of the rejuvenated mixture. Meanwhile, ITS value of rejuvenated mixtures at 60 °C was slightly lower than ITS at 25 ℃ values. This indicates that the moisture condition slightly affected the tensile strength of the RAP mixture in the case of wet condition. TSR values are presented in Figure 7. Higher TSR value implies better asphalt mixtures performance against moisture damage [22]. It can be seen that TSR value of RAP mixture significantly increased with the addition of PelletRAP™, where R100-4X recorded the highest values (98.41 %). This clearly indicates that adding PelletRAP™ into RAP mixture improved the adhesion and cohesion bond, and thus the moisture damage resistance of rejuvenated mixture was increased. The results of moisture damage are in agreement with El-Shorbagy et al. [23] who discovered an improvement in the moisture damage resistance when the rejuvenator was included into the RAP mixtures

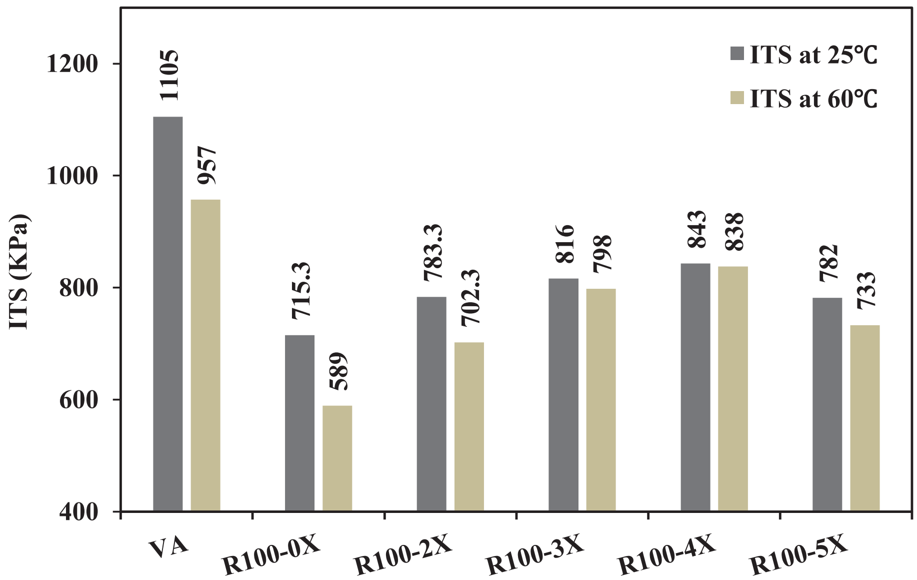

Figure 6. ITS of asphalt mixtures

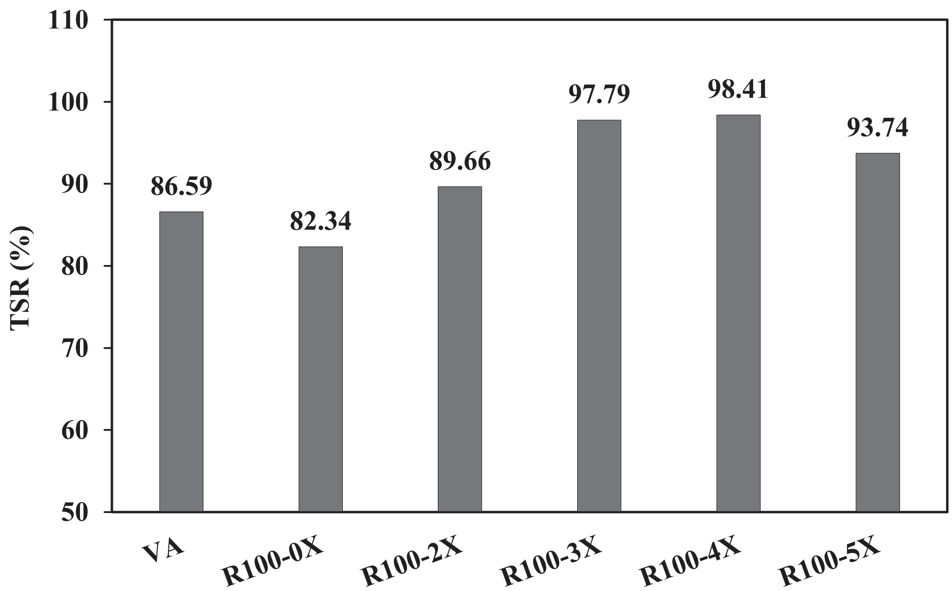

Figure 7. TSR of asphalt mixtures

4.3. Cantabro loss

Figure 8 illustrates the test results of mass loss for mixtures. It shows that R100-X exhibited the highest value of cantabro loss (12.99%), indicating that mass loss increases with ageing, and the mixture may become more prone to durability issues over time than VA mixture [24]. However, this value decreased with the addition of PelletRAP^{TM}. In precise, R100-4X recorded a cantabro loss of 7.07 %, which is close to that of VA mixture. This could be related to the increment in the adhesion and cohesion properties upon inclusion of PelletRAP^{TM}.

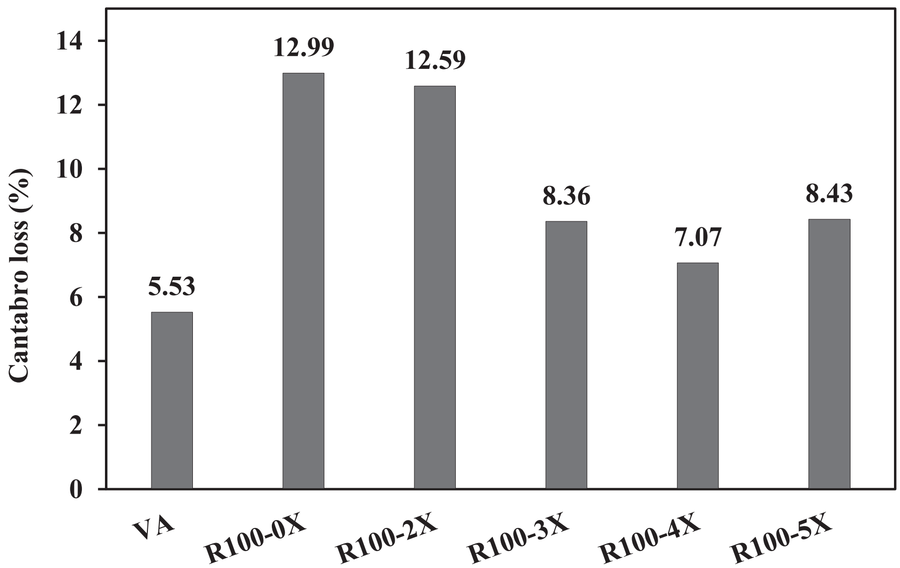

Figure 8. Cantabro loss results

5. Conclusion

This research aimed to examine the feasibility of using PelletRAP™ as a rejuvenator and its effect on the mechanical properties of RAP mixtures. The major outcomes obtained are summarised below:

1. Adding 4% of PelletRAP™ had increased the Marshall stability of rejuvenated mixture. Meanwhile, the flow and the stiffness values were decreased
2. Inclusion of PelletRAP™ significantly increased the ITS and TSR values of mixtures, indicating that the rejuvenated mixtures have the highest resistance to moisture damage than other mixtures.
3. The mass loss of RAP mixtures decreased by adding PelletRAP™, reflecting the resistance of rejuvenated mixture to disintegration caused by ageing
4. To better understand the PelletRAP™ effect on the mechanical properties of rejuvenated mixtures, future research should undertake the behaviour of rejuvenated mixtures after long-term ageing.

6. References

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