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Evaluating the Performance of Reclaimed Asphalt Pavement Incorporating PelletRAP as a Rejuvenator

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Evaluating the Performance of Reclaimed Asphalt Pavement Incorporating PelletRAP as a Rejuvenator

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Abstract. In the recent years, the use of reclaimed asphalt pavement (RAP) in the pavement has become inevitable for economic and environmental reasons. However, the brittleness property of aged asphalt in the RAP restrict its usage in a high percentage. Nevertheless, the rejuvenators are introduced into the mixtures to reverse the effect of ageing processes, decrease the stiffness and increase the workability of RAP mixture. In the present research, various percentages of PelletRAP rejuvenator were added to 100% of RAP mixtures. The performance characteristics of rejuvenated mixtures were investigated via resilient modulus (M_R), dynamic creep, and wheel tracking tests. The results showed that when the PelletRAP was included into the mixture, the M_R values and the creep stiffness modulus (CSM) decreased, while the permanent creep, the creep strain slope (CSS) and the rutting depth increased. However, all the rejuvenated mixtures exhibited better results than that of virgin mixture. Such a trend of findings suggested that PelletRAP can be used as a rejuvenator without a negative effect on the high-temperature performance of asphalt mixtures.

1. Introduction

Fluctuations in asphalt price, limited resources of aggregates, environmental issues and sustainability have encouraged the usage of reclaimed asphalt pavement (RAP) in asphalt mixtures [1, 2]. Previous work indicates that the usage of 100% RAP in the asphalt mixtures results in an approximately 50-70% decrease in the price of hot mix asphalt (HMA) [3]. Furthermore, the literature reported that the use of 100% RAP mixture with a rejuvenating agent could reduce the CO_2 emissions by 35% and achieved 20% energy savings compared to virgin asphalt mixture without RAP material [3]. However, the properties and efficiency of RAP mixtures are highly influenced by ageing of its binder during the lifespan [4, 5]. Thus, using a high percentage of RAP in asphalt mixtures may deteriorate the mixture’s characteristics [6] and cause fatigue and cracking problems [7-9]. These issues can be overcome using rejuvenators [10]. Rejuvenators are products (having chemical and physical characteristics) that added to asphalt mixtures containing high percentages of RAP [11]. These materials can enhance the dispersive of maltene phase and reduce the size of the asphaltene clusters, both contributing to improved ductility and decreased viscosity and rigidity of the aged asphalt [9]. Using rejuvenators date back to the late 1970s and early 1980s, where the ASTM D4552 was developed by classification of the rejuvenators into six grades depending on the viscosity measured at

60°C [12]. Some rejuvenators have been obtainable for decades. However, the usage of such rejuvenating agents has recently gained renewed interest with a move towards more sustainable practices, including the use of a high amount of RAP for economic and environmental reasons [12]. Nevertheless, some types of these rejuvenators can significantly diminish the stiffness of asphalt mixtures and cause potential rutting problem [7]. In other words, some softening and rejuvenating agents may be beneficial in cold region but unsuitable in hot region such as waste engine oil (WEO). The reason is associated with the fraction or chemical composition of agents. Therefore, using an additive such as nanomaterials or polymers in combination with rejuvenators as well as hybrid rejuvenators can be suitable solutions for overcoming this issue. For instance, Ziari et al. [7] explored the possibility of using nano-clay as a modifier to compensate the negative influence of rejuvenator on the performance of RAP. The outcomes reported that the reduction in flow number due to adding rejuvenator was compensated by adding nano-clay into the rejuvenated samples. Jahanbakhsh et al. [13] reported that the mechanical attributes of mixtures containing high percentages of RAP, waste engine oil, and crumb-rubber were better than or similar to that of virgin mixture. Al-Saffar et al. [10] evaluated the rheological properties of aged asphalt containing WEO and maltene as rejuvenators. The finding demonstrated that integration of WEO and maltene significantly enhanced the attributes of aged asphalt at both low and high temperatures. In the present research, the performance properties of 100% RAP mixtures containing different percentages of PelletRAP rejuvenator were investigated and compared with aged and virgin HMA mixtures. The aim is to evaluate the performance properties of 100% RAP mixture embraced with PelletRAP via resilient modulus (M_R), dynamic creep and wheel tracking tests.

2. Materials and experiments

2.1. RAP and virgin asphalt

Damaged pavement as the RAP material was collected within Yong Peng to Pagoh, Malaysia (134.6 km to 134.8 km) having a service life of about six years. Figure 1 shows the RAP material after sieving according to its gradation, while Figure 2 illustrates the distribution of the particle size of RAP aggregates at AC 14 gradation. Based on the distribution, the median gradation was selected between the lower and upper limits. The optimum asphalt content (OAC) of RAP was 5.1%. The aged asphalt was obtained via extraction method as per to ASTM D2172 [14] using methylene chloride. Virgin asphalt (PEN. 60-70) was obtained from Kemaman Bitumen Company (KBC), Malaysia. The characteristics of aged and virgin asphalt binders are shown in Table 1.

Figure 1. RAP material after sieving

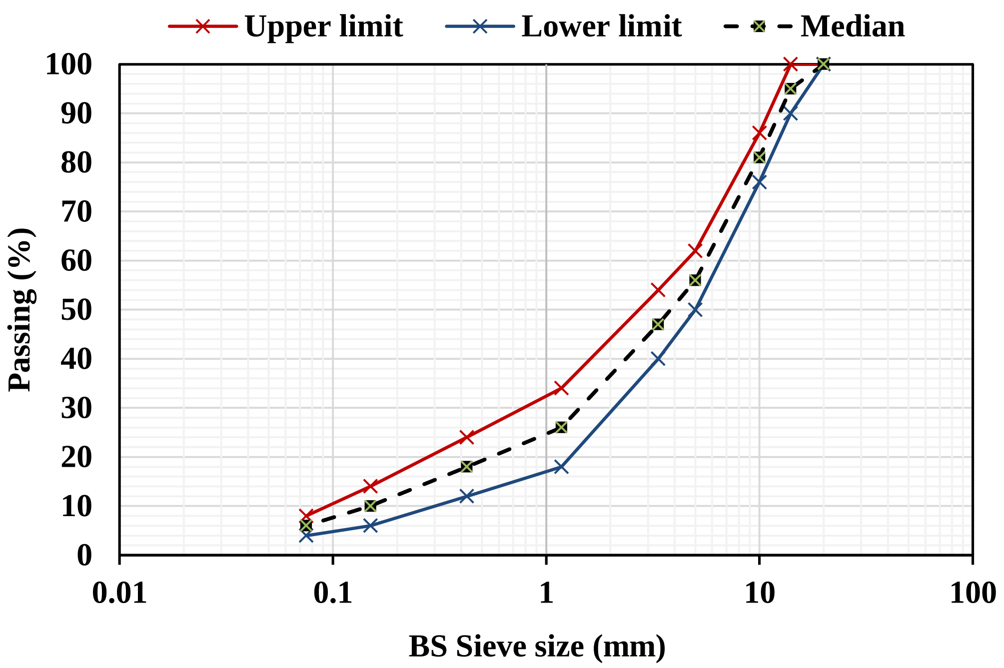

Figure 2. Gradation of RAP used in the research according to AC14

Table 1: Standard tests results of materials used in this research

Type of asphalt	Penetration (dmm)	Softening point (°C)	Ductility (cm)	Viscosity (mPa.s)	
				@ 135 °C	@ 160°C
Virgin asphalt	64	51.5	116	650	200
Aged asphalt	18.5	73	8	3500	700

2.2. PelletRAP

It is a high-performance rejuvenator brought from Phoenix Industries company-USA. It is composed of recycled scrap tires, asphalt cement, Bitunite, metal oxide and emulsion. The percentage of every material is presented in Table 2. It has different sizes similar to that of aggregates (see Figure 3), and it is utilised to improve the workability, compaction and performance characteristics of RAP mixtures.

Table 2. The components of PelletRAP

Chemical name	Concentration
Asphalt cement	45-65 %
Ground tire rubber	25-30
Bitunite	2-5
Portland cement II	2-4
Metal oxide	< 1
Latex emulsion pigment	< 1

Figure 3. PelletRAP material

2.3. Preparation of samples

2, 3, 4 and 5 % of PelletRAP (by weight of total mixture) were added to 100 % of RAP (AC 14 gradation). 1% of PelletRAP was not included since its effect on the mixture seems to semi neglected. The mixture was blended for 2 minutes using electrical mixer to rejuvenate the aged asphalt and obtain homogenous mixtures as well. Depending on the trial and error, it was found that increasing the mixing time with presence of high temperature will lead to increase the stiffness of aged asphalt. For comparison purposes, the OAC as well as the mixing and compacting temperatures (165℃ and 156℃) for every mixture depended on the OAC and the viscosity results of VA at both 135℃ and 165℃, respectively. This research comprised of six types of mixtures, namely the virgin mixture (VA), 100 % RAP mixture (R100-0PR), 100% RAP+2% of PelletRAP (R100-2PR), 100% RAP+3% of PelletRAP (R100-3PR), 100% RAP+4% of PelletRAP (R100-4PR) and 100% RAP+5% of PelletRAP (R100-5PR).

3. Tests

Universal Testing Machine (UTM-5P) IPC global brand, was used to conduct the resilient modulus (M_R) test at both 25 °C and 40 °C in accordance with ASTM D7369 [15] standard, as well as the dynamic creep test using performed in adherence to BS EN 12697-25 [16]. Later, the double wheel tracker (DWT) equipment was utilised to determine the rutting depth formed by repeated passes of a loaded wheel for 5 hours at 50 °C in accordance with EN 12697-22 standard [17] (See Figure 4). It is worthy of mentioning that M_R was calculated via Eq. (1). In addition, the data obtained from a repeated load creep test, as presented in the form of creep stiffness modulus (CSM) and creep strain slope (CSS), were calculated using Eqs. (2) and (3)

$$M_R = F/Ht\ (0.27 + \mu) \tag{1}$$

Where,
M_R = resilient modulus (MPa)
F = applied force (N)
t = sample thickness (m)
H = horizontal displacement (m)
μ = Poisson ratio

$$E = \sigma / \varepsilon \tag{2}$$

$$CSS = (Log\ \varepsilon 3600 - Log\ \varepsilon 1200) - (Log\ 3600 - Log 1200) \quad (3)$$

Where,
E = creep stiffness modulus (MPa)
σ = applied stress (kPa)
ε = Cumulative axial strain at 3600 cycles (mm)
ε3600 = Strain at 3600 cycles
ε1200 = Strain at 1200 cycles
CSS = Creep strain slope

Figure 4. (From left to right) Resilient modulus, dynamic creep and wheel tracking tests

4. Results

4.1. Resilient modulus (M_R)

Figure 5 illustrates the data of resilient modulus at 25°C and 40°C against different percentages of PelletRAP. It was found that R100-0PR recorded M_R value of 11765 Mpa at 25°C. This value was the highest compared to other samples, while VA mixture recorded the lowest values of M_R (3059 Mpa). This outcome is ascribed to the impact of stiffening in aged asphalt on RAP [18]. The highest M_R value at 25°C meaning the highest tendency of going back to original state after being loaded. Adding PelletRAP decreased the M_R values meaning that PelletRAP can reduce the stiffness, which was resulted from ageing process. The lowest M_R value of rejuvenated mixtures was recorded by R100-5PR (9109 Mpa). The reason is that adding PelletRAP (which contains 45-65% of soft asphalt) had decreased the stiffness of mixture, leading to decrease the M_R of sample. However, this value still much higher than VA, indicating that the RAP mixtures containing PelletRAP are less susceptible to fatigue deformation in comparison with VA mixture at 25°C. Upon increment in temperature, the variance in M_R turned more vivid, along with a decrease in stiffness at 40°C. M_R at 40°C results recorded the same trend as M_R at 25°C. In precise, R100-0PR recorded M_R value of 3544 Mpa, where VA recorded 1050 Mpa. In addition, rejuvenated mixtures showed lower M_R at 40°C compared to R100-PR. In precise the rejuvenated mixture containing the highest amount of PelletRAP (R100-5PR) exhibited M_R value of 2156 Mpa. The result was a slight higher than VA, meaning that the rejuvenated mixture is more resistant to rutting in comparison with the VA mixture.

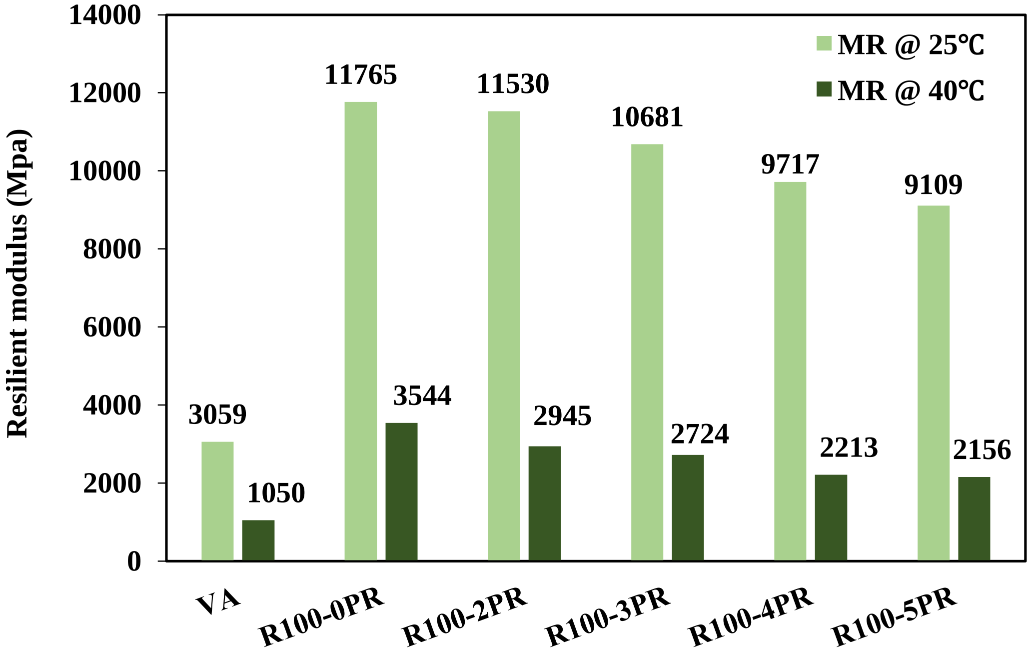

Figure 5. Resilient modulus results

4.2. Dynamic creep

Figure 6 illustrates the cumulative permanent strain of all mixtures. It was found that R100-0PR gave the lowest value of permanent strain (2010 µs), while VA mixture recorded the highest value (6393 µs). This is ascribed to the stiffening effect of ageing on the RAP, where maltene is low and asphaltene is high. However, when PelletRAP was included, the permanent strain of RAP mixture noticeably increased up to 4593 µs at 5% of PelletRAP. This is due to the reduction in stiffness of aged asphalt in the RAP mixture when mixed with rejuvenator [19]. On the other hand, the asphalt mixture resistance to permanent deformation was determined based on CSM and CSS. Figure 7 showed that R100-0PR recorded the lowest value of CSS (0.19), and this value increased by adding PelletRAP. In detail, R100-2PR recorded CSS value of (0.22), followed by R100-3PR (0.23), R100-4PR (0,25) and R100-5PR (0.26). Meanwhile, the CSS of VA mixture recorded the highest value of CSS (0.31). The highest CSS means the lowest resistance to permanent deformation.

Figure 8 presents that R100-0PR exhibited the highest value for CSM (849.64 Mpa), and this value decreased when PelletRAP was included into the mixture. Higher creep stiffness indicates high resistance to rutting. In precise, R100-2PR recorded a CSM value of 700.09 Mpa, followed by R100-3PR, which exhibited a value of 479.74 Mpa, R100-4PR (399.29 Mpa) and R100-5PR (286.85 Mpa). Meanwhile, VA mixture displayed the lowest value of CSM (182.27 Mpa). In other words, the rejuvenated mixtures exhibited better performance in term of rutting resistance than VA although inclusion of PelletRAP had reduced the stiffness of RAP mixture. The results obtained from the dynamic creep test are in agreement with M_R test.

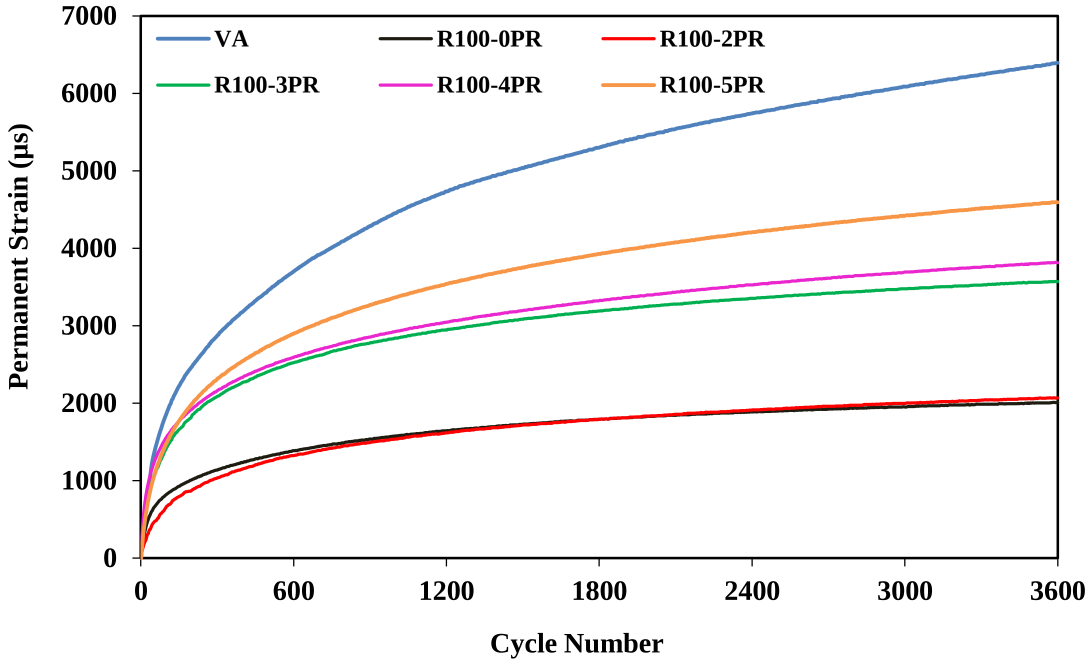

Figure 6. Permanent strain of selected mixtures

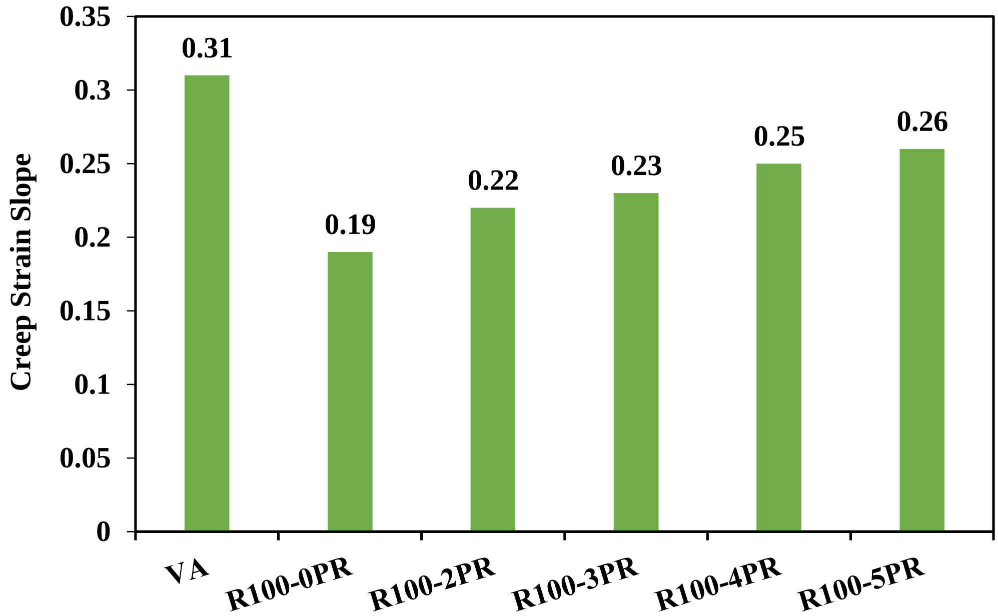

Figure 7. CSS of selected mixtures

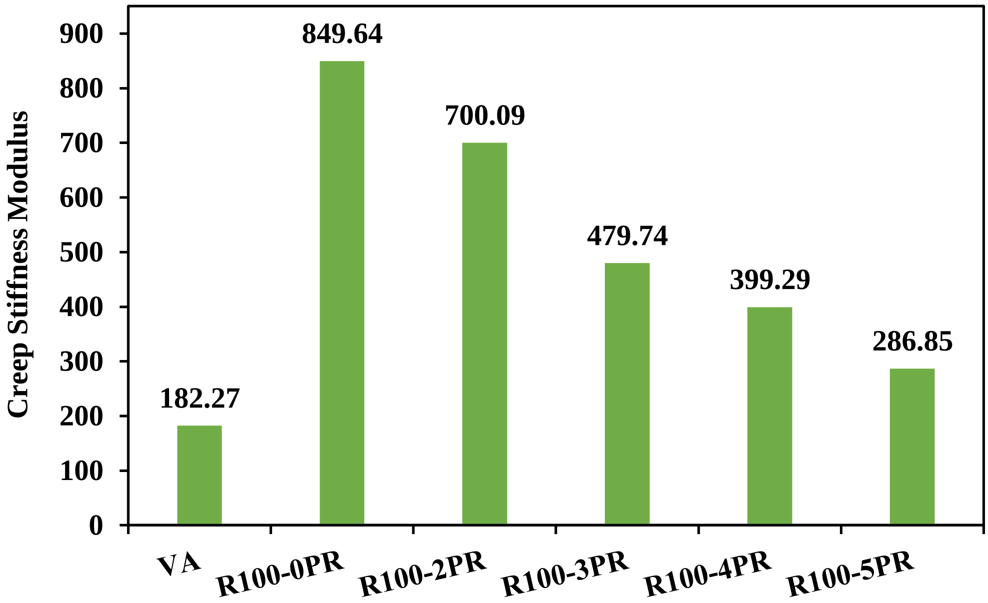

Figure 8. CSM of selected mixtures

4.3. Wheel tracking

Figure 9 reveals the development of rut depths for asphalt mixture samples. It can be seen that R100-0PR exhibited the lowest rutting depth after 10000 cycles of wheel loading (0.59 mm). This is due to the effect of short and long-term ageing with time. However, adding PelletRAP led to an increment in the rutting depth as a result of increasing the flexibility of asphalt. More specifically, R100-4PR exhibited rutting depth value of 0.84 mm, and followed by R100-5PR, which exhibited a rutting depth value of 1.24 mm. Meanwhile, VA mixture recorded the highest value of rutting depth (1.97 mm). These observations mean that the rejuvenated mixtures have better resistance to rutting than VA mixture. The outcomes obtained from wheel tracking are in agreement with findings obtained from M_R and dynamic creep tests.

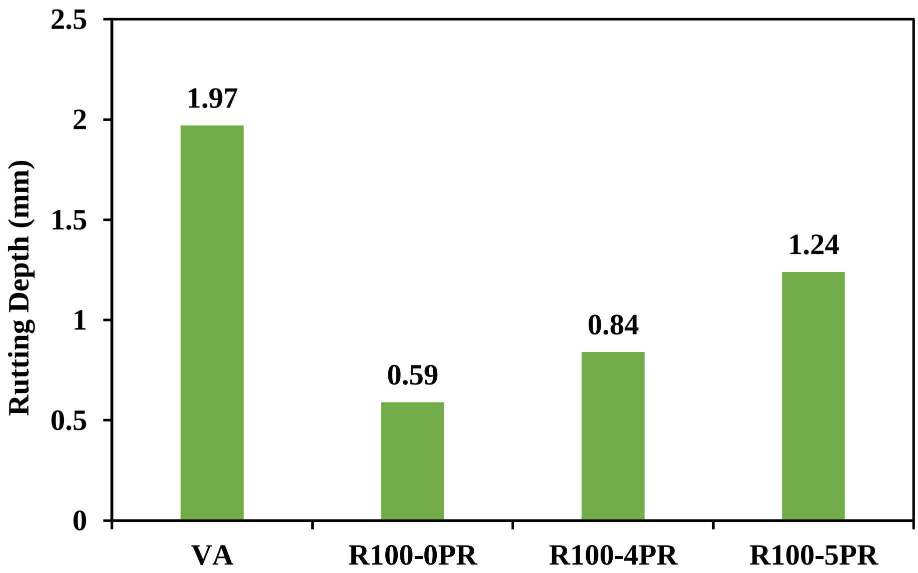

Figure 9. Rutting depth of selected mixtures

5. Conclusion

The PelletRAP significantly affected the characteristics of the RAP mixtures, where the resilient modulus and creep stiffness modulus of RAP mixtures decreased by inclusion of PelletRAP rejuvenator. On the contrary, the permanent strain, creep strain slope and rutting depth increased with the addition of PelletRAP. In other words, PelletRAP reduced the stiffness of aged asphalt, but it exhibited good resistance to deformation and even better than virgin asphalt mixtures. Thus, it can be used as a rejuvenator without any detrimental impact on the performance at high-temperature.

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