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A laboratory study of the effect of fiberglass additive on the behavioural properties of RAP asphalt mixtures

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Abstract. The increase in the amount of reclaimed asphalt pavement (RAP) and environmental concerns for bitumen production have contributed to the use of RAP in road construction and maintenance. The use of higher than 15% of RAP adversely affects the physical and rheological properties of the asphalt binder and the mechanical properties of mixtures. Therefore, the use of bitumen and asphalt mixture improver were necessary to reduce the negative effects generated with the use of RAP. This paper aims to study the effect of fiberglass (FG) (0.5%, 1.0%, 1.5%, and 2%) on the mechanical properties of asphalt concrete containing 25%, 50% RAP and 9% waste engine oil. The performance of RAP asphalt mixtures incorporated with FG was evaluated using the Marshall stability test, moisture susceptibility test, and immersion wheel rutting test. The results indicated that the use of FG and RAP materials to rejuvenated asphalt mixtures resulted in an increase in the values of Marshall stability and rutting resistance. Moreover, the study revealed that increasing the content of RAP material and FG results in increased resistance of asphalt to moisture damage. This paper concluded that using 0.15% of FG and 50% RAP materials gives the best results.

Keywords: Fiberglass; Marshall stability; Reclaimed asphalt pavements (RAP); Rejuvenator; Rutting.

1. Introduction

Recycling reclaimed asphalt pavement was used since 1980 in the state of Illinois. Reclaimed asphalt pavement (RAP) can be used as a material for saving cost and energy. that way, it is regarded as an important material that contributes to the moves towards the preservation of scarce resources [1, 2]. The high rigidity of RAP will accelerate cracking rates unless adequately designed to prevent producers and government agencies from increasing recycling RAP allowances. Despite an advantage mentioned above, there are certain issues with the use of high percentage RAP in asphalt mixture.

These concerns are related to resistance of moisture, plastic deformation and resistance to stripping, which explains why most organizations do not consent a high content of RAP materials in fresh asphalt mixtures [3]. The permanent deformation resistance of asphalt mixtures containing 30% RAP was explored [4]. The research outcomes indicated that rising the RAP material content could have a substantial effect on properties of mixes. Nevertheless, it has been recommended that higher content of RAP materials in asphalt concrete led to reduction in the plastic deformation resistance. The Marshal stability and flow asphalt concrete containing 50% RAP materials were investigated. The results revealed that rise in RAP amount could lead to a reduction in the values of Marshall stability and increase in values of flow [4, 5].

Thus, improving the rutting and moisture damage resistances of RAP asphalt mixtures has urged using a higher RAP percentage in hot mix asphalt [6-8]. Consequently, several rejuvenator types have been used to boost the performance of rigid RAP asphalt mixtures [9]. Zaumanis and Cavalli (2020) studied the effect of different rejuvenators on the performance of RAP asphalt mixtures [10]. The findings showed that waste oils could restore the properties of aged asphalt binder. A new study explored waste engine oil (WEO) as an asphalt binder rejuvenator for RAP mixtures at 30% to disregard the adverse consequence of high RAP content. It has been found that the performance of rejuvenated asphalt concrete is improved by modifying the RAP binder with 7% and 13% WEO [11].

However, aforementioned studies exhibited that the rejuvenators lead to decrease the rut resistance of pavements by dropping the viscosity [12]. Therefore, to solve this adverse effect on medium and high temperature performance, an additive must be added directly to the RAP mixture to enhance its performance. Fibers are a type of additives that can be applied directly to mixture to enhance its resistance to cracking, rutting, and moisture damage to RAP mixtures [13-16]. Different sorts of fibers have been used as additive for virgin asphalt mixture. Earlier experiments have shown that asphalt mixture's resistance to rutting and cracking increases after fibers are used [17-19]. The use of fiberglass as a modifier has been studied for virgin asphalt mixture [17, 20-23]. Studies have found that the asphalt's resistance to rutting, cracking, and moisture is enhanced.

Although fiberglass is widely used as a modifier for virgin asphalt concrete to improve asphalt mixture performance, however, very few studies have been conducted to study the effect of fiberglass on the properties of RAP mixtures. Therefore, the purpose of this study is to evaluate the impact of the use of fiberglass (FG) and RAP materials on the performance of RAP asphalt concretes. For this, the asphalt concretes containing 25%, and 50% RAP materials with WEO as a rejuvenator (9%. of aged asphalt binder) with different content of FG (0.5%, 1.0%, 1.5% and 2.0% by weight of the mixture) were evaluated in terms of Marshall stability, flow, quotient, retained stability, Marshall ratio, and immersion wheel rutting tests.

2. Materials, mix design, and samples preparation

Asphalt binder of penetration grade of 60/70 was used in this study. Bitumen was supplied from local oil refinery and the engineering properties of the virgin binder are shown in Table 1. The physical properties of the recovered RAP binder are shown in Table 1 (AASHTO T319).

The mineral aggregate used in this research is a limestone aggregate with a nominal maximum aggregate size of 12.5 mm. The aggregates gradation size was within the values specified by the ASTM D3515.

RAP materials were collected from the *Taman Univeristi* Expressway in Johor Bahru, Malaysia, which were milled during paving of two-lane highway. The bitumen used in RAP was made of PG 64-22 asphalt binder. Figure 1 shows the RAP materials used in this study. After collecting the RAP materials, the aged asphalt binder was determined from the cold extraction process. The bitumen content of the controlled asphalt mixture was determined at 5.71 %. The size of the gradient of raw aggregate and extracted from RAP are shown in Figure 2.

Table 1. The properties of virgin and aged asphalt binders.

Property	Virgin	Aged	Specification	Standards
Penetration (0.1 mm)	67	21	60-70	ASTM D5-37
Softening point (^{o}C)	53	71	48-52	ASTM D36 -76
Flash point (^{o}C)	249	-	>230	ASTM D92-78
Specific gravity	1.02	1.10	1.0-1.05	ASTM D70-76

Figure 1. The RAP materials used in this study.

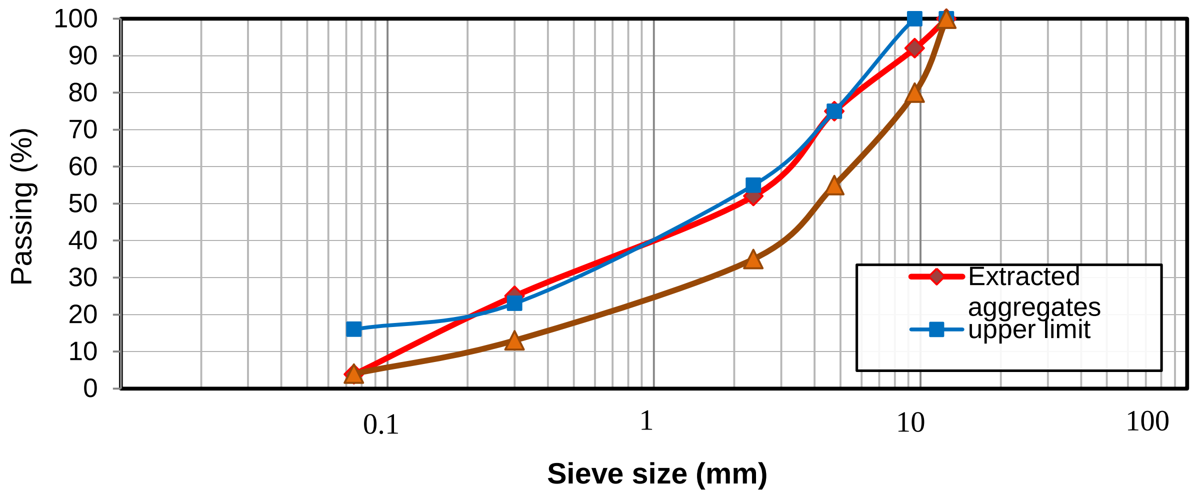

Figure 2. Gradation size of extracted aggregates from RAP.

The Fiberglass (FG) used in this study was collected from a local company. The FG used to enhance the performance of the asphalt aged binder. FG was made of plastic matrix and reinforced with fine fiberglass. One of the advantages of FG is that it distributes in the asphalt mixture very quick and regulates the distribution of cracks. The FG was heated up to 450 °C for 60 minutes to remove all organic materials. Fiberglass is presented in Figure 3 and their properties are shown in Table 2.

Figure 3. The FG used in this study.

Table 2. The engineering properties of FG.

Property	**Value**
Diameter (mm)	0.12
Length (mm)	6
Density (g/cm^3)	1.1
Young Modulus (GPa)	59.8
Melting point (°C)	685

RAP materials were added to the asphalt mixture in two different percentages; 25% and 50%, and waste engine oil (WEO) was used as a rejuvenator to soften the aged asphalt binder. 9% of WEO was found as an optimum value that can restore the properties of the aged RAP binder to the original bitumen (60/70) [11]. Fiberglass was added to the aged asphalt binder with different content of 0.5%, 1%, 1.5%, and 2% (by weight of bitumen). Fiberglass can be added in two methods either wet or dry process. In this study, the FG was added to aged asphalt binder by a wet process. FG was first blended with asphalt binder at 163 °C and then, aggregates were added to the mixture. Marshal's method revealed that the optimum bitumen contents of RAP 25% and 50% asphalt mixtures are 4.98 % and 3.56%, respectively.

3. Testing methods

3.1 Marshall stability test and retained stability

This test was performed to determine the Marshall stability and flow. The test is conducted as stated in ASTM D6927. Stability is defined as the maximum load that asphalt mixture can resist. Where the flow is the deformation that occurred in the sample as a result of subjecting it to the maximum load. The retained stability test was also performed on Marshall specimens made from virgin and aged RAP materials with changing fiberglass percentages. Samples were conditioned in a water bath for 30 minutes at 60 °C, and then the retained stability was estimated.

3.2. Immersion wheel rutting test

The test was done to assess the resistance of the asphalt mixture to plastic deformation. This experiment was executed according to AASHTO T324-11. Samples were submerged in a water bath at 50 °C for 30 min. The device was operated for up to 20,000 cycles to record the plastic deformation that has occurred in the asphalt mixtures.

4. Results and discussions

4.1 Marshall stability test and retained stability

Figure 4 displays the Marshall stability test results for asphalt mixtures examined in this study. The Marshall stability is defined as the ability of the asphalt mixture to withstand plastic deformation. It can be seen that all the asphalt mixtures met specification (minimum value 900 kg), in addition, the results show that an increase in the FG percentages leads to an increase in the Marshal stability values regardless of the content of RAP materials. On the other hand, an increase in RAP content enhance the Marshall stability values of the mixtures. The results showed that using 2% FG with 50% RAP materials achieved the best performance.

Figure 5 presents the Marshal tests flow value. The results showed that increasing in the FG content contributes to a decrease in the flow values of all mixtures regardless of the RAP content. Moreover, the flow values decrease as the RAP content increases. This may be due to aging of the asphalt binder which greatly increases the hardness of the asphalt binder. However, the flow values for all mixtures were within the recommended ranges of 2 to 4 mm.

Figure 6 revealed that Marshall's Quotient is affected by the addition of FG and RAP materials. The results showed that as FG content increased, the Marshall's Quotient also increased. Moreover, the results showed that 50% of RAP recycled asphalt mixtures had higher values Marshall's Quotient than RAP asphalt mixtures of 25%. The increase in Marshall Quotient is due to the stiffness contributed by RAP and FG.

Figure 7 shows the retained stability values for RAP and FG-containing asphalt mixtures. The addition of FG was observed to increase the retained stability values and thus enhancing the resistance of the asphalt mixture to moisture damage and stripping. However, increasing the FG content above 1.5% reduces the retained stability values. Figure 7 also shows the effect of RAP materials on the retained stability. It can be seen that the use of high RAP content in asphalt mixtures can enhance resistance to moisture damage.

The Marshall ratio was used in this study to estimate the resistance of the asphalt mixture to rutting. Figure 8 shows the Marshall ratios for different types of RAP mixtures containing FG. It can be seen that the Marshall ratio increases with increasing RAP and FG content. It can be observed that using 2% FG with 50% RAP provides the highest Marshall ratio values. Thus, it can be concluded that the addition of fiberglass and RAP materials increases the resistance of asphalt mixtures to rutting.

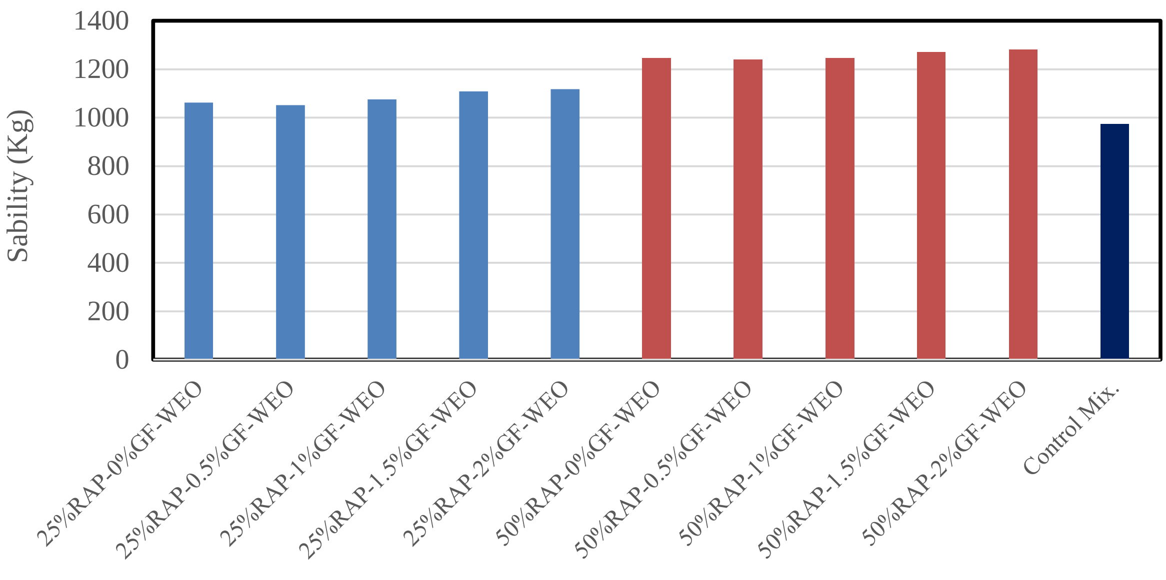

Figure 4. Marshall stability RAP asphalt mixtures with different dosages of FG and RAP materials.

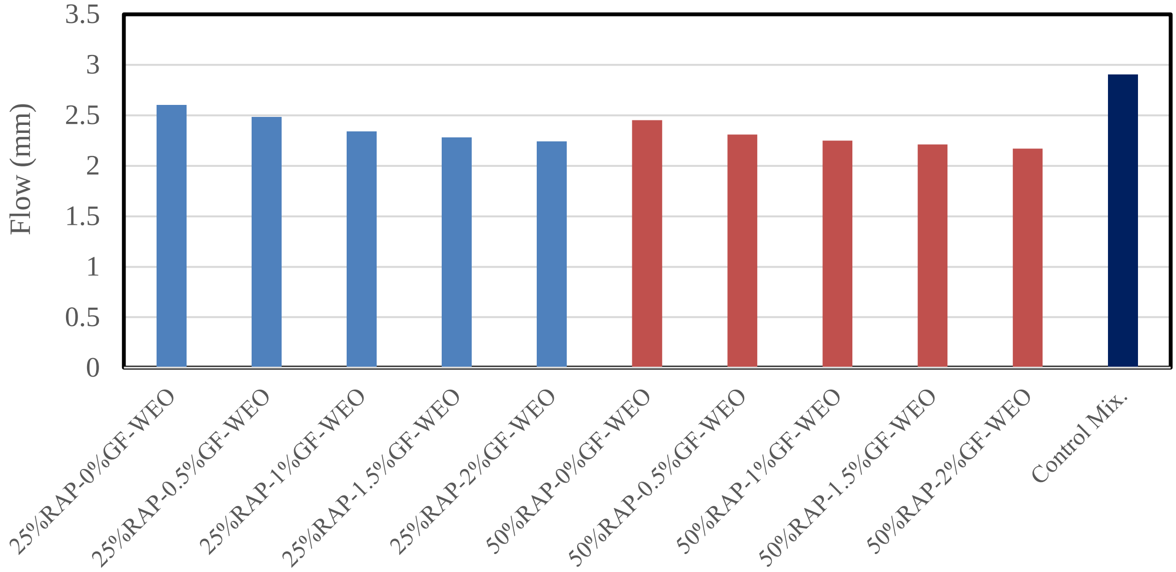

Figure 5. Flow values RAP asphalt mixtures with different dosages of FG and RAP materials.

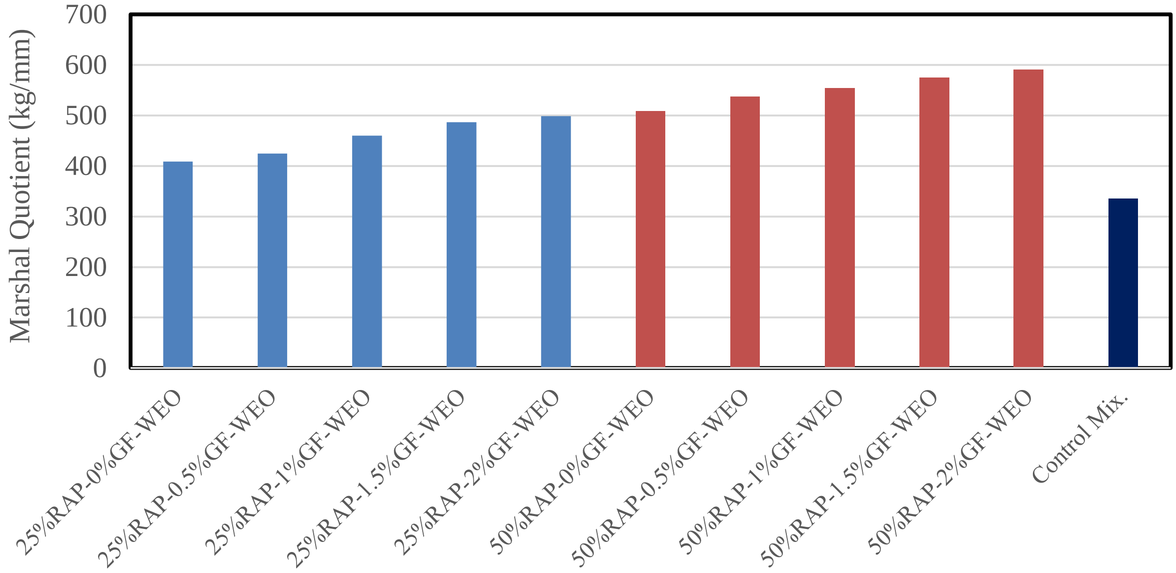

Figure 6. Marshall Quotient of RAP asphalt mixtures with different dosages of FG and RAP materials.

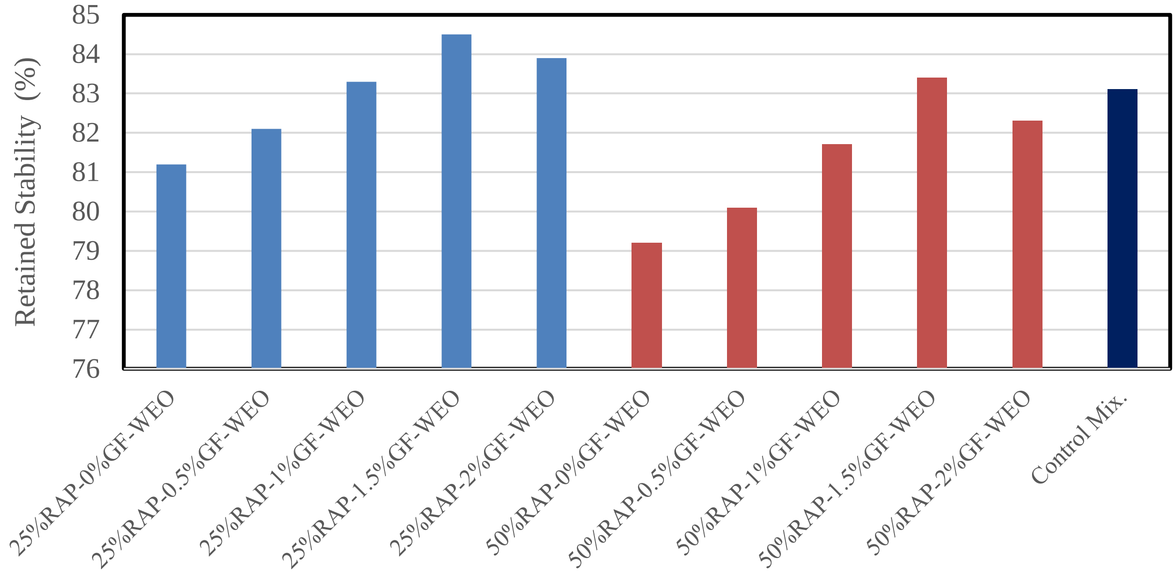

Figure 7. Retained stability of RAP asphalt mixtures with different dosages of FG and RAP materials.

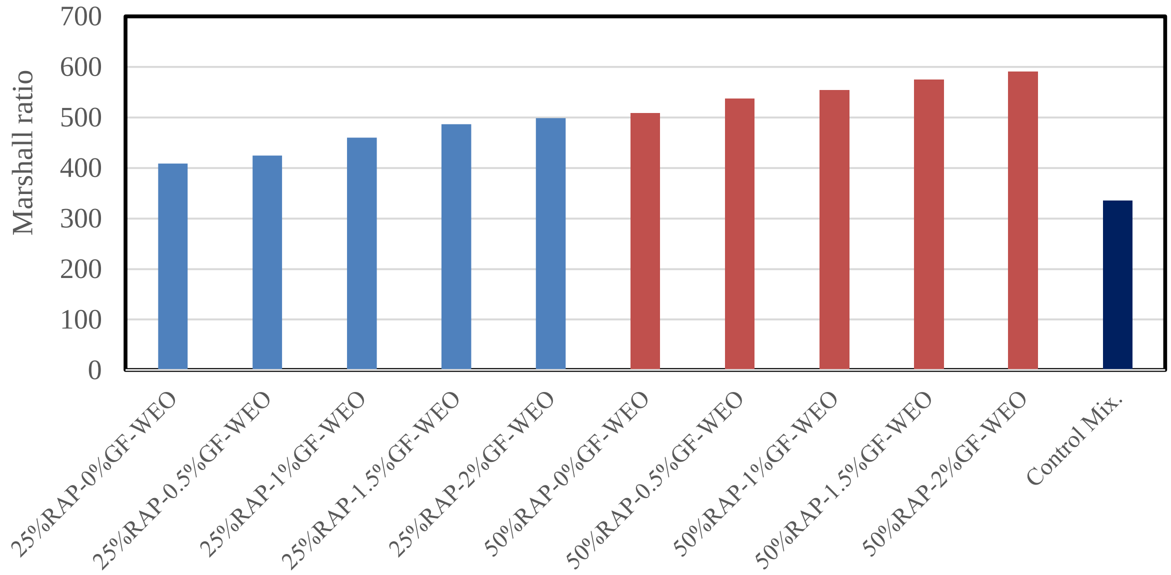

Figure 8. Marshall ratio of RAP asphalt mixtures with different dosages of FG and RAP materials.

4.2 Immersion wheel rutting test

Figure 9 shows the results of the immersion wheel track test. It can be observed that an increase in the FG content leads to an increase in the resistance of the asphalt mixture to dynamic loads and thus an increase in rutting resistance. The results also indicated that the high RAP content enhanced the rutting resistance of the asphalt mixtures. This is due to the strengthening of the mixture by incorporating fiberglass and RAP materials. In conclusion, mixing 2% of fiberglass and 50% RAP materials have the lowest values of rut depth.

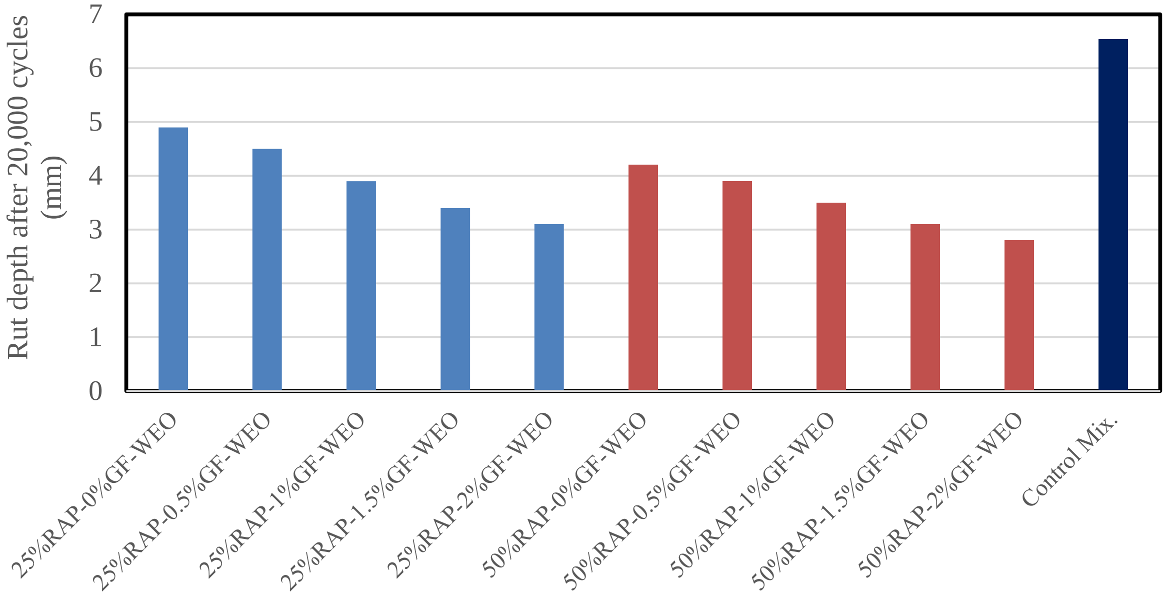

Figure 9. Rut depth of RAP asphalt mixtures with different dosages of FG and RAP materials.

5. Conclusions

Based upon the laboratory results in this research, the following conclusions can be summarized:

1. Marshall stability increases with increasing contents of fiberglass and RAP materials in asphalt mixtures. An increase in the contents of fiberglass and RAP materials also decreased Marshall flow.
2. The results show that adding 1.5% of fiberglass and 50% RAP to rejuvenated asphalt mixtures give the best resistance to moisture damage and stripping.
3. The rut resistance of rejuvenated asphalt mixtures increases with the increase in content of fiberglass and RAP materials.

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