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RESEARCH ARTICLE

The Effect of Mineral Bottle as Fine Aggregate for Manufacturing Sustainable Road Construction

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ABSTRACT - Sustainable construction in a variety of industries has motivated the use of waste materials in various forms as a substitute for raw materials. Currently, the plastic waste quantity in municipal solid waste is increasing due to population growth and lifestyle changes. Thus, disposal of waste mineral bottles is hazardous to the environment due to their non-biodegradable materials. Therefore, this study aims to evaluate the performance of mineral bottles (0,4,8 and 10%) as fine aggregate in hot mix asphalt. The waste mineral bottle was cleaned and crushed into the size passed through 5mm sieve with different contents (0, 4, 8 and 10%) were used as a fine aggregate in the asphalt mixture. Asphaltic concrete AC14 was used in this study. The weight for the total mixing of aggregates used is 1200g, while the bitumen 60/70 penetration grade. The Marshall stability and flow and Cantabro tests were performed to determine the optimum percentage of asphalt mixture incorporated with the mineral bottle as fine aggregate. It observed that 8% of mineral bottles as fine aggregates significant improvements in the properties of Marshall stability from 17.81kN to 31.87kN and reduced the Cantabro loss of the asphalt mixture from 2.17% to 0.96% compared to the conventional mix. Therefore, the usage of mineral bottles increases the road pavement life and contributes to environmental improvement.

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1.0 INTRODUCTION

Solid waste recycling has enormous potential to contribute to effective and sustainable construction. Sustainable construction of buildings, bridges, roads, and dams around the world can be greatly aided by using waste materials [1]. The economic, social, and environmental performance of the construction industry can be affected by the increased recycling of solid waste materials [2]. Population growth has led to the increase in the generation of solid wastes in Malaysia and it has become a crucial issue to be solved. By 2100, more than 11 million tonnes of solid waste will be produced per day in the world [3]. In addition, construction waste is part of the waste generated and categorized under solid waste. It also contributes to serious environmental issues in Malaysia [4]. Construction waste management is also a problem since improper management adversely affects the environment, society, and economy [5].

The utilization of waste material as secondary material is being developed worldwide. Plastic bottles are one type of waste material that is being produced in large amounts. Geyer et al. [6] predicted that there will be 12,000 million metric tonnes of plastic waste on earth by 2050 if current trends in plastic consumption persist. Waste plastic production becomes a major issue because plastic is not biodegradable material which can lead to environmental pollution [7]. By reviewing the possibility of incorporating waste mineral bottles to improve the performance of hot mix asphalt. Crusho et al [8] investigated the use of medical plastic waste in bituminous road construction. The results showed that medical plastic could provide strong, durable and eco-friendly roads. Tiwari et al [9] have used the waste plastic bottle in bitumen mixes for road construction and investigated the Marshall properties of bituminous mix containing waste plastic bottles about 2-12%. The result shows that 8% of plastic waste improves the stability value and increases the toughness of the mix. Mishra et al [10] study the use of plastic coated aggregate in a bituminous mix of flexible pavement. The result shows that 11% of plastic-coated aggregate indicated better stability than the control sample. Using plastic improves the properties of aggregates and bituminous concrete mix, providing longer life and improved pavement performance. Duggal et al [11] reported that the concrete having modified bitumen mix along with processed waste plastic leads to a substantial improvement in the fatigue life, strength and other properties desirable in bituminous concrete. Nayak [12] stated that using plastic wastes in bitumen as a modifier improvement in engineering properties like penetration value, softening point test and Marshall stability test of modified bituminous mixes. According to Tiwari et al [13], the waste plastic with 2.36mm in the bituminous mix had significantly increased the indirect tensile strength. It can be concluded that the added waste plastic improves the strength of the road and less susceptible to moisture damage.

According to previous studies, the results showed that waste mineral bottles could be used in road construction which improves the properties of asphalt mixture. Therefore, this study presents the influence of mineral bottles as fine aggregate in hot mix asphalt. This study focused on using the different percentages of mineral bottles from 0% to 10% to investigate

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the performance and determine the optimum percentage of the asphalt mixture incorporated with the mineral bottle as fine aggregate.

2.0 MATERIALS AND METHODS

2.1 Materials Properties

Hot mix asphalt (HMA) was developed in compliance with the Malaysia Standard Specification for Road Works [14]. The bitumen utilized in this study had a penetration grade of 60/70, commonly used in road construction. The aggregate gradation used in this study was asphaltic concrete AC14, as shown in Figure 1. The mineral bottle (Figure 2) was used as fine aggregate in this study. The mineral bottles were collected, cleaned, shredded and passed through a 5mm sieve (Figure 3). All mixes consisted of one conventional asphalt mixture and three modified asphalt mixtures with mineral bottle additions of 4,8 and 10%, respectively. The optimum percentage of mineral bottles was obtained by comparing the modified asphalt mixture to the conventional asphalt mixture.

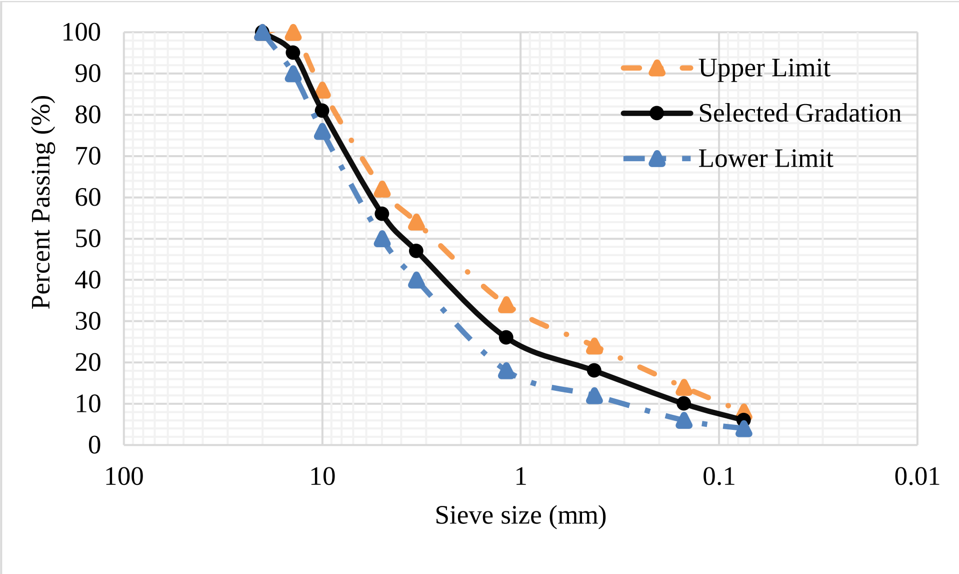

Figure 1. Aggregate gradation AC14

Figure 2. Mineral bottle

Figure 3. Fine mineral bottles

2.2 Aggregate Impact Value

Aggregate impact value test is used to evaluate the viability of road stone for road construction. The aggregate with size passing 14mm and retained on 10mm was employed. Three layers of aggregate were added to the mould, and each layer was tamped 25 times using a tamping rod. Weight the aggregate and transfer to the cylindrical steel cup in 3 layers, then compact each layer by tamping in 25 strokes. Allow the hammer to fall freely on the aggregate. The specimen is subjected to 15 times impacts from a dropping weight. The aggregate remove from the cylindrical steel cup, sieve through 2.36mm and the fraction that passes is weighed. The test was conducted in accordance with BS EN 1097-2:2020 [15]. Equation 1 can be used to calculate the Aggregate Impact Value (AIV).

$$Aggregate\ Impact\ Value = \frac{Weight\ Loss\ (M3)}{Initial\ Weight\ (M1)} \times 100\% \quad (1)$$

2.3 Aggregate Crushing Value

Aggregate crushing value is used to determine the strength of the aggregate used in road construction. The aggregate with size passing 14mm and retained on 10mm was used. Aggregate was divided into 3 layers and placed in a mould, where each layer subjected to 25 strokes with a tamping rod. Weight the samples, M1. The plunger is inserted once the cylinder's surface has been levelled. In order to achieve the required 400 kN in 10 minutes, a sample is loaded uniformly between the testing machine's platens. Removed the crushed material, sieved through 2.36 mm sieves and weighed the fraction passing. The test was performed in accordance with BS EN 1097-2:2020 [15]. The percentage loss of Aggregate Crushing Value (ACV) can be calculated by using Equation 2.

$$Aggregate\ Crushing\ Value = \frac{Weight\ Loss\ (M3)}{Initial\ Weight\ (M1)} \times 100\% \quad (2)$$

2.4 Softening Point

Softening point is used to determine the temperature at which bitumen changes from a solid to a liquid state. The test was conducted in accordance with BS EN 1427:2015 [16]. The bitumen was heated, poured into rings and cooled for 30 minutes. The rings and ball centering guides were placed on the ring holder in a liquid bath. Steel balls weighing 3.5g were then placed on each sample and heated at a constant rate of 5°C/min, as shown in Figure 4. The bitumen was heated until it touched the base plate and the temperature was recorded.

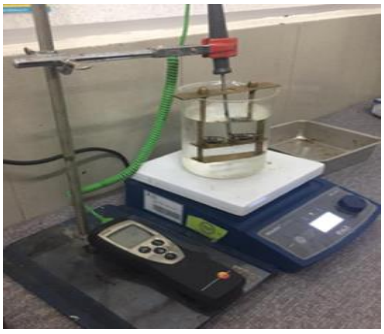

Figure 4. Softening point test

2.5 Penetration

Penetration test was used to evaluate the consistency of bitumen. Higher value of penetration indicated a softer binder. Prior to testing, the bitumen was heated and poured into a penetration cup. After cooling, the sample was then placed into a water bath for 1 h at 25°C. As shown in Figure 5, the test was conducted using the penetration apparatus with a total load of 100g applied for 5s at a temperature of 25°C. The penetration depth in the unit of 0.1mm is recorded. Penetration test was performed in accordance with BS EN 1426:2015 [16].

Figure 5. Penetration test

2.6 Marshall Stability and Flow

In the laboratory, the aggregate, bitumen and waste mineral bottle were respectively mixed and compacted at 180±0.5°C. The mixes were compacted using the standard Marshall hammer with 75 blows on each side to prevent material disintegration. After compaction, the specimens were removed from the moulds and allowed to cool down. The Marshall stability and flow test was conducted to the ASTM D6927 [17]. Firstly, the specimens were immersed in the water bath at 60°C for 40 minutes. The specimens are then placed in the compression testing machine and the flow meter is adjusted to zero. The load is applied to the specimen at a constant strain rate of 50.8mm/minute until the loading is stopped and the maximum load is recorded as indicated in Figure 6.

Figure 6. Marshall test

2.7 Cantabro

The Cantabro test was employed to examine the durability of bituminous mixtures in terms of resistance to disintegration between aggregate and bitumen under the effect of traffic. The initial weight of the sample was recorded before placing the sample into the LA abrasion machine. Each sample is subjected to a combination of abrasive and attrition forces for 300 revolutions without steel charges at the speed of 30rpm in a LA abrasion machine. The final weight of sample was recorded and the Cantabro loss can be calculated by using Equation 3. The test was performed in accordance with ASTM D7064 [18].

$$Cantabro\ Loss = \frac{Initial\ Weight - Final\ Weight}{Initial\ Weight} \times 100\% \quad (3)$$

3.0 RESULTS AND DISCUSSIONS

3.1 Aggregate Properties

Table 1 shows the results of aggregate properties. Based on the table, the aggregate impact value is 23.44%, which is within the 20% to 30% range required by the Malaysia Standard Specification for Road Works. While the aggregate crushing value is 10.52%, which is less than 25% and complies with Malaysia Standard Specification for Road Works. As a result, the aggregates are suitable for road paving because they can withstand crushing under traffic loads and strong enough to withstand a sudden shock.

Table 1. Aggregate properties results

Properties	Aggregates	Requirement values
Aggregate Impact Value	23.44%	20% - 30%
Aggregate Crushing Value	10.52%	<25%

3.2 Bitumen Properties

The results of bitumen properties are represented in Table 2. From the table, the softening point is 50.1°C and the penetration is 63.7mm. By referring to the Malaysia Standard Specification for Road Works, the softening point and penetration meet the specifications for bitumen with 60/70 penetration grade. So, the bitumen may be employed under different climatic conditions and types of construction.

Table 2. Bitumen properties results

Properties	Bitumen	Requirement values
Softening Point	50.1°C	49°C - 59°C
Penetration	63.7mm	60mm – 70mm

3.3 Stability

Figure 7 indicates the stability of mineral bottles with different percentages. The stability of modified asphalt mixture is higher than conventional asphalt mixture. The 8% of mineral bottle content was found higher than other mixtures with the stability of 42.61kN relative to the 10% of mineral bottle (31.87kN), 4% of mineral bottle (26.95kN) and conventional mineral bottle (17.81kN) mixtures. The stability increases as the mineral bottle content increase. Maximum stability has been achieved by the addition of mineral bottle of 8%. The findings indicated waste mineral bottle has the potential to increase the stability. The stability for all percentages fulfills the specification, with all the stability greater than 8kN, as clarified in the Malaysia Standard Specification for Road Works.

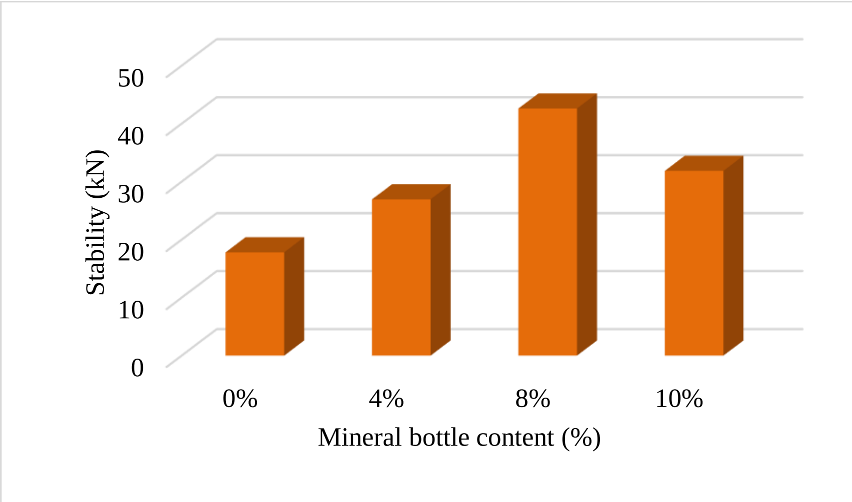

Figure 7. Effect of different percentage mineral bottle to stability

3.4 Flow

The flow of mineral bottles with different percentages is graphically represented in Figure 8. The value of the flow increased with the adding mineral bottle content. The 8% of mineral bottle exhibit higher value of flow (6.62mm) compared to the conventional asphalt mixture (3.17mm). Among modified asphalt mixture, the lowest flow value is 4% of mineral bottle (4.98mm), followed by 10% of mineral bottle (5.26mm) and 8% of mineral bottle (6.62mm). The property of the Marshall flow indicated the flexibility of the asphalt mixture. According to the Malaysia Standard Specification for Road Works, the flow value in the asphalt mixture should be in the range of 2mm to 4mm. An excessively high flow can lead to permanent deformation, whereas the opposite leads to cracking. Therefore, a good asphalt mixture should have a low flow value.

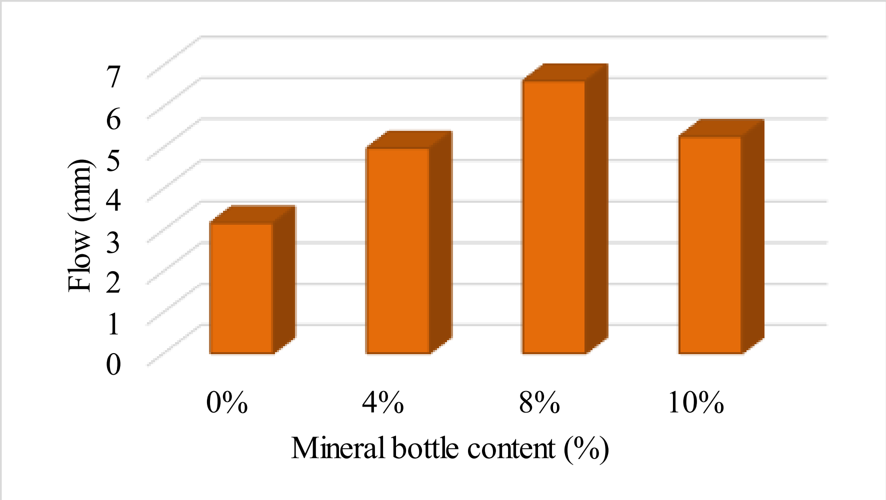

Figure 8. Effect of different percentage mineral bottle to flow

3.5 Stiffness

The stiffness of mineral bottles with different percentages is illustrated in Figure 9. Theoretically, higher stiffness of asphalt mixture will give better resistance and durability. Based on the figure, the stiffness value increases as the mineral bottle content increases, but it starts to decrease at 10% of the mineral bottle. It observed that 8% of mineral bottle provides the highest stiffness value with 4.67kN/mm compared to conventional mix with stiffness value 3.16kN/mm. Among modified asphalt mixture, the lowest stiffness value is 4% of mineral bottle (3.73kN/mm), followed by 10% of mineral bottle (3.96kN/mm) and 8% of mineral bottle (3.73kN/mm). This indicates that waste mineral bottle as fine aggregate in hot mix asphalt can improve the flexibility and increase the resistance against deformation failure. According to the Malaysia Standard Specification for Road Works, the stiffness value should be more than 2kN/mm and all mixtures succeed.

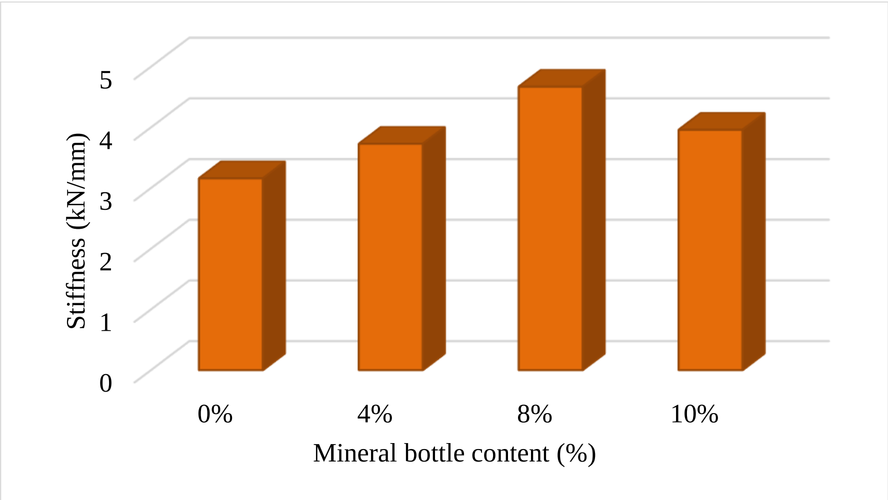

Figure 9. Effect of different percentage mineral bottle to stiffness

3.6 Stability and Flow

Figure 10 shows the effect of stability and flow of the mixture containing mineral bottle. Based on the figure, a mineral bottle improves the stability of the mixture. The 8% of mineral bottles demonstrated the highest stability with 42.61kN. The coefficient of determination R^2 for stability is R^2 = 0.6584 with equation $y = 189.04x + 19.414$. On the other hand, the modified asphalt mixture has a higher flow with 8% of mineral bottle at 6.62mm. The coefficient of determination R^2 for flow is R^2 = 0.6581 with equation $y = 25.958x + 3.5798$. Furthermore, the coefficient of determination R^2 = 0.6584 stability and R^2 = 0.6581 flow indicate a moderate correlation between mineral bottles and increased stiffness and strength.

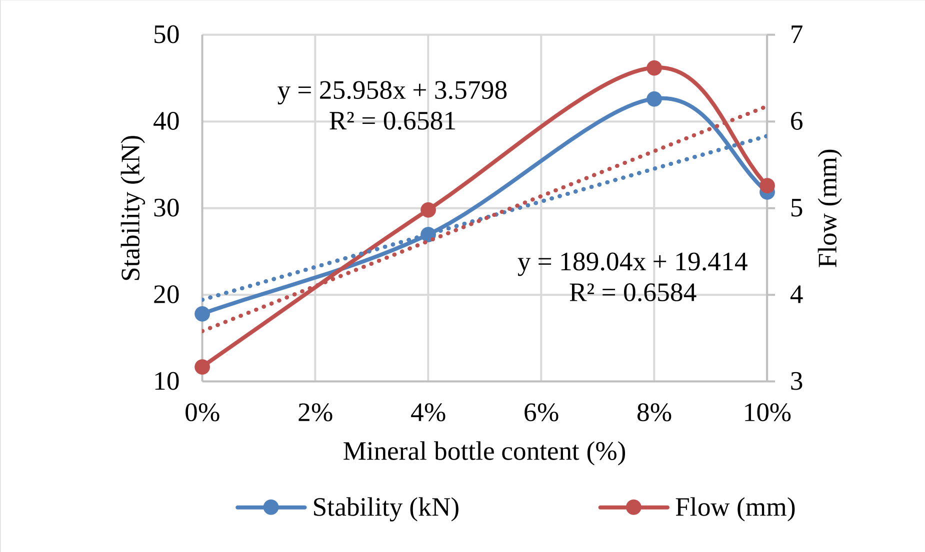

Figure 10. Stability and flow of asphalt mixture vs mineral bottle

3.7 Cantabro

Figure 11 presents the result of Cantabro test performed on conventional and modified asphalt mixture. The figure shows that the conventional asphalt mixture (2.17%) had a higher Cantabro loss than the modified asphalt mixture. The Cantabro loss decrease as the mineral bottle content increase. 8% of mineral bottle content recorded the lowest Cantabro loss after 300 revolutions, which is 0.96% loss followed by 10% of mineral bottle with 1.16% loss, 4% of mineral bottle with 1.42% loss and conventional mineral bottle with 2.17% loss. Thus, 8% of mineral bottle content has better durability than conventional mixture. The durability of the asphalt mixture has been improved by the addition of mineral bottles, which can ensure durable pavement patches. Based on the specification, the maximum Cantabro loss allowed for hot mix asphalt mixture was 25%, provided that all of the mineral bottle content meets the requirements.

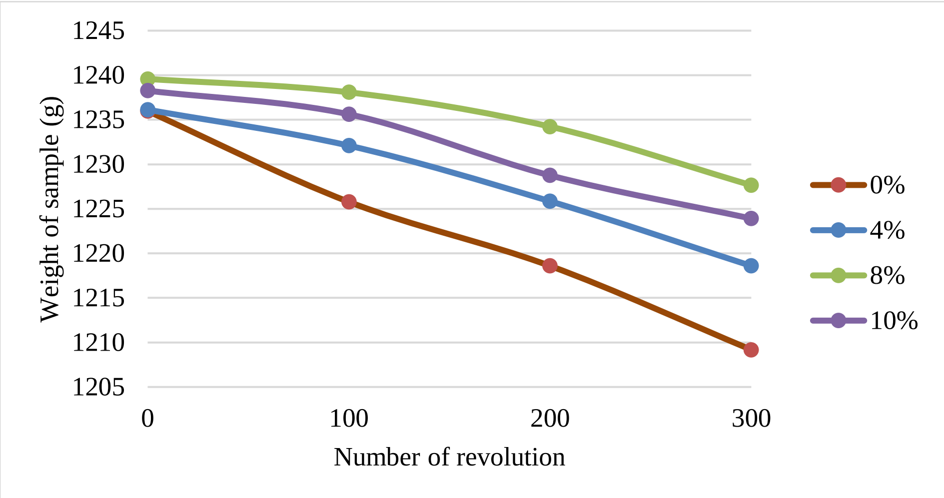

Figure 11. Effect of different percentage mineral bottle to Cantabro loss

4.0 CONCLUSION

This study aimed to investigate the performance of the asphalt mixture incorporated with the mineral bottle as fine aggregate for road application. In this study, mineral bottle was evaluated in different percentages 0, 4, 8 and 10%, respectively. The study found that waste mineral bottle has a good possibility as fine aggregate in asphalt mixture. Modified asphalt mixture with 4-10% of waste mineral bottles improves the properties of the asphalt mixture significantly compared with the conventional mixture. For Marshall stability and flow, the highest value of stability, flow and stiffness of the mixture with 8% of mineral bottle among all the other mixtures (42.61kN, 6.62mm and 4.67kN/mm), respectively. Also, for the Cantabro test, the modified asphalt mixture that contains 8% of mineral bottle (0.96%) shows the lowest loss compared to the conventional mixture (2.17%). Thus, it can be concluded that waste mineral bottles can be considered used in road construction, improving the performance of asphalt mixtures against rutting and reducing municipal solid waste.

5.0 AUTHOR CONTRIBUTIONS

Ng Cui Ming.: Conceptualization, Methodology, Software.

Nicole Liew Siaw Ing.: Data curation, Writing- Original draft preparation.

Nur Ailah Taklima Zukri.: Methodology, Investigation.

Ramadhansyah Putra Jaya.: Writing- Reviewing and Editing, Supervision.

Haryati Awang.: Supervision, Visualization.

All authors have read and agreed to the published version of the manuscript.

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7.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

8.0 ACKNOWLEDGEMENT

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9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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