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Effect of High Recycled Aggregate Content in Hot Mix Asphalt on Volumetric and Skid Resistance Characteristics

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Abstract Friction between vehicle wheels and the road surface is influenced by the performance of the asphalt mixture that forms the road surface. New road construction and maintenance programs require pavement materials that come from natural sources. Efficiency in using materials to preserve the environment can be achieved by recycling. The road surface layer can be recycled 50-60% so that old material can still be utilized by adding new aggregate at a certain gradation size. This research shows the performance of recycled Hot-mix Asphalt (HMA), which consists of a mixture of 50% recycled asphalt and a mixture of 50% recycled asphalt + 27% recycled cement concrete aggregate, compared to the new material HMA mixture. The aggregate recycled asphalt mixture of 77% and WEO utilization of 15% still show skid resistance performance close to that of the new aggregate asphalt mixture. This research shows that using large amounts of waste aggregate and waste engine oil can reduce the use of new materials on road pavement.

Keywords Recycle Material, Hot-Mix Asphalt, Skid Resistance, Green Environment, Pavement

1. Introduction

Skid resistance is the force that occurs when the vehicle wheels are prevented from rotating/sliding along the pavement surface. This value is an important parameter that affects driving safety on the road, which is influenced by weather conditions, where the value decreases when the temperature increases. Road pavements have three essential functions: safety, comfort, and service efficiency. In evaluating the safety of road pavements, a survey was conducted on texture and road roughness (skid resistance) [1]. Skid resistance is defined as the resisting force acting on the vehicle wheels along the road surface when braking, which is influenced by driving speed, vehicle wheels, road conditions, environmental factors, and the texture of the road surface. Road pavement macrotextures, influenced by aggregate characteristics, are believed to prevent aquaplaning on vehicle wheels [2].

Skid resistance is influenced by two components, namely adhesion and hysteresis. Adhesion comes from molecular bonding in areas with high local pressure due to the unevenness of the road surface. At the same time, hysteresis occurs due to loss of energy. This condition is affected by the deformation of the tire rubber around the protrusions and indentations on the road surface. Road surface texture is one characteristic that affects the value of skid resistance. Textures are divided into two, namely macrotextures and microtextures. Macrotextures are influenced by aggregate gradation, air void content (AVC), and binder characteristics of the asphalt mixture.

Meanwhile, microtextures are influenced by the aggregate's mineralogy and surface roughness. Other tests state that microtextures are affected by temperature, pavement age, and traffic. And macrotextures are affected by rain and freeze-thaw cycles [3-4]. The macrotextures component is believed to reduce the aquaplaning phenomenon when vehicles travel at high speeds where a layer of water covers the pavement surface with a thickness of more than 0.5 mm [5]. Some causes of low skid resistance values on asphalt pavements are aggregate quality, aggregate gradation, mix design methods, and higher bitumen content than recommended by mix design [6]. In addition to aggregate characteristics, skid resistance is also influenced by environmental factors such as temperature and rain. The temperature has been known for a long time to be one of the essential factors in the skid resistance value.

Skid resistance testing is generally carried out in the summer when skid resistance values are lowest and helps determine critical values for pavement design. This condition is due to increased tire resistance, and heat (hysteresis) energy loss decreases with increasing temperature [4]. In other words, vehicle tires made of rubber become more flexible with an increase in temperature so that energy loss (hysteresis) becomes smaller [7]. Increasing tire resistance and decreasing hysteresis when the temperature rises cause a decrease in skid resistance [6]. Rain can also cause variations in skid resistance values. Tests carried out immediately after it produces a higher skid resistance value than when the road is dry due to being swept away by contaminants such as dust from the road surface [4]. However, other tests say it is difficult to determine a good relationship between the effects of temperature and rain. Contaminants with many fine grains can reduce the road roughness value. On the other hand, coarse-grained pollutants can increase the slip resistance value. The reason is that they can add to the roughness of the road by scratching and peeling the asphalt surface.

Aged asphalt can be recycled or known as reclaimed asphalt pavement (RAP). Recycled pavement can be an alternative to using new materials to reduce the use of aggregate and new asphalt required in making HMA. These waste materials are mixed with new aggregate, rejuvenated asphalt, and other additives to become a recycled asphalt mixture. Recycling hot mix asphalt pavement utilizes the remaining strength of asphalt and aggregate materials by adding new materials to replace materials whose performance has decreased.

The extraction process is one way to identify aging asphalt and old aggregate so that their characteristics can be analyzed. The residual characteristic values of asphalt and aggregate determine the addition of new materials to the old asphalt concrete mixture. However, using high levels of RAP in hot-mix asphalt tends to be more brittle and has lower fatigue resistance, which can cause cracks in the pavement layers [8]. Therefore, studies are needed to obtain optimal benefits from using RAP as a road surface layer. Using RAP as an alternative asphalt mixture can minimize the use of new materials, streamline costs, reduce asphalt importers, and maintain the availability of aggregate and asphalt. The asphalt recycling method can also solve road construction problems without damaging the road geometry due to repeated overlay construction. The sustainability aspect in the manufacture of road pavements, until now, alternative aggregates derived from recycled materials are still being developed. In utilizing RAP, both aggregate and bitumen are recycled, and additives are needed in waste engine oil and asphalt with new asphalt so that the mixture is no longer stiff and its workability increases [9]. Based on the results of previous studies, the addition of RAP did not harm skid resistance performance. It increased the stability of asphalt mixtures at high temperatures with a recommended ratio of 20% RAP usage [10].

The addition of new aggregates to the RAP process is to replace aggregates at a specific grain size. The way to reposition the aggregate arrangement is not absolute by using a new aggregate. Under certain conditions, it is also possible to use aggregate from waste aggregate cement concrete whose grain size can fill the required grain size in the grain arrangement of the asphalt concrete mixture. Other recycled materials are also known besides RAP, namely recycled concrete aggregate (RCA). RCA can also increase the skid resistance performance of the mix with a maximum usage ratio of 25% [11]. Recycling technologies have been developed for road pavements to limit the use of new natural aggregates. Reducing aggregate concrete waste can reduce the need for landfills for construction waste, where aggregate is the main component in concrete waste as the most construction waste [12]. Waste concrete is from the original concrete from construction results made by separating mortar from stone that can be reused. One of the main reasons for using RCA in pavements is to make construction work greener and more environmentally friendly. On a global scale, the construction sector is a sector that contributes to solid waste, which increases every year. Therefore, concrete waste can be significantly reduced using natural materials such as pavement mixtures [12]. It is now recognized that using RCA is a promising and desirable technology for reducing the environmental impact of the construction sector and conserving natural resources [13]. Road pavement infrastructure development continues to increase. Toll road pavement construction (highway) uses around 30% of available natural aggregates and produces 25% of solid waste generation worldwide [14]. Reducing fuel and aggregate use can encourage the development and use of alternative road construction and maintenance technologies [15]. Research experience on the combination of RAP and RCA aggregates shows that adding the proportion of RCA in the mixture causes a decrease in load capacity and causes the optimum asphalt content to be higher [16]. Variability of the shape of the RCA will occur during the mix preparation due to the glued mortar. This condition can change the design gradation and affect the properties of the asphalt-RCA mixture. Therefore, rough RCA can be applied if the technical properties, especially the moisture susceptibility factor, are appropriately handled [17].

Using old asphalt mixtures in the RAP process requires asphalt softening materials, including waste engine oil (WEO). One reused WEO is used as a rejuvenating agent in the road asphalt industry. This oil can reduce old asphalt's viscosity and increase the potency of the asphalt mixture. Reusing used oil as a rejuvenating agent in the road paving industry can help reduce the amount of used oil waste as hazardous toxic (B3) waste. This waste is used as a softener or rejuvenating agent for old asphalt by curing for 24 hours at a certain percentage until the properties of the old asphalt approach those of the new asphalt, especially at the planned penetration value [18]. Previous studies have found that adding WEO can affect the penetration value, softening point, ductility, and basic viscosity index of asphalt and show a significant recovery effect [19]. Another study on old asphalt and modified binder materials, including WEO, showed increased penetration and decreased softening point temperature [20]. Similar observations have been made on softening and ductility properties, so using 50% RAP as a relative helps restore the physical properties [21]. The results show that all kinds of waste oil can enhance anti-aging properties. Used oil can improve the performance of old asphalt by adding lightweight components.

Meanwhile, as a modifier, the influence of WEO on the performance of various types of asphalt is getting more and more attention [22]. However, there are drawbacks to using WEO in asphalt mixtures. Some disadvantages, namely the viscosity of used oil, are quite high, causing uneven distribution in the asphalt mixture. In addition, using this softening material causes a decrease in the elastic properties of asphalt and groove resistance.

This study's use of waste materials aims to determine the combination of aggregate waste utilization in RAP and RCA by including WEO as a softening material for old asphalt to obtain savings in using new materials. This recycled material is processed to achieve aggregate asphalt mixture performance at certain specifications. The development of waste utilization in this study still refers to previous research by optimizing the remaining material performance. Thus, using materials in this way can contribute more to environmental sustainability.

2. Materials and Methods

2.1. Asphalt Binder

2.1.1. New Asphalt and Recycle Age Asphalt

The aggregate binder material in this study consisted of asphalt pen 60/70 as new asphalt and recycled aged asphalt. Conventional properties tests have been carried out on these two types of asphalt, namely the 25 °C penetration test (ASTM D5), which shows the consistency of asphalt against deformation resistance at 25 °C. The ductility test (ASTM D113) states the bitumen's ability to deform plastic before reaching failure. The softening point test (ASTM D36) shows resistance to high temperatures. As well as the viscosity test (ASTM D4402) shows the level of material viscosity related to the ease of mixing asphalt aggregate at a specific temperature. Asphalt changes its properties when used as an aggregate binder in road pavement, such as penetration and ductility values, which will decrease its service life.

These changes are a form of asphalt mechanism reaching the aging process. Therefore, old asphalt will lose its aromatic content and increase asphaltene content. Generally, asphalt with a low asphaltene content has a high-temperature susceptibility and ductility value. The results of the tests can be seen in Table 1.

Table 1. New Asphalt Pen 60/70 Characteristic

No.	Type of Testing	Testing Method	Unit	New Asphalt	Age Asphalt
1	Penetration at 25 °C	ASTM D-5	0.1 mm	68.2	11.4
2	Softening Point	ASTM-D36	°C	48.3	75.3
3	Flash Point	ASTM D-92	°C	281.4	273.3
4	Ductility at 25 °C	ASTM-D113	cm	102.7	5.43
5	Specific Gravity at 25 °C	ASTM-D70	gr/cm^3	1.07	1.42

2.1.2. Asphalt Softener

The old asphalt softener uses Waste Engine Oil (WEO), a waste vehicle engine lubricant. WEO is available in several car maintenance workshops. This research uses WEO from three car service workshop locations, two of which have almost the same characteristics. From this place, brownish-black waste engine oil is obtained, which is not used for a particular process. The viscosity value at 25 °C is 121-126 cP. WEO is a softening agent for old asphalt, part of the recycling mixture.

2.2. Aggregate Modified

In this study, three types of aggregate were used: the first was a mixture with new aggregate, and the second was 50% new aggregate as a replacement for RAP aggregate from changes in aggregate size to smaller grains due to vehicle loads. Meanwhile, the third is 23% new aggregate, 27% from concrete waste, and 50% aggregate from RAP. The test results of the three aggregates can be seen in Figure 1. These three aggregates were then blended until their contribution percentage was obtained in filling the aggregate composition according to specifications.

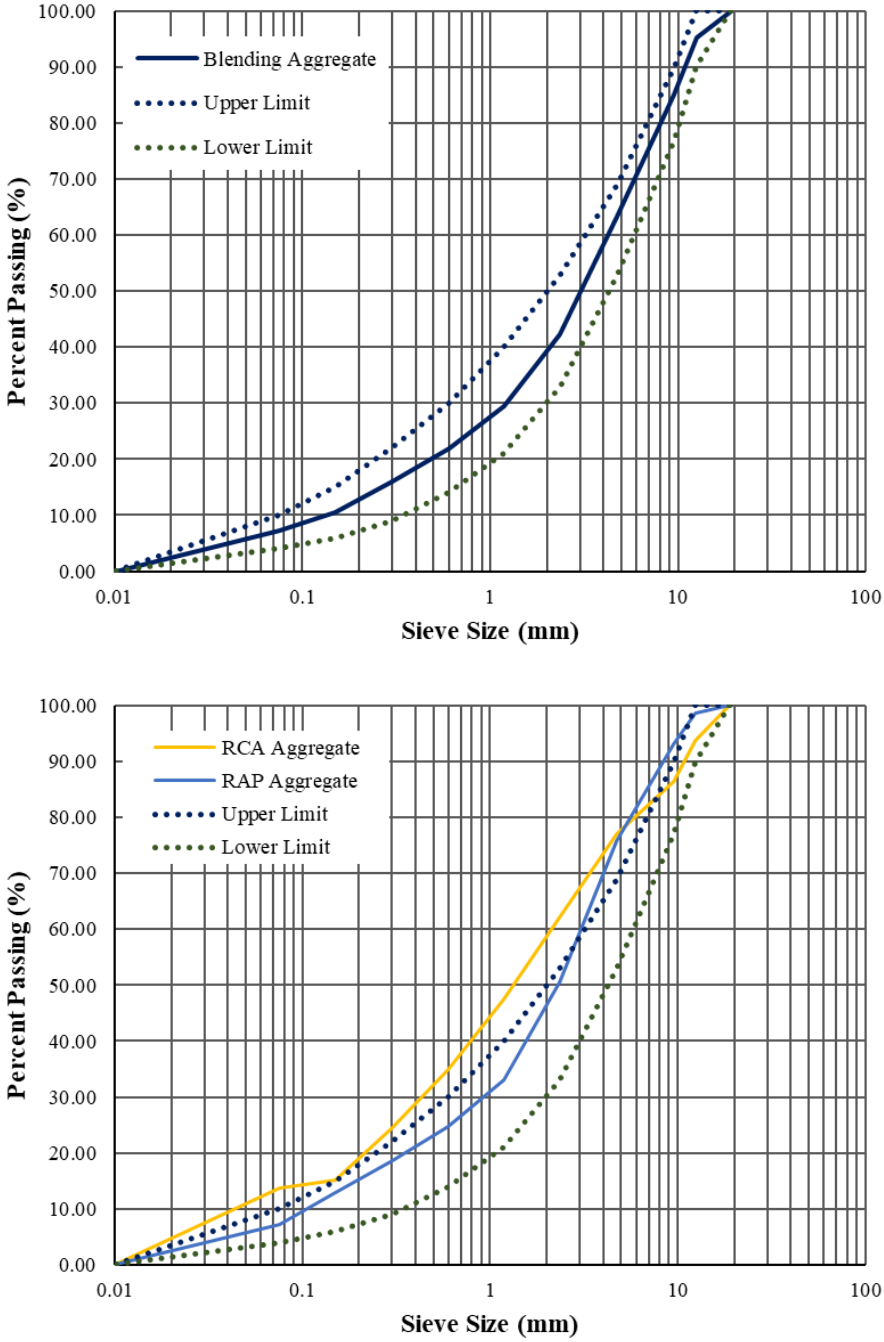

Figure 1. Blending Aggregate (New aggregate + RAP + RCA)

2.2.1. New Aggregate

This type of aggregate is obtained from a stone-crushing company as an aggregate user from stone mining in the quarry. Tests on the physical characteristics of the aggregate include the gradation test that passes the sieve, the Los Angeles test, and the specific gravity test. New aggregates are added to the recycling process to replace aggregate changes of a specific size due to the loading of vehicles during the service life.

2.2.2. Recycled Asphalt Pavement

This study's Recycled Asphalt Pavement (RAP) used a mixture of asphalt aggregate from toll road pavement scraping materials. Separation of asphalt and aggregate is carried out through an extraction process with a Centrifuge Extractor to determine the strength of the remaining asphalt, which has undergone an aging process and changes in the arrangement of its aggregate sizes. The results of the extraction test on the pavement scraping material obtained asphalt and aggregate content. The results of the extraction of the old asphalt mixture from the scrapings of the surface layer are shown in Figure 2.

2.2.3. Recycled Concrete Aggregate

Recycled Concrete Aggregate (RCA) can be obtained from where cement concrete waste piles up from demolition works or building renovations. When using RCA in asphalt mixtures, optimum asphalt content can be increased. This increase is proportional to the rise in RCA in the mix. RCA aggregate form differs from natural aggregate in comprising two materials: natural aggregate and embedded cement mortar. Cement mortar is the origin of the disadvantages of recycled aggregates: lower density and higher absorption, Los Angeles abrasion, and sulfate content [23]. RCA particle pretreatment studies can be carried out using thermal, chemical, and mechanical techniques to overcome this problem and improve the mixture's performance (especially resistance to moisture breakdown) [24].

The RCA used in this research was obtained from concrete waste in the Batching Plan. Before use, this cement concrete waste must be removed from the aggregate using vibrations on a small stone crusher. Then, a washing process is carried out using water so that the aggregate grains do not contain dust or other fine materials. The characteristics of RCA aggregates are shown in Table 2 and Figure 3.

Figure 2. RAP (bitumen and aggregate) extraction

Figure 3. RCA granules before and after the washing process

Table 2. Aggregate characteristics

No.	Type of Testing	Testing Method	Unit	New aggregate	RAP aggregate	RCA aggregate
1	Specific Gravity	SNI 1970:2016	gram/cm^3	2.75	2.58	2.60
2	Absorption	SNI 1970:2016	%	1.58	1.64	1.84
3	Los Angeles abrasion	SNI 2417:2008	%	17.6	18.36	23.6

2.3. Test Methods

2.3.1. Asphalt-Aggregate Mixing

This study uses the specifications of Asphalt Concrete Wearing Coarse (ACWC) hot mix asphalt (HMA). In this study, three types of HMA materials were used, namely, a new aggregate asphalt mixture as a test result control. At the same time, the other two were recycled asphalt mixtures and recycled asphalt mixtures using RCA aggregates.

In the early stages, the viscosity of the mixture of RAP asphalt binder and WEO softener was tested using a Brookfield viscometer according to ASTM D4402 specifications. The torque required to maintain spindle 62 at a constant speed of 50 revolutions per minute determines the viscosity at the mixing temperature. Viscosities of all mixtures were also measured at 110 °C, 135 °C, and 150 °C. In addition, ring and ball tools were used to measure the softening point of asphalt according to AASHTO T53 specifications.

The first stage is washing the RAP mixture and the RCA aggregate, which is dried. The next step is to soften the RAP mixture with waste engine oil by putting both in a sealed bag for 24 hours. This hot asphalt mixture consists of 3 types: coarse aggregate, medium aggregate, and fine aggregate. The percentage of each type of aggregate is determined based on the results of the aggregate blending analysis. Meanwhile, the composition of new asphalt and softened RAP asphalt is determined based on the analysis of achieving optimum asphalt content from Modified Asphalt between new asphalt, RAP asphalt, and WEO. This research was conducted to assess the effect of using RAP as the primary material, so the percentage of RAP used is quite large, namely 50% of the total mixture. Previous researchers have suggested using RAP in HMA no more than 25% [10].

The mixing process was done by heating the RCA aggregate and RAP aggregate, which had been soaked in used oil for 24 hours. These aggregates were heated at 150 °C until the RAP aggregates were no longer clumped. Next, a new asphalt pen 60/70, heated to a temperature of up to 140 °C, is poured into the modified aggregate asphalt mixture. Using RCA as an HMA material for ACWC together with RAP material requires careful calculations.

2.3.2. Marshall Standard and Immersion Test

Marshall testing has two testing methods in this study: the standard Marshall test and Marshall immersion. The two tests are distinguished from the immersion period of the test object in the water bath. The standard Marshall test takes ±30 minutes to immerse the test object at 60 °C while immersion in a water bath for the Marshall immersion test is carried out for ±24 hours.

2.3.3. Skid Resistance Test

This skid resistance test uses a British Pendulum Tester (BPT) tool following the SNI 4427:2008 standard. The test object is compacted according to the density of the Marshall test object and then shaped according to the needs of the BPT test object. This BPT tool has been modified by adding a test object immersion pool in terms of the surface of the BPT test object in wet conditions. Therefore, the apparatus has been modified to adapt the laboratory test to temperature variations. A test object immersion tub is added to obtain wet surface conditions at a specific temperature. The test object was compacted in a mold measuring 30 x 30 cm^2 with a height of 5-6.5 cm with the same density as the Marshall test object. Furthermore, the test object is cut with a 7.5 x 12.5 cm^2 size, as shown in Figure 4. The sample is put into a water-filled tub and submerged to the surface, as shown in Figure 5. Skid resistance testing is carried out until the specimen reaches the desired temperature, 25 °C to 50 °C at five °C intervals with a water heater. The thermometer measures the surface temperature of the wet sample in the soaking tub. Two testing methods were used, namely 24-hour immersion and standard test. This test is intended to determine the effect of the mixture's resistance on the skid resistance value.

Figure 4. BPT sample printing in the laboratory

Figure 5. BPT test tool modification

3. Results and Discussion

3.1. The Effect of WEO on the Penetration Value of RAP

Old asphalt obtained from RAP extraction was added with WEO at 150 °C with a rotation speed of 2000 rpm for 15 minutes to ensure homogeneous mixing. WEO is added gradually, starting from 5% to the amount of RAP asphalt up to 20% with intervals of 5% addition. Penetration value grade 60/70 is achieved at the addition of 15%, as shown in Figure 6. This test method only determines the WEO requirements of the old asphalt contained in the RAP. WEO is added directly to the RAP granules in the asphalt-aggregate mixing process. The penetration value of asphalt-modified WEO is close to the penetration value of new asphalt.

The addition of 15% WEO to aged asphalt has increased the penetration value from 11.4 to 64.6. And the softening point has decreased from 73.3 to 63. The flash point temperature has increased from 281.4 °C to 262.5 °C. Overall, its characteristics are almost close to new asphalt with the addition of 15% waste oil, except that the ductility value is still small, as shown in Table 3.

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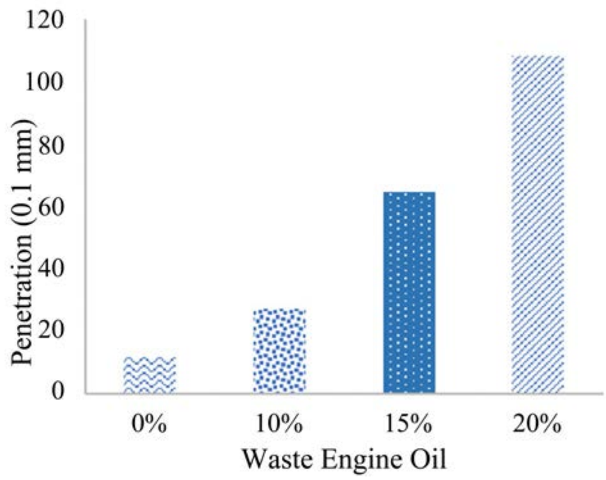


Figure 6. Changes in the RAP Asphalt Penetration value

Table 3. Asphalt Modified with WEO

No.	Type of Testing	Testing Method	Unit	Virgin Asphalt	Asphalt modified WEO
1	Penetration at 25 °C	ASTM D-5	0.1 mm	68.2	64.6
2	Softening Point	ASTM-D36	°C	48.3	63.0
3	Flash Point	ASTM D-92	°C	281.4	262.5
4	Ductility at 25 °C	ASTM-D113	cm	102.7	6.7
5	Specific Gravity at 25 °C	ASTM-D70	gr/cm^3	1.07	1.24
6	Solubility in Trichlor Ethylene	RSNI M - 04 - 2004	% Weight	98.97	-

3.2. Effect of Modified Asphalt and Aggregate Waste on Volumetric Characteristics

Through calculations, the percentage of RAP/RCA is 50%/27% and 23% new aggregate. This process has reduced the use of new aggregates by adding RCA to adjust the composition of the coarse, medium, and fine aggregates in the middle range of the HMA specification envelope as used in control HMA mixture.

Figures 7, 8, and 9 show the volumetric changes between the hot asphalt mixture using new asphalt and new aggregate at the same asphalt content variation, namely 5.5% to 7.5% by weight of the asphalt and aggregate mixture. This new material mixture is the control value of the HMA modification of recycled materials. Two types of modified asphalt mixtures are modified asphalt HMA RAP 50% and HMA RAP50% + RCA 27%.

Using 50% RAP and 50% new aggregate has shown a decrease in voids in the mixture at asphalt content below 7%. Other data occur in HMA RAP50% + RCA27%. Even in this asphalt mixture, the value of voids is slightly lower than that in the RAP50% mixture. From this fact, the RCA aggregate has smaller voids than the new aggregate. It is possible that RCA aggregates still contain mortar, as shown in Figure 7. The use of waste concrete aggregate with a content of 27% has shown a slight increase in the VFA value and a decrease in the VIM value. This change is due to the mortar contained in the RCA (Figure 8).

This recycled material has a higher absorption rate, so asphalt tends to seep into the aggregate so that the cavities between the aggregates are filled with more asphalt, thereby reducing air voids (Figure 9).

3.3. Residual Strength Index of Waste-Modified Asphalt Mixture

RAP50% on HMA has shown a higher Marshall Stability value than the control HMA new material. The aggregate size distribution of the RAP only changes slightly from the size of the granules due to traffic loads. The percentage of use of RAP as an aggregate material for recycled bitumen aggregate depends on the condition of the RAP aggregate arrangement. Furthermore, HMA RAP50% + RCA27% decreased the Marshall stability value and Marshall Quotient, although the Marshall stability value was still slightly higher than the HMA control (Figures 10-11). This performance shows that reducing new aggregate by 27%, replaced by RCA aggregate, still benefits preserving natural resource materials with this recycling process.

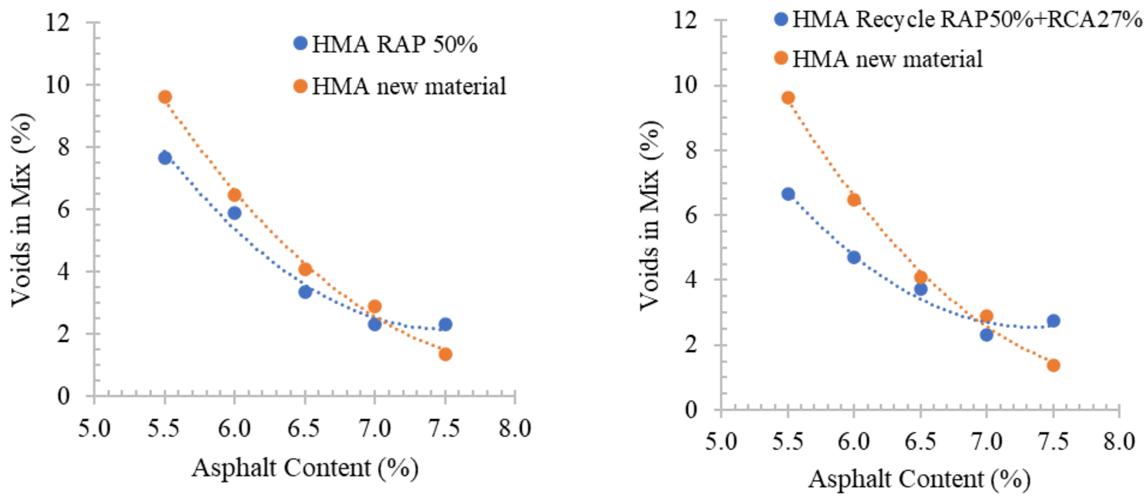


Figure 7. Comparison of Void in Mix

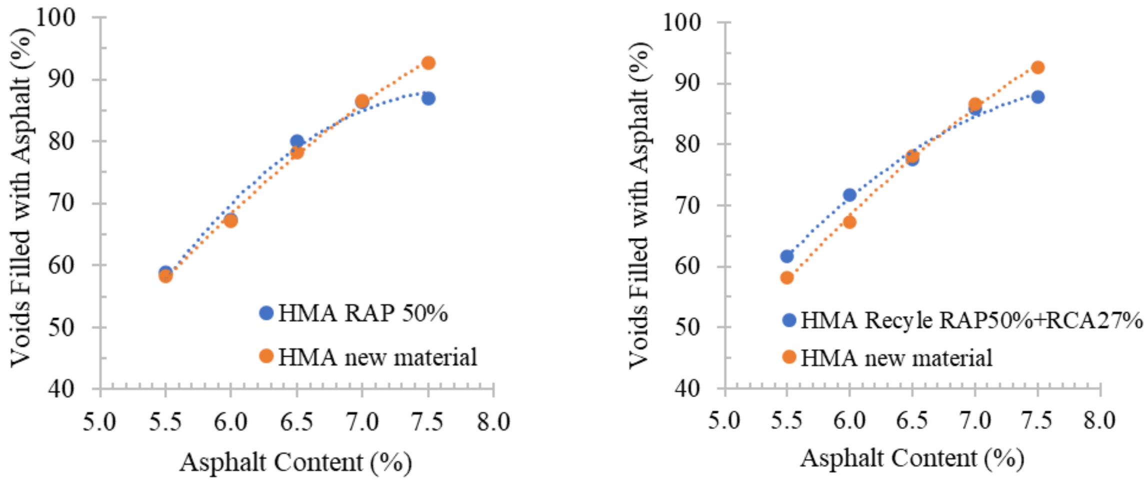


Figure 8. Comparison of Voids Filled with Asphalt

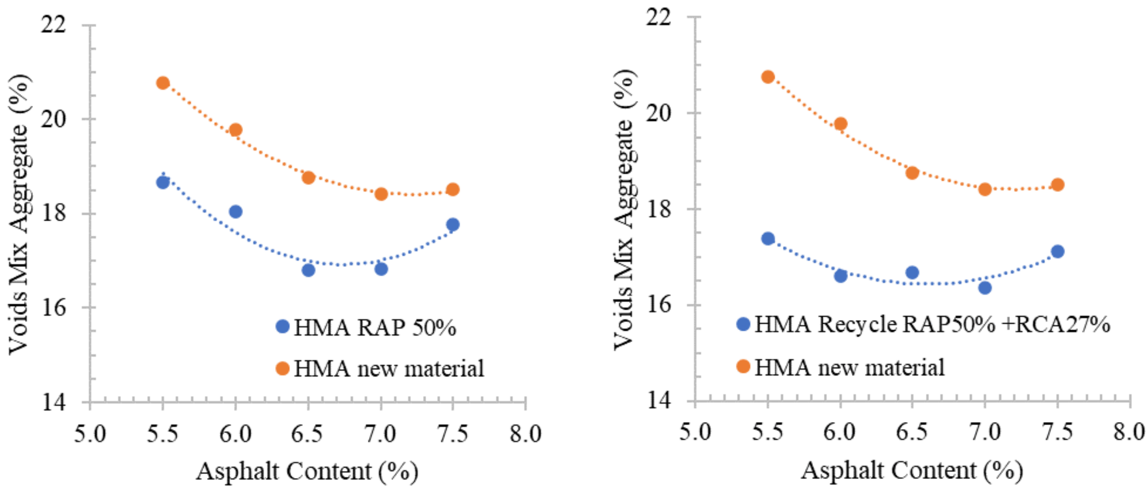


Figure 9. Comparison of Void Mix Aggregate

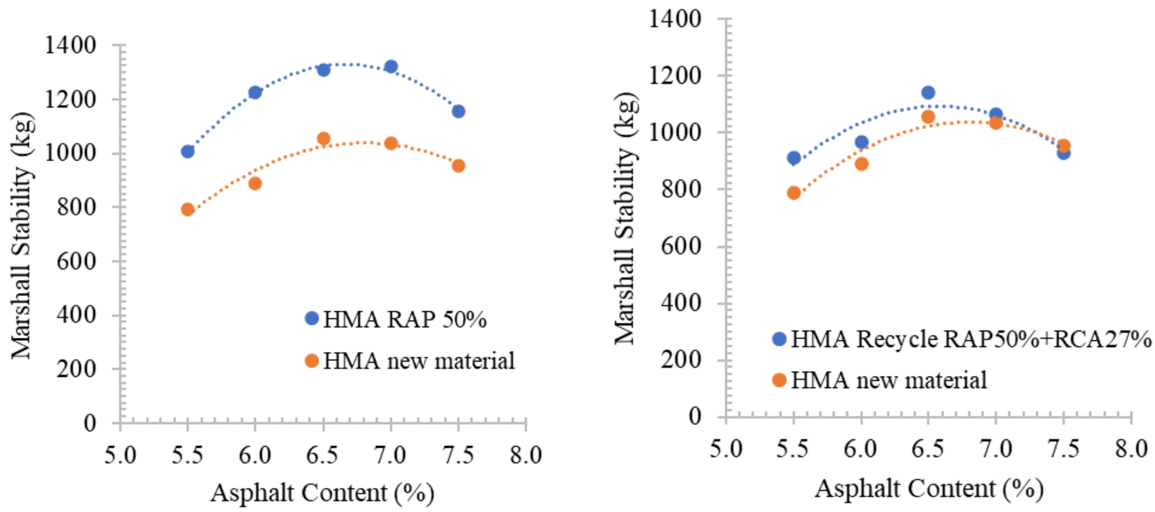


Figure 10. Comparison of Marshall Stability

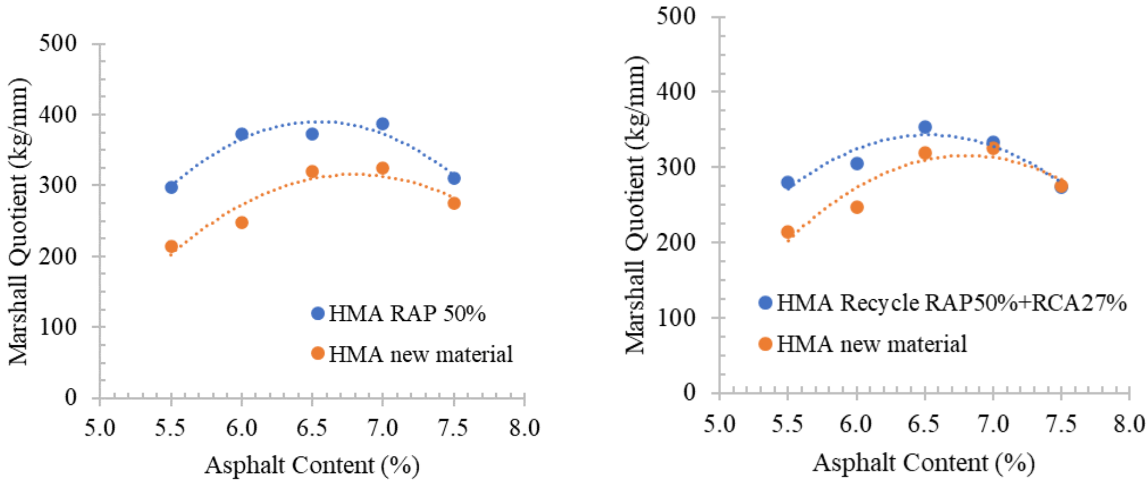


Figure 11. Comparison of Marshall Quotient

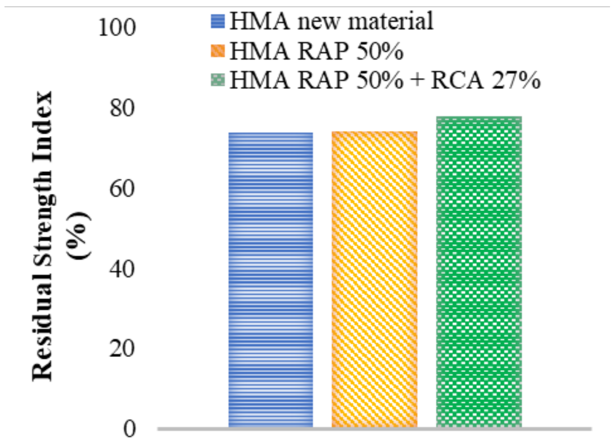


Figure 12. Comparison of RSI values of the three types of HMA

Residual Strength Index (RSI) is used to measure the resistance level of aggregate asphalt mixture to the influence of temperature 60 °C and water immersion for 24 hours. The residual Strength Index is used to measure the resistance level of aggregate asphalt mixture to the influence of temperature 60 °C and water immersion for 24 hours. The formula expresses the calculation:

$$RSI = (MS_s - MS_i)/MS_s \times 100\% \quad (1)$$

MS_s is the value of the Marshall Stability standard, MS_i is the value of Marshall Stability after immersion, and RSI is the percentage reduction in the value of Marshall Stability.

Figure 12 shows the Residual Strength Index (RSI) value increase in the RAP-modified and RAP+RCA-modified asphalt mixture. HMA with new material offers the highest level of vulnerability with an RSI value of 73.7%. The modified asphalt mixture showed a slightly higher RSI value of 74.1% for RAP50% recycling and 78% for RAP50%+RCA27% recycled mixture.

3.4. Effect of Temperature on the Value of Skid Resistance

3.4.1. Degree of Resistance to Temperature Changes

A heating sample in the test bath illustrates the increase in surface temperature. In Figure 13, it can be seen the change in the Skid Number (SN) value. There are three types of HMA at a measurement temperature of 25 °C to 50 °C with an interval of 5 °C increase.

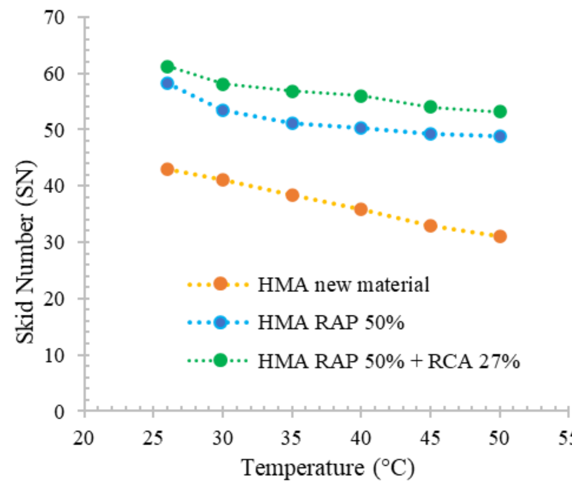


Figure 13. Comparison of Skid Number of three types of HMA due to temperature changes

At a temperature of 25 °C, the SN value was achieved at 43.02; at a temperature of 50 °C, it became 31. There was a decrease of 27.94%. The trend of decreasing SN values with increasing temperature in recycled modified HMA and new material HMA has shown results from previous studies. Furthermore, at 50% HMA RAP, an SN value of 58.29 was achieved at 25 °C, and after heating to 50 °C, there was a decrease with a value of 48.81. In this mixture, there is a decrease of 16.26%. This value is lower than the new HMA material. From these two tests, it appears that RAP50% recycled HMA has more resistance to the effect of increasing temperature.

The third HMA of aggregate RCA27% showed an SN value at 25 °C of 61.21. And after heating to 50 °C, an SN value of 53.15 was obtained. Thus, there was a decrease in the SN value of 8.06. Compared to the two previous types of HMA, this asphalt mixture shows a lower level of resistance to the effects of increasing temperature on the surface. Figure 13 shows that using waste concrete aggregate to replace new aggregate by 27% has increased the highest skid resistance performance compared to the HMA of new materials and the HMA of 50% recycled RAP.

3.4.2. Skid Resistance Susceptibility

The susceptibility of the modified HMA and control HMA mixtures to the effects of temperature and water is illustrated by immersion in water at 60 °C for 24 hours. The effect of temperature changes on the road surface on skid resistance has been investigated on three types of HMA (new materials, recycle RAP, recycle RAP+RCA).

In this study, the effect of temperature on Skid Resistance has been evaluated by the percentage reduction in SNr expressed:

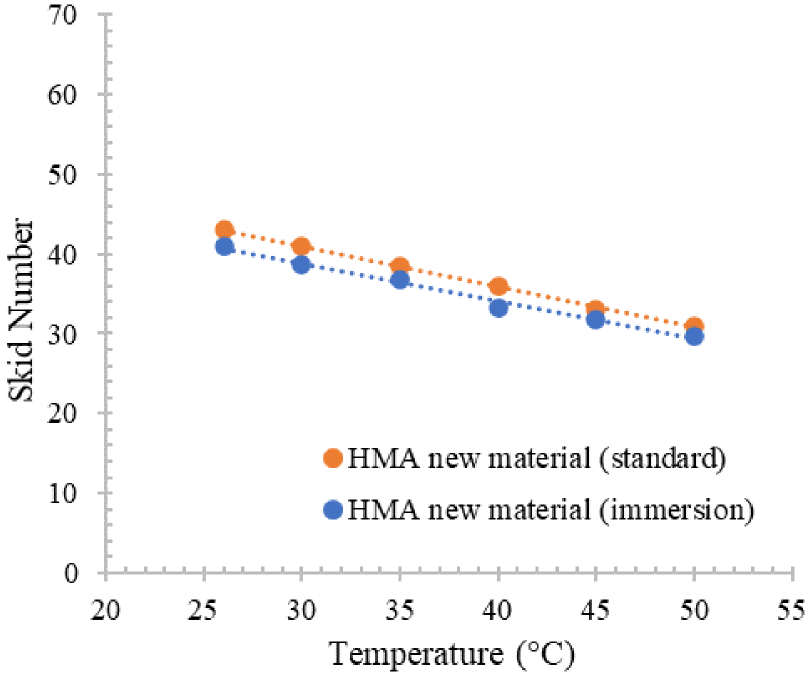
$$SN_r = (SN_s - SN_i)/SN_s \times 100\% \quad (2)$$

Initial SN_s at a standard temperature of 25 °C were unsoaked, and SNi values were after immersion.

In Table 4, it can be seen the susceptibility of HMA to SN values by measuring changes in temperature on the surface. For the new HMA material mixture, the mixture's susceptibility level was recorded with an SN reduction value of between 3.92% and 7.21%. Compared to a mixture of HMA RAP, it has a lower level of susceptibility with an average SN reduction value of -0.21%. However, the addition of RCA to the HMA RAP has shown a higher level of susceptibility. An SN reduction value is between 6.34% and 17.35%. The SN value of the HMA RAP+RCA mixture is higher than the HMA of the new material, as shown in Figure 14.

Table 4. $SN_{reduction}$ at increasing temperature

Temperature °C	HMA new material	HMA modified RAP50%	HMA modified RAP50% + RCA27%
26	4.91%	2.69%	6.34%
30	5.78%	< 0%	5.86%
35	4.16%	< 0%	12.20%
40	7.21%	0.23%	15.18%
45	3.92%	0.48%	14.27%
50	4.03%	0.88%	17.35%



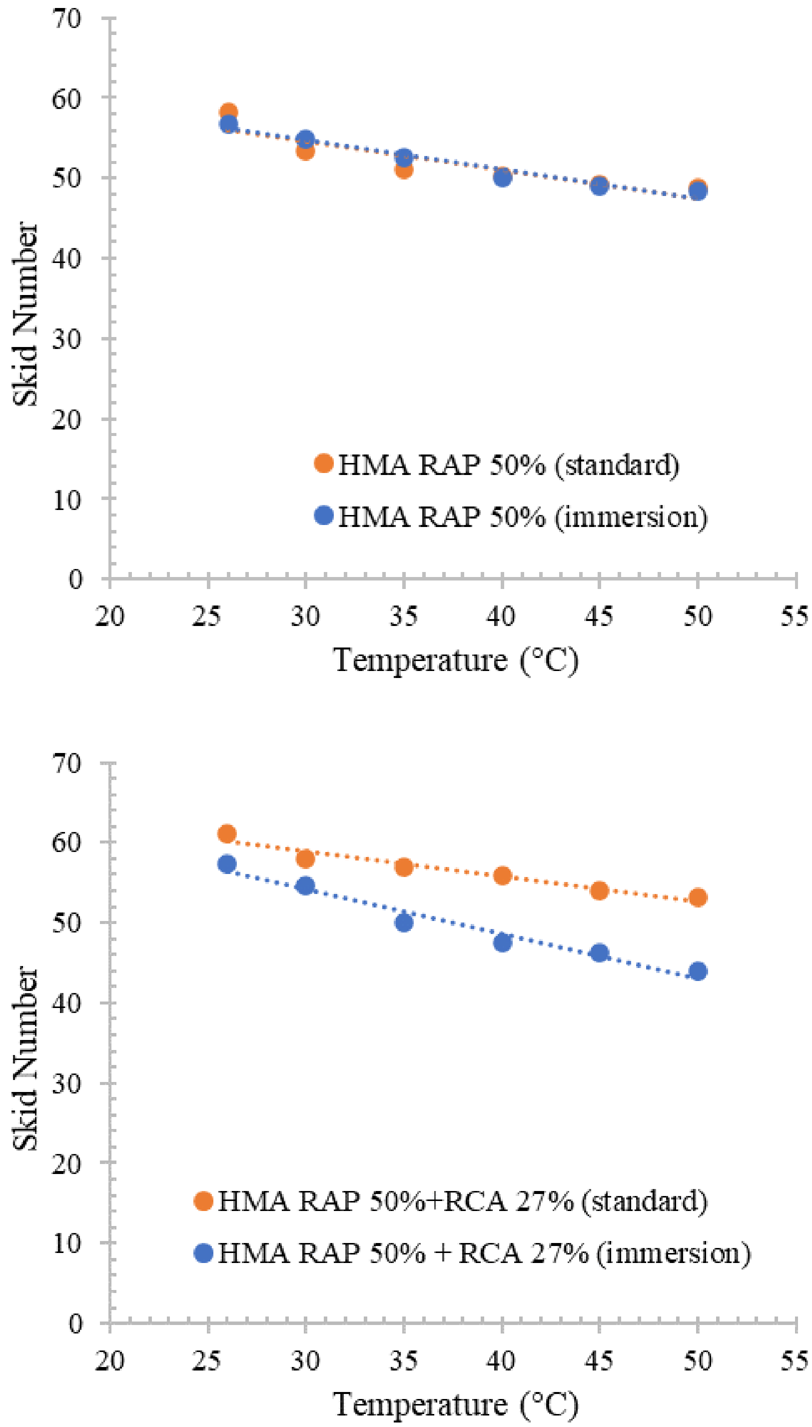


Figure 14. Comparison of SN standard and immersion due to temperature changes

4. Conclusions

This research has shown the results of HMA modification of RAP and HMA modification of RAP+RCA with a comparison of HMA of new materials. This study can be summarized into conclusions as follows:

- WEO can be used as a softening agent for aging asphalt at a certain percentage according to RAP conditions. This is indicated by its characteristics, which can increase the penetration value, reduce the softening point, and reduce the flash point but do not improve the ductility value.
- Using 50% RAP recycled material with WEO softener has shown Marshall's stability performance to be on par with new materials. This is indicated by the remaining strength index values of 74.1% and

78% for recycling 50% RAP + 27% RCA. This value is higher than the residual strength index of the new material HMA.

- The contribution of waste material as a form of HMA has shown savings in new aggregate material of 77% of the total mix and another increase in WEO of 15% of the asphalt content, thus saving the use of new asphalt by 15%.
- Adding the 27% RCA aggregate to the 50% RAP HMA has increased the Skid Resistance value. Meanwhile, the susceptibility of the asphalt mixture to the SN value is indicated by the $SN_{reduction}$ value. From this value, the use of RAP50% has a lower level of susceptibility compared to RAP50% + RCA 27%. However, these two recycled asphalts have a higher SN value than the new material HMA.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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