CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 3, ISSUE 1, 2023, 75 – 86
DOI: https://doi.org/10.15282/construction.v3i1.8910

RESEARCH ARTICLE

Analysis of Reclaimed Asphalt Pavement with Rejuvenating Materials

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ABSTRACT - Reclaimed asphalt pavement (RAP) is currently commonly used in road construction. Reclaimed asphalt pavement can enhance environmental sustainability while also reducing reclaimed pavement disposal issues. In this study, waste cooking oil (WCO) was utilized as rejuvenating material. There are different samples, where Sample A is the control mixture which is virgin mixture without rejuvenator contain 0% of RAP content. Sample B is the rejuvenated RAP mixtures including 25% and 50% of RAP content combined with WCO, while sample C is the non-rejuvenated RAP mixture containing 25% and 50% of RAP content. In addition, sample D is for 100% RAP content. Therefore, to evaluate the engineering properties, different experimental test, including Marshall stability and flow, dynamic creep modulus and indirect tensile strength are applied, and the optimum percentage was determined based on the result. The findings revealed that reclaimed asphalt pavement with rejuvenating materials enhanced the performance of stability and deformation resistance. Moreover, the indirect tensile strength increases with the increase of RAP content. Based on the findings, it can conclude that 100% of reclaimed asphalt pavement showed the optimum value and significantly enhanced the performance of reclaimed asphalt pavement with rejuvenating materials by reducing pollution.

ARTICLE HISTORY
Received : 29th Nov. 2022
Revised : 09th Jan. 2023
Accepted : 10th Jan. 2023
Published : 27th Apr. 2023

KEYWORDS
Reclaimed asphalt pavement,
Rejuvenating material,
Waste cooking oil,
Indirect tensile strength,
Dynamic creep modulus,

1.0 INTRODUCTION

Reclaimed asphalt pavement is now widely used due to advances in flexible pavement design and construction. Reclaimed Asphalt Pavement (RAP) is made up of asphalt and aggregate components that have been recovered and reprocessed from the existing pavement [1]. Road agencies have been exploiting RAP materials to minimize the burden on natural aggregate, to enhance environmental sustainability and to reduce the disposal problems of reclaimed pavements [2]. Nevertheless, removing asphalt concrete has to be evaluated from a cost efficiency perspective, since it significantly reduces the overall costs of new bituminous products [3]. By using recycled materials in asphalt pavements, it can reduce the extraction of aggregates and bitumen and decrease the amount of material landfilled.

Many potential recycling agents can rejuvenate the reclaimed asphalt pavement (RAP). Rejuvenating agents contain additives that can aid in restoring the original rheological properties of an aged RAP binder. According to the Solid Waste Corporation of Malaysia (SWCorp) statistic, approximately 16,688 tonnes of cooking oil would be wasted daily in Malaysia by 2020 [4]. Thus, the waste cooking oil was selected as rejuvenating material in RAP. Many researchers have been explored that waste cooking oil as a rejuvenator can lead to efficient resources use and contribute toward a more sustainable pavement construction [5-8].

Extensive research on the use of RAP to increase pavement longevity and conservation has been conducted. Yi et al [9] have examined the rejuvenating effects of used waste cooking oil. The result showed that rejuvenation with 10% waste cooking oil improved the aging resistance. Shorbagy et al [10] reported that the optimum percentages of the waste cooking oil as rejuvenators was in the range 3.5% to 4% based on the softening point and penetration value. Rodrigues et al [11] have evaluated the mechanical performance of waste cooking oil in reclaimed asphalt pavement. The findings indicated that waste cooking oil improved the Marshall stability, reduced the fatigue cracking and had good performance in terms of permanent deformation resistance. Maharaj et al [12] discovered that waste cooking oil used as a rejuvenating material in asphalt binder increase the resistance to fatigue cracking and reduce the rutting resistance with temperature. According to the Bilema et al [13], they found that 25% and 40% of reclaimed asphalt pavement (RAP) with waste cooking oil and crumb rubber increased the penetration value and decreased the softening point. Similarly, Zargar et al [14] discovered that using 3-4% waste cooking oil to the binder can increase the penetration value, which resembles virgin asphalt.

As a result, the road industry is exploring alternative materials and construction methods for road maintenance and upkeep that seem to be environmentally friendly, energy-efficient, and cost-effective. Therefore, the significance of the study is to investigate and monitor the performance of reclaimed asphalt pavement (RAP) with rejuvenating materials toward sustainable pavement materials. To evaluate the performance of RAP with rejuvenating materials in the asphalt mixture, the Marshall stability and flow, dynamic creep modulus and indirect tensile strength have been conducted. The optimum percentage of RAP with rejuvenating material in the asphalt mixture has been determined based on the performance.

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2.0 MATERIALS AND SAMPLE PREPARATION

2.1 Materials

The aggregate gradation employed in this study was asphaltic concrete AC14, which conformed to the Malaysia Standard Specification for Road Works [15]. Figure 1 depicts the aggregate gradation AC14, with a total weight of approximately 1200g for each sample. In this study, bitumen with a penetration grade of 60/70 was used and 5% of bitumen content was selected. Each sample had a bitumen content of 5%, weighing 63.16g. The rejuvenated materials were waste cooking oil (WCO) with 3% of WCO content (1.90g).

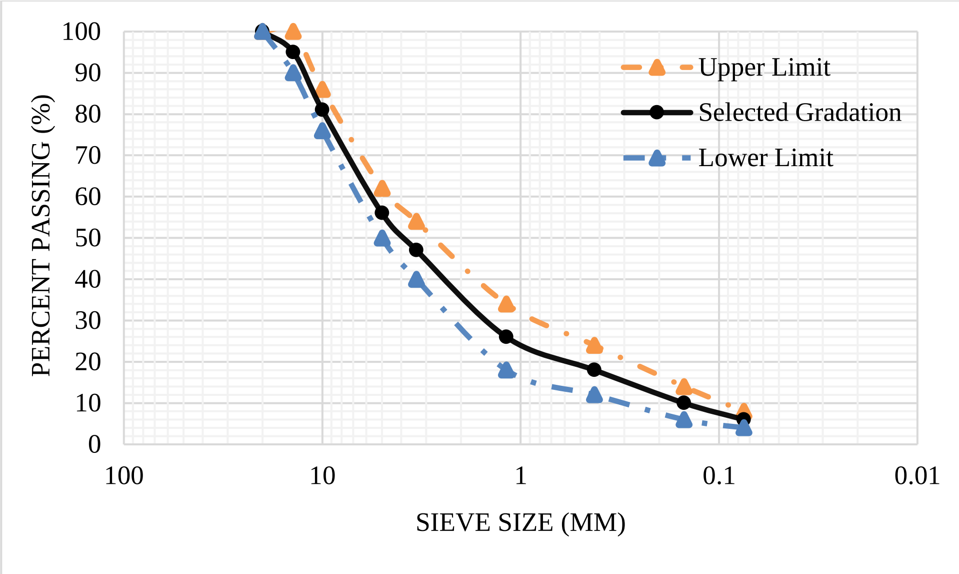

Figure 1. Aggregate gradation AC14

2.2 Preparation of reclaimed aggregate and asphalt mixture

Localized sampling is essential for generating a suitable mix design within an acceptable range of specifications. The damaged and scraped pavement was collected from Batu 11, Jalan Gambang to Kuantan, Malaysia (Figure 2 (a)). The cutting edge should be removed manually before carrying out further evaluation for onward analysis. The reclaimed asphalt pavement (RAP) material was cleaned first to eliminate any sand or other undesirable material (Figure 2 (b)). The RAP material was then evenly distributed on a tray to ensure that the drying oven heating procedure was effective until it became separate (Figure 2 (c)). The RAP samples were heated for approximately 1 hour at 140ºC. Then, the RAP samples were burned in the furnace for approximately 3 hours at 540ºC and cooled down to 200 ºC. Figure 2 (d) illustrates the final product of RAP aggregates.

Table 1 demonstrates the designated samples are allocated among samples A, B, C and D. Sample A is the control parameter in which the virgin mixture without rejuvenator contains 0% of RAP content. Sample B is the rejuvenated RAP mixture with 25% and 50% of RAP and WCO content. Sample C is the non-rejuvenated RAP mixture with 25% and 50% RAP content. Sample D is 100% RAP content.

Figure 2. Process of extracting the aggregate from RAP samples

Table 1. Designated sample

Sample	RAP (%)	State
A: Control Parameter	0%	Virgin mixture without RAP and rejuvenators (Control)
B: Rejuvenated RAP Mixtures	25%	RAP and rejuvenators mixtures (RAP + WCO)
	50%	
C: Non-Rejuvenated RAP Mixtures	25%	RAP without rejuvenators mixtures
	50%	
D: RAP only	100%	Fully RAP with WCO

3.0 METHODOLOGY

3.1 Aggregate Impact Value

The aggregate impact value is used to indicate how effectively an aggregate will withstand a sudden impact in road construction. Aggregate with a size passed 14mm and retained on a 10mm sieve was utilized. The mould was filled with three layers of aggregates, and each layer required 25 strokes with a tamping rod. Then, the 60kg hammer was released and fell onto the aggregate, as depicted in Figure 3. A total of 15 blows were allowed to fall on the aggregate. After being taken out of mould, the aggregate was sieved using a 2.36mm sieve. The aggregate that passes through the sieve at 2.36mm was weighed and recorded. The test was conducted in accordance with BS EN 1097-2:2022 [16].


Figure 3. Aggregate impact value

3.2 Aggregate Crushing Value

Aggregate crushing value is a quantitative measurement of aggregate strength used in road infrastructure. Aggregate with a size passed 14mm and retained on a 10mm sieve had been used. The sample was composed of three layers, which each layer receiving 25 strokes using tamping rod. A tamping rod on a straight edge can be flattened the surface. After leveling the surface, the plunger was placed on the aggregate surface. The assembly was then placed on the loading platform of the compression testing machine. As shown in Figure 4, a load of 400 kN was applied within 10 minutes and ensured that every 1 minute was at the uniform rate. The force was released, and the material was removed from the cylinder. A 2.36mm sieve was used to sieve the aggregate. The aggregate that passes through the sieve at 2.36mm was weighed and recorded. The test was conducted in compliance with BS EN 1097-2:2022 [16].

Figure 4. ACV compression equipment

3.3 Softening Point

The softening point determines the temperature at which bitumen changes from a solid to a liquid state. The test was conducted in accordance with BS EN 1427:2015 [17]. The bitumen was heated, poured into rings and allowed to cool 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 5. The bitumen was heated until it touched the base plate and the temperature was recorded.

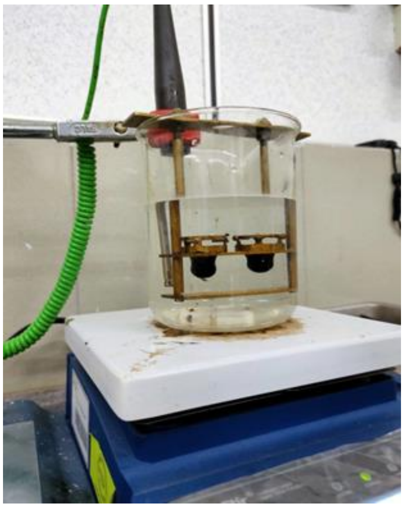

Figure 5. Softening point test

3.4 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 6. 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 [18].

Figure 6. Immersed in the water bath at 25°C for 1 hour

3.5 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 [19]. Firstly, the specimens were immersed in the water bath at 60°C for 40 minutes, as shown in Figure 7. 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 8.

Figure 7. Immersed in a water bath for 40 minutes

Figure 8. Marshall stability and flow test

3.6 Dynamic Creep Modulus

Dynamic creep modulus is a destructive test conducted to evaluate the rutting potential of an asphalt mixture. The test was conducted in accordance with BS EN 12697 [20] at 40°C. The samples were conditioned for at least 2 hours in the Universal Testing Machine (UTM-25) at 40°C. At the initial stage of testing, the preloaded stress of 150 kPa was applied for 30second in order for the load bar to completely come into contact with the sample. Then, the sample was subjected to cyclic loading stress of 300 kPa for 3600 cycles, as shown in Figure 9. After the completion of the 3600 cycles, the total permanent strain and displacement of the sample were determined. Equation 1 was used to calculate the dynamic creep modulus.

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where;
E = Dynamic creep modulus, MPa
σ = Applied stress, psi
ε = Measured vertical strain, mm

Figure 9. Dynamic creep modulus test at 40°C

3.7 Indirect Tensile Strength

The ability of the asphalt mixtures to withstand cracking is assessed using indirect tensile strength. The test was performed in accordance with ASTM D6931 [21]. As shown in Figure 10, the sample was conditioned at 25°C for 4 hours, and then the sample was applied to the vertical diametric plane at a constant rate of deformation until the failure occurred. The peak load at failure is recorded and the indirect tensile strength can be calculated by using Equation 2.

$$S = \frac{2P}{\pi t D} \tag{2}$$

where;
P = maximum load, kN
t = specimen height immediately before test, m
D = specimen diameter, m

Figure 10. Indirect tensile strength test

4.0 RESULTS AND DISCUSSION

4.1 Aggregate Properties

Table 2 shows the aggregate properties results. The table shows that the aggregate impact value for virgin aggregate is 21.79%, which is stronger than the RAP aggregate (26.54%). According to the Malaysia Standard Specification for Road Works, the impact value for virgin and RAP aggregates are between 20% to 30%. Hence, this shows that virgin aggregate and RAP aggregate have the ability to withstand sudden shock or impact. Meanwhile, the aggregate crushing value for virgin aggregate is 17.07%, whereas the RAP aggregate is 24.25%. The crushing value for virgin and RAP aggregates considered as satisfactory for road surfacing, which is less than 25% according to the Malaysia Standard Specification for Road Works.

Table 2. Aggregate properties results

Properties	Virgin aggregate	RAP aggregate
Aggregate Impact Value	21.79%	26.54%
Aggregate Crushing Value	17.07%	24.25%

4.2 Bitumen Properties

Table 3 indicates the bitumen properties results. Bitumen 60/70 penetration grade was used in this study. Based on the table, it observed that bitumen commences to soften and reaches its softening degree at 53.05°C. According to the Malaysia Standard Specification for Road Works, the softening point must be between 49°C to 56°C. Moreover, the penetration value of 67.33mm falls within 60 mm to 70 mm by referring to the Malaysia Standard Specification for Road Works for bitumen grade 60/70. The PI value necessitates determining bitumen stiffness at any temperature and loading duration. Based on the calculation, the penetration index PI is +0.28, which is suitable for road pavement. This bitumen is primarily utilised in the production of hot mix asphalt for bases and wearing courses.

Table 3. Bitumen properties results

Properties	Bitumen 60/70
Softening Point	53.05°C
Penetration	67.33mm

4.3 Stability

Figure 11 represents the relationship between RAP and WCO on stability. It can be seen that the stability of rejuvenated reclaimed asphalt pavement was higher than the control sample. From the figure, the stability increases uniformly from sample A until sample D. The highest stability was sample D (100% RAP) with 32.36kN, followed by sample C with 50% RAP (26.12kN), sample C with 25% RAP (25.13kN), sample B with 50% RAP + WCO (20.32kN), sample B with 25% RAP + WCO (17.47kN) and control sample (16.94kN). This demonstrates that 100% RAP asphalt mixture has the highest stability performance and deformation resistance. The result obtained for all samples was greater than 8kN, which satisfied the criteria for wearing course based on Malaysia Standard Specification for Road Works.

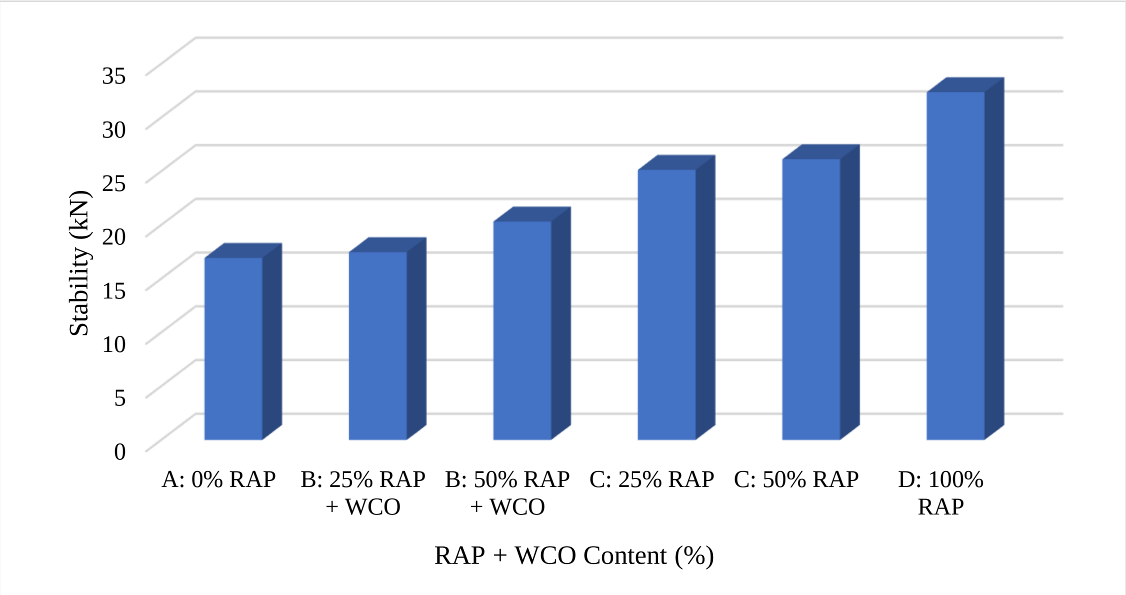

Figure 11. Effect of RAP and WCO on Stability

4.4 Flow

The relationship between RAP and WCO on flow is illustrated in Figure 12. Based on the Malaysia Standard Specification for Road Works, the flow requirement should be between 2mm to 4mm. Only control sample meet the requirement. The flow value gradually declines when adding rejuvenators as shown in sample B with 25% RAP + WCO (5.03mm) and Sample B with 50% RAP + WCO (4.98mm). The high flow has a tendency easily exposed to deformation when the traffic load is applied. 100% of RAP recorded the lowest flow at 4.70mm, which can resist to permanent deformation.

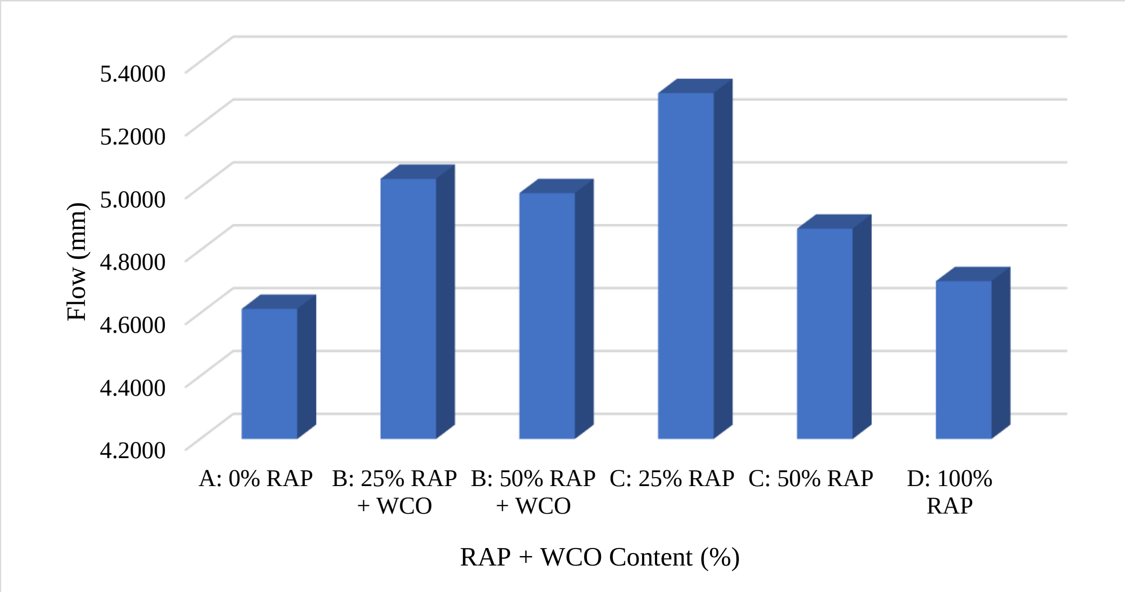

Figure 12. Effect of RAP and WCO on Flow

4.5 Bulk Density

Figure 13 shows the relationship between RAP and WCO on bulk density. The bulk density of rejuvenated reclaimed asphalt pavement was higher than the control sample. The highest bulk density was sample D (100% RAP) with 2.36g/cm^3, followed by sample B with 25% RAP + WCO (2.33g/cm^3), sample C with 50% RAP (2.32g/cm^3), sample B with 50% RAP + WCO (2.31g/cm^3), sample C with 25% RAP (2.30g/cm^3) and control sample (2.27g/cm^3). There are no specifying limitation values for bulk density in Malaysia Standard Specification for Road Works.

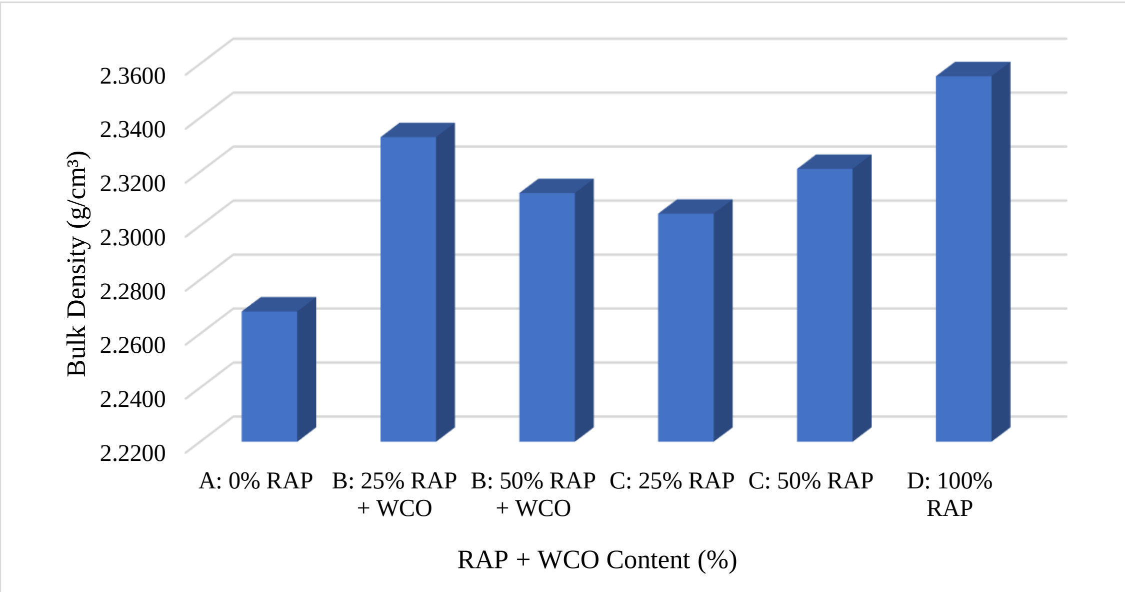

Figure 13. Effect of RAP and WCO on Bulk Density

4.6 Air Void

The relationship between RAP and WCO on air void is illustrated in Figure 14. The air void of rejuvenated reclaimed asphalt pavement was higher than the control sample (3.79%). The highest value of air void was sample C (25% RAP) with 4.10%, and the lowest air void was sample B (50% RAP + WCO) with 3.11%. The lowest air void will produce fewer air voids and make it to less moisture damage. Based on the Malaysia Standard Specification for Road Works, the air void requirement should be between 3% to 5%, and all the mixtures comply with this criterion.

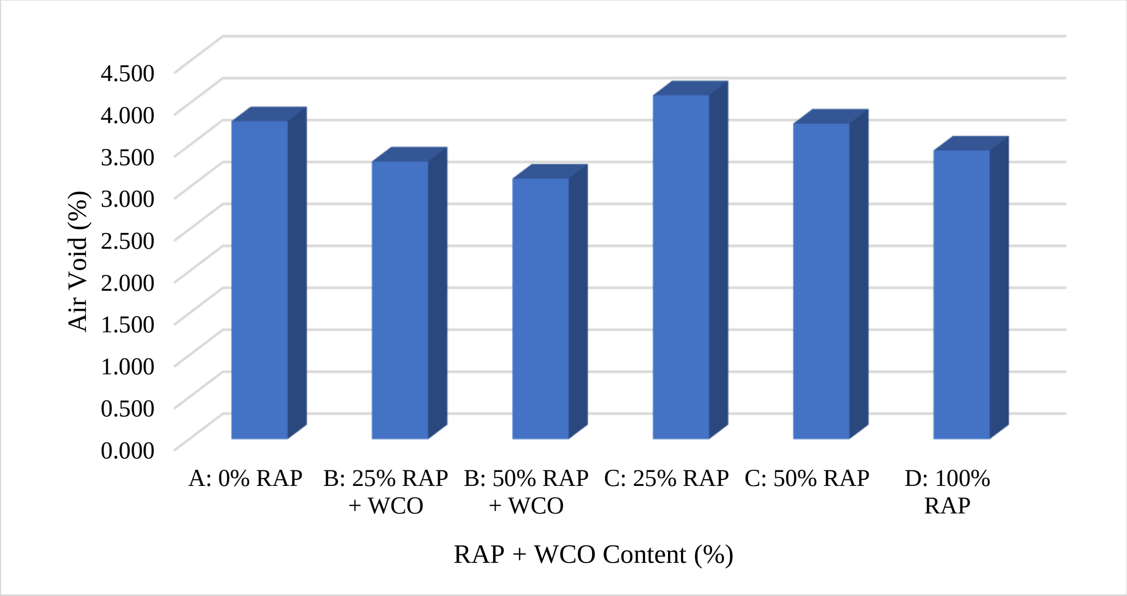

Figure 14. Effect of RAP and WCO on Air Void

4.7 Voids in the Mineral Aggregates (VMA)

Figure 15 indicates the relationship between RAP and WCO on VMA. Based on the figure, the VMA for the control sample (16.03%) was higher than rejuvenated reclaimed asphalt pavement. Among the rejuvenated reclaimed asphalt pavement, the highest VMA value is sample B with 50% RAP + WCO (15.48%), and the lowest VMA value is sample B with 25% RAP + WCO (14.63%). Thus, the waste cooking oil as rejuvenating materials in reclaimed asphalt pavement (RAP) produces fewer air voids, making it less moisture damaged and homogeneous.

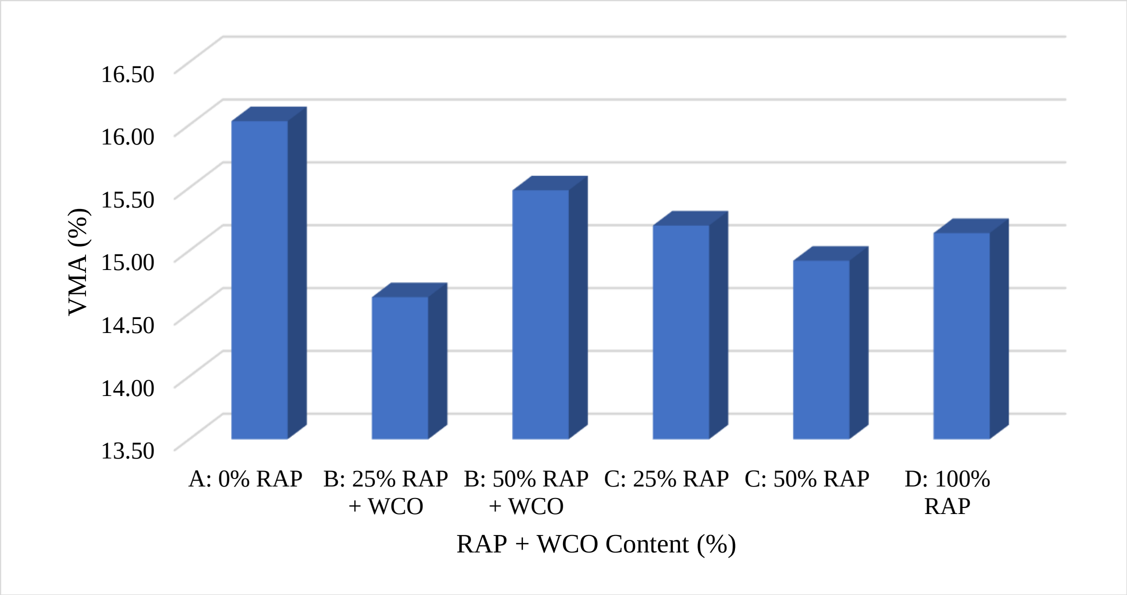

Figure 15. Effect of RAP and WCO on VMA

4.8 Voids Filled with Asphalt (VFA)

The relationship between RAP and WCO on VFA is illustrated in Figure 16. Referring to the figure, the highest VFA was control sample with 75.02%, followed by sample B with 50% RAP + WCO (74.76%), sample C with 25% RAP (74.38%), sample D with 100% RAP (74.23%), sample C with 50% RAP (73.89%) and sample B with 25% RAP + WCO (73.52%). From the figure, all the samples are meet the requirement of Malaysia Standard Specification for Road Works, where the values fall between 70% to 80%.

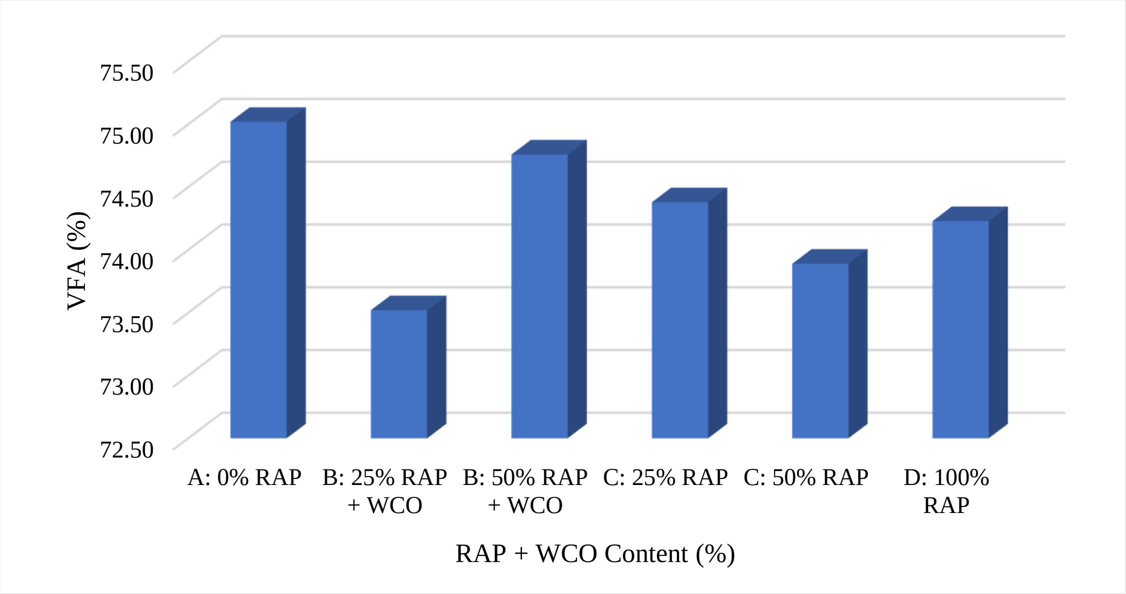

Figure 16. Effect of RAP and WCO on VFA

4.9 Dynamic Creep Modulus

According to Figure 17, a clear differentiation exists between the curves representing the reclaimed asphalt pavement content and waste cooking oil. Based on the figure, the control mixture is found to be less susceptible to rut in comparison with typical RAP mixtures. Higher axial strain results imply that the mixtures are less rutting resistant. The increasing amount of RAP aggregate affects the accumulated strain value of the sample. Thus, adding the amount of rejuvenator dosages, waste cooking oil indicates the lowest permanent deformation. The uses of very high RAP contents in asphalt mixture also warrant the application of higher cyclic stress and test temperature to achieve tertiary creep. Based on the figure, the lowest value was Sample B (25% RAP +WCO) with 270.99 and the highest value was Sample A (0% RAP) with 3148.90 strain.

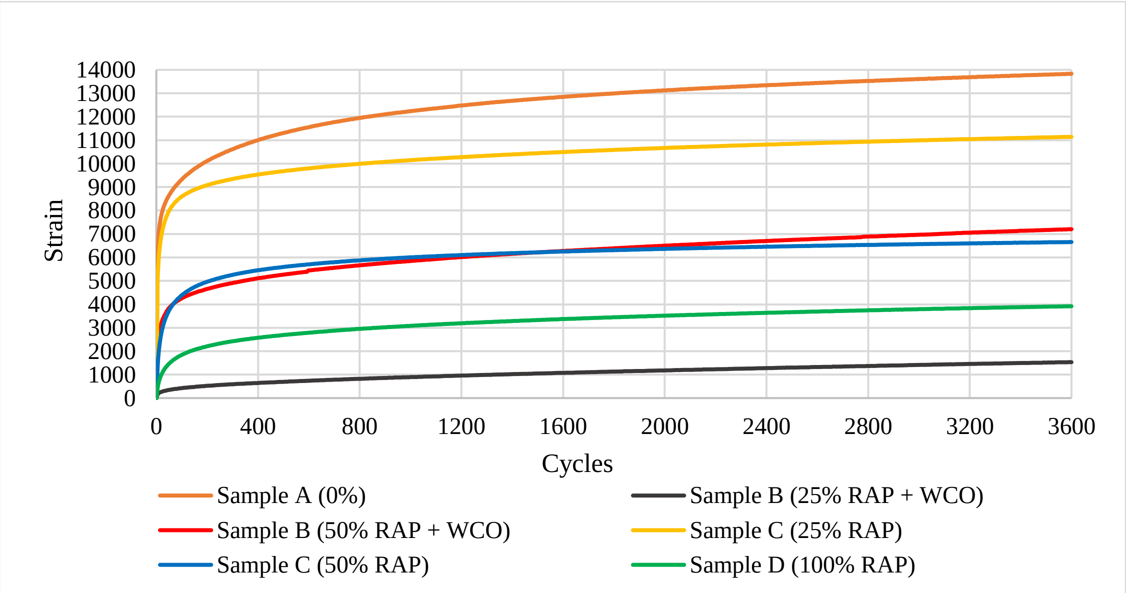

Figure 17. Effect of RAP and WCO on Dynamic Creep Modulus at 40°C

4.10 Indirect Tensile Strength

The ability of the asphalt mixture to resist rupture or crack initiation was investigated. The indirect tensile strength result (ITS) is shown in Figure 18. Based on the figure, the tensile strength of the control asphalt mixture is higher than the reclaimed asphalt pavement with rejuvenators. Based on the figure, the tensile strength for the control (0%) sample is 604.63kPa. The second highest tensile strength within the reclaimed asphalt pavement mixture is 100% of RAP with 596.87kPa, followed by 50% RAP with 587.04kPa, 25% RAP with 506.99kPa. For the RAP and WCO as rejuvenators, the 25% RAP with WCO is 449.35kPa and followed by the lowest tensile strength is 50% of RAP with WCO containing 439.01kPa. From the testing ITS, the result shows that adding the rejuvenators can decrease it tensile strength. Weakened aggregates in RAP would attribute to relatively lower ITS, and hence ITS reduces as RAP content increases. The indirect tensile strength of 0% of RAP has been an indicator for optimum performance. Thus, this control sample (virgin aggregates) has better bituminous quality and less cracking tendency than other modified asphalt mixtures. To conclude, the ITS of rejuvenated mixtures are comparable with the control mixture, but relatively weaker than typical RAP mixtures. Based on the Malaysia Standard Specification for Road Works, the ITS requirement should exceed 200kPa, and all the mixtures comply with this criterion.

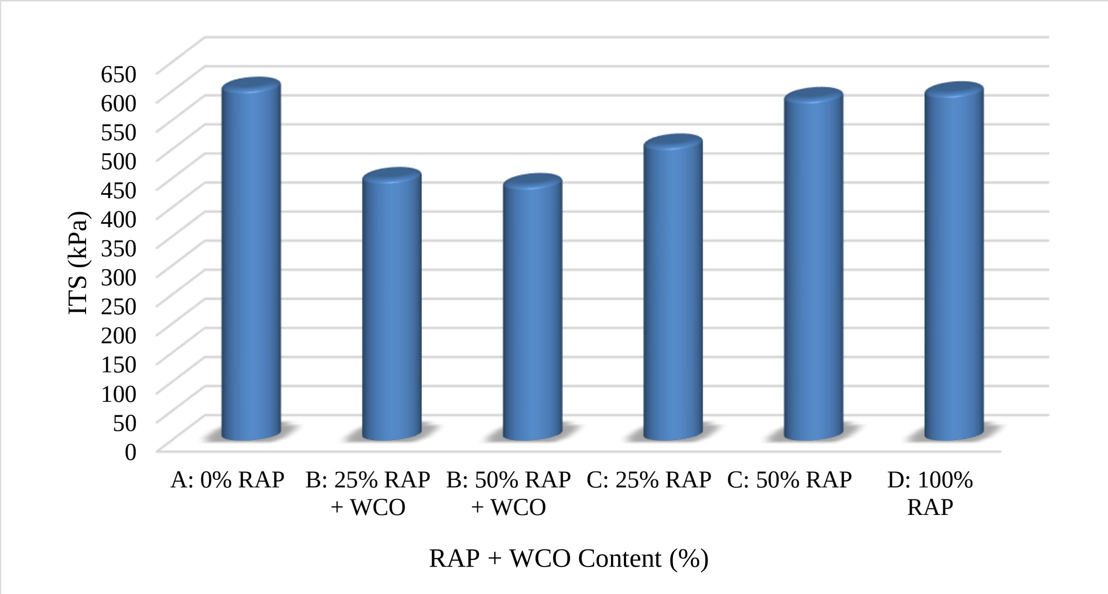

Figure 18. Effect of RAP and WCO on Indirect Tensile Strength

5.0 CONCLUSION

a) The optimum percentage of reclaimed asphalt pavement with rejuvenating material is 100% RAP content based on the stability, dynamic creep modulus and indirect tensile strength.

b) The stability increases uniformly and the 100% RAP asphalt mixture has the highest stability performance and deformation resistance.

c) Based on the dynamic creep analysis in comparison to usual RAP mixtures, the control mixture is shown to be less prone to rut.

d) The increasing amount of RAP aggregate affects the accumulated strain value of the sample. The amount of rejuvenator dosages, waste cooking oil indicates the lowest permanent deformation. Moreover, 100% RAP showed the lowest strain value of 822.60 and had greater rutting resistance.

e) The indirect tensile strength results demonstrated that the rejuvenators had reduced its tensile strength. However, compared to other modified asphalt mixtures, the 100% RAP with 596.87kPa demonstrated the highest tensile strength, which has optimal performance and can lessen the tendency to crack.

6.0 AUTHOR CONTRIBUTIONS

Ng Cui Ming.: Writing- Original draft preparation, Methodology, Software.

Anis Aina Adnan.: Methodology, Investigation.

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

Nicole Liew Siaw Ing.: Data curation, Conceptualization.

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

7.0 FUNDING

This research was funded by Universiti Malaysia Pahang: PGRS210376.

8.0 DATA AVAILABILITY STATEMENT

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

9.0 ACKNOWLEDGEMENT

The support provided by Malaysian Ministry of Higher Education and Universiti Malaysia Pahang in the form of a research grant for this study is highly appreciated.

10.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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