

Demarcation Study on Reclaimed Asphalt Pavement Contents in Recycled Hot Mix Asphalt Mixtures for Wearing Course in Asphalt Pavements

Bereket Samuel Zemedkun^{a,1}, Osamu Takahashi^{a,2}

^a Department of Civil and Environmental Engineering, Nagaoka University of Technology, Japan.
E-mail: ¹bereketsamue18@gmail.com; ²roadman@vos.nagaokaut.ac.jp

Abstract— The present study evaluated reclaimed asphalt (RAP) containing hot mix asphalt (HMA) mixtures performance, to assess the effect of 5% RAP alteration on the marginal change in performance between 20%, 25%, and 30%. Then, the results from assessment were used to classify the RAP contents in HMA mixtures as low, moderate, and high by comparing the performance of the mixtures. The HMA specimen's preparation followed the Marshall mix design procedure with a 12.5 mm nominal maximum aggregate size (NMAS). Rutting and stripping resistance were selected as the primary performance. The wheel tracking (WTT) and indirect tension strength (IDT) tests were done to assess rutting and stripping performance, respectively. The WTT results indicated that a mixture with 30% RAP performed well in rutting resistance, followed by 25% and 20% RAP mixtures. The results of the tensile strength ratio (TSR) from the IDT showed that mixtures with 0% RAP and 20% RAP were susceptible to stripping. On the other hand, mixture with the 25% RAP had good stripping resistance. From the test results, it was observed that RAP contents up to 20 % had similar performance as 0% RAP mixture. Mixtures containing 25% RAP and 30% RAP found better on rutting and stripping resistance. Based on the experiment results, the 5% variation in RAP content affects the performance of the mixtures significantly. The present study concluded that RAP content could be tiered as follows; up to 20 % is low content, above 20% to 30% as moderate, and above 30% is high content.

Keywords— reclaimed asphalt; marginal change; rutting resistance; moisture damage.

I. INTRODUCTION.

From the 1970's year by year, the use of reclaimed asphalt pavement (RAP) is an indispensable part of pavement technology due to its feasibility in terms of environmental, economic, and technical benefits. At the same time, industrial waste products such as coal ash and blast furnace slag usage in road construction were supplements with RAP [1], [2]. Most issues related to RAP among researchers are its characterization, variability, durability, production methods, and handling system. RAP characterization is one of the mechanisms to study its impact on the performance of HMA mixes. Investigation of RAP is a challenging task due to its nature of variability, undocumented source of its origin, and contamination with foreign materials. The present study evaluated recycled HMA mixtures containing various percentages of RAP. Evaluation tests were conducted with a five percent RAP increment interval to assess the marginal difference in mixture performance. Then, the results obtained from performance tests were used to categorize RAP proportion in the recycled HMA as low, moderate, and high contents.

The following part of the literature review deals with the impacts of RAP inclusion on rutting performance and moisture susceptibility. Additionally, the list of literature with the contradictory categorization of RAP contents was mentioned. Numerous studies have addressed RAP addition in HMA mixtures. An inclusion of RAP in asphalt mixes changes the physical, mechanical, and chemical properties of the final HMA mixes. Based on some researchers' addition of RAP in HMA improves the rutting performance of the mixture. [3]–[5]. By some researchers, it was mentioned that increased rutting performance is due to stiffness by aged asphalt.

For moisture damage, some researchers indicated that adding RAP materials enhanced moisture resistance or exhibits as good as virgin HMA. This is because the aggregates from RAP are already enclosed and protected with old binder [6]–[10]. On the other hand, some studies mentioned adding RAP materials might significantly decrease the moisture resistance of a mixture [11]. Another researcher indicated that the inclusion of a certain amount of RAP in mixtures has an insignificant change in mixes performance [12].

It is challenging to have consent among researchers on predicting the effect of RAP in a performance of mixes with certainty. This is due to various research approaches followed and a difference in materials sources used for experimental work. Additionally, even if many kinds of research were done on RAP related issues; the confusion was happening throughout stakeholders on how to come up with a common base to level the RAP percentage as low, moderate, and high content. To clarify this hypothesis, the followings are some works of literature with subjective classification.

The national asphalt specification document released by Australian Asphalt Pavement Association (AAPA) proposed three levels of RAP contents, i.e. (0–15%), (15–30%), and greater than 30%, as a reference to use or not to use softening agents [13]. American Association of State Highway Transportation Officials (AASHTO) M-323 used three tiers to classify the RAP contents in recycled HMA mixtures; up to 15% as low contents, (16-25%) as intermediate contents, and more than 25% as high content [14]. The tiered approach used to decide on the irrelevance of change of asphalt grade for low contents, to change one grade softer asphalt for intermediate contents, and to use a blending chart for high contents.

The classification by AASHTO and AAPA has similarities. Despite their similarity, in terms of their functionality, both are different. A study on practical usage of recycled asphalt pavement within asphalt mixtures defined 25% or more RAP content as high quantity based on the total weight of mixture [15]. Another researcher stated that percentages of RAP content in a mix greater than 15% could be categorized under high content [16]. Study on a high content of reclaimed asphalt pavement, a high modulus asphalt concrete performance mentioned no more than 30% as less content of RAP and 40% or more as the high content [17].

Research on maximizing the re-use of reclaimed asphalt pavement-output two mentioned over 30% as very high RAP mixtures. The same document was also mentioned more than 10% by mass is a higher percentage of RAP [18]. A study on RAP materials usage in the Superpave design procedure described relatively low levels of RAP, below 15% or 20% in a mix [19].

Journals papers and agency documents related to the RAP, such as the above pieces of literature, mentioned different percentages of RAP proportion as low, moderate, or high contents. However, most of the documents were not explicitly mentioned their base to classify. Therefore, to have improvements toward efficient usage of RAP materials consents between stakeholders on how to classify this material is a necessity. For classification purposes, the following approaches may be used as a base, chemical and physical properties of RAP, production mechanisms, treatments used, and inclusion of RAP on final mixtures properties. In the current study, the performance of the final mixture was chosen as one approach to categorize RAP contents as low, moderate, and high content. Hence, special attention was given for RAP contents commonly have overlapping categories, namely twenty percent, twenty-five percent, and thirty percent of RAP contents.

II. MATERIALS AND METHODS

In this section, the materials used for research work and mix design procedure are discussed.

A. Materials

1) *RAP material*: The aggregate was found from RAP producing company, which chunk slab processed to have NMAS of 12.5mm. The processed aggregate gradation of RAP materials is shown in Table 3.

2) *Old asphalt from RAP*: The asphalt binder was extracted by the solvent extraction method. The physical characteristics of the asphalt binder from reclaimed pavement were shown in Table 1.

TABLE I
PHYSICAL PROPERTIES OF OLD ASPHALT

Penetration 1/10mm	15
Softening point °C	65.5
Spec. gravity	1.03
Asphalt content (%)	5.75

3) *New aggregate*: The source of new aggregates is a crushed natural aggregate from Japan. The physical and mechanical properties were pre-determined by following appropriate testing procedures before mix design. The gradation of virgin aggregate is shown in Table 3.

4) *New asphalt*: The asphalt used in the study was 60/80 penetration grade, supplied by a road construction company in Japan. The new asphalt physical properties were shown in Table 2.

TABLE II
PHYSICAL PROPERTIES OF NEW ASPHALT

Penetration 1/10mm	71
Softening point °C	46.5
Spec. gravity	1.034
Flashing point °C	348

B. Mix Design of Mixtures

The design method of the study followed the Marshall mix design procedure, as stipulated in Asphalt Institute 1994 specifications. Furthermore, the proportionating of RAP constitutes, and virgin materials were done following the Asphalt Institute 1986 manual. For the study, mix designs with RAP were done, assuming 100% reactivation of asphalt from RAP. Previous researchers demonstrated this assumption that significant blending occurs between the new asphalt and asphalt from RAP [20]. Combined grading of aggregates: RAP aggregates were fractionated into fine (0-5mm) and coarse (5-13mm). The combined gradation of new aggregates and RAP were presented in Table. 4. The gradations for all mixtures were within the specified limit of Asphalt Institute. The mid-range of the specification used as the target gradation by assuming that the gradation might exhibit better performance [21].

C. Laboratory Tests

For the study, four different mixtures prepared based on the Marshall mix design method. Additionally, two performance tests, namely, the indirect tensile (IDT) strength

test for evaluating moisture-induced damage and the wheel tracking test (WTT) for assessing the rutting performance, were conducted. The HMA mixtures were 0% RAP (new materials mix) as a controlled mixture, 20%, 25%, and 30% RAP containing mixtures as study mixtures were prepared.

1) *Marshall test procedure:* Marshall mixtures design procedures in general consist of; aggregate and asphalt selection, specimen preparation, volumetric parameter calculation, stability and flow determination, finally optimum asphalt content selection. The combined grading for the wearing course mixture with NMAS of 12.5mm pre-determined and all mixtures types' gradation was in the limit as per Asphalt Institute specification for dense-graded mixtures. For 0% RAP HMA mixtures, specimens were prepared with different asphalt content from (4-6%) with a 0.5% interval. And for 20%, 25%, and 30% RAP containing HMA mixtures, specimens were prepared for five distinct binder contents from (4.5-6.5%) with an interval of 0.5% to estimate the optimum binder content for each mixture. All samples were compacted at 75 blows by the Marshall hammer on both sides. Then volumetric parameters were calculated before testing the Marshall stability test. The stability value was interpreted to determine the relative stability of mixture types in the study. The Marshall stability test was conducted at 60°C with a constant deformation rate of 50mm/min. The detailed procedure for conducting the test can be found elsewhere.

2) *Moisture susceptibility test:* moisture damage is the deterioration of asphalt mixtures important performance properties due to the presence of water inside the mass of mixtures. One of the moisture susceptibility tests is an indirect tensile strength test. The moisture damage resistance was conducted by following the Modified Lottman Test (AASHTO T283) procedure. The test started by preparing six specimens per mixture types, the specimens were divided into two sets; 3 specimens for unconditioned test and three specimens for the conditioned test. The unconditioned set of specimens was soaked in water kept at 25°C for 2 hours before conducting the test. On the other hand, conditioned specimens were saturated in water according to the procedure. After achieving the required saturation, the specimens were conditioned in 60°C heated water for a day.

Before the test was conducted, the specimens once more soaked in water, the water temperature kept 25°C, for 2

hours. The indirect tension strength for each sample can be calculated by using equation 1.

$$ITS = \frac{2P}{\pi \times h \times d} \quad (1)$$

Where:

ITS= the indirect tensile strength in (MPa)

P= Peak load at failure in N

h= specimen thickness in mm

d= specimen diameter in mm)



Fig. 1 IDT testing setup

The tension strength ratio (TSR) was used as an indicator for damages caused by moisture on mixtures, by providing the retained indirect tensile strength of specimens after conditioning the samples as per the AASTHO T-283 procedure. The TSR of specimens was calculated using equation 2:

$$TSR = \frac{ITS_{conditioned}}{ITS_{unconditioned}} \quad (2)$$

Where $ITS_{conditioned}$ = conditioned specimen indirect tensile strength. $ITS_{unconditioned}$ = unconditioned specimen indirect tension strength

The TSR value calculated by the equation can show the susceptibility of mixtures for moisture damage. The higher TSR value indicates mixtures with which are resistant to moisture damage. In general, a value above 0.70 is the most likely acceptable limit.

3) *Permanent deformation test:* Rutting is one of a common type of distress in which permanent deformation happens on pavement structure. Wheel tracking test (WTT) is the typical type of test used to assess the rutting performance of HMA.

TABLE III
GRADING OF AGGREGATE FROM RAP AND NEW AGGREGATE

Sieve size(mm)	12.5	9.5	4.75	2.36	0.6	0.3	0.15	0.075
RAP aggregate passed (%)	100	99.5	93.8	75.5	44.6	27.4	12.9	8.8
New aggregate passed (%)	100	97.5	62.5	42.5	24	15.5	11	6

TABLE IV
COMBINED AGGREGATE GRADATION

Sieve size (mm)	19	12.5	4.75	2.36	0.3	0.075
Specification range	100	100 - 94	74 - 44	58 - 28	21 - 5	10 - 2
0 % RAP	100	98.8	60	44.3	15.1	6.1
20 % RAP	100	99.9	63.6	42.7	14.1	4.4
25% RAP	100	94	56.5	42.7	13.9	6.5
30% RAP	100	94	57.3	42.2	13.7	6.4

Fig. 2 shows the WTT setup during testing. In Japan, dynamic stability (DS) is used as an indicator in evaluating the rutting performance



Fig. 2 Wheel tracking testing setup

$$DS = 1.5x \frac{42x15}{d_{60}-d_{45}} \quad (3)$$

Where:

D_{60} and d_{45} rutting depth at 60th and 45th minutes respectively in mm

The WTT conducted at a temperature of 60°C, the wheel speed of 42 passes/min, and loaded 686N. Dynamic stability expressed in cycles per millimeter was used as an indicator of the rutting performance of the mixture in the Japanese standard.

III. RESULT AND DISCUSSION

A. Marshall Stability Test

The mechanical (stability and flow) and volumetric properties of mixes were collected from the test and presented in Table 5. From the Marshall mix design, the air voids of all mixtures in the study were within the limit of the design specification. The void filled with asphalt (VFA) and voids in mineral aggregate (VMA) of RAP added mixtures were lesser when compared to the 0% RAP mixtures.

Despite lesser values of VMA and VFA of the RAP containing mixtures, the stability which indicates the mixture's resistance to deformation, the RAP containing mixtures performed well compared to 0% RAP mixture. This may be due to the stiffness of mixtures from hardened asphalt from RAP. Moreover, even if the mix contains more fines than a controlled mix, the Marshall Stability test showed that mixtures with RAP were stable for deformation under the applied force. The optimum asphalt contents for all mixtures were selected, considering the achieved air void, maximum density, and maximum stability. The selected OAC was reasonable for conducting the two performance tests, i.e., the indirect tensile strength and wheel tracking tests.

Another Marshall mix design was also conducted by using only the fine portion of RAP aggregates, i.e., 0 mm- 4.75 mm, these mixtures were used to compare the Marshall mix design parameters between RAP containing mixtures. From fine RAP replaced Marshall test results, the density of mixtures improved at 25% RAP comparing to the 20% and 30% RAP, the results were displayed in Fig 3. On the other hand, the result from the rice test, which determines the theoretical maximum specific gravity (G_{mm}) of mixtures, 20% RAP as has less value, the result was shown in Fig. 4. The values of void in VMA for 20% RAP were higher compared to 25% and 30% RAP mixtures; the results were shown in Fig.5. The optimum asphalt content for the fine RAP replaced mixtures was determined as 6.5%. At OAC, 25% of RAP mixture has a relatively small air void; it is shown in Fig. 6. On the other hand, for all the three RAP contents, VFA showed a similar tendency to its values, the results were shown in Fig. 7. The stability value of 20% RAP was lesser compared to 25% and 30% mixtures; the results were shown in Fig. 8. In general, replacing fine portion HMA aggregates with fine RAP aggregates in mixtures affects the Marshall mix design parameters, and it has a complex trend to predict its effects.

TABLE V
MARSHALL MIX DESIGN RESULTS

Type of Mixture	Air voids (%)	VMA (%)	VFA (%)	G_{mb}	Stability	Flow	OAC (%)	NB(gram)	OB(gram)
0%	4	14.84	73	2.419	10.34	29	5.61	67.5	0
20%	4.7	11.2	57.2	2.333	12.8	38	6	53.6	12.7
25%	4.5	11.2	59.2	2.337	12.8	40	6	50.6	16
30%	4.1	11.1	61.7	2.347	12.5	38	6	47.2	18.8

G_{mb} - Mixture bulk specific gravity, OAC- optimum asphalt content, NB-new binder added, OB -old binder added

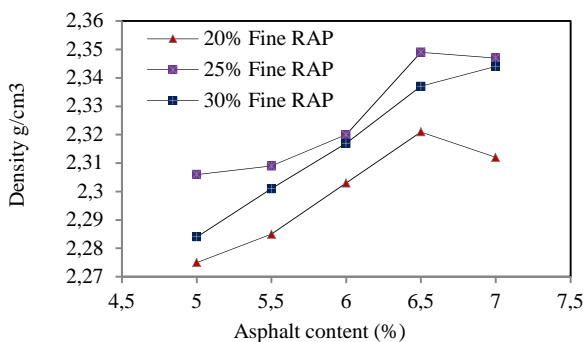


Fig.3 density versus asphalt content

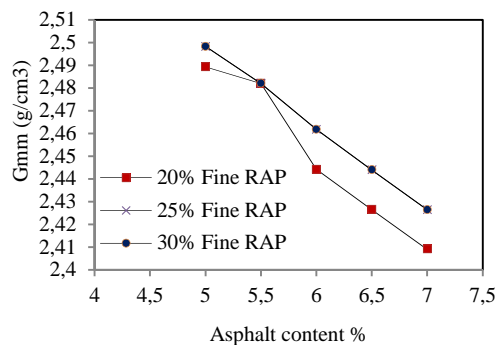


Fig. 4 Theoretical maximum specific gravity versus asphalt

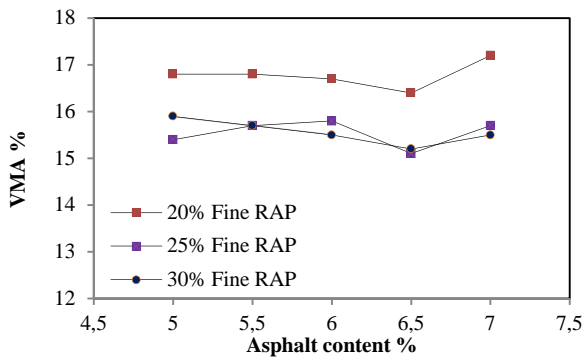


Fig. 5 Void in mineral aggregates versus asphalt content

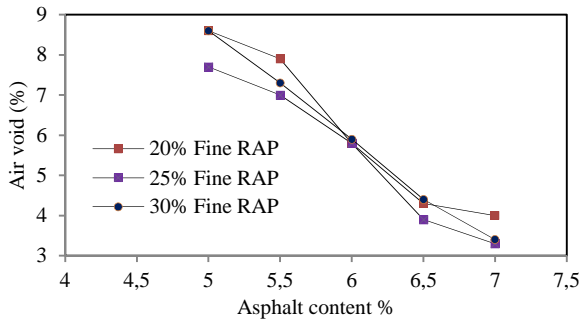


Fig. 6 Air voids versus Asphalt content

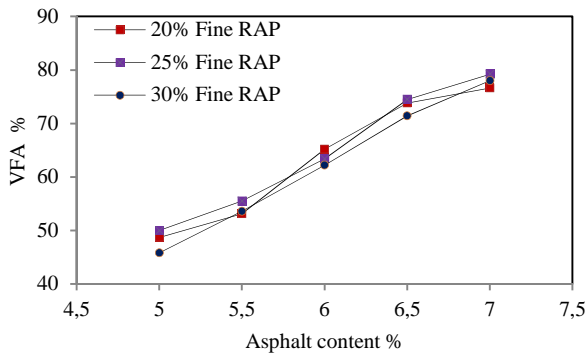


Fig. 7 Voids filled with asphalt versus asphalt content

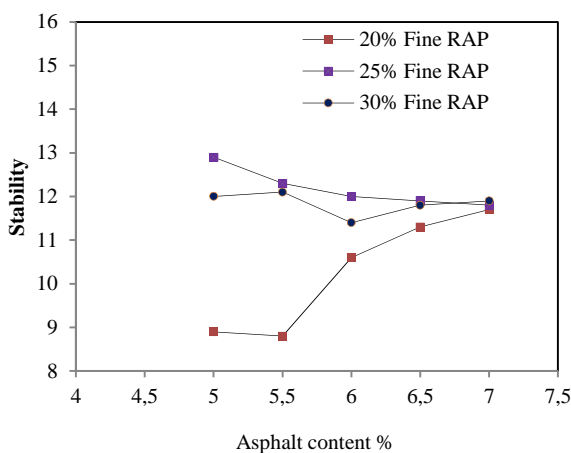


Fig. 8 Stability versus asphalt content

B. Indirect tension strength test results

Results from the IDT test, for specimens which were conditioned and unconditioned sets of all mixture types, the result were illustrated in Fig. 9.

From Fig. 9, the 0% RAP mixture and 20% of RAP mixtures have insignificant differences in the IDT values. Previous findings also implied that the inclusion of less than 20% of RAP material had a very limited influence on mixture stiffness and indirect tensile strength characteristics [22]. On the other hand, adding 30% of RAP showed significant improvement of IDT on unconditioned specimens. In general, the IDT of the unconditioned specimens increased as the RAP content increased; this might happen mainly due to the stiffness of asphalt from the RAP. For the conditioned specimens, it has been seen that the IDT values increased up until 25% RAP inclusion, and it declined slightly at 30% RAP mixture.

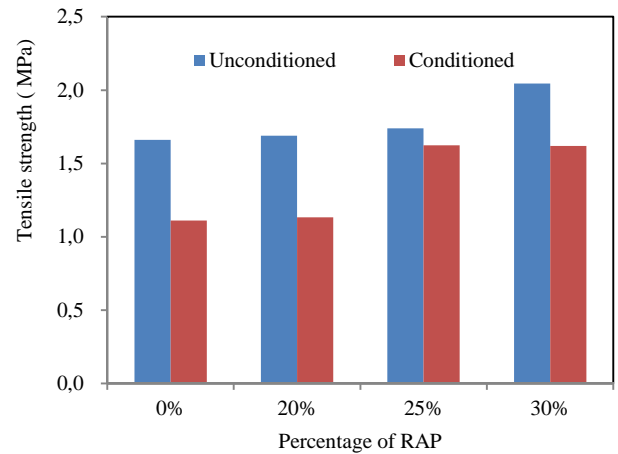


Fig. 9 Indirect tension test results

Fig. 10 presented the relationship between the tensile strength ratio and RAP content in the mixtures. The test results showed that the tensile strength ratio of 0% (controlled) and 20% RAP mixtures exhibit a similar tendency in moisture susceptibility.

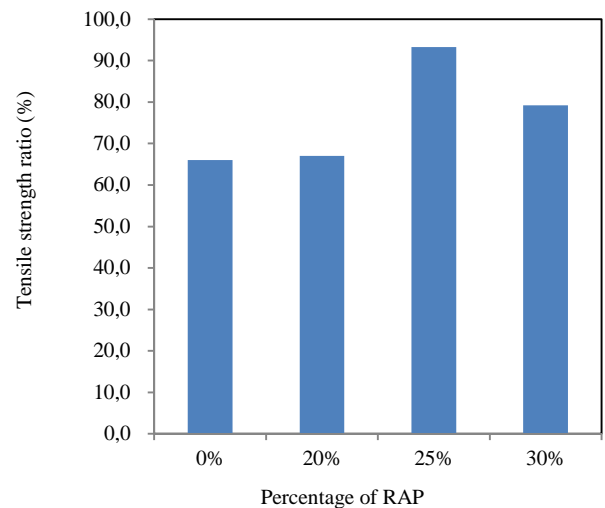


Fig. 10 Tensile strength ratio results

On the other hand, the addition of 25% RAP improved the resistance to damage due to moisture present in the HMA mixture. Here it was seen that 5% RAP increment, i.e., from 20% to 25%, increased the TSR value of about 54%. On the

other hand, increasing RAP from 25% to 30% in mixtures declined the TSR value by 15%. A certain amount of adding RAP enhances the moisture damage resistance of mixtures.

C. Wheel tracking test results

From the wheel tracking test, the rutting depth versus wheel cycle is illustrated in Fig. 11. It is seen that as the RAP content increased in the mixtures, the rutting depth of mixtures decreased.

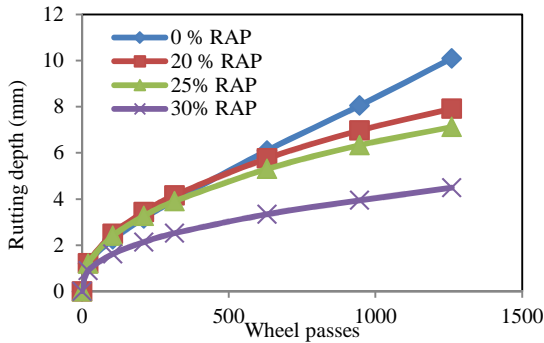


Fig.11 Rutting depth versus wheel cycles

In other words, mixture with 0% RAP had a higher rutting depth comparing to the 30% RAP mixtures. The test results show that the aging of asphalt binders in the mixtures influences the rutting resistance of pavements. The dynamic stability of mixtures from the WTT was also collected and presented in Fig. 12. It has been seen that adding RAP on HMA, about 20%, 25%, and 30% RAP increased the DS values of mixtures by 107%, 121%, and 248%, respectively.

From Fig. 12 RAP increment by 5%, i.e., from 20% to 25%, had an insignificant change in DS values. Whereas adding more 5% RAP on 25% RAP mixture improved the DS value by about 57%. The DS value of 0% RAP found lesser compare to the RAP containing mixtures. On the other hand, mixture with 30% RAP achieved higher resistivity in rutting distress. The lower DS value of 0% RAP may be due to the instability of virgin asphalt at the testing temperatures.

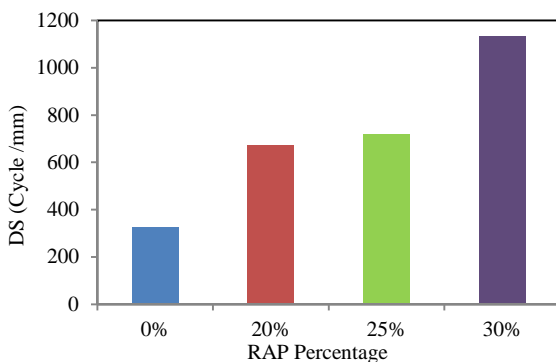


Fig.12 Dynamic stability values

From the test result, it can be interpreted that adding more RAP to the mixture results in a higher value of the dynamic stability of the mixture. As a result, the more rutting resisting mixtures would be achieved. Generally, previous studies found that the stiffness and resistance to permanent deformation of the mixtures improved with increasing RAP

content. On the other hand, increasing stiffness might decrease fatigue life. The stiffness of a mix can be affected by the aggregate and gradation, but the major factor is the stiffness of the binder in the recycled mixture [23].

IV. CONCLUSION

The findings of the current study are summarized as follows; The stability of mixtures increased when RAP was added to the mixtures. This means, as the percentage of RAP increased by 20%, 25%, and 30%, the Marshall stability value increased by about 23%. On the other hand, mixes containing RAP exhibit similar performance. Therefore, it can be concluded that 5% of RAP content change between RAP containing mixes was insignificant on stability value. The results from the IDT strength test showed that the TSR values of 0% and 20% of RAP had negligible differences. It was also seen that when RAP content increased from 25% to 30% in the mixture, the TSR value decreased slightly. The HMA mixture with 25% RAP had the maximum TSR value. The results showed that the variability in the performance of recycled HMA mixtures for moisture damages was considerable for 5% RAP content alteration. Rutting resistance evaluation by wheel tracking test indicated that, when 20%, 25%, and 30% RAP was added in the HMA mixtures, the DS value increased by 107%, 121%, and 248% respectively. In general, RAP inclusion in mixtures improved the deformation resistance of mixes. The 5% RAP content alteration highly affects the rutting resistance. From the results of the IDT test and WTT, it was found that the 5% RAP content difference in the RAP containing mixtures had considerable effects on the performance of recycled HMA mixtures. Notably, the DS value from WTT was affected significantly. Based on the executed performance assessment of the mixes, this study categorizes RAP contents as follow, up to 20% as low, above 20% to 30% as intermediate, and 30% and above as high content is the feasible way to classify the RAP content based on final mixtures performance. Finally, the authors recommend further study should be undertaken in more inclusive ways by asphalt pavement associations and practitioners to have uniformity on the classification of RAP contents.

ACKNOWLEDGMENT

Japan Society for Promotion of Science, Grant-in-Aid for Scientific research (C) provided financial support for the research work, 15K06162, 2015-2017s.

REFERENCES

- [1] Mroueh, U. M. and Wahlström, M. (2002). By-products and recycled materials in earth construction in Finland-an assessment of applicability, Resources, Conservation and Recycling, 35,117-129.
- [2] Abd. R, Aminaton. M, and Ahmad .M Morphological and Strength Properties of Tanjung Bin Coal Ash Mixtures for applied in Geotechnical Engineering Work, (International Journal on Advanced science, Engineering, and Information Technology. 7 ,no 2, 2017).
- [3] McDaniel, R., Soleymani, H., Anderson, RM., Turner, P & Peterson, R., Recommended use of reclaimed asphalt pavement in the Superpave mix design method, NCHRP web document 30, (Transportation Research Board, Washington, DC, 2000).
- [4] AL-Zubaidi, I., and S.I Sarsam, Resistance to deformation under repeated loading of aged and recycled sustainable pavement, (Am.J. Civil Structural Eng.1, 2014). PP 4-39.

- [5] Silva HM, Oliveira JR, Jesus CM. Are totally recycled hot mix asphalt a sustainable alternative for road paving? Resource Conservation Recycling 2012).
- [6] Al-Qadi I.L., Elseifi, M., and Carpenter, S.H., Reclaimed Asphalt Pavement- A Literature Review, Research Report FHWA, (Illinois Center for Transportation, Urbana, 2007).
- [7] Celauro, C., C. Bernado and B. Gabriele, Production of innovative, recycled and high-performance asphalt for road pavements, Resource conservation v-54, issue 6, Palermo (2010), pp 655-662.
- [8] Tran NH, Taylor A, Willis R. Effect of rejuvenator on performance properties of HMA mixtures with high RAP and RAS contents. Auburn, AL: National Center for Asphalt Technology; 2012).
- [9] Mogawer WS, Bennert T, Daniel JS, Bonaquist R, Austerman A, Booshehrian A. Performance characteristics of plant produced high RAP mixtures. Transportation Pooled Fund Programm 2012;13)
- [10] Karlsson R, Isacsson U. Material-related aspects of asphalt recycling-state-of-the-art. Journal of Mater Civil Eng 2006)
- [11] Huang, B., Shu, X. and Vukosavljevic, D. Laboratory Investigation of Cracking Resistance of Hot-Mix Asphalt Field Mixtures Containing Screened Reclaimed Asphalt Pavement. Journal of Materials in Civil Engineering, 2010).
- [12] Paul, H.R. Evaluation of Recycled Projects for Performance. Proceedings of the Association of Asphalt Paving Technologists, 1996).
- [13] Erik Denneman, Melissa Dias, Shannon Malone, Young Choi, Elizabeth Woodall, Robert Urquhart, Maximising the Re-use of Reclaimed Asphalt Pavement: Binder Blend Characterization (Austroads Ltd, Sydney, 2013), pp5.
- [14] AASHTO M 323 Standard Specification for Superpave Volumetric Mix Design, (American Association of State Highway and Transportation Officials, 2007).
- [15] Federal Highway Authority (FHWA). Asphalt Pavement Recycling with Reclaimed Asphalt Pavement. <http://www.fhwa.dot.gov/pavement/recycling/RAP>.
- [16] Park T.W., Kim S.U., Park N.W. and Kim K. W, Mixing Method Renovation for Reducing Stiffness of Recycled Asphalt Mixture, (Proceedings of the Fifth International Conference on Maintenance and Rehabilitation of Pavement, Park city, 2007).
- [17] Lei Geng, Y. G, research on high modulus asphalt concrete performance with high content of reclaimed asphalt pavement, (Proc. of the Eighth Intl. Conf. on Maintenance and Rehabilitation of Pavements Singapore, 2016).
- [18] Dr Jeffrey Lee, Dr Erik Denneman & Dr Young Choi, Maximising the re-use of reclaimed asphalt pavement: outcomes of year two: RAP mix design (Austroads Ltd, Sydney, 2015).
- [19] McDaniel, R, Soleymani, H, Anderson, RM, Turner, P & Peterson, R, Recommended use of reclaimed asphalt pavement in the Superpave mix design method, NCHRP web document 30, (Transportation Research Board, Washington DC, 2000).
- [20] McDaniel, R, Shah, A, Huber, GA & Copeland, A, Effects of reclaimed asphalt pavement content and virgin binder grade on properties of plant produced mixtures', (Taylor & Francis, Virginia, 2012), pp. 161-82.
- [21] Arief, S, Latif B , Agus Taufik, M, Modelling Effect of Aggregate Gradation and Bitumen Content on Marshall Properties of Asphalt Concrete, (International Journal on Advanced science, Engineering and Information Technology, Vol. 7 ,no 2, 2017).
- [22] Imad Al-Qadi, Qazi, Aurangzeb, Samuel H, Carpenter, William J, pine , James Trapanier, Impact of high RAP content on structural and performance properties of asphalt mixtures (Illinois Center for Transportation, Urbana, 2012).
- [23] Rebbechi J. and Green M., Going green: innovations in recycling asphalt, AAPA Pavements Industry Conference, Surfers Paradise, (Australian Asphalt Pavement Association, Queensland, 2005).