3rd Conference on Sustainability in Civil Engineering (CSCE'21)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

FRACTURE RESISTANCE OF WARM MIX ASPHALT MODIFIED WITH RECLAIMED ASPHALT PAVEMENT

[a] Saad Tayyab*, [b]Arshad Hussain, [c] Fazal Haq, [d] Afaq Khattak,

a: School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST) Islamabad,
b: School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST) Islamabad, drarshad@nit.nust.edu.pk
c: National Institute of Transportation (NIT), Military College of Engineering NUST Risalpur, fhaq.tn15@nit.nust.edu.pk
d: Department of Civil Engineering, International Islamic University Islamabad (IIUI), afaq.khattak@iiui.edu.pk

* Corresponding author: Email ID: saadtayyab@nit.nust.edu.pk

Abstract- The two-key requirement of asphalt pavement are sustainability and durability. Sustainability of pavement includes replacing percentages of virgin aggregate with Reclaimed Asphalt Pavement (RAP) with the help of Warm Mix Asphalt (WMA) additives, however durability involves performance parameters like fracture resistance of asphalt. The addition of RAP content increases the production temperature of asphalt and may degrade its performance. Therefore, researchers recommend different percentages of WMA additives to lower mixing and compacting temperature of asphaltic pavement. The current research work has been carried out to optimize the percentages of RAP and Sasobit that have best fracture resistance as compared to Hot Mix Asphalt (HMA) and thus allow us to minimize the construction cost of pavement structure. Varying percentages of RAP (0%, 20%, 40% and 60%) and Sasobit (0%, 2%, 4% and 6%) as WMA additive were used. Fracture resistance of asphalt was evaluated by Semi Circular Bending (SCB) test in the laboratory. The resistance of WMA to fracture was improved with the increase in percentages of RAP and Sasobit up to certain limit, whereas the addition of RAP to HMA showed a decrease in fracture resistance due to the stiffer nature of aged binder in RAP.

Keywords- Fracture Resistance, Sasobit, Warm Mix Asphalt (WMA) and Reclaimed Asphalt Pavement (RAP),

1 Introduction

The emerging trend on conserving natural materials over the last decades and reducing the consumption of fuel in road construction gaining popularity throughout the world. Utilizing WMA additives and RAP in combination may have significant contribution to achieve durable, sustainable and green pavement structures [1]. WMA additives reduce the compacting and mixing temperature of asphalt mix by 20-55ºC than the traditional HMA. The compaction and mixing of traditional HMA are 145-150ºC and 150-155ºC respectively. Owing to the reduction in mixing and compacting temperature with the help of WMA additives will result in numerous benefits including longer service life, fuel saving, decreases in greenhouse gases and ease in mixing and compaction [2]. Another recent research by World Bank on temperature reduction concluded that every 10ºC of temperature during asphalt preparation results in decrease of greenhouse gases emission by 1 kg and fuel by 1 liter per ton of asphalt mix [3].

WMA additives are new technology in pavement and initiated in Europe over the last decade and still achieving high interest in the world. WMA additives are broadly classified as; chemical additives, organic additives and foaming based additives. Workability of asphalt mix increases with the addition of these additives and/or decreases the viscosity of asphalt binder using nominal heat. WMA technologies permits the mixing, transporting, and paving practice at considerably reduced temperature. By using these latest technologies, we can produce asphalt mix as much as 100ºF lower than ordinary HMA. Sasobit is an organic WMA additive and used in this study for WMA preparation. It is an artefact of Sasol Wax in South Africa, which is a long-chain hydrocarbon, fine crystalline and formed from gasification of natural gas or coal feed stocks by the process of Fischer-Tropsch (FT) which produce a mix of hydrocarbons with molecular chain lengths of more than C5 to C100 carbon atoms. The chemical formula of Sasobit is C_nH_{2n+2} and registered as number 8002-74-2 by Chemical Abstract Service [4, 5]. For production of WMA, Sasol endorses to add Sasobit at a rate of 0.8% to 3% by mass of bitumen, but not to exceed 4% but numerous researchers have been concluded that addition of Sasobit up to 8% of the binder can improve mechanical properties of asphalt mix.

RAP material is obtained from asphalt pavement structure which may consider incapable of carrying further traffic load, having distresses beyond a certain level or has passed its service lifetime. The partial replacement of RAP in fresh asphalt mixes helps in cost reduction of material, preserving fresh binder and natural aggregate and RAP disposal problem [6]. The virgin asphalt pavement recycling dates back to 1915 [7] but momentous use of RAP in HMA indeed initiated in the mid of 1970s due to excessive prices of asphalt binder as a result of the oil impediment. Many latest researches have been carried out to better use RAP in both WMA and HMA [8-10]. Moreover, historical data as mentioned by West [11] stated that mixes having RAP will have the same or even better performance as compared to virgin HMA, but it will need to be carefully designed and constructed. In typical asphaltic mix design with the addition of RAP rarely crosses the limit of 20% to 25% in addition to hot-in-place recycling (HIPR) or cold-in-place recycling (CIPR), which can make use of 80-100% of RAP. The limited usage of RAP in asphalt pavement is due to the miss management and not correctly separation of different stockpiles of RAP sources. Due to economic crises together with environmental related issues, Departments of Transportation (DOT) in US are being enforced for raising the RAP contents up to 50% in Flexible pavements. The increased percentage of RAP usage has the potential to impact structural performance and durability of the pavements. Researches have concluded that higher RAP contents effect the rutting, fatigue and fracture characteristics of HMA as well as WMA [12].

Singh, Ashish et al. [6] evaluate the WMA mix containing different percentages (0%, 10%, 20%, 30%, and 40%) of RAP and different WMA technologies (2% Sasobit and 0.5% Evotherm) for tensile strength ratio and SCB tests. The virgin bitumen used in this research work was viscosity graded (VG-30) or 60/70 penetration grade. It was concluded from the SCB test results that Sasobit based WMA mix performed better in fracture than Evotherm based WMA. Pirmohammad, Khanpour et al. [13] conducted a comparative study of virgin WMA and crumb rubber modified WMA for fracture strength. In both cases WMA was prepared by using 3% of Sasobit by weight of 60/70 penetration grade binder. The result of fracture test showed that crumb rubber greatly enhances the fracture strength of WMA. Lee, Park et al. [14] and Yeon, Kim et al. [15] compared the resistance to fracture of HMA and WMA. Three different types of WMA additives (Pewo, Evotherm and Sasobit) were utilized in this research works. They concluded from their research works that WMA was better in fracture resistance than HMA irrespective of WMA technologies. As a result, WMA is less susceptible to brittle fracture than HMA. Pirmohammad and Ayatollahi [16] find out that fracture resistance of WMA is similar to HMA and some WMA additives make the mixture stronger than HMA even without any RAP. Yoo, Jeong et al. [17] compared the HMA and WMA mixture for fracture resistance by using 60/80 penetration grade bitumen. Both the mixtures were further modified by different polymers. The results showed that the fracture resistance of unmodified (without any polymers) WMA mixture was higher than the unmodified HMA. While the addition of polymers to HMA adversely affect the fracture resistance.

Mogawer, Austerman et al. [18] conducted a research on WMA with high percentage of RAP to evaluate the fatigue cracking, fracture resistance, reflective cracking, stiffness, moisture damage and rutting. Sonne Warmix was chosen as WMA additive and 1% by weight of base binder (PG58-28) was added to produce WMA mix. Different mixtures of HMA and WMA with 0%, 25% and 40% RAP were prepared for comparison. The results indicated that asphalt mixture's resistance to fracture decreases with the addition of high percentage of RAP and the same trend was observed for the addition of Sonne Warmix. The SCB test results indicated that HMA with 0% RAP performed better in fracture resistance than HMA with 25% and 40% RAP. On the other side, WMA with 25% and 40% RAP performed better in fracture resistance than WMA with 0% RAP. Kim, Mohammad et al. [19] characterized the fracture properties of HMA and WMA on 5 laboratory mixtures and more than 20 field projects by SCB and indirect tension test. Three different percentages of RAP (15%, 20% and 30%) were used. They concluded from the test results that addition of WMA additives does not adversely affected the fracture properties of asphalt mix as compared to HMA mixture at intermediate temperature.

Furthermore, it was observed that the addition of RAP up to 30% improve the fracture resistance of WMA mixture. Thus, the best possible percentages of RAP and Sasobit are 40% and 6% respectively keeping in view the fracture resistance of Asphalt Mix. Thus, WMA technology provide the opportunity of using higher percentages of RAP thus the production temperature of Asphalt will reduce along with better performance and additional environmental benefits.

2 Objective and Scope

To promote the pavement recycling approach and lower temperature by WMA technology in Pakistan. This research has been planned to explore the fracture resistance of asphalt mixes with varying percentages of RAP and Sasobit as WMA additive and to categorize any special attentions that must be met to consume higher RAP content at lower temperature. Test matrix for performance test is shown in Table 1.

Table 2: Test Matrix for Performance Testing

S.no	Gradation	Binder	Percentage of RAP replaced	Sasobit content (% of bitumen)	Fracture Resistance of HMA by SCB test
1	NHA Class B Gradation	ARL 60/70	0	0	3
				2	3
				4	3
				6	3
2			20	0	3
				2	3
				4	3
				6	3
3			40	0	3
				2	3
				4	3
				6	3
4			60	0	3
				2	3
				4	3
				6	3
Total					**48**

3 Research Methodology

3.1 Asphalt Binder.

In the current research study bitumen having penetration grade of 60/70 were utilized as a base binder supplied by Attock Refinery Limited (ARL) Rawalpindi. Selecting 60/70 penetration grade of bitumen is that it is appropriate for colder to moderate range of temperature and typically used in Pakistan. The fundamental properties of the binder after laboratory evaluation are given in Table 2.

3.2 WMA Additive.

Sasobit is used as WMA technology in this research study in the form of prills and was imported from the chemical manufacturing South African company Sasol as shown in Figure 1. The recommended dosage of Sasobit by the manufacturer is 0.8 % to 3% by weight of binder but in this research 0%, 2%, 4% and 6% of Sasobit has been added by weight of OBC. The reason of selecting the percentage of Sasobit beyond the recommended dosage limit is due to their better performance according to past literature. Sasobit can be added either pre-blended to the binder or can be introduced directly to the mix bowl. The technical specifications of Sasobit as per manufacturer data sheet are shown in Table 3.

Table 1-Laboratory Tests Performed on Virgin Bitumen

S No	Test Description	Standard	Results
1	Penetration Test	AASHTO T 94-03	62
2	Flash Point (°C)	AASHTO T 48-89	261
3	Fire Point (°C)	AASHTO T 48-89	282
4	Specific gravity	AASHTO T 228	1.03
5	Softening Point (°C)	AASHTO T 53	48
6	Viscosity Test (Pa.sec)	AASHTO T 316	0.271
7	Ductility Test (cm)	AASHTO T 51	>100

Table 2-Basic Properties of Sasobit

Properties	Test Method	Units	Specification	Typical Values
Congealing Point	ASTM D 938	^{0}C	100 - 110	101
Penetration at 25 ^{0}C	ASTM D 1321	0.1 mm	0 - 2	<1
Penetration at 65 ^{0}C	ASTM D 1321	0.1 mm	0 - 13	11
Brookfield Viscosity at 135 ^{0}C	Sasol 1010	cP	10 - 15	12
Visual Color Compliance	Visual	-	Pass / Fail	Pass

3.3 RAP Material.

To accomplish the objective of this research work, milled RAP material was collected from Islamabad-Lahore Motorway (M-2) and brought to Transportation Laboratory (SCEE, NUST) for replacing natural aggregates and preparation of samples for Marshall Mix Design and fracture resistance. Aged binder content of RAP was determined by ignition method and found to be 3% of the total RAP.

Figure 1: Sasobit Prills

3.4 Virgin Aggregates.

Virgin aggregates were collected from Margalla crush plants in Margalla Hills Taxila Pakistan. These natural aggregates were tested in the laboratory as per standard procedures to check the suitability of aggregates in road construction. The properties of aggregate are presented in Table 4. NHA Class B gradation was used, which was specified by National Highways Authority (NHA) Pakistan in 1998 and widely used for flexible pavement in all over the country. The virgin aggregates were blended with 20%, 40% and 60% RAP, the gradation falls within the upper and lower limits of NHA Class B gradation as presented in Figure 2.

Table 3: Physical Properties of RAP and Virgin Aggregates

Test	Standard		Result	Limits
Flakiness Index	ASTM D 4791		10.20%	≤ 15 %
Elongation Index			3.80%	≤ 15 %
Aggregate Absorption	Fine	ASTM C 128	2.50%	≤ 3 %
	Coarse	ASTM C 127	0.69%	≤ 3 %
Impact Value	BS 812		15%	≤ 30 %
Los Angles Abrasion	ASTM C131		20.60%	≤ 45 %
Specific Gravity	Fine Agg	ASTM C 128	2.62	-
	Coarse Agg	ASTM C127	2.64	-

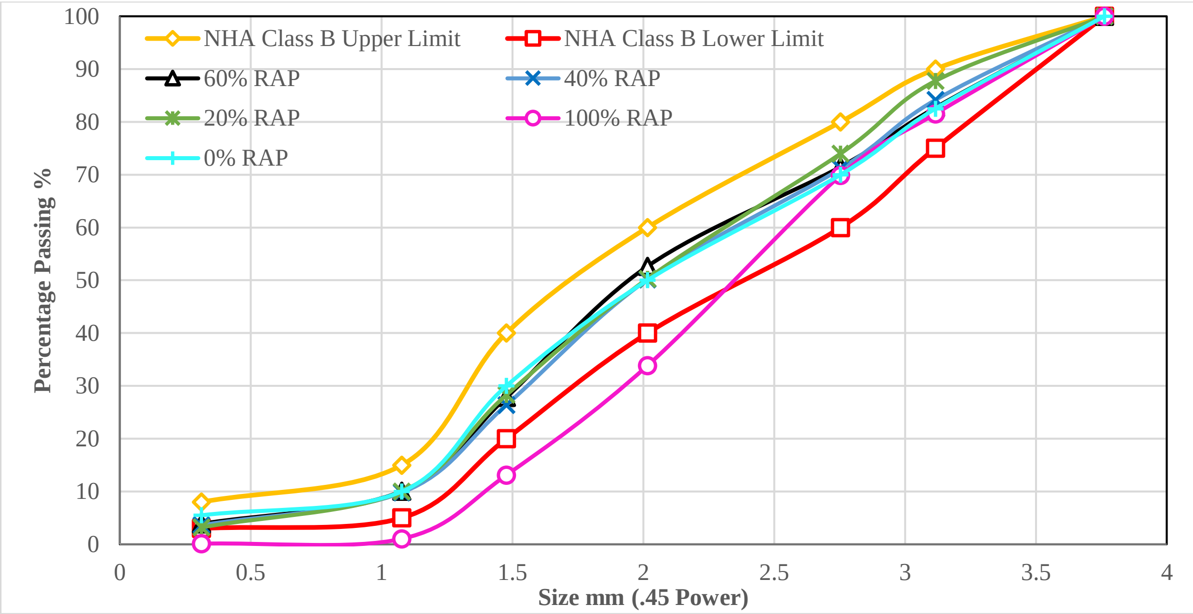

Figure 2: Gradation Curves

4 Laboratory Investigation

4.1 Marshall Mix Design

Marshall Mix Design was carried out for HMA with different percentages of RAP (0%, 20%, 40% and 60%) to determine Optimum Binder Content (OBC) as per ASTM D6927. Total 1200 grams of samples with standard dimensions were prepared by mixing at 160ºC and compacted at 135ºC temperature subjected to 75 number of blows on each side. Three replicates were prepared for each percentage of binder at the increment of 0.5%, ranging from 3.5% - 5.5%. The OBC at 4% air voids was determined to be 4.34%.

4.2 Semi Circular Bending Test

For SCB tests and checking fracture resistance via UTM, specimens were prepared through Superpave mix design procedure. The materials were heated after sieving at 105°C - 110°C until a constant weight achieved. The HMA was mixed and compacted at a temperature of 160±5ºC and 135ºC respectively. However, the WMA was mixed and compacted at a temperature of 125±5ºC and 100ºC respectively. Samples of 150 mm diameter for SCB test were prepared through Superpave Gyratory Compactor by providing 125 gyrations to each sample. Three replicates' samples were prepared for each percentage of change in RAP and Sasobit. Water-cooled masonry sawing machine was used for cutting the sample into our desired dimensions of 150 mm diameter and 57 mm thick circular discs. These circular discs were halved by the said machine. In the end, an artificial crack called notch in the center of the specimen of lengths (25 mm, 32 mm and 38 mm) with a thickness of 3 mm was generated to provide a predefined path for the crack. Figure 3 shows the overall procedure from gyratory sample to a cracked SCB test sample.

Figure 3: Preparation of Semi Circular Shaped SCB Test Samples from Gyratory Samples

SCB test for fracture resistance of asphalt was conducted in Transportation laboratory (SCEE, NUST) through a 25KN capacity (25KN of static loading at various frequencies) of Universal Testing Machine (UTM-25KN). This equipment had an environmental chamber for maintaining the desired test temperature (-16ºC to 60ºC), a hydraulic chamber for pressure application and a central system for data acquisition.

Subsequently, the samples were kept in the environmental chamber of UTM-25KN and permitted to a minimum of two hours to achieve a constant test temperature before testing. Afterward, a sample was kept on three-point bending fixture for testing. The fixture was composed of two roller supports and the span length between the support was 120 mm and lubricating oil was applied on the supports before test to lessen the effect of friction during testing. Then a monotonic load was applied vertically on the top center of semi-circular sample at the rate of 0.5 mm/min and the load continue to increase with deformation and decline gradually with the initiation of crack. The load Vs displacement were recorded from start to the end of test. The test was stopped after the load reaches to 25-50% of peak load.

A widely used parameter for the interpretation of fracture resistance of asphalt mix is critical strain energy release rate which is also known as J-integration. Greater the value of J-integration for a given mix more will be its resistance to fracture. It can be obtained by using "(1)":

$$J\text{-integral} = -\frac{1}{b}\left(\frac{dU}{da}\right) \qquad (1)$$

Where:

- J-integral = release rate of critical strain energy (kJ/m2)
- b = sample thickness (m)
- U = Strain energy to failure (KJ)
- a = depth of notch in (m)
- dU/da = variation of strain energy with the depth of notch (kJ/m).

5 Results and Discussion

While evaluating the resistance of asphalt mix to fracture comparison between control specimens and specimens modified with different percentages of RAP and Sasobit according to ASTM D 8044-16 were considered. Total of 48 samples were prepared at OBC. The samples were tested at 25ºC ((HT+LT)/2+4ºC) by adjusting the temperature of environmental.

The load (KN) and displacement (m) data after each test was plotted on a graph as shown in Figure 4. The information obtained from the graph are: (i) strain energy to failure (U) as per the provided (ii) peak Load and (iii) displacement at peak load. The strain energy to failure was calculated by finding the area under the curve up to peak load. The strain energy to failure was plotted against each notch depth and a best fit line joining these three points was drawn as shown in Figure 5. The slope of which is known as change of strain energy with notch depth $\left(\frac{dU}{da}\right)$. The change of strain energy with notch depth was divided by the average thickness of the specimen to determine critical strain energy release rate (J-integration) as explained in "(1)".

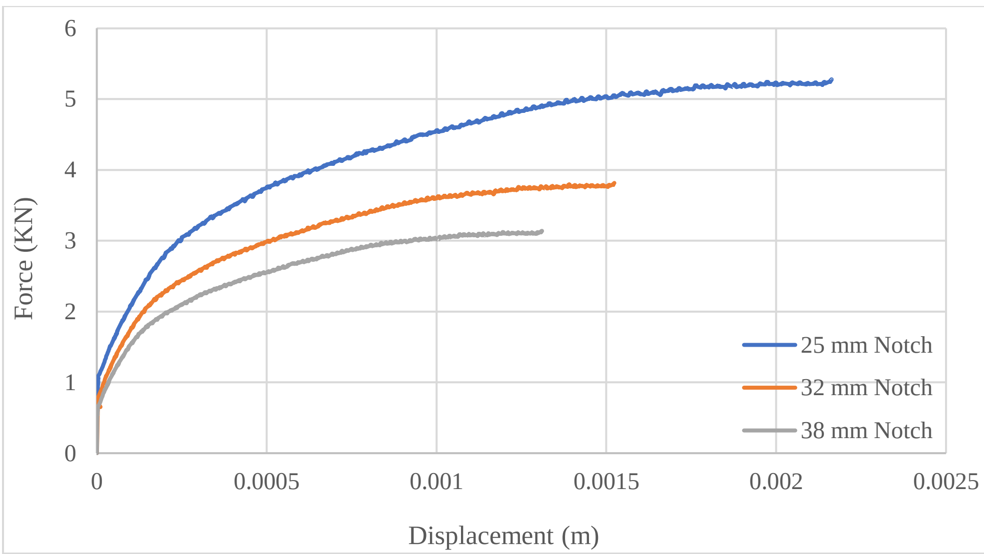

Figure 4: Force vs Displacement Curve

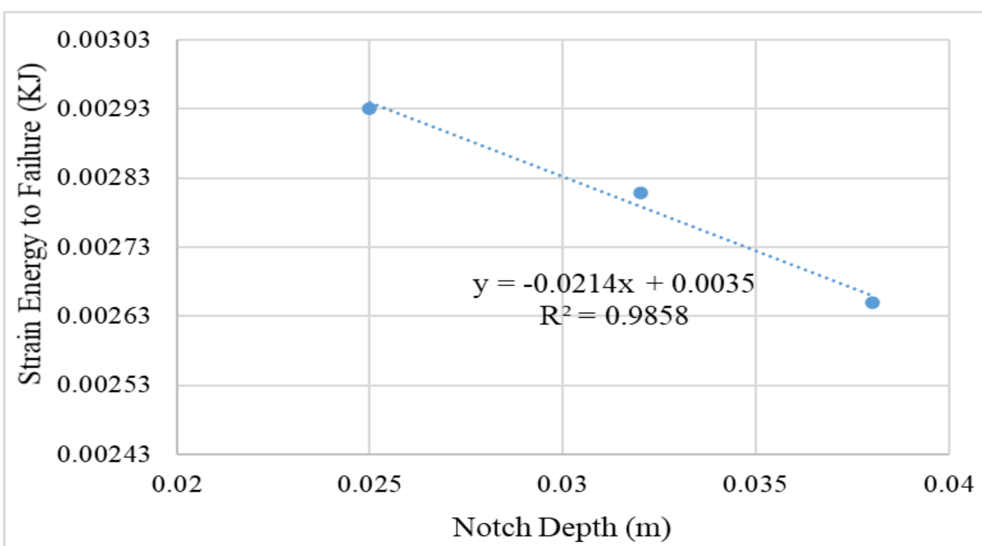

Figure 5: Strain Energy to Failure Vs Notch Depth

5.1 Effect of Mix Properties on Fracture Resistance

Fracture resistance of asphalt mix vary greatly by increasing or decreasing the percentages of RAP and Sasobit. J-integral vs each percentage change of RAP and Sasobit is presented in Figure 6.

It can be extracted from the results that fracture resistance of asphalt mix increases as the Sasobit percentage increases as it acts as asphalt flow improver and results in more flexible matrix. However, the resistance of WMA to fracture increases by adding RAP in the mix up to 20 percent but fracture resistance tends to decrease by increasing the percentage of RAP beyond 20 percent of the mix. However, fracture resistance decreases with the addition of RAP to HMA which is because of stiffness of aged binder in RAP.

Furthermore, fracture resistance of WMA is negatively affected as compared to control samples when the percentage of RAP increases beyond 40% because of higher percentage of aged binder coming from RAP. COV for each percentage of RAP, Sasobit and notch depth are presented in Figure 7. The COV value of every mix falls within the range of acceptable limit, which is 20%.

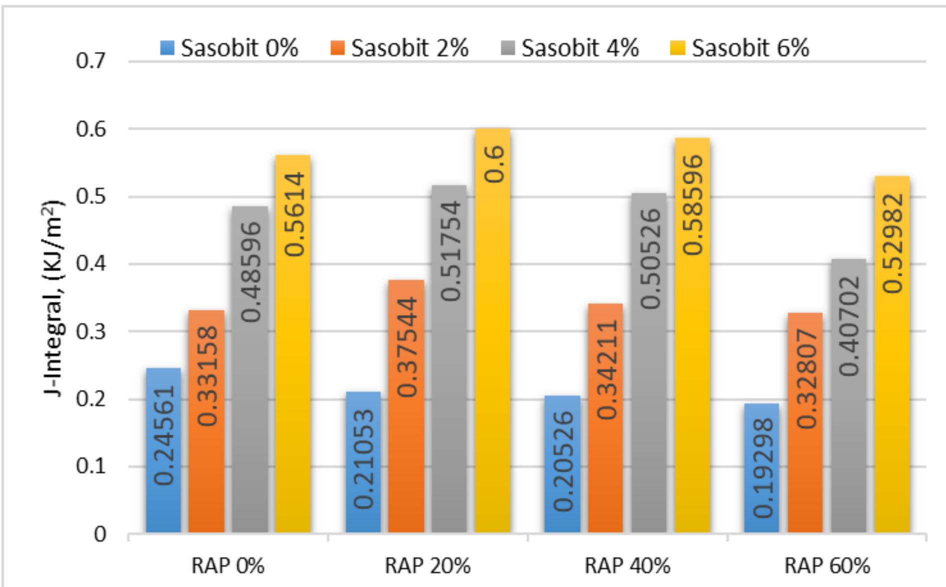

Figure 6: J-Integral for Each Mix

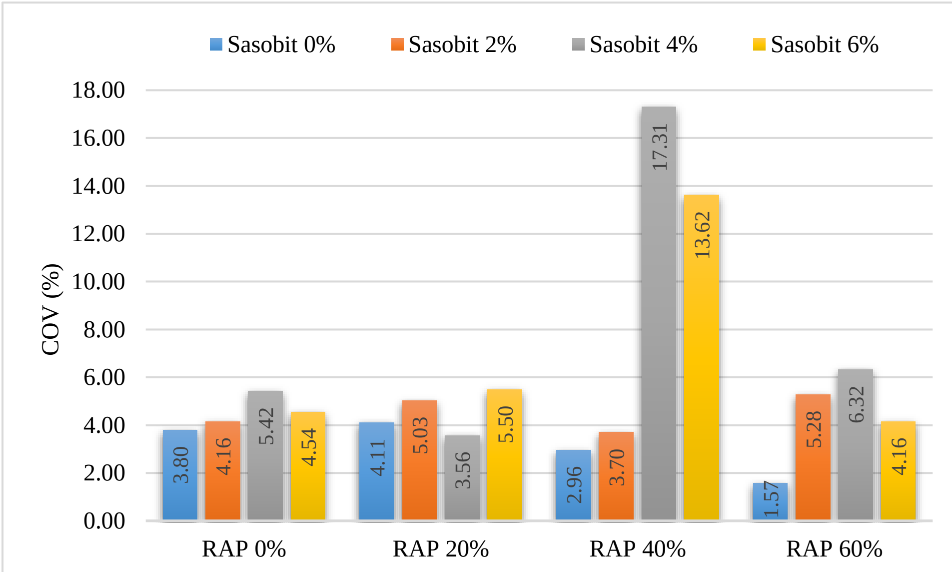

Figure 7: Coefficient of variance

Keeping in view the enhanced properties in term of fracture resistance of Sasobit addition and RAP to the HMA, it should be encouraged in field as the construction cost will reduced to higher extent by addition of recommended percentage of RAP equal 40%. Furthermore, it will provide additional benefits like longer haul distances because of reduced production temperatures and will be helpful in pavement construction in cold areas. It will also reduce the emission of greenhouse gases because of lower mixing temperature at asphalt plant.

6 Conclusion

Based on the Performance tests, the following conclusions can be summarized.:

- Addition of RAP alone to HMA results in decrease of fracture resistance due to the increase in stiffness characteristics with the RAP addition and then increases by the addition of Sasobit as WMA additive.
- The effect of RAP might be compromised in fracture resistance by introducing RAP more than 40%.

Based on the results, it is recommended with confidence that WMA containing RAP content can be designed to meets the required volumetric and desired criteria that can perform equal to or better than virgin HMA.

Acknowledgment

We owe enormous gratitude to Sasol chemicals, a division of Sasol South Africa (Pty) Ltd for providing Sasobit for our research work whenever requested.

References

[1] S. Caro, D. P. Beltrán, A. E. Alvarez, C. J. C. Estakhri, and B. Materials, "Analysis of moisture damage susceptibility of warm mix asphalt (WMA) mixtures based on Dynamic Mechanical Analyzer (DMA) testing and a fracture mechanics model," vol. 35, pp. 460-467, 2012.
[2] J. Zhu, K. Zhang, K. Liu, X. J. C. Shi, and B. Materials, "Performance of hot and warm mix asphalt mixtures enhanced by nano-sized graphene oxide," vol. 217, pp. 273-282, 2019.
[3] M. M. Taher, M. J. J. o. F. Aman, and A. Sciences, "Effects of advera® warm mix additive on the rheological properties of unaged and short term aged asphalt binders," vol. 9, no. 7S, pp. 650-666, 2017.
[4] K.-W. Damm, "Asphalt flow improvers-a new technology for reducing mixing temperature of asphalt concrete mixes with high resistance against permanent deformation," in *PERFORMANCE TESTING AND EVALUATION*

OF BITUMINOUS MATERIALS PTEBM'03. PROCEEDINGS OF THE 6TH INTERNATIONAL RILEM SYMPOSIUM HELD ZURICH, SWITZERLAND, 14-16 APRIL 2003, 2003.

[5] A. Syroezhko, M. Baranov, S. Ivanov, N. J. C. Maidanova, and Chemistry, "Influence of natural additives and those synthesized by the Fischer-Tropsch method on the properties of petroleum bitumen and quality of floated asphalt," vol. 54, no. 1, pp. 26-31, 2011.

[6] D. Singh, P. K. Ashish, S. F. J. C. Chitragar, and B. Materials, "Laboratory performance of recycled asphalt mixes containing wax and chemical based warm mix additives using semi circular bending and tensile strength ratio tests," vol. 158, pp. 1003-1014, 2018.

[7] S. Zhao, B. Huang, X. Shu, M. J. C. Woods, and B. Materials, "Comparative evaluation of warm mix asphalt containing high percentages of reclaimed asphalt pavement," vol. 44, pp. 92-100, 2013.

[8] I. Maha, B. S. Subagio, F. Effendhi, and H. J. J. o. t. E. A. S. f. T. S. Rahman, "Performance of Warm Mix Asphalt Concrete Binder Course (AC-BC) With Reclaimed Asphalt Pavement," vol. 11, pp. 1745-1753, 2015.

[9] T. B. Moghaddam, H. J. C. Baaj, and B. Materials, "The use of rejuvenating agents in production of recycled hot mix asphalt: A systematic review," vol. 114, pp. 805-816, 2016.

[10] A. A. Tayebali, P. N. P. Khosla, H. Malladi, and A. Kusam, "Impact of WMA Technologies on the Use of RAP Mixtures in North Carolina," 2015.

[11] R. West, "Performance studies of asphalt pavements with greater than 25% RAP," in *RAP ETG meeting in December*, 2009, pp. 12-09.

[12] I. L. Al-Qadi, Q. Aurangzeb, S. H. Carpenter, W. J. Pine, and J. Trepanier, "Impact of high RAP contents on structural and performance properties of asphalt mixtures," 0197-9191, 2012.

[13] S. Pirmohammad, M. J. R. M. Khanpour, and P. Design, "Fracture strength of warm mix asphalt concretes modified with crumb rubber subjected to variable temperatures," vol. 21, no. sup1, pp. S57-S75, 2020.

[14] S.-J. Lee, J. Park, J.-P. Hong, and K. W. Kim, "Fracture Resistance of Warm-Mix Asphalt Concretes at Low Temperatures," 2013.

[15] K.-S. Yeon, S. Kim, H.-J. Lee, K. W. J. J. o. T. Kim, and Evaluation, "Low temperature tensile characteristics of warm-mix asphalt mixtures," vol. 42, no. 4, pp. 903-911, 2014.

[16] S. Pirmohammad and M. R. Ayatollahi, *Fracture Behavior of Asphalt Materials*. Springer Nature, 2020.

[17] M.-Y. Yoo, S.-H. Jeong, J.-Y. Park, N.-H. Kim, and K.-W. J. T. r. r. Kim, "Low-temperature fracture characteristics of selected warm-mix asphalt concretes," vol. 2208, no. 1, pp. 40-47, 2011.

[18] W. Mogawer, A. Austerman, L. Mohammad, M. E. J. R. M. Kutay, and P. Design, "Evaluation of high RAP-WMA asphalt rubber mixtures," vol. 14, no. sup2, pp. 129-147, 2013.

[19] M. Kim, L. N. Mohammad, and M. A. J. T. r. r. Elseifi, "Characterization of fracture properties of asphalt mixtures as measured by semicircular bend test and indirect tension test," vol. 2296, no. 1, pp. 115-124, 2012.