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Designand Properties of Crumb Rubber Aggregates Additive in Hot Mixture Asphalt Concrete

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Abstract: This research aims to establish the design and properties of crumb rubber aggregates additive in hot mixture asphalt concrete. Rubber crumb is rubber waste which is processed through mechanical grinding or tire milling into small splinters. The objective of this research is to have high durability of flexible pavement with different percentages of crumb rubber. The experiment was done respectively through several phases as follows: preparation, quality examination of materials such as aggregate and asphalt, mixed-planning, and specimen testing implementation with Marshall Test. Properties of crumb rubber-like type stability and flow of durability can affect the different stability and flexibility of pavement. The data collected from the laboratory experiments were presented in different forms like tables, charts, diagrams, etc. The results from the crumb rubber asphalt mixture show that there is an increase in the amount of crumb rubber in a mixture of hot mix concrete asphalt. This mixture can increase the Marshall stability by 2.5 % crumb rubber higher than the other mixtures with crumb rubber.
Keywords: Tire wastes, HMA, Marshall Test, stability, Flow, MQ and VMA.

I. INTRODUCTION

Roadways are an important part of the infrastructure for transportation in many countries. Road construction engineers should take into account both the safety requirements of Vehicle drivers and the economic considerations of road construction. In general, to achieve safe and economical road design road designers have to implement the safety and economy into three basic requirements for designing good roads, which are: environmental factors, traffic flow conditions, and pavement mixtures quality (Peralta, 2009).

A properly designed road will endure to the end of the road designed life without so much maintenance. However, due to certain distress such as fatigue failure, rutting, and other pavement deteriorations, the pavement performance will be greatly affected by time, the pavement characteristics change with time, and this may lead to pavement cracking (Mahrez, 1999). The discomforts on the pavement surface generally are more associated with the properties of pavement binder and pavement mixture, in which an asphaltic binder of the flexible pavement is the most common in causing poor pavement performance. Rutting, fatigue cracking, and water-related damages are among the main distress that causes the pavement surface to fail permanently.

The purpose of this analysis is to realize the feasibility of using crumb rubber as an additive in modified hot mix asphalt with some contrast to improve the quality of asphalt and learn the properties of crumb rubber asphalt. Comparing the two types of properties of the hot mix asphalt (without and with crumb rubber). Comparing the two types of the hot mix asphalt materials (without and with crumb rubber) to the Marshall properties (stability, flow, Marshall Quotient (MQ), Void in Total Mix(VITM), Void Filled with Asphalt(VFWA), and air void for optimum asphalt contact (Mashaan, 2013).

II. MATERIALS AND PROPERTIES

The primary materials used in this analysis are: coarse aggregate asphalt AC 60/70, fine aggregate, and CR All the key properties of the materials used were tested for further research; multiple experiments were carried out to determine their properties in compliance with the AASHTO, and Bina Marga 2014, Britsh standard conditions referred to as standard AASHTO and Bina Marga specifications (Bina Marga, 2014).

A. Asphalt

Asphalt Properties Test AC 60/70 produced by CO. PERTAMINA. The table presents the results of properties test asphalt AC 60/70, Table.1 shows some properties of the bitumen 60/70. This test was conducted according to (Bina Marga, 2010) presents the properties test results for each form of 60/70 asphalt.

TABLE 1
RESULT OF PROPERTIES TEST OF ASPHALT 60/70

No	Characteristics	Result	Specification (Bina Marga |2014)
1	The Specific gravity of asphalt	1.035	Min.1
2	Penetration	64.3 mm	60-79
3	Ductility	142 cm	Min. 100
4	Flashpoint and fire point	328 -399 ^{O}C	Min. 200
5	Softening point	52.5 ^{O}C	48 - 58
6	Asphalt solubility in TCE (tri chlore enthelyn)/CCL	99.115	MIN.99

B. Aggregate

The mixture used as the ingredients for the hot mixasphalt. The analysis as a Table is based on the properties testing of coarse aggregate and fine aggregate.

1) Properties of Aggregates

At the preliminary stage, the aggregate was sieved followingIndonesian standards and separated on the selected aggregate gradation according to the size of sieves.The total weight needed for aggregates was 1200 grams. Table.2 and Figure.1 show the aggregate gradation specification for HMAand the gradation used in this study.

Based on Figure.1, it can be concluded that the selected aggregate gradation used in this study can meet Bina Marga's graduation requirement. (2014). Similar to hot mix asphalt, aggregate products need to be tested to determine whether the requirements are met by their properties. In this analysis, many aggregate properties have been evaluated, specific gravity, abrasion, flakiness and elongation indices, and so on, to ensure that the aggregates used in asphalt mixtures can be used.

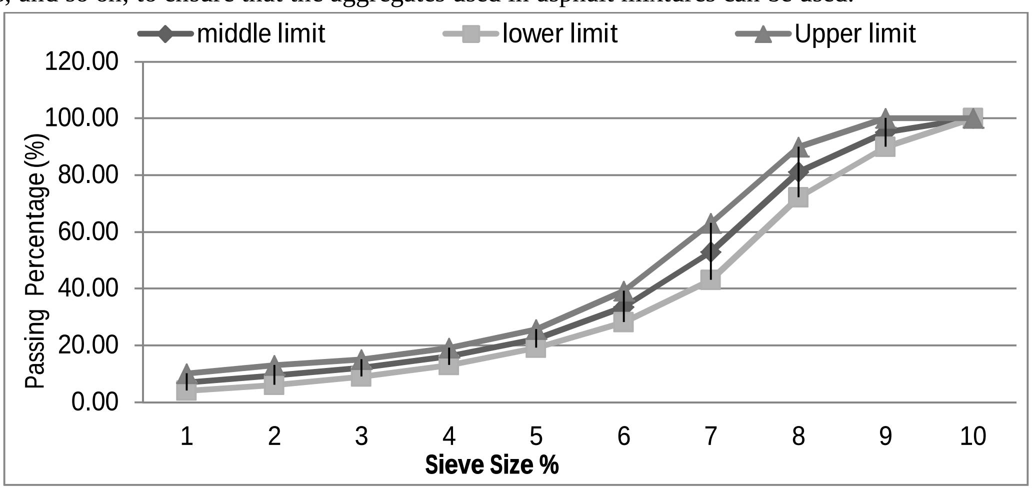

Fig.1 Gradation limit for Hot Mix Asphalt Concrete

TABLE.2
PROPERTIES OF COARSE AGGREGATE

No	Properties	Result	Specification (Bina Marga2014)
1	The Bulk specific gravity of coarse aggregate	2.64 ^{O}C	≥ 2.5
2	SSD specific gravity of coarse aggregate	2.67 ^{O}C	≥ 2.5
3	Apparent specific gravity of coarse aggregate	2.714 ^{O}C	≥ 2.5
4	Water absorption of coarse aggregate	1.02 ^{O}C	≤ 3
5	Abrasion	24.08 ^{O}C	≤ 40
6	Adhesiveness	92.15 ^{O}C	≥ 95

TABLE.3
PROPERTIES OF FINE AGGREGATE

No	Properties	Result from Fine aggregate	Specification (Bina Marga 2014)
1	The Bulk specific gravity of fine aggregate	2.52^{O}C	≥ 2.5
2	SSD specific gravity of fine aggregate	2.59 ^{O}C	≥ 2.5
3	Apparent specific gravity of fine aggregate	2.723 ^{O}C	≥ 2.5
4	Water absorption of fine aggregate	2.94 ^{O}C	≤ 3

III. MARSHALL PROPERTIES TEST RESULTS.

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. Aggregate is used in this study consist of course and fine aggregates, coarse aggregate is characterized as the aggregate that exceeds the sieve size of 4.75 mm. Where fine aggregate is the aggregate, whose size is less than 4.75 mm, for example, sand is used as a fine aggregate in the preparation of HMA. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch sieve.

The test is conducted to have the optimum results of the hot mix asphalt with crumb rubber. The tests here wereperformed for various types of mix with CRcomposition of 0% (without CR), 2.5%,4.5%,6.5%, and 8.5% CR.In every CR content, the results from Marshall Stability tests are presented. The test results include the following Marshall Properties, which are: Marshall Stability (in Kg), Flow (in mm), Void (containing air) in Mix, VIM (in %), Marshall Quotient, MQ (in Kg/mm), (Total) Void in Mineral Aggregates, VMA (in %), and Void Filled with Asphalt, VFWA (in %).

For the gradation of aggregates used in this study, the following specification is used to determine the optimum bitumen content to be used in the field (Bina Marga, Indonesia, 2017):

1) Marshall Stability, minimum value = 800 Kg.
2) Marshall Flow, minimum value = 3 mm to maximum value = 5 mm.
3) MQ, minimum value =250 Kg/mm to maximum value = 350 Kg/mm.
4) VIM, minimum value = 3.5% to maximum value = 6%.
5) VMA, minimum value = 15%, no maximum value.
6) VFWA, minimum value = 65%, no maximum value.

The above specification will determine the optimum asphalt content to be prescribed for the actual design AC mixture in the field.

A. *Mixture without Crumb Rubber Content (0% CR)*

Summaryof the results of complete Marshall Tests for hot AC mixture with 0% CR can be given in Table.4, while the Stability correlations are given in Figure 2

TABLE.4
RESULTS OF MARSHALL PROPERTIES OF HOT MIX ASPHALTIC CONCRETE WITHOUT CRUMB RUBBER (0% CR)*

AC (%)	Stablity (Kg)	Flow (mm)	VIM (%)	Mq (kg/mm)	VMA (%)	VFWA (%)
5.0	1685.49	4.45	1.06	378.76	9.24	52.67
5.5	1813.50	4.90	7.67	370.10	17.28	55.63
6.0	1621.48	4.92	5.22	329.57	17.01	66.43
6.5	1173.44	4.97	4.99	236.10	16.95	70.58
7.0	803.63	5.73	1.05	140.25	16.57	93.64

The minimum value of VMA, in this case, is 16%, which primarily depends on the maximum diameter of the aggregate used in the mixtures. In this study, the maximum diameter of the aggregate is 1 inch (= 2.5 cm).

In Figure 2 by plotting only the asphalt contents that are meeting the specification of each Marshall parameters. The range of asphalt contents that are meeting all the parameters are those between 5.9 % - 6.30 % and this narrow percentage of the range are the numberof asphalt contents to be specified for application of AC mixture with 0% CR.

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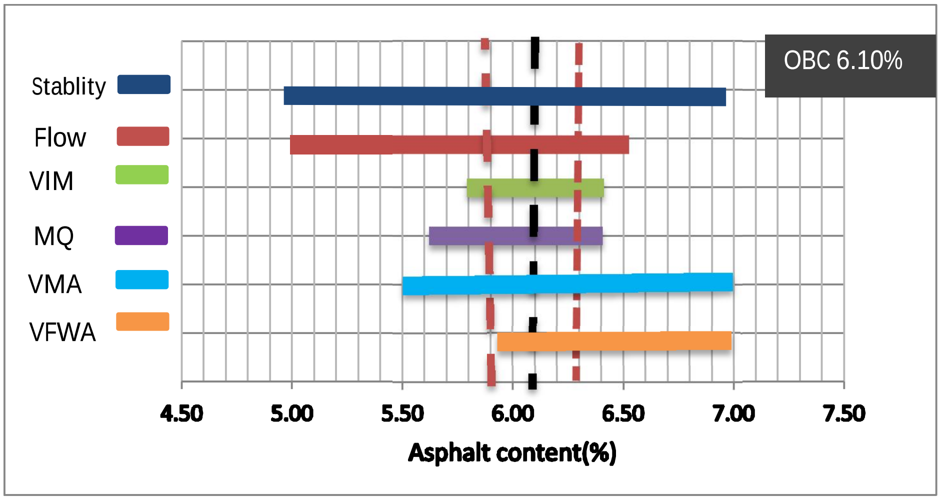

Fig 2. Summary of Optimum Bitument Content, OBM, for Marshall Properties for AC mixtures with 0% CR. (CR = crumb rubber).

B. Mixtures with Crumb Rubber Content of 2.5%.

The results of the complete Marshall Test for hot AC mixture with 2.5% CR can be given in Table.5, while the Stability correlation is given in Figure 3 the percentage of crumb rubber here is a percentage of weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 2.5% CR represents the weight of a 30-gram crumb rubber.

TABLE 5

. HOT MIX ASPHALT CONCRETE OF CRUMB RUBBER AT 2.5 %

AC (%)	Stability (kg)	Flow (mm)	VIM (%)	Mq (kg/mm)	VMAm (%)	VFWA (%)
5.0	576.05	3.00	4.34	192.02	15.23	66.53
5.5	917.42	3.15	4.94	291.24	15.84	68.80
6.0	1322.79	3.80	4.83	348.10	16.78	71.22
6.5	960.09	4.20	3.15	228.59	17.95	82.43
7.0	853.41	4.90	2.07	174.17	18.05	88.52

Marshall Properties test are analyzed in Table 5 were obtained the following observations that the OBC when added 2.5% crumb rubber is 6.20% bitumen which is shown in Figure 3.

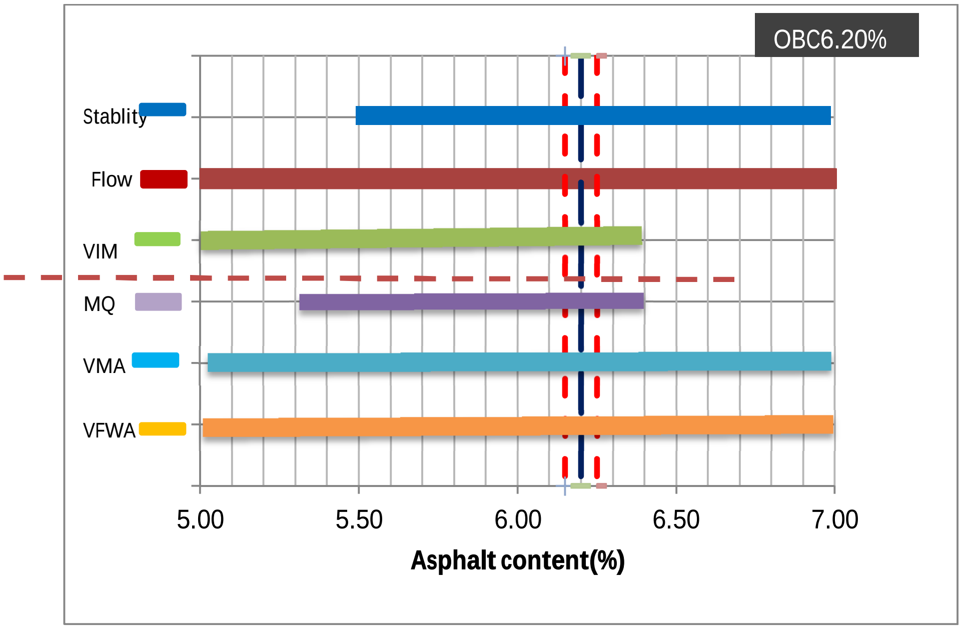

Fig 3Summary of Optimum Bitumen Content, OBM, for Marshall Properties for AC mixtures with 2.5% CR. (CR = crumb rubber).

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C. Mixtures with Crumb Rubber Content of 4.5%

The results of the complete Marshall Test for hot AC mixture with 4.5% CR can be given in Table 6 and the Stability correlations are given in Figure 4. The percentage of crumb rubber here is by weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 4.5% CR represents the weight of 54-gram crumb rubber.

TABLE.6
. RESULTS OF MARSHALL PROPERTIES OF HOT MIX AC WITH 4.5% CR*

AC (%)	Stability (Kg)	Flow (mm)	VIM (%)	Mq (Kg/mm)	VMA (%)	VFWA (%)
5.0	426.71	3.10	4.30	137.65	13.20	67.42
5.5	533.38	3.20	3.48	166.68	13.52	74.30
6.0	746.73	3.35	4.63	222.91	24.45	73.18
6.5	1066.76	3.40	5.36	313.75	21.64	67.14
7.0	917.42	3.45	7.60	265.92	22.22	65.78

The data can be summarized in Figure 4 by plotting only the asphalt contents that are meeting the specification of each Marshall parameters. The range of asphalt contents meeting all the parametersis those between 6.1 % - 6.40%. With the OBC = 6.25%. This is the asphalt content specified for application of AC mixture with 4.5% CR

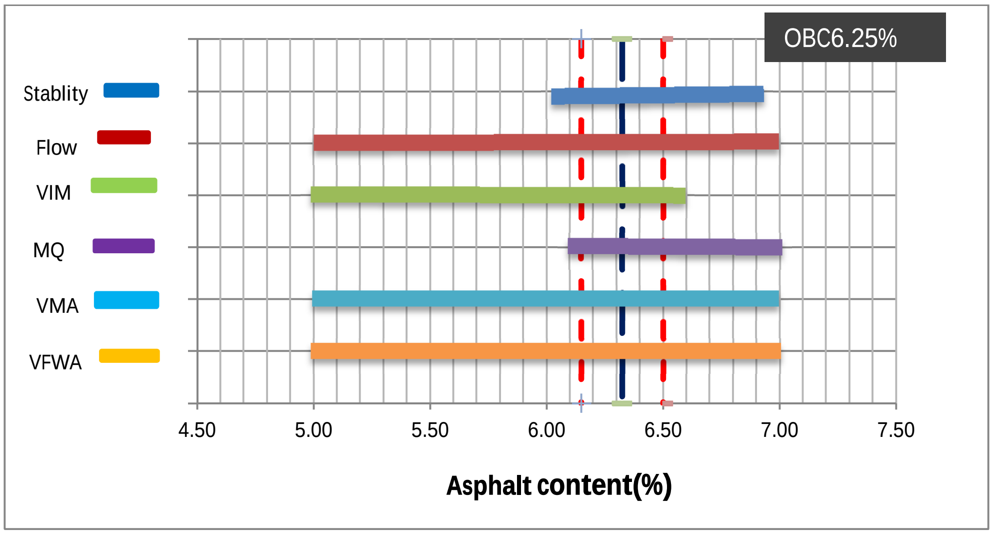

Fig 4 Summary of Optimum Bitumen Content, OBM, for Marshall Properties for AC mixtures with 4.5% CR. (CR = crumb rubber).

D. Mixtures with Crumb Rubber Content of 6.5%.

The results of the complete Marshall Test for hot AC mixture with 6.5% CR can be given in Table.7. And the Stability correlations are given in Figure 5. The percentage of crumb rubber here is by weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 6.5% CR represents the weight of 78-gram crumb rubber.

TABLE.7
. RESULTS OF MARSHALL PROPERTIES OF HOT MIX AC WITH 6.5% CR*

AC(%)	Stability (Kg)	Flow (mm)	VIM (%)	MQ (kg/mm)	VMA (%)	VFWA (%)
5.0	1280.12	3.20	5.23	400.04	14.04	62.77
5.5	1429.46	3.45	5.03	414.34	14.91	66.29
6.0	1280.12	3.66	5.42	349.76	16.31	66.74
6.5	960.09	3.70	5.77	259.48	17.63	67.29
7.0	746.73	3.80	3.66	196.51	18.82	80.54

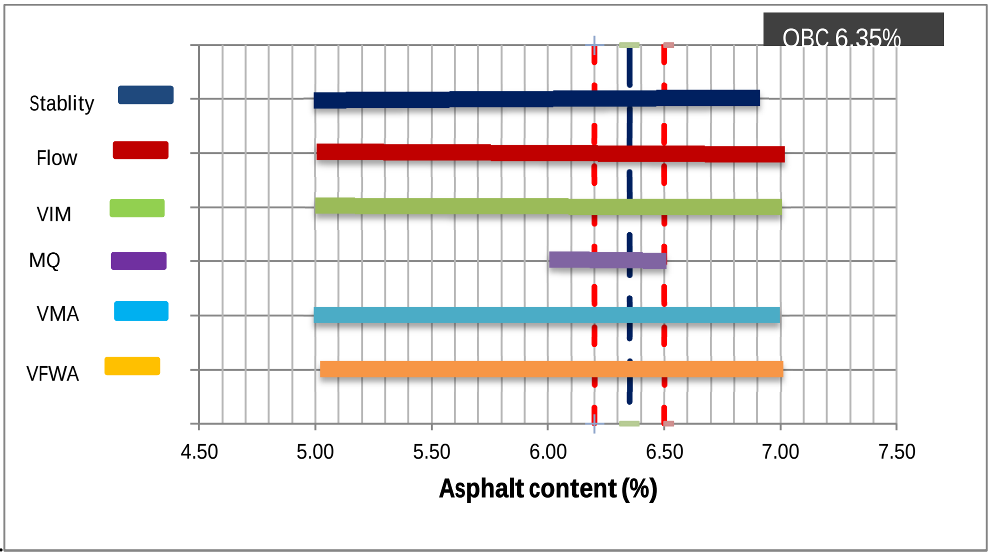

Fig 5. Summary of OptimumBitumen Content, OBM, for Marshall Properties for AC mixtures with 6.5% CR. (CR = crumb rubber).

E. Mixtures with Crumb Rubber Content of 8.5%.

The results of the complete Marshall Test for hot AC mixture with 8.5% CR can be given in Table 8. And the Stability correlations are given in. The percentage of crumb rubber here is by weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 8.5% CR represents the weight of 102-gram crumb rubber.

TABLE 8
. Results of Marshall Properties of Hot Mix AC with8.5% CR*

Asphalt Content (%)	Stability (Kg)	Flow (mm)	VFWA (%)	VMA (%)	MQ (kg/mm)	VIM (%)
5.0	810.74	3.35	34.97	11.84	242.01	14.74
5.5	1216.11	3.70	48.14	11.46	328.68	11.05
6.0	597.39	3.90	42.58	9.77	153.18	11.60
6.5	469.38	4.10	52.31	10.10	114.48	12.42
7.0	256.02	4.20	50.06	11.02	60.96	14.27

IV. ANALYSIS OF THE MARSHALL PROPERTIES FOR DIFFERENT CR CONTENT

The analysis here is performed by comparing the results of the Marshall Properties in Section 5.3.1 to 5.3.5. To find the best CR content based on for the following rationales:

A. Marshall Stability

Marshall Stability represents the strength of the AC mixture against compressive and shear stresses caused by the repetition of vehicle tire passing, especially for heavy truck tires. The higher Stability means the stronger the AC mixture against damages due to heavy truck traffic.

B. Flow

The flow values represent the resistance of asphaltic pavement against permanent deformation under the repetitive load of heavy truck traffic. The higher flow means the pavement is more vulnerable to rutting, while lower flow means the pavement is more rigid and less vulnerable to permanent deformation or rutting. However, the flow values are limited to certain upper and lower limits (in this case is 5% and 3%, respectively). Too high value of flow means softer asphaltic pavement that is more easily to undergo permanent deformation; yet, too low value of flow means the pavement is too brittle. Therefore, the better AC mixtures are those with lower flow, providing that the values are still within the corridor of the specified upper and lower limits.

C. Marshall Quotient (MQ)

Marshall Quotient (MQ), also represents the strength of asphaltic mixture against tire-induced stresses, especially heavy truck traffic. The higher MQ also means the stronger pavement against tire stresses. Yet, the MQ values are restricted to certain upper and lower limits (in this case is 350 Kg/mm and 250 Kg/mm, respectively). Too high MQ also means the pavement is too rigid and too brittle, so that it may be more prone to cracking. Whereas, too low MQ means the pavement is more easily to undergo permanent deformation under repetitive loading of heavy truck traffic. Therefore, MQ is the reflection of the toughness and resilience of the mixture against stress and deformation. Because MQ = Stability/flow, the same Stability of specimen tested but with the lower flow will yield higher MQ. This means, even if the Stability values are the same, the AC pavement with higher MQ will have more resistance to deformation after subjected to repetitive loading than those with lower MQ. Therefore, higher MQ values mean better AC mixtures, providing that the values are still within the corridors of the specified upper and lower limits.

D. VIM

VIM represents the amount of air still remains inside the AC mixture after the mixture is compacted to become pavement. The amount, in this case, is limited to 3.5% to 6%. The lower limit 3.5% is the minimum air still needed inside the mix so that bleeding will not occur in the pavement after the pavement is subjected to many years of repetitive heavy truck traffic. Repetition of truck traffic will cause the pavement will become further densified, so that when no more enough void of air remaining inside the pavement, bitumen binder will be forced to flow outside to the surface of the pavement and to cause bleeding. Bleeding is not permitted in the asphaltic pavement because it may cause the pavement more slippery and hazardous to the traffic. On the opposite side, the higher limit of VIM, 6%, is the limit for the pavement not to become too porous so that water may enter the pavement and dwell inside the pavement. This condition has been known to cause the pavement to deteriorate and crumble more easily so that the pavement is more likely to be damaged prematurely. Therefore, the better quality of AC mixtures is those with VIM values closer to the average value of the specification, which is (3.5 + 6)/2 = 4.75%.

To find the better quality of the AC mixtures with different content of CR, each of the results of the Marshall Properties should be given scores. The score is 1 for the best one, 2 for the second one, 3 for the third, etc. The scores are finally accumulated by just simple addition and the CR content with the least value is chosen as the best AC mixtures for all the Marshall properties describes above.

It should be noted here that the VMA and the VFWA are not included in the qualitative analysis, because the VMA and VFWA are only for the initial condition for the aggregates and gradation; they are not related to the asphalt content or CR content. Therefore, as long as the VMA and VFWA specifications are already met according to the specification, the other Marshall properties should be used as the determining factors.

TABLE..9
Comparison of Marshall tests of HMA with CR and without CR

Results of	%Crumb Rubber content in mix			
	%CR	2.5%CR	4.5%CR	6.5%CR
(OBC)	6.10	6.20	6.25	6.35
Stability (kg)	1621.48	1322.79	1066.76	1280.12
Flow (mm)	4.92	3.80	3.40	3.66
Marshall Quotient (kg/mm)	329.56	377.94	313.75	349.76
VIM (%)	5.22	4.83	5.36	5.42
VMA (%)	17.01	16.78	21.64	16.31
VFWA (%)	66.43	71.22	67.14	66.54

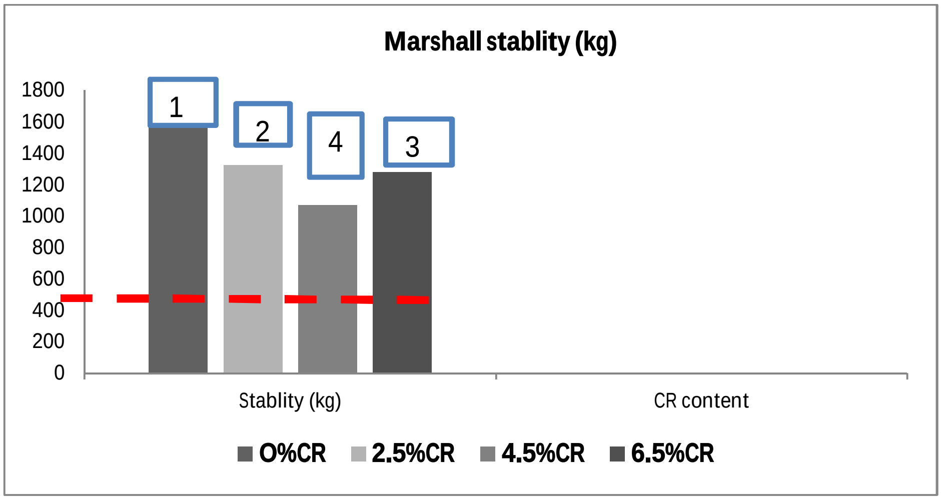

Fig 6. Comparison of cases Stability test for HMA with and without CR

E. The Marshall Stability

When comparing the test results for Stability in Table.9 and Figure 6 optimal stability. The results in stability tests respectively without CR at AC 6.0% was 1621.48 kg, with 2,5% CR at AC 6% was 1322.79kg, with 4.5%CR at AC 6.0% was 1066.76kg, with 6.5%CR at AC6 % was 1280.12kg.

Factor since extensive crumb rubber application reduces the coarse aggregate point of contact within the mixture. The use of crumb rubber can result in higher density or more porous bitumen. Consequently, the mixture becomes more flaccid to lead to a drop in the stability value. The resilience of aggregates reduces as the crumb rubber content increases (Mashaan et al. 2013). Increasing crumb rubber has been found to reduce HMA stability, with a higher percentage of crumb rubber yielding the lowest stability value.

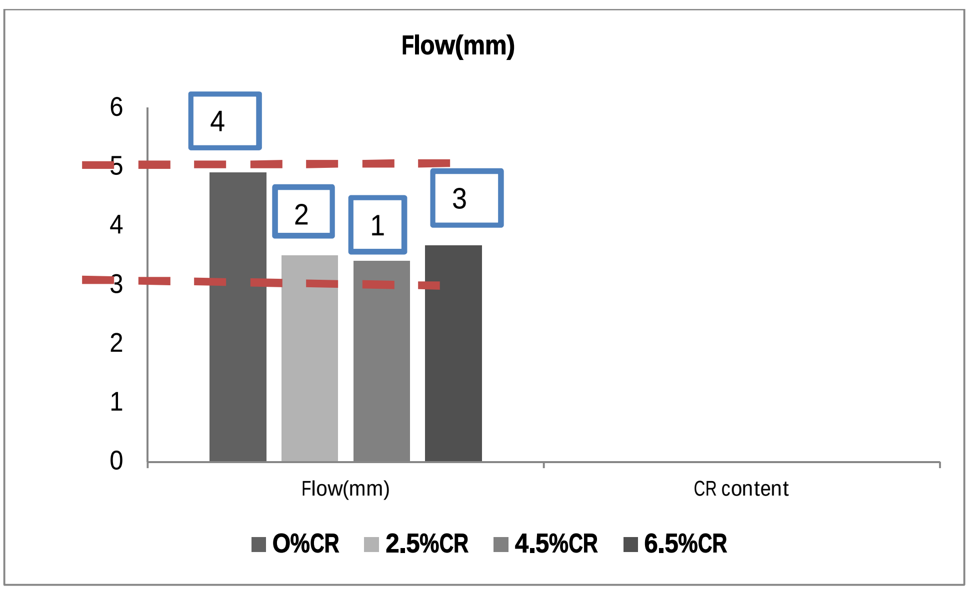

Fig .7 Comparison of cases flow test for HMA with and without CR

F. The Marshall Flow

Comparing the outcome of the Flows check-in Table 7 Figure 7, the hot mix asphalt concrete flow test volume improved as the CR quality rose from 5% to 7%. Higher flow values can be associated with increased air void (more compaction required) by using more CR in the mixture, resulting in a more versatile mix. Therefore, it can be inferred that the lower amount of crumb rubber increases the flow but the higher volume of asphalt reduces the flow. The mixtures are more stable with the inclusion of asphalt content; while the resistance to deformation decreases, it can result in a high flow value (Mashaan et al. 2013).

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It has been stated that applying crumb rubber additive to asphalt concrete increases the mixture flow before maximum crumb rubber content is obtained. Crumb rubber with additional content is good at higher temperatures with high flow. While very low permeability and more rigidity in small flow.Asphalt content with additional crumb rubber can lead to high flow value, this means that good against rutting, and permeability.

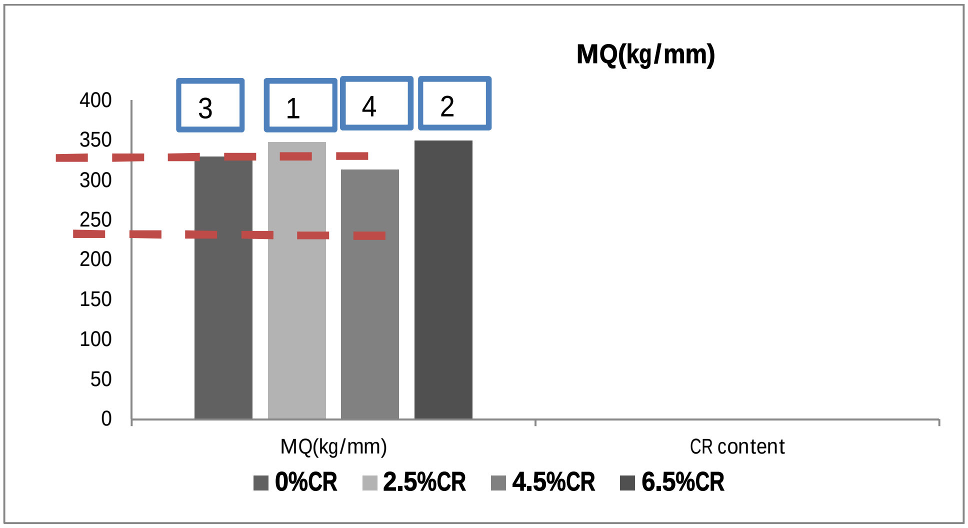

Fig.8 Comparison of cases of MQ test for HMA with and without CR

G. Marshall Quotient (MQ)

The MQ test results evaluated in Figure 8 show that HMA without crumb rubber, 2.5%, 4.5%, and 6.5% CR have maximum MQ values of 303.01, 348.10, 313.75, and 349.76 kg/mm, accordingly at AC 6%. Therefore, it can be inferred that MQ can improve by increasing the percentage of crumb rubber content. This is because voids have space within the compacted mix to transfer the HMA. The combination of asphalt construction and rubberized HMA mixtures is a trade-off in high binder quality to boost long-term longevity and efficiency. Moreover, enough space in place can prevent rutting, instability, flushing, and bleeding. The details can be seen in Table.9 the MQ.

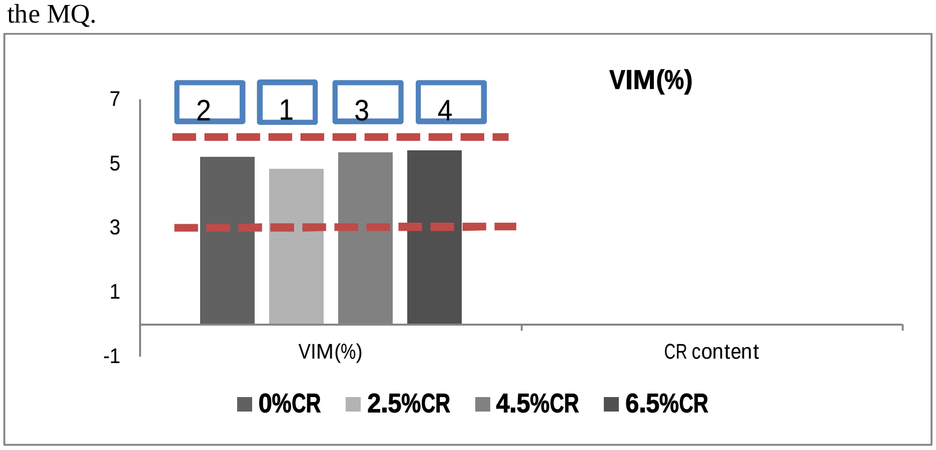

Fig .9 Comparison of cases VIM test for HMA with and without CR

H. Void in Mix (VIM)

The VIM test results analyzed in Figure 9 showed that HMA without crumb rubber, 2.5%, 4.5%, 6.5%, CR have maximum. The VIM has the values of 5.22, 4.83, 6.36, and 5.77 respectively. Therefore, it can be inferred that an increase in the amount of crumb rubber content can increase the VIM.

Al-Azri et al. (2006) concluded that The use of petroleum asphalt as a pavement mixture although it meets the requirements of the specification, often shows a decrease in service behavior due to rutting, fracture, and other forms of damage. Fractures from or on the sidewalk make water easy to enter so that it can damage the paving structure due to the movement of air and water on the sidewalk, causing oxidation and evaporation to occur in the binder.

As a result, sidewalks have relatively low durability. There is strong evidence that asphalt oxidation happens in the whole depth of pavement, dramatically affecting pavement durability. Shu and Huang (2014) stated that an increased amount of crumb rubber in the mixture of asphalt concrete would reduce the strength of Marshall. Nevertheless, this was not always accompanied by enough flow; thus, as expressed by the Marshall Quotient parameter, it resulted in less versatility. Waste tires pose significant health and environmental concerns if not recycled and/or discarded properly. Over the years, recycling waste tires into civil engineering applications, especially into asphalt paving mixtures. Crumb rubber or waste rubber is a mixture of natural rubber synthetic rubber, black carbon, antioxidants, fillers and extender form of oils that are soluble in warm paving grade.

TABLE.10
Comparison of Flow (mm) of Hot Mix Asphalt Concrete with CR and

Results	Scores for quality of Marshall properties			
	%CR	2.5%CR	4.5%CR	6.5%CR
Marshall stability (kg)	1	2	4	3
Flow (mm)	4	2	1	3
Marshall Quotient (kg/mm)	3	1	4	2
VIM (%)	2	1	3	4
Σ score	10	6	12	12
Ranking of overall quality	2	1	4	3*

* Having total scores = 12 similar to 4.5% CR, but it selected as no.3 because of the more amount of CR used as more desirable for environmental concern.

V. CONCLUSION

Several measurable chemical properties are believed to be associated with the mechanical or organizational resistance of a pavement. From the result, the comparative outputs of the elastic and viscous behavior differed with the structure. The conclusion as follows: the best CRMA mixture for overall condition according to the criteria of the Marshall Test is the one with the CR content = 2.5%. This 2.5% CR will exhibit the best mixture for hot mix asphalt concrete against fatigue cracking and rutting.

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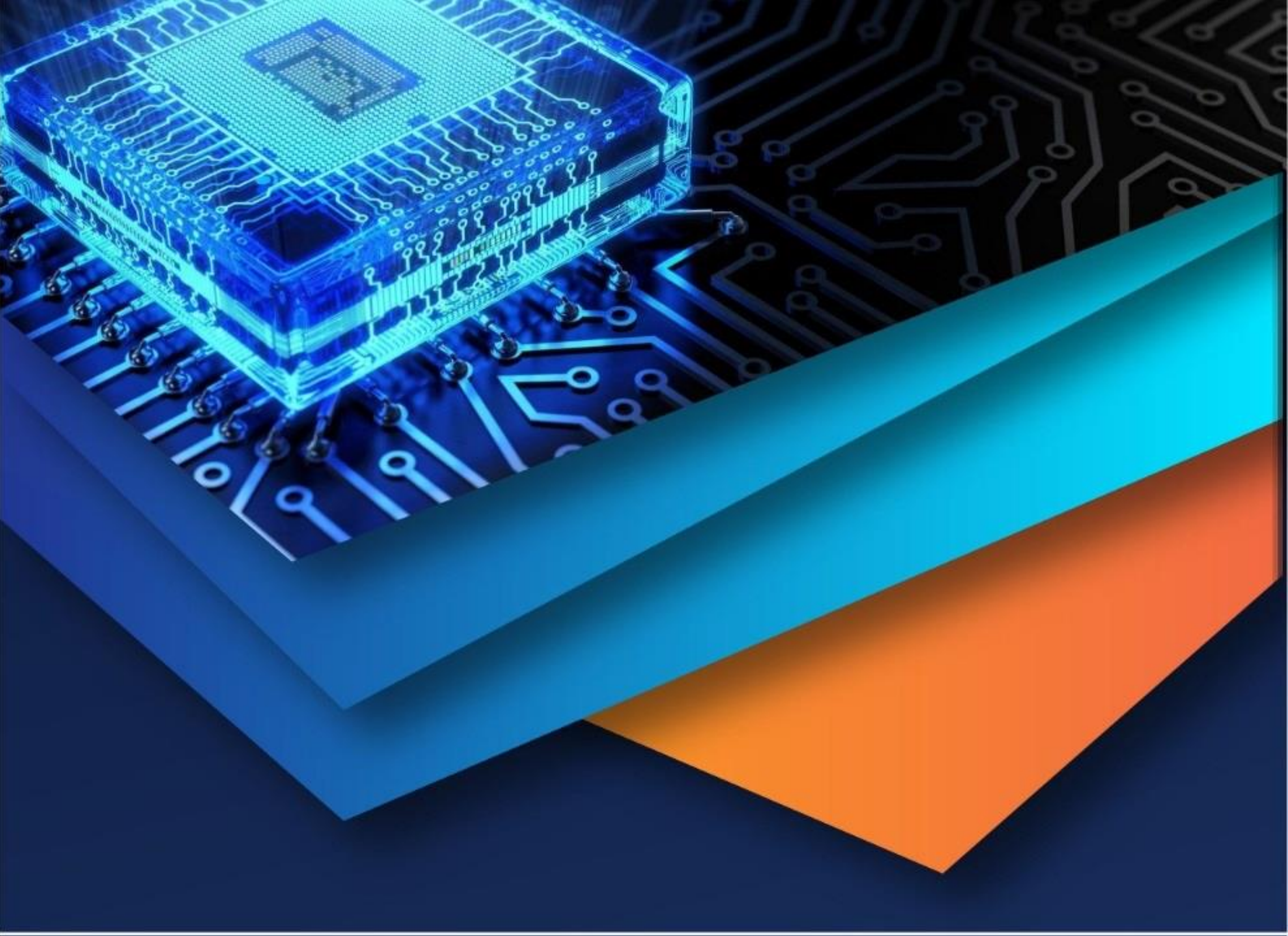

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