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Index Retained Strength Mixture of Fine Stone Mastic Asphalt using Concrete Waste Aggregate

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***Abstract*—** *Concrete waste that is left untreated will cause its own problems for the environment. The purpose of this study is to analyze the Retained Strength Index for Stone Mastic Asphalt mixtures that use concrete construction demolition waste aggregate. The test method used is the Marshall method. Aggregate test results from waste concrete meet the requirements for use as a fine SMA material. This can be seen from the results of the aggregate resistance test and the specific gravity obtained. The results of the Stability and Flow tests as well as the VIM and VMA analysis show that the values meet the Bina Marga standards. The results of the Marshall Immersion test show that the Retained Strength Index Value is 92.71%. Based on these values, it can be concluded that road pavements using concrete waste aggregate in a mixture of fine Stone Matrix Asphalt (SMA) can withstand temperature and the length of time they are submerged in water.*

***Keywords*—** *Concrete waste, Marshall Method, Index Retained Strength.*

I. Introduction

Limited natural resources in providing concrete-forming materials is an important issue. The existence of several old buildings that are no longer used must be demolished because these buildings need to be renewed, are damaged, or are no longer fit for habitation. On the other hand, the demolition of buildings and civil infrastructure consisting of concrete materials creates concrete waste. Concrete waste that is left untreated will cause its own problems for the environment. Disposal of waste requires a fee and a landfill. Currently ready mix concrete is being widely used for the manufacture of building construction, however, in its application, excess supply often occurs and the remainder is sometimes disposed of in any place, which can cause new problems. With all the advantages that can be observed from various recent studies, the reuse of concrete waste in the form of fractions as a substitute for coarse aggregate deserves research because besides being cheap and environmentally friendly, it is also expected to be able to provide satisfactory results.

Stone mastic Asphalt (SMA), which is a type of hot asphalt mixture consisting of coarse aggregate, fine aggregate, and filler and adhesive in the form of rich asphalt binder mortar and has contact between the coarse aggregate to form a rock framework known as Stone-on stone skeleton. contact for load distribution [1] [2]. SMA is used as a road pavement surface layer with Open graded aggregate composition or it can also be called a uniform gradation which means it only contains a small amount of fine aggregate so that there are many voids or empty spaces between the aggregates. On the surface layer there is a wear layer and an intermediate layer, where the Asphalt Stone matrix as the wear layer lies above the intermediate layer [3]

To analyze the Retained Strength Index, a material characteristic test is needed in the form of aggregate characteristics, asphalt characteristics and filler characteristics used [4] [5]. In addition, the characteristics of the mixture through the Marshall Conventional and Marshall Immertion tests [6].

Research that has been done under the title Utilization of Recycled Concrete Aggregates in Stone Mastic Asphalt Mixtures [7]. Use of Waste Concrete as Aggregate in Fine Asphalt Stone Mastic Mixture [8]. Laboratory evaluation of treated recycled concrete aggregate in asphalt mixtures [9]. Behavior of a hot mix asphalt made with recycled concrete aggregate and crumb rubber [10].

The purpose of this study is to analyze the Retained Strength Index for Stone Mastic Asphalt mixtures that use concrete construction demolition waste aggregate. The specifications used are the specifications that apply in Indonesia, namely Road and Bridge Work Specifications [11].

II. Methodology

A. Materials

The research was conducted in a laboratory at the Road Pavement Laboratory of the Civil Department, Paulus Indonesian Christian University. The aggregate used is building demolition waste from various locations in Makassar City, South Sulawesi Province, Indonesia (Figure 1). The asphalt used is Pen 60/70 with an asphalt content of 6.00% for each mixture; 6.25%; 6.50%; 6.75% and 7.00% by weight of the mixture. While the filler used is Portland Cement.

Fig.1. Concrete waste

B. Mixture Composition and Test Objects

Determination of the composition of the mixture is based on the results of the analysis of the mixture gradation. The results of the analysis can be seen in Table 1. While the number of samples used was 5 for each bitumen content and a total of 25 samples for the Conventional Marshal test and 5 samples for Marshall Immersion.

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TABLE 1. Mixture Composition

Material	Asphalt content (%)				
	6,00%	6,25%	6,50%	6,75%	7,00%
Coarse aggregate (gr)	834	832.5	831	829.5	828
Fine aggregate(gr)	192	191	190	198	188
Filler (gr)	102	101.5	101	100.5	100
Asphalt(gr)	72	75	78	81	84
Total	1200	1200	1200	1209	1200

C. Marshall Conventional

Conventional Marshal is one of the methods used to analyze the characteristics of the mixture used.

a. Stability

Stability is the ability of the asphalt mixture to withstand deformation due to the work load, without experiencing permanent deformations such as waves, grooves and bleeding expressed in units of kg or lbs.

The corrected stability value is calculated by the formula

$$S = q\ x\ C\ x\ k\ x\ 0.454 \qquad (1)$$

Where: S: Stability value; q: Stability reading on Marshall tool dial; k: Tool calibration factor; C: Thickness correction number; 0.454: Conversion of units from lbs to kg

b. Flow

Flow is the magnitude of the vertical deformation of the sample that occurs at the start of loading until the stability conditions begin to decline. The Flow value is obtained from the tool reading

c. Density

Density is the weight of the mixture expressed in units of volume. Density is influenced by several factors, including the gradation of the mixture, the type and quality of the stacking materials, the asphalt content, the viscosity of the asphalt, the amount and temperature of compaction. The formula used to analyze bulk density and theoretical maximum density is as follows:

1) Density bulk

$$Gmb = \frac{B_k}{B_{ssd} - B_a} \qquad (2)$$

Information:
Gmb: Bulk specific gravity of dense asphalt concrete
Bk: Dry weight of solid asphalt concrete (gr)
Bssd: Surface dry weight of compacted asphalt concrete (gr)
Ba: Weight of solid asphalt concrete in water (gr)

2) Density maximum teoritis

$$G_{mm} = \frac{100}{\left(\frac{P_s}{G_{se}} + \frac{P_a}{G_a}\right)} \qquad (3)$$

Information:
Gmm: Maximum specific gravity of asphalt concrete that has not been compacted
Ps: Aggregate content, % by weight of dense asphalt concrete
Pa: Asphalt content by weight of solid asphalt concrete (%)
Ga: Specific gravity of asphalt
Gse: Effective specific gravity of the aggregate forming dense asphalt concrete

D. Void in Mix (VIM)

Air voids in asphalt pavement mixtures consist of air spaces between aggregate particles covered with asphalt. The volume of air voids in the mixture can be determined by the formula:

$$VIM = \left(100x\frac{G_{mm} - G_{mb}}{G_{mm}}\right)\%\ from\ volume\ Bulk \ldots\ldots(4)$$

Where:
VIM: pore volume in dense asphalt concrete, % of the bulk volume of dense asphalt concrete
Gmm: maximum specific gravity of dense asphalt concrete, % of the bulk volume of dense asphalt concrete

E. Void in the Mineral Aggregate (VMA)

VMA is the void space between aggregate particles on a pavement, including air voids and effective asphalt volume (not including aggregate-absorbed asphalt volume). VMA can be calculated by:

$$VMA = 100 - \left((100 - P_a)x\frac{G_{mb}}{Gs_{agg}}\right) \ldots\ldots\ldots\ldots(5)$$

Where:
VMA: Pore volume between aggregate grains in dense asphalt concrete (%)
Gmb: Bulk specific gravity of dense asphalt concrete
Gsagg: Bulk specific gravity of the aggregate forming dense asphalt concrete
Pa: Asphalt content, % by weight of aggregate

F. Index Retained Strength

The Retained Strength Index of the Smooth Stone Mastic Asphalt mixture is obtained from the ratio of the Stability of the mixture after soaking for 24 hours to the Stability of the mixture soaked for 0.5 hours with the formula:

$$Index\ Retained\ Strength = \frac{Stability\ of\ Marshall\ Immersion}{Marshall\ Conventional\ Stability}x100\% \ldots\ldots\ldots\ldots(6)$$

III. Results and Discussion

A. Aggregate Characteristics

In testing the characteristics of the concrete waste aggregate, the test results met the 2018 General Highways specification standards.

a. Abrasion with a Los Angeles machine

The results of the wear test with the Los Angeles Machine tool from the four fractions obtained the wear resistance value of the coarse aggregate wear from Fraction A was 28.88%, Fraction B was 26.12%, Fraction C was 23.52% and Fraction D was 20.4%. So that the average aggregate resistance is 24.73%. This average value indicates that the aggregate can be used as a mixture. The requirement from Highways is a maximum of 30%.

b. Coarse aggregate specific gravity

Based on the test results for specific gravity and absorption of coarse aggregate for the two samples, the values for bulk density were 2.60%, SSD specific gravity was 2.64%, apparent specific gravity was 2.71% and water absorption was 1.57%. All test results meet the 2018 General Highways Specifications, namely for Bulk Specific Gravity, SSD Specific Gravity and Apparent Specific Gravity is at least 2.5% and Maximum Water Absorption is 3% or it can be said that the aggregate absorption is small.

c. Specific Gravity of Fine Aggregate

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Based on the specific gravity test and fine aggregate water absorption, it can be seen that the level or ability of the aggregate to absorb water is low, voids or pores are present in the aggregate. Aggregate that has a large pore content has a large absorption value, so it will require more asphalt. The results of the aggregate absorption test for water were 1.21%. This value meets the specification requirements, namely a maximum of 3%.

d. Sieve analysis

Based on Figure 2, the results of the sieving analysis are in the form of aggregate gradations that are between the upper and lower limits, but towards the lower limit which indicates a lack of passing percentage so that the aggregate from the concrete waste used is classified as fine gradation and meets the 2018 General Highways Specifications.

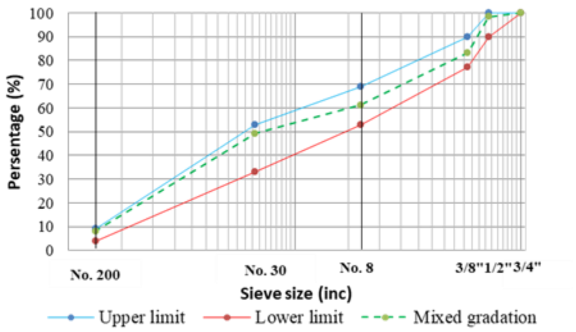

Figure 2. Results of sieve analysis

e. Aggregate Test Results Passing sieve No. 200

The results of the material test pass the No. sieve. 200 obtained a yield of 1.3%. This meets the General Specifications of Highways, namely a maximum of 10%. From the results of this test, it can be seen that the aggregate from concrete waste is clean from clay and silt.

f. Sludge content testing

The results of testing the mud equivalent value using 2 (two) samples obtained an average result for the Sand Equivalent (SE) value of 96.40% and 3.60% mud content. Both meet the 2018 Bina Marga General Specifications, namely a minimum of 50% for Sand Equivalent and a maximum of 5% for silt content.

g. Coarse Aggregate Flat and Oval Particles

The results of testing flat particles and oval coarse aggregate obtained flat particles, namely 4.20%, 3.60%, 2.90%. And oval particles, namely 4.45%, 3.86%, 3.15%. These two values have met the 2018 General Highways Specifications, which is a maximum of 10%.

B. Characteristics of the Conventional Marshall

a. Specific gravity

In Conventional Marshall analysis, asphalt specific gravity, Bulk Specific Gravity Aggregate and Effective Specific Gravity Aggregate are needed. Asphalt specific gravity is one of the parameters in determining the quality of solid asphalt based on the specification of the penetration graded bitumen and is one of the primary data for analyzing voids in the Marshall test [12]. Bulk specific gravity is the ratio between the weight of dry aggregate and the weight of distilled water whose contents are equal to the contents of the aggregate in a saturated state at a certain temperature [13]. The results of the Specific gravity test can be seen in Table 2.

TABLE 2. Specific gravity

Specific gravity	**Asphalt content (%)**				
	6,00 %	**6.25 %**	**6,50 %**	**6,75 %**	**7,00 %**
Asphalt specific gravity	1.017				
Bulk Spesific Gravity Agrerat	2.86	2.86	2.87	2.88	2.89
Effective Spesific Gravity Agrerat	2.89	2.9	2.91	2.91	2.92

The Marshall method aims to determine the characteristics of a flexible pavement. This marshall method consists of Marshall Test and Marshall Parameters for Stone Mastic Asphal mixture according to Road and Bridge Work Specifications, namely Stability, flow, VIM and VMA. The results of conventional Marshal testing and analysis can be seen in Table 3.

TABLE 3. Conventional Marshal test results

Asphalt content (%)	**Stability**	**Flow**	**VIM**	**VMA**
6	742.17	2.73	4.75	17.59
6.25	762.34	2.57	4.68	17.92
6.5	766.54	2.45	4.54	18.35
6.75	753.78	2.59	4.36	18.67
7	729.56	2.97	4.09	18.92
Regulations	**Min. 600 (kg)**	**2 - 4.5 (mm)**	**4 - 5 %**	**Min. 17 (%)**

b. Stability

Stability testing aims to measure the resistance of an asphalt concrete mixture to deformation during traffic loading or the maximum ability of a test object to withstand loads until plastic melting occurs. The stability value is obtained based on the value indicated by the dial needle on the stability proving ring mounted on the Marshall Test tool. This stability value is then converted with the Calibration Table according to the proving ring used, then the Stability value must be corrected with a correction factor for the thickness of the test object. The test results are as in Table 3.

Based on Table 3 and Figure 3, using an asphalt content of 6.00% - 7.00%, a stability value of 742.17 kg –729.56 kg is obtained, where the asphalt content of 6.00% - 6.75% increases and decreases in asphalt content 7 ,00 %. Stability values at asphalt content of 6.25%, 6.50%, 6.75% and 7.00% meet the 2018 General Highways Specifications. Based on Figure 3 it can be concluded that the use of a small asphalt content in the SMA Smooth mixture will produce a blanket thin asphalt on the surface of the aggregate resulting in weak inter-aggregate bonds so that the stability of the mixture is small, but if the asphalt is added again, the asphalt blanket becomes thicker so that the bonds between the aggregates become strong / the stability of the mixture is large. Then if there is more asphalt then the asphalt blanket becomes thicker which will result in the bond between the aggregates or the stability of the mixture decreasing again.

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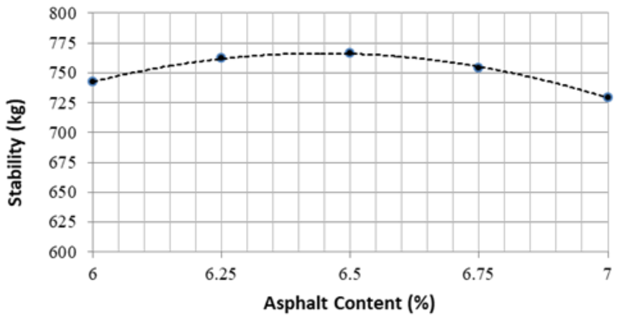

Fig. 3. Relationship between Stability and Aspalt content

c. Flow

The yield value obtained from the Marshall test is the Stability strength limit value of the test object which has been destroyed between the material components on the test object.

Based on Table 3 and Figure 4, using an asphalt content of 6.00% - 7.00% a Flow value is obtained between 2.73 mm - 2.97 mm where at an asphalt content of 6.00 - 6.75 it decreases then at an asphalt content of 7.00% increased. All Flow values meet the 2018 Highways General Specifications. Based on Figure 4, it can be concluded that if the use of asphalt in the asphalt mixture is small, the bonds between the aggregates are reduced which causes large melting. But if the use of asphalt increases, the bond between the aggregates in the mixture becomes stronger which results in decreased melting of the mixture, then if the use of asphalt increases, the asphalt cover becomes thicker which results in reduced strength of the mixture but increased melting, which means mixed strength/stability. will be inversely proportional to the melting mixture/flow.

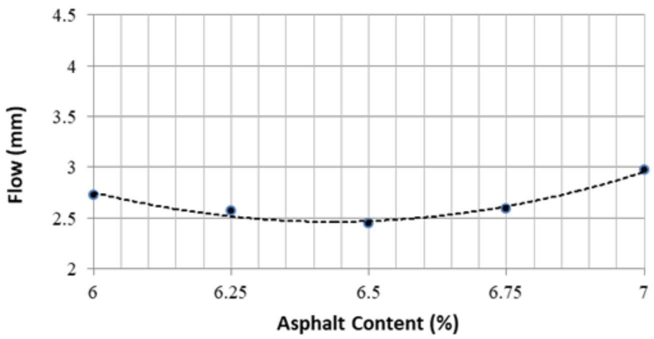

Fig 4 Relationship between Flow and asphalt content

d. VIM

Void In Mix or also called cavities in the mixture is used to determine the size of the mixed voids in percent. The resulting air voids are determined by the arrangement of the aggregate particles in the mixture and the non-uniformity of the aggregate shape. Air voids are an indicator of the durability of the asphalt mixture so that the voids are not too small or too large.

Based on Table 3 and Figure 5, using an asphalt content of 6.00% - 7.00%, a value of between 4.75% - 4.09% is obtained, this fulfills the 2018 General Highways Specifications where the VIM value at asphalt content is 6.00% - 7.00 % decrease. Based on the graph above, it can be concluded that the higher the asphalt content used, the smaller the VIM value and vice versa, if the lower the asphalt content used, the higher the VIM value, because asphalt functions as a binder and cavity filler in the asphalt mixture.

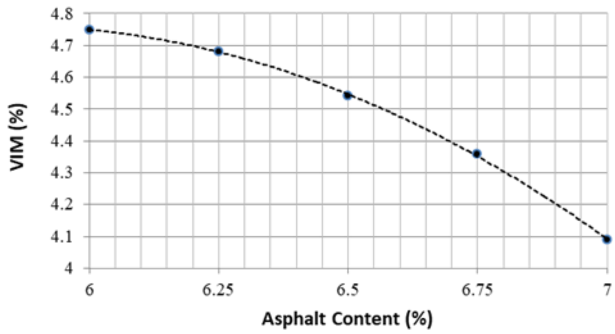

Fig. 5 Relationship between VIM and asphalt content

e. VMA

Cavities in the aggregate mixture are voids between aggregate grains in the compacted asphalt mixture and the effective asphalt expressed as a percentage of the total volume of the mixture. Continuously graded aggregates provide small voids between VMA grains and produce high stability but require a low bitumen content to bind the aggregates. The small VMA causes the asphalt to cover the limited aggregate, causing the pavement layer to not be watertight so oxidation can easily occur and cause damage.

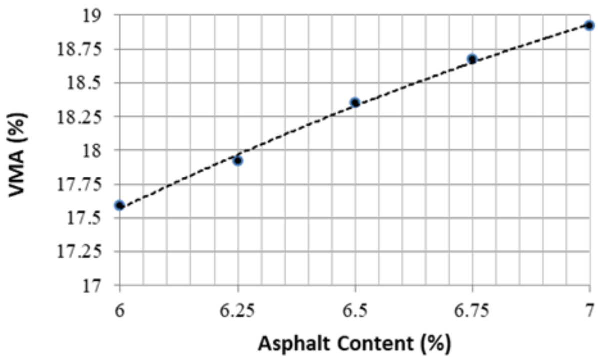

Fig. 6 Relationship between VMA and asphalt content

Based on Table 3 and Figure 6, using an asphalt content of 6.00% - 7.00%, the VMA value is obtained between 17.97% - 19.70% fulfilling the 2018 General Highways Specifications. From the graph it can be seen that the asphalt content is 6.00 % - 7.00% VMA value continues to increase. This is influenced by the amount of asphalt used, because the function of asphalt besides covering (effective asphalt) also serves to fill voids between aggregates and in aggregate particles. From Figure 6 it can be concluded that the more asphalt is used, the larger the voids in the aggregate filled with asphalt so that the VMA value will increase. This is influenced by the use of a lot of asphalt where during mixing and compaction, the asphalt

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will cover the aggregate, fill the voids between the aggregates and fill the voids in the aggregate.

C. Optimum asphalt content

The optimum asphalt content is determined by averaging the asphalt content which gives the maximum stability value, maximum density and asphalt content in the required VIM-PRD. These results are then checked whether at this average value the requirements for other asphalt mixtures such as VMA, VFB and mixed flow meet the specifications.

Based on the results of the analysis of the characteristics of the Fine SMA mixture, it can be determined the practical asphalt content in the Smooth SMA mixture, namely the asphalt content that meets all the criteria or characteristics of the mixture and the practical asphalt content is the asphalt content range of 6.00% to 7.00%.

For the optimum asphalt content, the Smooth SMA mixture is chosen which has the lowest VIM value at an asphalt content of 7.00% because the SMA layer is a wear layer or surface layer which must be watertight to protect the underlying layer. If the VIM value is too high, it will cause the mixture to become impermeable, premature cracking, grain release and flaking will result, so a lower VIM value is needed. The asphalt content used is the highest asphalt content because asphalt is able to fill more cavities so that the voids in the mixture become smaller.

D. Index Retained Strength

After determining the optimum asphalt content, the next step is to make a different test based on the optimum asphalt content, namely 7.00% which is then soaked for ± 24 hours at a temperature of ± 60˚C.

The Retained Strength index of the Smooth Stone Matrix Asphalt mixture is obtained from the ratio of the stability of the mixture after soaking for 24 hours to the stability of the mixture soaked for 0.5 hours

From the results of the Marshall Immersion test (Table 4), an Index Retained Strength of 92.71% was obtained with an asphalt content of 7.00%. This Retained Strength Index value has met the 2018 General Bina Marga Specifications, namely a minimum of 90%. Based on these values, it can be concluded that road pavements using concrete waste aggregate in a mixture of fine Stone Matrix Asphalt (SMA) can withstand temperature and the length of time they are submerged in water.

TABLE 4. Results of Index Retained Strength analysis

Asphalt content (%)	Marshall Conventional Stability	Stability of Marshall Immersion	Index Retained Strength %
7,00	728.54	673.45	92.71
7,00	729.44	684.34	
7,00	730.71	671.45	
Average	729.56	676.41	

IV. Conclusion

Aggregate test results from waste concrete meet the requirements for use as a fine SMA material. This can be seen from the results of the aggregate resistance test and the specific gravity obtained. The results of the Stability and Flow tests as well as the VIM and VMA analysis show that the values meet the Bina Marga standards. The results of the Marshall Immersion test show that the Index Retained Strength is 92.71%. Based on these values, it can be concluded that road pavements using concrete waste aggregate in a mixture of fine Stone Matrix Asphalt (SMA) can withstand temperature and the length of time they are submerged in water.

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