Characteristics of the Stone Matrix Asphalt Coarse using the Tabu River Stone North Toraja Regency

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Abstract. The purpose of this research is to make use of Tabu River's stones as a Stone Matrix Asphalt (SMA) mixture. The methodology used in this research is to do multiple inspections and examining characteristics of course, fine, and filler aggregates and devise a mixture composition of Stone Matrix Asphalt. The Marshall testing method was used to determine the mixture characteristics and Marshall Immersion Testing to ascertain Immersion Index (IP) / Residual Strength Index (IKS) / durability of the mixture with optimum asphalt content. The research was done at Road and Asphalt Laboratorium, Department of Civil Engineering, Christian University of Indonesia, Makassar, Indonesia. The research demonstrated that the composition of aggregates produced by Tabu River's Stones at Tikala Sub-District fulfills the specifications of Bina Marga 2018 as a paving material. Marshall Examination showed the characteristic mixture of Stone Matrix Asphalt with asphalt levels of 6.00%, 6.25%, 6.75%, 7.00%. The Marshall Immersion Examination determined that the optimal asphalt level of 7.00% with an immersion index (IP)/Residual Strength Index (IKS)/Durability as high as 95.05% satisfies the Bina Marga 2018 requirements of at least 90%.

1. Introduction

North Toraja Regency is one of the regencies located in South Sulawesi Province. In this area, there are several rivers that have a large stock of rock material, one of which is the Tabu River. Stones from the Tabu River in this study will be used as an aggregate for the mixture of the Coarse Asphalt Stone Matrix. Stone Matrix Asphalt (SMA) is defined as a mixture with an uneven gradation having a high enough coarse aggregate content, thereby increasing the stone-to-stone contact in the mixture, so as to provide an efficient wheel load distribution network. The coarse aggregate particles will blend well with the filler, fiber and / or polymer in a thick asphalt film [1] [2]. The constituent materials of Stone Matrix Asphalt are coarse aggregate, fine aggregate, filler and asphalt. Before being used as a material for road surface coating, characteristic testing must be carried out first to determine its suitability as a surface layer mixture material [3] [4] [5] [6] [7].

The characteristics of the aggregate are very important in the formation of the asphalt mixture, because it can determine the strength of the pavement against stability, the aggregate itself has a proportion of 90% - 95% of the total total weight. Asphalt is also used as a binder for aggregates. Asphalt at low temperatures will become solid or semi-solid, while asphalt at high temperatures will soften. The use of asphalt in research is hard asphalt with penetration of 60/70. This asphalt is asphalt which in use is preheated until it becomes liquid at 350°C, and is solid at room temperature around 25-30 °C. Coarse aggregate is rock that is held in sieve No.4 (4.75 mm). In the implementation of testing the asphalt mixture, the aggregate used must be of the same source and type. Coarse aggregate must consist of crushed stone or crushed gravel which is clean, dry, strong, durable and free from other disturbing materials and 95% of coarse aggregate has one or more broken plane faces and 90% of coarse
aggregate has two or more broken plane faces. Fine aggregate is rock that has passed sieve no. 8 (2.38 mm) and held by sieve no. 200 (0.075 mm). Fine aggregate must be clean, dry, strong, free from clumps of clay and other disturbing substances and consist of grains that are sharp angled and have a rough surface. Filler or filler is material that passes filter no. 200 (0.075 mm). The filler should be dry and free from other irritants. The filler content in the asphalt concrete mixture will affect the mixing, spreading, and compaction processes. In addition, filler affects the elasticity of the mixture and its sensitivity to water [8] [9].

To obtain good pavement quality, a fairly good aggregate is required and is in accordance with the requirements of Bina Marga. One indication of good aggregate is that it is hard enough to withstand wheel friction. In addition, the Ministry of Public Works for Public Housing, through the Directorate General of Highways, accommodates the use of materials around the road construction site in order to exploit the natural potential of the area [10] [11]. In testing the characteristics of the asphalt concrete is carried out in order to determine the properties of the asphalt concrete mixture. The tests include the stability test with the Marshall test apparatus and the Marshall immersion test for the Remaining Marshall Stability (%). In order to obtain the maximum mixture characteristics, it must be tested under conditions where the asphalt percentage of the mixture is optimum [12] [13].

Previous researchers who examined Stone Matrix Asphalt include testing a graded mixture of Stone Matrix Asphalt (SMA) using reclaimed asphalt pavement and coal charcoal waste [14]. Draindown Characteristics of Stone Matrix Asphalt (SMA) Mixture Using Ash and Cement Filler [15]. Alternative Use of Water Hyacinth Fiber in Fine Graded Stone Matrix Asphalt Mixtures Increases Stability of Hot Asphalt Mixtures [16].

The purpose of this study is to determine the characteristics of the aggregate, design the composition and characteristics of the mixture through conventional Marshall testing and residual strength index value through Marshall immersion testing

2. Methodology

2.1. Research location

The location for material collection is the Tabu River, Tikala District, North Toraja Regency. This location is located ± 5 km from the City of Rantepao. The research location can be seen in Figure 1.

![Figure 1. Research Location](image)

2.2. Testing of aggregate and filler characteristics

Examination of aggregate characteristics is carried out on the Sieve Analysis test (SNI ASTM C136: 2012), this test aims to create a coarse aggregate size distribution in the form of a graphic that can show the grain distribution (gradation) of an aggregate using a sieve. Examination of Bulk Specific Gravity (Bulk) and Water Absorption of Coarse Aggregates (SNI 1969: 2016), and Fine Aggregates
The purpose of this examination is to determine the specific gravity value and absorption of coarse aggregates and classify them based on their specific gravity. Sludge Content Inspection (SNI 03-4428-1997) The purpose of the examination is to determine the percentage level of sludge content of a fine aggregate. Wear Testing (Abraation) with Los Angeles Machines (SNI 2417: 2008). The objective of this experiment is to determine the level of aggregate wear using a Los Angeles machine with the ratio of the weight of the object that passes through sieve No.12 (1.7) and its original weight, in%. Flat and Oval Particle Inspection (ASTM D4791-10). The purpose of this check is to determine the flakiness and slack index of a usable aggregate in the asphalt mixture expressed in%.

Testing of Aggregate Adhesiveness to Asphalt (SNI 2439: 2011) This test is intended to determine the adhesiveness of aggregates to asphalt. The adhesiveness of the aggregate to the asphalt is the percentage of the surface area of the rock. The Aggregate Test Passes Sieve No.200 / 0.075 mm (SNI ASTM C117: 2012) The purpose of the test is to measure the percentage of the amount of material in the aggregate that passes the 200 / 0.075 mm sieve so it is useful for planners and implementers road construction. The specific gravity test for the filler refers to the SNI ASTM C136: 2012 reference standard. The purpose of this test is to determine the specific gravity of the filler used as a filler for asphalt mixture.

2.3. Asphalt Characteristics Testing
The methodology used in this research is Penetration Testing at 25°C (SNI 2456: 2011). The purpose of the test is to determine the level of hardness of the asphalt, namely where a needle enters the asphalt at a certain temperature which is loaded with a certain load for a certain time. Flash Point Testing (OC) (SNI 2433: 2011), the purpose of testing is to determine / determine the temperature at which the flame appears on the surface of the test object (asphalt). Softening Point Testing (OC) (SNI 2434: 2011), the purpose of testing is to determine / determine the temperature at which the asphalt starts to soften. Density Testing (SNI 2441: 2011), the purpose of the test is to determine the density of asphalt against distilled water. Ductility test at 25°C (SNI 2432: 2011), the purpose of the test is to determine the elasticity of the asphalt which is expressed by the stretching length of the asphalt that can be reached before breaking.

Weight loss test (%) (SNI-06-2441-1991), the purpose of the test is to determine the oil loss in asphalt due to repeated heating and this test also aims to measure changes in asphalt performance due to weight loss.

2.4. Mix composition
The planning of the Stone Matrix Asphalt mixture used is based on graphical and analytical methods, namely by using a table of limitations of the mixed gradation specifications and then determining the ideal gradation, which is the mean value of each gradation specification boundary. Furthermore, calculating the proportion of each fraction, namely fine fraction and filler fraction as well as mixed asphalt needs. Finally, the mixed gradation is drawn in the form of a gradation graphic to see whether each proportion of the mixed gradation is still within the grading limits according to the 2018 General Specifications.

After all the required ingredients meet the specifications the next step is to calculate the composition of the mixture and the number of test objects.

Calculation of the initial estimate asphalt content:

Effective bitumen content min. = 6%
Effective asphalt content max = 7%

then the draft asphalt content used for the mixture is 6%, 6.25%, 6.50%, 6.75% and 7%.

Based on the calculation of the initial estimated asphalt content for the combined aggregate gradation above, the mixture composition and the proportion of the filler are obtained as in table 1.
Table 1. Composition of the mixture

| Material                  | 6,00% | 6,25% | 6,50% | 6,75% | 7,00% |
|---------------------------|-------|-------|-------|-------|-------|
| Coarse Aggregate (1"; ¼"; ½"; ¾"; ⅜" dan No.4) | 72,57 | 72,43 | 72,29 | 72,14 | 72,00 |
| Fine Aggregate (No.16; No.30; No.50; No.100)  | 12,79 | 12,71 | 12,64 | 12,57 | 12,50 |
| Filler (No.200)           | 8,64  | 8,61  | 8,57  | 8,54  | 8,50  |

2.5. Marshall Testing

Conventional Marshall Testing was conducted to determine the value of resistance, stability and melting (flow), as well as density and pore analysis of the formed solid mixture. In this case the test object or solid asphalt concrete briquettes are formed from certain gradations of mixed aggregate according to the specifications of the mixture. Before making the briquette mixture of asphalt concrete, the optimal asphalt content estimate was sought using the approximate formula. Marshall testing to obtain stability and flow of the specimen follows the SNI 06-2489-1991 AASHTO T245-90 procedure. The calculated Marshall parameters include: Stability, VIM, VMA, and Flow according to the mixed specifications. After all the briquette parameters have been obtained, a graph of the relationship between the asphalt content and its parameters is drawn which can then be determined the optimum asphalt content.

The optimum asphalt content is obtained from the highest value from the VIM relationship graph, the density of the mixture compacted with asphalt content. For optimum asphalt content, the coarse SMA mixture is chosen which has the smallest VIM value because the SMA layer is a wear layer or a surface layer that must be waterproof to maintain the layer underneath.

Marshall Immersion testing refers to SNI 06-2489-1991. The purpose of this test is to determine the ability of the mixture to immersion time, temperature, and water. or residual strength index.

3. Result and Discussion

3.1. Aggregate characteristics

The results of aggregate wear testing using the Los Angeles Abrasion tool, obtained the value of the coarse aggregate resistance to wear from Fraction A was 22.56%, Fraction B was 20.18%, Fraction C was 16.30% and Fraction D was 15.40% the maximum allowable requirement of 30%. From the results of this test it shows that the aggregate is resistant to wear.

Tests for density and absorption of coarse aggregate using two samples, obtained the value for bulk density is 2.71, density for SSD is 2.73, apparent density is 2.77 and water absorption is 0.75%. Meanwhile, the requirement for apparent density is a minimum of 2.5 and a maximum of 3% water absorption. The test results show that the aggregate absorption is small.

The results of testing for density and absorption of fine aggregates showed that the value for bulk density was 2.66, SSD specific gravity was 2.67, apparent density was 2.71 and water absorption was 0.71%. The required requirements are, for bulk density, density, apparent density is at least 2.5 and the maximum water absorption is 3%.

Figure 2 shows the results of the sieve analysis in the form of aggregate gradations and their specifications where the aggregate gradation is in the middle between the upper and lower limits.
Figure 2. Sieve analysis test results

The results of material testing passed No. 200 results in 4.60 requirements, namely a maximum of 10%. The results of this test show that the material is clean from clay and silt. Testing the content of fine aggregate sludge using 2 (two) samples, the average result for the Sand Equivalent (SE) value was 96.19% and the sludge content was 3.81%. requirements, namely a minimum of 60% for Sand Equivalent and a maximum of 5% for sludge content. The results of testing for flaky particles and gaps in coarse aggregates obtained flat particles, namely 4.07%, 3.71%, 4.74%, and 0%. The oblong particles were 4.75%, 4.44%, 3.34% and 0%. The requirement is a maximum of 5%. From the results of the Aggregate Stickiness test to Asphalt. This test is only a visualization that does not go through the calculation process. The adhesiveness value is determined from the surface area of the sample covered with asphalt (less than 95% or more than 95%). From these observations it can be seen that asphalt adheres well to aggregates

3.2. Asphalt characteristics
The asphalt used in this study was 60/70 penetration oil asphalt. Penetration test results obtained for the penetration value of 66.7 mm. The requirements for the General Specifications of Bina Marga 2018 are a minimum of 60 (0.1) mm - a maximum of 70 (0.1) mm. From the results of the ductility test, an average value of 150 cm is obtained. Requirements are Min 100 cm. The results of the asphalt softening point test obtained an average value of 50.2 ° C, namely a minimum of 48 ° C. The Flash Point test results obtained an average value of 2900C. The terms specified in the 2018 Highways General Specifications are Min 2320C. Density test results obtained an average value of 1.051. requirements namely Min 1.0. The results of the weight reduction test of asphalt obtained an average value of 0.434% where the max requirement is 0.8%. The results of penetration testing on the TFOT of the weight of asphalt obtained an average value of 84.7%. Min requirement of 54%.

3.3. Marshall Conventional
The specimens were made with asphalt content for the Stone Matrix Asphalt mixture, namely: 6.00%, 6.25%, 6.50%, 6.75%, 7.00%. The results of the calculation of bulk specific gravity and effective specific gravity can be seen in Table 2. The results of testing the characteristics of conventional marshall which include stability, VIM (Void in Mix), Flow, VMA (Void in Mineral Aggregate), VFB can be seen in table 3. Graph of test results can be seen in Figure 3
Table 2. Bulk Specific Gravity dan Effective Specific Gravity Aggregate

| Testing                          | Content of Asphalt (%) |
|---------------------------------|------------------------|
|                                 | 6.00 % | 6.25 % | 6.50 % | 6.75 % | 7.00 % |
| Bulk Specific Gravity Aggregate | 2.91   | 2.91   | 2.92   | 2.93   | 2.94   |
| Effective Specific Gravity Aggregate | 2.93 | 2.94   | 2.95   | 2.96   | 2.96   |

Table 3. Values of Conventional Marshall Characteristics

| Content of asphalt (%) | Characteristics of a Conventional Marshall Conventional |
|------------------------|--------------------------------------------------------|
|                        | VIM | Stabilities | Flow | VMA |
| 6.00                   | 4.87| 972.01       | 3.50 | 18.94|
| 6.25                   | 4.63| 1280.77      | 2.80 | 19.33|
| 6.50                   | 4.54| 1440.87      | 2.50 | 19.85|
| 6.75                   | 4.39| 1177.85      | 3.10 | 20.31|
| 7.00                   | 4.13| 869.09       | 3.80 | 20.69|

Requirements 4 - 5 (%) Min 600 (kg) 2 - 4.5 (mm) Min 17 (%)

Figure 3. Graph of Conventional Marshall test results

3.3.1. Stability
The value of the stability test as in table 4 is made a comparison graph with the asphalt content value as shown in Figure 3a. The graph in Figure 3a shows that the stability has increased in addition to the asphalt content of 6.5% to 6.5%, then with the addition of up to 7% the stability has decreased. Even though there is a decrease in stability, it is still within the required limit of 600 kg. From the equation of the line in Figure 3a, the maximum stability value is 1386.98 kg.
Based on Figure 3.a, it can be concluded that the use of a small amount of asphalt in the SMA coarse mixture will produce a thin asphalt blanket on the aggregate surface which results in weak interlocking so that the stability of the mixture is small, but if the asphalt increases again, the asphalt blanket becomes thick. so that the bond between the aggregates becomes strong / the stability of the mixture is great. Then if the asphalt increases even more, the asphalt blanket becomes thicker which will result in the bond between the aggregates or the stability of the mixture again decreasing.

3.3.2. Void In mix (VIM)

Table 3 and Figure 3b show that asphalt content increases, VIM will decrease, this VIM value decrease follows the second order polynomial line equation. Although in this test the VIM value decreases, the use of asphalt content of 6% to 7%, the VIM value is still within the limits required. From this figure it can be seen that the use of a lot of asphalt in the asphalt mixture will help fill the voids between the aggregates in the asphalt mixture. Based on this figure and the line equation $y = -0.0846x^2 + 0.3998x + 5.4906$, it shows that every 0.25% increase in asphalt content, VIM decreases. From the regression equation, it is found that the VIM value reaches the minimum limit of 4% at the asphalt content of 7.18%, while the VIM reaches the maximum limit of 5% at the asphalt content of 5.737%.

3.3.3. Flow

The results of testing and analysis of flow as in Table 3 and Figure 3c, show that the increase in asphalt content between 6% and 6.5%, the flow value will decrease, on the other hand, in the addition of asphalt content, 6.5% to 7%, the flow value will increase. The use of asphalt content 6% to 7% is still within the limits to meet the requirements. Based on the figure, it is found that if the use of asphalt in the asphalt mixture is small, the bond between the aggregates is reduced which causes great flexibility. But if the use of asphalt increases, the interaggregate bonds in the mixture become stronger which results in decreased flexibility of the mixture. If the use of asphalt increases even more, the asphalt blanket becomes thicker which results in reduced strength of the mixture but greater flexibility, meaning that the strength of the mixture or stability will be inversely proportional to the flexibility of the mixture or flow. From the equation of the line $y = 4x^2 - 51.72x + 169.8$ shows that for every 0.25% increase in asphalt content, the flow decreases by an average of 1.30 mm until the asphalt content is 6.50%, but if the asphalt content continues to increase, then Flow will increase. The results of the calculation of the regression equation in Figure 9 and Table 28 show that the minimum flow value (curve turning point) is at asphalt content of 6.47% with a value of 2.62 mm.

3.3.4. Void in Mineral Aggregate (VMA)

The results of testing and analysis of VMA show that adding asphalt with a level of 6% to 7% will increase VMA. From the analysis, it can be seen that the more asphalt is used, the bigger the cavity in the aggregate filled with asphalt will increase the VMA value. This is influenced by the use of a lot of asphalt where during mixing and compaction, the asphalt will cover the aggregate, fill the voids between the aggregate and fill the voids in the aggregate. The line equation $y = -0.0729x^2 + 2.7226x + 5.2092$ in Figure 3a shows that every 0.25% increase in asphalt content, the VMA increases. From this equation, it can also be seen that the minimum VMA limit is 17% at 5% asphalt content. The use of asphalt content 6% to 7% fulfills the requirements.

3.4. Determination of the Optimum Asphalt Content

Based on the results of the Marshall test analysis, the characteristics in table 4 can be determined the practical asphalt content in the asphalt concrete mixture, namely the asphalt content that meets all the criteria or characteristics of the marshall mixture and the practical asphalt content is in the range of asphalt content 6.00% - 7.00%. However, the optimum asphalt content was chosen which had the highest VIM value, namely at the asphalt level of 7.0% because the Stone Matrix Asphalt layer was the top layer or protector.
3.5. Residual Strength Index

After determining the optimum asphalt content, the next step is to make the test object based on the optimum bitumen content, which is 7.00% then soaked for ± 24 hours at a temperature of ± 60°C. To get the immersion index value / residual strength index of the mixture. The residual strength index test results can be seen in Table 4.

| Asphalt content (%) | Stability | Conventional | Immersion | RSI  |
|---------------------|-----------|---------------|------------|------|
| 7.00                | 891.97    | 857.66        | 96.15      |
| 7.00                | 869.09    | 835.79        | 96.05      |
| 7.00                | 846.22    | 811.92        | 95.95      |
| Average             | 869.09    | 834.79        | 96.05      |

To get the immersion index value / residual strength index of the mixture. The residual strength index test results can be seen in Table 5. The side strength index value is obtained from the stability ratio test results by comparing the stability of the Marshall specimens after immersing in a temperature of 60ºC in a water bath for 24 hours to the stability of the Marshall specimens by immersing 30 minutes. From the Marshall Immersion test results, the immersion index was 96.05% with asphalt content of 7.0%. This immersion index value has met the standards set by the Research and Development Agency of the Ministry of Public Works 2018, which is at least 90%.

4. Conclusion

a. The test results of coarse aggregate and fine aggregate and filler meet the requirements for mixing the coarse HRA mixture.
b. The test results for the characteristics of the asphalt meet the requirements for the use of a coarse HRA mixture binder.
c. The mixture of Stone Matrix Asphalt (SMA) with predetermined asphalt levels has various compositions so that the Optimum Asphalt Content (KAO) value is obtained with the smallest VIM value that meets the 2018 Bina Marga General Specification standards.
d. Based on the results of the conventional Marshall characteristic test mixture of Stone Matrix Asphalt (SMA), namely the values of Stability, VIM, VMA, and Flow meet specifications. Meanwhile, based on the results of the residual Marshall stability in the SMA mixture is obtained from the comparison of the quotient between Marshall Immersion Stability and Conventional Marshall Stability which meets the general specifications of Bina Marga 2018.

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