The Effect of the use of Gypsum Waste as a Filler Substitution on Stone Matrix Asphalt Coarse

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Abstract. This research is intended to test the use of gypsum waste as a cement filler substitution in a mixture of coarse stone matrix asphalt (SMA). The methodology in this research is to conduct a series of tests for the characteristics of coarse, fine, and filler aggregates, then design the composition of the coarse Stone Matrix Asphalt (SMA) mixture as well as Marshall immersion testing to obtain the remaining Marshall Stability. The results of research conducted at the Road and Asphalt Laboratory of the Faculty of Engineering, Department of Civil, Indonesian Christian University, Paulus Makassar, through the Marshall immersion test obtained a mixture of rough Stone Matrix Asphalt (SMA) with the proportion of gypsum waste as cement filler substitution, namely 100%: 0%, 75%: 25%, 50%: 50%, 25%: 75%, 0%: 100% meets the requirements issued by the Directorate General of Highways of the Ministry of Public Works of the Republic of Indonesia, General Specifications 2018. Test results for Marshall Immersion mixture of Stone Matrix Asphalt (SMA) coarse in all proportions of gypsum waste to obtain Marshall Stability Time meet the limit requirements, namely ≥ 90% so that the mixture is resistant to immersion in water.

1. Introduction
Road pavement is a layer that is above the compacted subgrade which functions to carry the traffic load to the subgrade so that the load received by the subgrade does not exceed the allowable bearing capacity of the soil [1]. Various types of surface coatings used in Indonesia include Stone Matrix Asphalt (SMA). This mixture of SMA consists of three types of thin SMA, smooth SMA and rough SMA. In this study, a modified SMA Kasar was used. For the implementation of mixing, it must meet the requirements set by the Ministry of Public Works of the Republic of Indonesia in the specification of bina marga. These specifications define the conditions and durability of Stone Matrix Asphalt mixtures for surface or wear layers, whether using 60/70 penetration asphalt or modified asphalt. The current design process uses the Marshall testing method (ASTM D6927-06). Basic planning to determine the volumetric parameters of the mixture in the pore in the mixture (VIM), the pore between the mineral aggregates (VMA) and the contact between the coarse aggregate grains. Stone Matrix Asphalt which uses 60/70 penetration asphalt binder using modified asphalt binder is called SMA Mod [2].

The use of waste as an added material for road surface layers has been widely studied by several researchers in Indonesia, among others, the use of added materials with rattan fiber for HRS [3] [4], the use of nickel slag as an added material [5] [6], use of bagasse [7], use of dolomite powder [8], use of fibers [9], use of palm fiber [10] [11].
Stone Matrix Asphalt consists of several materials mixed into one. Therefore, the ingredients of Stone Matrix Asphalt are good quality materials consisting of coarse aggregate, fine aggregate, filler and asphalt.

In a mixture, the function or role of coarse aggregate is as a mortar barrier, that is, if there is pressure on the mixture it will cause the flow tendency to be held back by coarse aggregate so that the amount of coarse aggregate in the mixture greatly affects the stability and strength of the pavement [12]. Fine aggregate must be a clean, hard, clay-free material or other undesirable material. The function of fine aggregate is to fill the cavities between coarse aggregates so as to make the bond stronger between aggregates so as to increase the stability of the mixture [12] [13]. The function of asphalt as a road pavement material is as a binder for asphalt and aggregate or between the asphalt itself, and also as a material for filling the cavities between aggregate grains and pores in the aggregate grains themselves.

Gypsum is an example of an evaporated mineral with a predominant calcium content and the most commonly found is the hydrate type of calcium sulfate with the chemical formula CaSO4·2H2O which goes through a natural formation process. Gypsum board is a form of artificial board based on gypsum flour, which is made using auxiliary materials or adhesives. Gypsum board is a finished product formed through advanced processing of gypsum material which has the advantage of being fire resistant and easy to repair. Gypsum waste which is used as a filler substitution material is a mineral adhesive which has better properties than organic adhesives because it does not cause air pollution. Gypsum which is the main ingredient is calcium sulfate hydrate. As with minerals and stones, gypsum will become stronger when it is pressed. The gypsum waste used in this research is gypsum board with specifications based on SNI 03-6384-2000.

Research that has been done on gypsum waste includes the effect of adding rubber tire waste as an additive to the AC-WC mixture with gypsum filler [14]. Effect of Using Gypsum Powder as a Filler in Asphalt Mixtures [15]. The Effect of Addition of Plastic Waste as Additive to AC-WC Asphalt Concrete with Gypsum Filler [16].

This study aims to determine the effect of using gypsum waste as a filler substitution in the Coarse Asphalt Stone Matrix. The percentage ratio of use of gypsum waste: cement is 0: 100; 25:75; 50:50; 75:25 and 100: 0. The asphalt used is 60/70 pen with asphalt content of 6.0%.

2. Methodology

2.1. Sampling

Coarse aggregate and fine aggregate use aggregate from the Jeneberang River, Bili-bili District, Gowa Regency, South Sulawesi Province. The asphalt to be used is asphalt with a penetration of 60/70. The filler used is a mixture of Portland cement and gypsum waste with a certain level. The gypsum waste used is waste from demolition and building work. An example of gypsum waste can be seen in Figure 1.
2.2. Model Analysis
The analysis was carried out by testing the characteristics of coarse aggregate, fine aggregate, filler and asphalt, where this test refers to the Indonesian National Standard (SNI). If the characteristics of the material meet the specifications then proceed with a mixed design, but if it does not meet the specifications then it is reviewed for several material characteristic tests. Furthermore, the design of the mixed composition is based on the graphical method and the analytical method, namely using a table of limitations of the gradation specifications that pass the filter and then determining the mixed gradation, namely the middle value of each of the gradation specification limits. The mix design composition is based on the aggregate of the selected aggregate mix. The composition of the mixed design in this study is shown in table 1.

| Material     | Proportion of Substitution Cement with Gypsum Waste (%) |
|--------------|--------------------------------------------------------|
|              | 100 : 0 | 75 : 25 | 50 : 50 | 25 : 75 | 0 : 100 |
| Coarse Agregat (gr) | 870.84 | 870.84 | 870.84 | 870.84 | 870.84 |
| Fine aggregate (gr)  | 153.45 | 153.45 | 153.45 | 153.45 | 153.45 |
| Filler (gr) | Gypsum Waste | 103.71 | 77.78 | 51.85 | 25.93 | 0 |
| Cement        | 0 | 25.93 | 51.86 | 77.78 | 103.71 |
| Asphalt      | 72 | 72 | 72 | 72 | 72 |
| Total         | 1200 | 1200 | 1200 | 1200 | 1200 |

The requirements for Marshall testing use the 2018 Highways Specification division. The number of test objects to be used in Marshall testing is 18 pieces, each for testing Marshall conventional 15 pieces and Marshall Immersion 3 pieces. The procedure for implementing the Conventional Marshall test takes a long soaking time that is carried out for 30 minutes at a temperature of 60°C. After the conventional marshall testing was continued with the calculation of the optimum asphalt content and Marshall Immersion. This test aims to determine the ability of resistance and damage to the mixture due to immersion time and temperature, after knowing the optimum level of gypsum waste. For the procedure for implementing the Marshall Immersion test, the immersion time is carried out for 24 hours with a temperature of 60 °C to obtain the Remaining Marshall Stability (%). This test is based on reference standards (SNI 06-2489-1991). The analysis model used is Excel Windows 10.
Analysis of the test results to see whether the test results meet the requirements of the specifications of Bina Marga and the Indonesian National Standard.

2.3. Aggregate Characteristics
The results of the wear test with Los Angeles showed that the value of the coarse aggregate resistance to wear from Fraction A was 5.36%, Fraction B was 3.36%, Fraction C was 2.84% and Fraction D was 4.32%. The test results for each fraction meet the requirements, namely a maximum value of 30%. Thus, it can be seen that the aggregate used as a road surface coating material can withstand wear due to friction between the aggregate and the aggregate or the aggregate with the wheels of the vehicle.

Based on the results of testing for density and absorption of coarse aggregate using two samples, the value for bulk density is 2.62, SSD specific gravity is 2.67, apparent weight is 2.75 and Water Absorption is 1.86%. All test results meet the requirements, namely for Bulk Density, SSD Density and False Density is at least 2.5 and maximum Water Absorption is 3% or it can be said that the aggregate absorption is small.

Based on the results of the Density and Fine Aggregate Absorption test results, the value for bulk density is 2.55, SSD density is 2.58, artificial density is 2.62 and water absorption is 1.11%. All test results meet the 2018 Bina Marga Specifications, namely Bulk Specific Gravity, SSD Specific Gravity and Artificial Specific Gravity are 2.5 and the maximum Water Absorption is 3%.

The results of the sieve analysis test in the form of aggregate gradient and its specifications where the aggregate is between the upper and lower limits shows that the aggregate used contains ideal gradations and meets the requirements.

From the test results, the specific gravity of the cement filler is 3.06% and the density of the gypsum waste filler is 2.58%. The Bina Marga specification does not include a limit value for the specific gravity of the filler. The results of material testing passed No. 200 yields 2.83 so that it meets the specified specifications, namely a maximum of 10% and the material is clean from clay and silt.

The results of testing the equivalent value of sludge using 2 (two) samples showed that the mean value of Sand Equivalent (SE) was 97.28% and sludge content was 2.72%. Both of them meet the 2018 Bina Marga General Specifications for Equivalent Sand, which is a minimum of 50% and a maximum sludge content of 5%.

The test results of flat and oval particle coarse aggregates obtained flat particles namely 2.27%, 3.07%, 2.57% and oval particles namely 2.85%, 2.04%, 2.42%. Both of these values have met the 2018 Highways General Specifications, namely a maximum of 5%.

2.4. Asphalt Characteristics
The asphalt used in this study for the manufacture of the Crude Stone Matrix Asphalt mixture is 60/70 penetration oil asphalt where the characteristic test results are as follows:

The results of the penetration test showed that the penetration value was 66.7 mm. The test results have met the General Specifications of Bina Marga 2018, namely 60 - 70 (0.1 mm) for the asphalt penetration value.

The test results obtained an average value of 50.2 °C. These results are included in the requirements specified in SNI 2434: 2011, namely > 48 °C.

From the results of the Flash Point test, it was found that an average value of 240 was included in the requirements specified in SNI 2433: 2011, namely > 232 °C.

The results of the weight loss test obtained an average value of 0.434%. This result is included in the requirements specified in SNI 06-2441-1991, namely < 0.8%.

The results of the penetration test of the thin film oven test obtained an average value of 84.7% originally. This result falls within the requirements stipulated in SNI 2456: 2011, namely > 54% of the original penetration.

The ductility test results obtained an average value of 150 cm. These results are included in the requirements specified in SNI 2432: 2011, namely > 100 cm.
The results of the specific gravity test obtained an average value of 1.051. These results are included in the requirements specified in SNI 2441: 2011, namely > 1.0.

2.5. Marshall Conventional
The conventional Marshall method has basic principles, namely checking stability, flow and analysis of Void In Mix and Void In Mineral Aggregate.

2.5.1. Stability
Stability is the ability of an asphalt mixture to accept loads until plastic melting occurs while flow is a condition in which a change in the shape of an asphalt mixture occurs due to a load up to a certain time limit [17].

The results of the stability test carried out are made a comparison graph between the level of gypsum waste and the stability value of the test results as in Figure 2.

From Figure 2 it can be seen that the line equation model follows the second order polynomial trend line with the equation:

\[ y = -0.0253x^2 - 2.9928x + 1192 \]  (1)

From equation 1, the stability value for the comparison of 0% gypsum waste and cement 100%, the stability value is 1.192 kg, for a comparison of 25% gypsum waste with 75% cement, the stability value is 1.101.37 kg, for a comparison of 50% gypsum waste with 50% cement, the value is obtained. stability 979.11 kg, for a comparison of 75% Gypsum waste with 25% cement, the stability value was 825.23 kg and for a comparison of 100% Gypsum waste with 0% cement, the stability value was 639.72 kg. From the results of this analysis, it can be seen that the addition of gypsum waste between 0% and 100% decreased stability. Even though there is stability, this value still meets the requirements, namely 600 kg.

From the results of the analysis in Figure 2 shows that the use of the proportion of gypsum waste filler which is increasing will result in decreased stability in the mixture. This is because the addition of gypsum waste filler affects the function of asphalt as an adhesive between aggregates. In other words, the addition of gypsum waste filler cannot be absorbed by the cavities in the mixture which causes the bonds between the aggregate grains to become weak and separate from one another, resulting in a decreased stability value.

2.5.2. Void in mix (VIM)
The results of the VIM test are made a graph of the comparison line between the gypsum waste content and the VIM value as shown in Figure 3.
Figure 3. Relationship between Gypsum content and VIM

From Figure 3 it can be seen that the line equation model follows the second order polynomial trend line with the equation:

$$y = 1 \times 10^{-5}x^2 + 0.0039x + 4.3994$$

From equation 2, the stability value for comparison of 0% Gypsum waste and 100% cement, the VIM value is 4.4%, for a comparison of 25% Gypsum waste with 75% cement, the VIM value is 4.50%, for a comparison of 50% Gypsum waste with 50% cement is obtained. The value of VIM value is 4.62%, for comparison of 75% Gypsum waste with 25% cement, the VIM value is 4.75% and for comparison of 100% Gypsum waste with 0% cement, the value is 4.89%. From the results of this analysis, it can be seen that the addition of gypsum waste between 0% and 100% has an increase in VIM. This value still meets the requirements, namely 4% to 5%.

Based on Figure 3, it can be seen that the smaller the proportion of gypsum waste filler used, the smaller the VIM value and if the proportion of gypsum waste filler used increases, the VIM value will increase due to the low bitumen so that it forms more cavities.

2.5.3. Flow

The results of the VIM test are made a graph of the comparison line between the gypsum waste content and the VIM value as shown in Figure 4.
From Figure 4, it can be seen that the Trand line follows the second order polynomial line equation with the following equation:

$$y = -1E-05x^2 + 0.0155x + 2.8957$$  \hspace{1cm} (3)

From equation 3, the flow value for comparison of 0% Gypsum waste and 100% cement, the Flow value is 2.90 mm, for a comparison of 25% Gypsum waste with 75% cement, the Flow value is 3.28 mm, for a comparison of 50% Gypsum waste with 50% cement is obtained The value of Flow value is 3.65 mm, for comparison of 75% Gypsum waste with 25% cement, a Flow value of 4.00 mm is obtained and for a comparison of 100% Gypsum waste with 0% cement, a flow value of 4.35 mm is obtained.

Based on Figure 4, it can be seen that the greater the proportion of gypsum waste filler, the greater the flow value. The increase in flow in the mixture is due to the addition of the gypsum waste filler content which causes more cavities in the mixture, this is because the gypsum waste filler is not able to fill the cavities in the aggregate grains so that it reduces the performance of the asphalt as an aggregate adhesive which causes the mixture to become more elastic and the flow value increases.

2.5.4. Void in Mineral Aggregate (VMA)

The results of the VMA test are made a graph of the comparison line equation between the gypsum waste content and the VMA value as shown in Figure 5.

From Figure 5 it can be seen that the Trand line follows the second order polynomial line equation with the following equation:

$$y = -3E-05x^2 + 0.0057x + 17.241$$  \hspace{1cm} (4)

From equation 4, the flow value for comparison of 0% Gypsum waste and 100% cement, the VMA value is 17.24%, for a comparison of 25% Gypsum waste with 75% cement, the VMA value is 17.36%, for a comparison of 50% Gypsum waste with 50% cement is obtained The VMA value is 17.45%, for a comparison of 75% Gypsum waste with 25% cement, the VMA value is 17.5% and for a comparison of 100% Gypsum waste with 0% cement, the VMA value is 17.51. The VMA value meets the specifications, which is a minimum of 17%.

It can be seen in Figure 5 that the greater the proportion of the gypsum waste filler used, the greater the cavity in the aggregate filled with asphalt, because the asphalt whose function is besides covering also functions to fill the voids between the aggregates and in the aggregate particles, which means that the asphalt enters to fill the cavities in the rock. Filled a lot because the cavity between the aggregates is not properly filled by the gypsum waste filler.
2.6. Marshall Immertion
Remaining Marshall Stability in the Coarse Stone Matrix Asphalt mixture is obtained from the ratio / ratio / distribution of the stability of the mixture after soaking for a duration of 24 hours with the stability of the mixture soaked for 0.5 hours.

Marshall Immersion is one of the tests to see the stability of the residual marshall (resistance to load and temperature effects) or the durability of a mixture, the result of this test is the stability ratio. This ratio compares the stability of Conventional Marshall specimens after immersing in 60º C in a water bath for 30 minutes to the stability of Marshall Immertion specimens with 24 hours immersion which is commonly called Remaining Marshall Stability.

From the Marshall Immertion test results obtained Marshall Stability Remaining at 0% gypsum waste content with an average value of 98.08%, for an increase of 25% obtained an average value of 97.96%, for waste content obtained an average value of 96.36% where the value of the gypsum waste content 0% - 100% decreased by 0.43%. The stability value of this residual marshall has 50% gypsum with an average value of 97.56%, for gypsum waste content is 75% with an average value of 97.34% and for gypsum waste content 100% meets the General Specifications of Bina Marga 2018. This value can be concluded that the pavement using the aggregate from the Jeneberang river, Bili-bili District, Gowa Regency in a mixture of Coarse Asphalt Stone Matrix can withstand the temperature and duration of being submerged in water.

![Figure 6. Marshall Immersion test results](image)

3. Conclusion
- The aggregate characteristics of the Jeneberang River, 60/70 penetration bitumen, cement filler specific gravity, and gypsum waste filler density as filler substitution material meet the requirements for the Coarse Stone Matrix Asphalt mixture based on the General Bina Marga 2018 Specifications.
- Based on the composition design of the Coarse Stone Matrix Asphalt mixture on the use of gypsum waste as a filler substitution material, with variations in levels of 0%, 25%, 50%, 75%, and 100%. Then obtained the composition of a mixture of coarse aggregate 72.57%, fine aggregate 12.79%, filler 8, 64% and asphalt 6%.
- Based on the results of testing the characteristics of the Coarse Stone Matrix Asphalt mixture through Conventional Marshall testing, the characteristics of the asphalt mixture that meet all specifications are obtained, namely stability, flow, VIM, VMA issued by the Directorate General of Highways in the General Specifications of Bina Marga 2018. And Marshall Immertion testing (Stability Marshall Time).
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