The effect of gradation on the mixed characteristics of HRS-WC using campurejo material

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Abstract. Hot Rolled Sheet (HRS) is a type of hot asphalt mixture as a layer of the road surface that will transmit traffic loads to the layer below to the subgrade. To get good results, the mixture must be designed in accordance with the provisions in the specifications with due regard to the limitations of the limits. The purpose of this study was to determine the effect of gradation on the characteristics of the HRS-WC mixture using gaps. The asphalt content used for the top gradation test was 5.50%, 6.00%, 6.50%, 7.00% and 7.50%, the middle gradation was 5.00%, 5.50%, 6.00%, 6.50% and 7.00% while the lower gradation used asphalt content 4.50%, 5.00 %, 5.50%, 6.00% and 6.50%. The results showed that the use of Campurejo aggregate as seen in the results of the aggregate characteristic test can be used as a mixture for HRS-WC, however in the use of grading it is recommended to use a gradient closer to the middle grading. Likewise, the use of asphalt content uses a percentage of asphalt content above ideal asphalt content. The use of upper and lower aggregate grading results in cavities that are close to specification limits. It is feared that if it is applied in a field with a control that is not the same as in the laboratory, it will result in a cavity outside the specification. In addition, using a middle grading can optimize stability and minimize the use of asphalt.

1. Introduction

Campurejo Hamlet is located in Walenrang District, Luwu Regency, South Sulawesi, where in this hamlet there is a river that has a lot of stock of river stone material. In this study, the material was tested for utilization of the road surface layer for hot mixtures for Hot Rolled Sheet (HRS) mix types. To be used as a surface layer mixture, it is necessary to test the characteristics of the material. As a guideline for inspection, the 2018 Highways Specifications are used [1]. Hot Rolled Sheet (HRS) is a type of hot asphalt mixture as a layer of the road surface that will transmit traffic loads to the layer beneath it to the subgrade [2]. HRS, consists of two types of mixtures, namely HRS-Base and HRS-Wearing Course (HRS-WC) where the gradations used in this mixture are gap gradations and semi-gap gradations. The boundary of this gradation specified in the Highways specification is between the upper and lower limits [3].

This gradation limit is needed to measure the tolerance limit which is a way of stating whether the aggregate can be used. Aggregate consists of coarse, medium and fine fractions with a certain ratio. If the grading graph is inclined towards the upper boundary, then the aggregate can be said to be smoother, and vice versa if the graph is sloping downward, the aggregate can be said to be coarser [4]. The aggregate gradient is the division of the grain size variation of the aggregate expressed as a percent of the total weight. The aggregate gradation affects the size of the cavity in the mixture and
determines the workability and stability of the mixture [5] - [6]. The aggregate gradation can be divided into open graded, continues graded and gap graded. Gap graded is an aggregate grading where the size of the aggregate is incomplete or there is no aggregate fraction or a small amount. The mixed aggregate with gaps has a transitional quality from open graded to continues graded [7].

To get good results, the mixture must be designed in accordance with the provisions in the specification with due regard to the limitation limits [8]. The characteristics of the HRS-WC mixture were determined from the results of the characteristic examination using the Marshall tool. The characteristics of the HRS-WC mixture include Marshall test parameters, namely Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Bitumen (VFB), Stability and Marshall Quotient (MQ).

Research that has been carried out for the HRS mixture includes the characteristics of the HRS-BASE mixture using Dolomite Powder as a filler [9], Study of HRS-WC Mixture Performance Using the Waste of Crude Palm Oil Ash as Filler [10], Marshall Characteristics Test On Hot Rolled Sheet Base Combine Using Nickel Slag For Half Gap Graded [11]. Study Characteristics of Nickel Slag For Gradient Gap on Mixture Hot Rolled Sheet Base [12].

The purpose of this study was to determine the effect of gradation on the characteristics of the HRS-WC mixture using gaps. The asphalt content used for the top gradation test was 5.50%, 6.00%, 6.50%, 7.00% and 7.50%, the middle gradation was 5.00%, 5.50%, 6.00%, 6.50% and 7.00% while the lower gradation used asphalt content 4.50%, 5.00 %, 5.50%, 6.00% and 6.50%.

2. Methodology

2.1 Location of material

The materials came from Campurejo Hamlet, Harapan Village, Walenrang District, Luwu Regency. The location of aggregate collection from the center of Palopo City is approximately ± 18 km. The material is in the form of large chunks with a size of 20 cm to 30 cm and is processed in the asphalt laboratory and roads in the Civil Engineering Study Program of Paulus Indonesia Christian University, Makassar. The filler using portlan cement is obtained from the nearest UKIP campus shop, while the asphalt used by ex-Pertamina Pen 60/70 is obtained from the distributor.

![Figure 1. Material Location](image)

2.2 Characteristics of aggregates and asphalt

Examination of material characteristics is the characteristics of coarse aggregate, fine aggregate characteristics, filler and asphalt. Examination of characteristics and limitations using SNI stipulated in the specifications of Bina Marga 2018 Division 6 Revision 1 [1]. Examination of the characteristics of coarse and fine aggregates is the Abrasion Inspection with a Los Angeles machine with SNI 2417: 2008, adhesiveness of aggregates to asphalt with SNI 2439: 2011, Broken Grains on Coarse
Aggregates with SNI 7619: 2012, Flat and Oval Particles with ASTM D4791-10 Comparison of 1: 5, Material passing No.200 sieve with SNI ASTM C117: 2012, Sand Equivalent Value with SNI 03-4428-1997, Clumps of Clay and Crumbling Grains in Aggregate with SNI 03-4141-1996, Aggregate Passing Sieve No.200 SNI ASTM C117: 2012. Inspection of asphalt characteristics of asphalt penetration at 25°C (0.1 mm) with SNI 2456: 2011, Ductility at 25°C, (cm) with SNI 2432: 2011, Flash Point (OC) with SNI 2433: 2011 , Specific Gravity with SNI 2441: 2011, Weight Loss (%) with SNI 06-2441-1991, Penetration at 25°C (% originally) with SNI 2456: 2011, Ductility at 25°C (cm) with SNI 2432: 2011.

2.3 Mixed Planning
The determination of the composition of the mixture is based on the upper, middle and lower gradations. From the calculation of the ideal asphalt content, the estimated ideal asphalt content is 6% as an estimate to obtain the optimum asphalt content. The test object was made with 5 variations of asphalt content with the difference between each asphalt content being 0.5%. The number of test objects for each mixed gradation is 5 specimens each. The results of mixed planning calculations for each gradation can be seen in table 1, table 2 and table 3.

| Material             | Asphalt Content (%) |
|----------------------|---------------------|
|                      | 5.50    | 6.00    | 6.50    | 7.00    | 7.50    |
| Coarse Aggregate (gr)| 397.43  | 395.33  | 393.23  | 391.13  | 389.03  |
| Fine aggregate (gr)  | 647.03  | 643.61  | 640.19  | 636.77  | 633.35  |
| Filler (gr)          | 89.54   | 89.06   | 88.58   | 88.10   | 87.62   |
| Asphalt (kg)         | 66.00   | 72.00   | 78.00   | 84.00   | 90.00   |
| Total                | 1,200.00| 1,200.00| 1,200.00| 1,200.00| 1,200.00|

| Material             | Asphalt Content (%) |
|----------------------|---------------------|
|                      | 5.00    | 5.50    | 6.00    | 6.50    | 7.00    |
| Coarse Aggregate (gr)| 499.99  | 497.38  | 494.77  | 492.16  | 489.55  |
| Fine aggregate (gr)  | 591.21  | 588.09  | 584.97  | 581.85  | 578.73  |
| Filler (gr)          | 48.80   | 48.53   | 48.26   | 47.99   | 47.72   |
| Asphalt (kg)         | 60.00   | 66.08   | 72.16   | 78.24   | 84.32   |
| Total                | 1,200.00| 1,200.00| 1,200.00| 1,200.00| 1,200.00|

| Material             | Asphalt Content (%) |
|----------------------|---------------------|
|                      | 4.50    | 5.00    | 5.50    | 6.00    | 6.50    |
| Coarse Aggregate (gr)| 597.85  | 594.73  | 591.61  | 588.49  | 585.37  |
| Fine aggregate (gr)  | 539.57  | 536.75  | 533.93  | 531.11  | 528.29  |
| Filler (gr)          | 8.58    | 8.52    | 8.46    | 8.40    | 8.34    |
| Asphalt (kg)         | 54.00   | 60.00   | 66.00   | 72.00   | 78.00   |
| Total                | 1,200.00| 1,200.00| 1,200.00| 1,200.00| 1,200.00|

2.4 Mixed characteristics examination
The characteristics of the mixture in this study followed the requirements of Bina marga 2018 [3] analyzed against the values of Void in Mix (VIM) with a limit value of 4% to 6%, Void in Mineral Aggregate (VMA) with a limit of 18%, Void Filled with Bitumen (VFB), with a minimum limit of 68%, Stability with a minimum limit of 600 kg and Marshall Quotient (MQ) with a minimum limit of 250 kg/mm.
2.5 The optimum bitumen content

The optimum asphalt content is a condition in which an asphalt content in the mixture is able to produce characteristics that meet specifications and is at the approximate calculation of the optimum asphalt content in the plan [13]-[14]. The optimum bitumen content is obtained from the analysis of the characteristics of the mixture for each gradation that meets the specifications. The optimum asphalt content is analyzed for upper, middle and lower gradations.

2.6 Grading effect analysis

After obtaining the optimum asphalt content for each gradation, 3 samples were made again for each type of gradation. The analysis of the effect of gradation was analyzed from the results of testing the characteristics of the mixture using the optimum bitumen content.

3. Result and Discussion

3.1 Aggregate Characteristics

The results of the aggregate wear test obtained consisting of four fractions obtained the value of the coarse aggregate resistance to wear from Fraction A was 6.92%, Fraction B was 4.12%, Fraction C was 4.52% and Fraction D was 3.68%. This shows that the aggregate meets the requirements as a surface layer because it is resistant to wear due to vehicle tire friction and is smaller than the allowable requirement of 40%. Tests for density and absorption of coarse aggregate consisting of two samples showed a value for bulk density (b jb) of 2.64%, SSD specific gravity (b js) of 2.72% and water absorption (pa) of 1.05%. The required requirements are b jb SSD = minimum 2.5%, and pa = maximum 3%. Density and uniformity of fine aggregates obtained the value of b jb = 2.55%, SSD = 2.57 and b js = 2.61% while pa = 0.91%. The results of the absorption test for coarse and fine aggregates meet the requirements, and from these two tests the absorption of aggregate against small water.

Material testing passes No. 200 test results obtained 4.86% and testing of sludge content using two samples obtained an average value of sand equivalent (SE) obtained a value of 96.03% and sludge content obtained a value of 3.97%. Both tests met the requirements. Tests for the flake index of the four test objects obtained the respective values of 8.73%, 7.95%, 9.43%, and 2.11%, while the spike index obtained values of 9.27%, 8.39%, 9.57% and 1.76, respectively. %. While the cement density test obtained 3.05. Testing the combined aggregate grading between coarse aggregate and fine aggregate as shown in Figure 2, it is found that the gradation of the mixed design is between the upper and lower limits.

![Figure 2. Gradation Aggregate](image-url)
3.2 Asphalt Characteristics
In this test, local type 60/70 penetration bitumen was used with the following results. The results of the asphalt penetration test showed that the penetration value was 66.8 (0.1 mm). The ductility test obtained an average value of 119.67, the asphalt softening point test results obtained an average value of 50.5 °C, the flash point test results obtained an average value of 300°C, the asphalt density test results obtained an average value of 1.044, the test results the weight reduction of asphalt using the TOFT tool obtained an average value of 0.14 and the results of penetration testing after reducing the weight of asphalt obtained an average value of 98.50%.

3.3 Mixed characteristics
3.3.1 Upper limit gradation
The results of the analysis and examination of the characteristics of the mixture are as shown in Table 4, the VIM and VFB values for the use of asphalt content of 5.50% and 6.00% do not meet the requirements. The use of 5.5% to 7% asphalt content, the volume of cavities in the mixture is reduced, then the addition of 7.50% asphalt content in the volume of cavities in the mixture increases. Another case with VMA, the asphalt content of 5.5% to 6.00% VMA tends to decrease but due to the addition of asphalt content, the volume of VMA increases again. VFB in the mixture showed an increase in the use of asphalt content between 5.5% to 7.0% then the use of asphalt content of 7.5% VFB decreased again. The large volume of voids filled with asphalt affects the durability, flexibility, watertightness and shear resistance of a pavement. The stability of the mixture increases with the use of asphalt content from 5.5% to 7.0%, then the stability again decreases when using asphalt content of 7%. MQ in this mixture shows an increasing trend in the use of asphalt content of 5.5% to 6.0%, then decreases in the use of asphalt content of 6.5% to 7.5%.

Table 4. Upper Boundary Gradient Mixed Characteristics

| Asphalt content (%) | VIM (%) | VMA (%) | VFB (%) | Stabilities (kg) | MQ (kg/mm) |
|---------------------|---------|---------|---------|-----------------|------------|
| 5.50                | 9.53    | 20.78   | 54.13   | 758.87          | 337.96     |
| 6.00                | 7.12    | 19.74   | 63.93   | 848.85          | 339.15     |
| 6.50                | 5.34    | 19.27   | 72.27   | 932.84          | 322.28     |
| 7.00                | 4.61    | 19.71   | 76.62   | 953.83          | 299.52     |
| 7.50                | 5.16    | 21.21   | 75.70   | 827.86          | 255.11     |

3.3.2 Middle limit gradation
Analysis and examination of the characteristics of the mixture at the middle boundary gradation as in Table 5, it is known that VMA for the use of 5% and 5.5% asphalt content does not meet the requirements, while VFB with the use of 5% asphalt content also does not meet the requirements. From this table it is also known that the addition of asphalt content of 5.0% to 6.5% reduces the volume of cavities in the mixture, then the addition of asphalt content of 7. 0% of the volume of cavities in the mixture increases. Another case with VMA, there tends to be an increase in volume along with the increase in the use of asphalt content. VFB in the mixture shows an increase in volume when used asphalt content between 5.0% to 7.0%. The stability of the mixture in the middle boundary gradation increases along with the use of asphalt content from 5.0% to 6.0%, then the stability again decreases when using asphalt content of 6.5% to 7%. MQ in the mixture with the middle limit decreases when using asphalt content of 5% to 7%.

Table 5. Mixed Characteristic of Middle Boundary Gradation

| Asphalt | VIM | VMA | VFB (%) | Stability | MQ |
|---------|-----|-----|---------|-----------|-----|

Analysis and examination of the characteristics of the mixture at the lower boundary grading as in Table 6, shows that the VIM and VMA values for the use of asphalt content of 4.5%, 5%, 5.5% and 6% do not meet the requirements. From this table, it is known that the use of asphalt content of 4.5% to 6.5% makes the volume of cavities in the mixture decrease along with the increasing use of asphalt content. The use of asphalt content between 4.5% to 5.5% of VMA volume tends to decrease, while the use of asphalt content between 6% to 6.5% of VMA value increases. VFB in the mixture shows an increase in volume when used asphalt content between 4.5% to 6.5%. The stability of the mixture in the middle boundary gradation increases with the use of asphalt content from 4.5% to 6.0%, then the stability again decreases when using asphalt content of 6.0% to 6.5%. MQ in the mixture with the middle limit decreased when using asphalt content 4.5% to 6.5%.

Table 6. The characteristics of the lower bound gradation mixture

| Asphalt content (%) | VIM (%) | VMA (%) | VFB (%) | Stability (kg) | MQ (kg/mm) |
|---------------------|---------|---------|---------|---------------|------------|
| 4.50                | 9.87    | 18.95   | 47.91   | 1,085.81      | 452.83     |
| 5.00                | 7.97    | 18.34   | 56.54   | 1,099.61      | 444.95     |
| 5.50                | 6.64    | 18.25   | 63.60   | 1,105.61      | 417.49     |
| 6.00                | 6.15    | 18.90   | 67.47   | 1,079.81      | 351.12     |
| 6.50                | 5.76    | 19.63   | 70.64   | 1,026.42      | 295.34     |

3.4 The optimum bitumen content

The optimum asphalt content is effective asphalt which functions to cover the aggregate, to fill the pores between aggregates, plus what is absorbed into the pores in the aggregate grain. From Figure 3 it can be seen that the optimum asphalt content of the upper limit gradation is 7.00% which is greater than the optimum asphalt content of the middle limit of 6.50%. This is because the filler in the upper limit gradation has more filler content and the mixture is smoother than the middle and lower limit. From Figure 3 it is also found that the optimum asphalt content of the middle gradation is the same as the lower limit of the gradation, namely 6.5%, this is because the lower gradation is coarser, so the need to fill the cavity in the mixture is more.
Figure 3. The optimum bitumen content

3.5 Effect of grading on VIM
In Figure 4 shows the VIM value for the upper gradient boundary is 3.05%, the middle gradient is 5.5% and the lower gradient is 5.75%. From Figure 4 it is also shown that the lower the gradation of the mixture of higher VIM values. This happens because the upper boundary gradation has a smoother mixture and contains more filler than the middle and lower boundary gradations so as to minimize the cavity formed.

Figure 4. Effect of grading on VIM

Whereas the lower gradation of the mixture tends to be coarse and contains a little filler, as a result it leaves a large cavity. The same thing was also shown in another study [15], coarse mixtures have more air cavities and porous, porous mixtures result in increased permeability to water. The increase in water permeability can accelerate the asphalt blanket to oxidize, the mixture becomes brittle, so that its durability decreases. The size of the pores shows the durability of the asphalt concrete in withstanding traffic loads, wheel friction and wear due to weather and climate. Apart from pores in the mixture, the bitumen content can also affect durability. The thicker the asphalt blanket, the more waterproof the asphalt concrete, so it is very good at resisting wear and tear. But a sheet of tar that is too thick can cause bleeding and slippage. However, the presence of cavities in the mixture is also needed, its function is to place the aggregate grains shifting due to traffic loads or where the asphalt softens due to high temperatures.

3.6 Effect of gradation on VMA
Figure 5 shows that the value of the upper gradation is 18.36%, lower than the middle gradation of 17.78% and the lower gradation of 18.58%. At certain asphalt levels the VMA value is able to reach its optimum point, then it will increase as the asphalt content increases. The VIM value will increase if
the asphalt blanket is thicker, or if the aggregate used is an open grade [2]. VIM also plays a role in determining the durability of asphalt concrete. The smaller the VIM the higher the level of durability. The middle gradation has the lowest VIM because the asphalt content used is less than the upper and lower gradations. This can occur because the middle gradation mixture has a balanced fine and coarse aggregate. So that the aggregates fill each other's cavities and minimize the use of asphalt.

3.7 Effect of gradation on VFB
Figure 6 shows that the VFB of the upper border gradation is 83.43%, which is greater than the middle gradation which is 74.46% and the lower limit gradation is 70.72%. This happens because the use of asphalt in the upper gradation is higher than the middle and lower gradations. The volume of voids filled with asphalt in a mixture is influenced by the asphalt content, the more the use of asphalt, the more VFB volume is used [10]. The middle gradation has a VFB volume greater than the lower gradation, while the asphalt content is low. This may occur because the lower gradation has a mixture that tends to be coarse which can absorb the asphalt into the material, so that the VFB volume becomes small.

VFB will increase along with the increase in the amount of fine aggregate. Increasing the volume of voids filled with asphalt further reduces VIM.

3.8 Grading effect on stability
From Figure 7 it can be seen that the stability of the upper boundary gradation is 889.76 kg, the middle gradation is 1032.30 kg, and the lower limit gradation is 998.84 kg. The more coarsely graded the mixture, the resulting stability tends to increase. Middle gradation provides higher stability than upper and lower gradations, this is possible because middle gradations have balanced aggregates, minimum
voids, high density and the least use of asphalt. In contrast to the upper grading, although the cavity is minimum, the aggregate tends to be fine, causing a lack of internal friction arising from the surface roughness of the aggregate and the interlocking ability of the grains. Likewise with the down gradation, although the aggregate tends to be coarse and can produce friction, but the cavity formed is quite large, consequently affecting interlocking and the resulting stability.

As coarse aggregate increases, its strength and stability at high temperatures decrease. This could happen because the aggregate used is open-graded. Open graded aggregate is a grain distribution whose pores are not well filled [3]. High stability shows the ability to accept loads without changing shape, the better.

### 3.9 Effect of grading on the Marshall Quotient

Figure 8 shows that the MQ of the lower gradation is 374.32 kg / mm, which is greater than the middle gradation of 349.46 kg / mm and the upper gradation of 308.22 kg / mm. MQ is the quotient of the stability and flow values, so to achieve a large MQ requires high stability and low flow, and vice versa. A large MQ indicates that the mixture is stiffer and less deformable. This differs from the above gradations which have lower stability and greater flow, this illustrates that the mixture is less rigid and more deformable. In addition, a large MQ shows the mixture is more resistant to shear or abrasiveness. This rigidity serves to provide a friction force on the wheels of the vehicle so that it does not slip, especially during wet conditions.
4. Conclusion
The use of Campurejo aggregate as seen in the results of the aggregate characteristic test can be used as a mixture for HRS-WC, however in the use of grading it is recommended to use a gradient closer to the middle grading. Likewise, the use of asphalt content uses a percentage of asphalt content above ideal asphalt content. The use of upper and lower aggregate grading results in cavities that are close to specification limits. It is feared that if it is applied in the field with different controls as in the laboratory, it will result in voids outside the specifications. In addition, using a middle grading can optimize stability and minimize the use of asphalt.

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