Analysis the use of steel slag as a replacement of natural aggregate in the asphalt concrete binder course (AC-BC) mixture

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Abstract. Aggregates are the largest component of the flexible pavement structure. The quality of the road is largely determined by the nature and type of aggregates used. Currently, the development of road infrastructure in Indonesia continues to experience increasing amount of natural aggregate use, so this will cause the availability of natural aggregate raw materials to continue to thin out. For that reason, an effort should be made to find alternatives to the use of natural aggregates, one of which is the utilization of steel slag. In this study, it will be examined the characteristics of the steel slag aggregates by referring to the 2018 Bina Marga specifications and the Marshall characteristic test method. This study used steel slag addition with variations of 0%, 50%, 80% and 100%.

The results obtained in this study are that the values of the slag aggregate meet the standard specifications. The use of steel slag at 80% variation in coarse aggregate produces the best stability value which is equal to 2320.19 Kg. Overall, the use of steel slag can be an alternative to the use of natural aggregates. Moreover, steel slag can also be an alternative to an effort to reduce waste.

1. Introduction
Material is an important aspect that greatly influences the quality of road pavement construction, including aggregate type, soil carrying capacity, and asphalt. The selection of the appropriate type of aggregate for use in pavement construction is influenced by several factors, namely gradation, strength, grain shape, surface texture, viscosity to asphalt and cleanliness, and chemical properties. The material used must produce a pavement mixture that is able to withstand strong and durable loads [1]. The biggest component in the construction of pavement is an aggregate. In the classification of processing, the aggregate is divided into two, namely natural aggregate and artificial aggregate. Natural aggregates are aggregates that are produced from rock exploration in nature, whereas artificial aggregates are aggregates obtained from physical or chemical processes of a material so that their properties resemble aggregates. Flexural hardness is very dependent on the form of aggregate and gradation used. Therefore, the shape of the aggregate also affects the skid-resistance of pavement. Aggregates must have properties that are capable of adhering to asphalt [2].

Infrastructure development in Indonesia, particularly road infrastructure, continues to increase in the use of natural aggregates, so this will cause the availability of natural aggregate raw materials to run low. Road improvement by adding additional layers continuously will cause the thickness of the...
pavement layer to get thicker and the required materials to be reduced [3]. For this reason, an effort should be made to find alternatives to the use of natural aggregates, one of which is the utilization of steel slag.

Steel slag is an irregularly shaped cubical rock. This rock is formed from minerals that are used as steel purification from a high kitchen, and then the steel slag is channelled and accommodated in a slag pot. To form splinters, the spread steel slag is sprayed with water. A sudden change in temperature makes the slag steel break and form an aggregate. The steel slag which has a rough shape and pits (porous) will provide a better bond. Steel slag is also more resistant to chemical reactions and temperature changes because the metal has been excreted through high combustion. When viewed from its potential, steel slag is an alternative material that has a high degree of stability, resistant to chemical reactions, and resistant to extreme temperature changes [4].

Steel slag is a good type of aggregates with excellent durability and surface specifications as features of friction and durability. Steel slag has a high effect on road resistance and plays an important role to prevent aggregates from stripping [5]. Porosity in steel slag can increase bonding strength in mixtures. Blends containing steel slag show short-term and long-term Marshall stabilities, and the use of steel slag in the mixture can increase the aging index of asphalt mixture [6]. Steel slag has a number of advantages with high engineering properties, and economically, the steel slag may be cheaper if utilized in urban roads, but it would be expensive for rural roads due to the transportation charges [7].

Besides the aggregates, the quality of asphalt used also largely determines the quality of the mixture. Asphalt is a brownish black material that is thermoplastic, so it will soften and melt when heated to a certain temperature. Asphalt freezes again if the temperature drops. Asphalt used in road construction has important physical properties, including: consistency, long-lasting or weathering resistance due to weather, degree of hardening, and resistance to water [8]. Asphalt with low penetration is used in areas with hot weather or high volume traffic, whereas asphalt cement with high penetration is used for areas with cold weather or low volume traffic. In Indonesia, asphalt cement is generally used with 60/70 penetration [9].

For all above reasons, this study is intended to explore the properties of steel slag aggregates for road pavement mixture. The aggregate test follows the 2018 Bina Marga specification standards. This research was conducted to see the characteristics of the mixture with Marshall parameters. In this study, four variations of slag mixture are made, namely 0%, 50%, 80% and 100%. In variations 2 and 3, steel slag aggregates are only used in coarse aggregates and combined with natural aggregates, whereas in variation 4 steel slag aggregates will be used in coarse and fine aggregates.

2. Method
In this study, the method is the characteristics of steel slag material used as aggregate for road pavement mixtures were examined of properties. Checks are carried out on coarse aggregates and fine aggregates, while material checks are carried out to determine the characteristics of the material used as a mixture that meets the requirements specified in the specification.

![Figure 1](image1.png)

(a) Aggregate Filter; (b) Los Angeles Machine; (c) Ball Mill Machine.

Tests conducted include abrasion value with *los angles* machine, specific gravity, absorption and affinity aggregate of asphalt. The testing is carried out on coarse and fine aggregates. Because aggregate slags are chunks, they must be grounded using a ball mill machine.
Examination of characteristic values is guided by the 2018 Bina Marga specification standards. Requirements for specifications can be seen in Table 1 below:

**Table 1. Requirements for aggregate characteristics of Bina Marga Specifications (2018).**

| Test                              | Requirements value for aggregate characteristic |
|-----------------------------------|-------------------------------------------------|
| Bulk Specific Gravity, (gr/cm³)   | -                                               |
| Absorption, (%)                   | Maks. 3                                         |
| Abrasion, (%)                     | Maks. 40                                        |
| Affinity Aggregate of Asphalt, (%)| Min. 95                                         |

In the previous studies, the use of slag steel aggregates in asphalt mixes was 10%, 20%, and 30%. The results obtained by adding 30% slag aggregate still meet the requirements [10]. The results of this analysis provide the still small use of steel slag in the mixture, so it needs to be developed with the use of more steel slag aggregates to reduce the use of massive natural aggregates.

The prepared aggregate is then mixed with asphalt using the Marshall Method following the 2018 Bina Marga Specifications. Asphalt mixture variations in this study are:

a) Variation 1, 100% Natural Aggregate (NA).

b) Variation 2, 50% Slag Aggregate (SA) and 50% Natural Aggregate (NA).

c) Variation 3, 80% Slag Aggregate (SA) and 20% Natural Aggregate (NA).

d) Variation 4, 100% Slag Aggregate (SA).

In variations 2 and 3, steel slag aggregates are only used in coarse aggregates and combined with natural aggregates, whereas in variation 4 steel slag aggregates will be used in coarse and fine aggregates.

This study uses continuous gradations following the 2018 Bina Marga Specifications. Gradations used can be seen in Figure 2.

![Continuous graded distribution](image_url)

**Figure 2. Continuous graded distribution.**

**2.1 Marshall Test**

The Marshall test is an important step in determining the characteristics of an asphalt mixture. The Marshall Design method for porous asphalt mixes is the most widely used as mixed-design method for experimental laboratory studies at present [11]. Asphalt mixture characteristics which are Marshall parameters are density, stability, flow, void in mixture (VIM), void in mineral aggregates (VMA), void...
filled with asphalt (VFA), and Marshall Quotient. Requirements for the Marshall Characteristics of 2018 Bina Marga Specifications can be seen in Table 2 below:

Table 2. Bina Marga specifications (2018) of asphalt concrete binder course of flexible pavement.

| Properties         | Requirements Value for Marshall characteristic |
|--------------------|------------------------------------------------|
| Density (g/cm³)    | -                                              |
| Stability (Kg)     | Min. 800                                       |
| Flow (mm)          | 2 - 4                                          |
| VIM (%)            | 3 - 5                                          |
| VMA (%)            | Min. 14                                        |
| VFA (%)            | Min. 65                                        |
| MQ (Kg/mm)         | Min. 250                                       |

3. Result and Discussion

3.1 Steel Slag Aggregate Characteristics

To find out the aggregate characteristic values used in asphalt mixtures, several tests were conducted. This is needed to see the feasibility of the aggregates used in the mixtures. Tests carried out include specific gravity, aggregate wear, absorption and adhesion to asphalt. In Table 3, it is presented the result of testing the steel slag aggregate characteristics.

Table 3. Result of steel slag characteristics.

| Test                              | Specification | Result |
|-----------------------------------|---------------|--------|
| Coarse Aggregate                  |               |        |
| Bulk Specific Gravity, (gr/cm³)   | -             | 5.405  |
| Absorption, (%)                   | Maks. 3       | 1      |
| Abrasion, (%)                     | Maks. 40      | 20.60  |
| Affinity Aggregate of Asphalt, (%)| Min. 95       | 97     |
| Fine Aggregate                    |               |        |
| Bulk Specific Gravity, (gr/cm³)   | -             | 3.378  |
| Absorption, (%)                   | min. 95       | 2.229  |

Based on Table 3, it can be seen that the value of slag aggregate characteristics obtained meets the specifications. Therefore, the aggregates can be used in an asphalt mixture.
Figure 3. (a) Asphalt Penetration 60/70; (b) Natural Aggregate; (c) Steel Slag Aggregate

3.2 Characteristics of Asphalt Mixture
After checking the characteristics of the material used, the next step is to plan the asphalt mixture using the Marshall method.

3.2.1 The Determination of Optimum Asphalt Content
This test will produce optimum asphalt content in each mixture variation including VIM, VMA, VFA, stability, flow and MQ values. Optimum asphalt content values are obtained from the average asphalt content that meets all the properties of the mixture. The optimum asphalt content (KAO) in each variation can be seen in Figure 4.

Figure 4. (a) KAO 100% Natural Aggregate; (b) KAO 50% Slag Aggregate; (c) KAO 80% Slag Aggregate; (d) KAO 100% Slag Aggregate

In figure 4, it can be seen the optimum asphalt content values in Variations 1, 2, and 3 have met the specified specifications. However, in Variation 4, the optimum asphalt content cannot be determined because the VIM and VFA values cannot meet the 2018 Bina Marga specifications.

3.3 Marshall Test Optimum Asphalt Content
Marshall testing on optimum asphalt content (KAO) was carried out to determine the best Marshall characteristics in each mixture variation. Marshall KAO testing is only on variations that meet the 2018 Bina Marga specifications. From the results of this test, it will be obtained a mixture of steel slag...
aggregate variations that are suitable for use in the Asphalt Concrete Binder Course flexible pavement. Following are the Marshall testing results for each variation using optimum asphalt content.

**Table 4.** Result of marshall characteristic on optimum asphalt content (100% natural aggregate).

| Marshall Characteristic | Results | Specification |
|-------------------------|---------|---------------|
| Optimum Asphalt Content (%) | 5.35 | - |
| Density (g/cm³) | 2.37 | - |
| Flow (mm) | 3.85 | 2 - 4 |
| VIM (%) | 3.10 | 3 - 5 |
| VMA (%) | 17.62 | ≥ 14 |
| VFA (%) | 82.42 | ≥ 65 |
| Stability (Kg) | 1245.21 | ≥ 800 |
| MQ (Kg/mm) | 323.66 | ≥ 250 |

**Table 5.** Result of marshall characteristic on optimum asphalt content (50% slag aggregate).

| Marshall Characteristic | Results | Specification |
|-------------------------|---------|---------------|
| Optimum Asphalt Content (%) | 5.85 | - |
| Density (g/cm³) | 2.70 | - |
| Flow (mm) | 3.22 | 2 - 4 |
| VIM (%) | 4.06 | 3 - 5 |
| VMA (%) | 21.63 | ≥ 14 |
| VFA (%) | 81.26 | ≥ 65 |
| Stability (Kg) | 1937.06 | ≥ 800 |
| MQ (Kg/mm) | 603.38 | ≥ 250 |

**Table 6.** Result of marshall characteristic on optimum asphalt content (80% slag aggregate).

| Marshall Characteristic | Results | Specification |
|-------------------------|---------|---------------|
| Optimum Asphalt Content (%) | 5.80 | - |
| Density (g/cm³) | 2.99 | - |
| Flow (mm) | 2.92 | 2 - 4 |
| VIM (%) | 4.76 | 3 - 5 |
| VMA (%) | 23.16 | ≥ 14 |
| VFA (%) | 79.47 | ≥ 65 |
| Stability (Kg) | 2320.19 | ≥ 800 |
| MQ (Kg/mm) | 800.66 | ≥ 250 |

Based on tables 4, 5 and 6, it can be seen the value of the characteristics of Marshall was produced at each of optimum asphalt contents. The effect of steel slag gives different results on each mixture variation, and the testing results using optimum asphalt content show that all variations of the mixtures have met the specifications set by Bina Marga 2018.
3.4 Marshall Test Analysis
After Marshall test results have been obtained on each variation of the mixture, an analysis is carried out to see the effects of the slag steel aggregates on the characteristics of asphalt mixtures.

3.4.1 The Effect of Slag Aggregate on Density Value
In figure 5, it can be seen the comparison of density values for each mixture variation. The density value continues to increase with the increasing levels of steel slag in the mixture. The highest density is found in the addition of 80% steel slag mixture of 2.99 g/cm³. This is due to the specific gravity of the large steel slag, so more steel slag content is used, the density value will increase.

![Figure 5. The effect of slag aggregate on density value.](image)

3.4.2 The Effect of Slag Aggregate on VIM Value
In figure 6, it can be seen that the value of Void in Mix (VIM) on each variation of the mixture has met the specified requirements. VIM value continues to increase with the increasing levels of steel slag in the mixture. This is because the steel slag is porous, causing more cavity volumes in the mixture. A good VIM value is needed to provide enough space for the compaction process caused by traffic loads.

![Figure 6. The effect of slag aggregate on VIM value.](image)

3.4.3 The Effect of Slag Aggregate on VMA Value
In figure 7, it can be concluded that the effect of adding steel slag to the mixture gives higher Void in Mineral Aggregate (VMA) values than that of the natural aggregates. VMA value continues to increase with increasing levels of steel slag. This is due to the nature of the steel slag which has a cavity (porous) so that the fine aggregate fraction in the mixture does not fill the empty cavities between the aggregates. VMA values that are close to the minimum limit indicate that the mixture has more durability, while VMA values that are too high will result in the mixture experiencing a large deformation. However in this case, the VMA value in each mixture variation still meets the specifications set by the 2018 Bina Marga of ≥14%.
3.4.4 **The Effect of Slag Aggregate on VFA Value**
Figure 8 shows the comparison of VFA values in each variation of the mixture which has fulfilled the 2018 Bina Marga minimum limit of ≥65%. The use of steel slag aggregates in the mixture tends to decrease in the VFA value. This decrease is due to the nature of the slag steel which has many cavities, so that smaller particles fill the cavities in the aggregate and cause the aggregate not covered by asphalt to the maximum.

3.4.5 **The Effect of Slag Aggregate on Stability Value**
The use of steel slag as a mixture of pavement tends to increase the value of stability. It can be seen in figure 9 that the highest stability is found in an 80% steel slag mixture of 2320.19 kg, and it can be seen that the stability values in each variation still meet the minimum limit of ≥800 kg. The physical properties of hollow and irregularly shaped steel slag aggregates cause good interlocking. Therefore, the addition of higher levels of steel slag will result in a road more able to withstand deformation due to traffic loads that work on it without undergoing a change in shape or tendency to be rigid.
3.4.6 The Effect of Slag Aggregate on Flow Value

In figure 10, it can be seen that the flow value in each variation still meets the specified requirements. The flow value decreases with increasing levels of steel slag in the mixture. Mixtures that have low flow values and high stability tend to be stiff, brittle and prone to cracking, while mixtures that have high flow values and low stability tend to be plastic and easily deformed due to traffic loads on them.

![Figure 10. The effect of slag aggregate on flow value.](image)

3.4.7 The Effect of Slag Aggregate on Marshall Quotient

In figure 11, it can be seen that all variations of the mixture meet the specified requirements. MQ values that are too large indicate a mixture which tends to be rigid so that it is not easily deformed, and vice versa. The highest MQ value is found in the variation of 80% steel slag mixture that is equal to 800.66 kg/mm and the lowest MQ value is found in a mixture of 100% natural aggregate, which is 323.66 kg/mm.

![Figure 11. The effect of slag aggregate on marshall quotient.](image)

4. Conclusions

Based on the research that has been carried out, the tests for the values of round steel slag aggregate characteristics have fulfilled the specified specifications so that they can be used on asphalt concrete binder course (AC-BC). The use of steel slag aggregate gives high density values due to the specific gravity of the large steel slag. In addition, low abrasion value in steel slag aggregates can increase the stability value in the mixture. This increased stability is also caused by the characteristics of hollow steel slag and irregular shape which cause good bonding interlocking. The highest stability value was found in the addition of 80% slag steel in the amount of 2320.19 kg.

The optimum asphalt content in each variation of the mixture produces different values. KAO value in variation 1 is 5.35%, in variation 2 is 5.85%, in variation 3 is 5.80%. Meanwhile, in variation 4 the optimum asphalt content cannot be identified because VIM and VFA values do not meet specifications of Bina Marga 2018. The resulting characteristic values for all variations with optimum asphalt content meet the specified specifications. The addition of steel slag aggregates in the mixture results in a higher VIM, VMA and Marshall Quotient value.
Based on the results of this study, the use of slag aggregates in asphalt mixtures can be an alternative to the use of natural aggregates. If the use of slag aggregates can be applied, this will help protect the nature from damages caused by the continuing use of natural aggregates. The use of slag aggregate can also become an effort to reduce waste that can damage the environment.

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