Aging effect condition on hot asphalt mixtures marshall (AC-BC) performance by using slag

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Abstract. The technology of using waste for road construction by using slag as an aggregate substitute can reduce costs as well as environmentally friendly technology. Hot mix asphalt pavement (HMA) will experience aging both short and long term, this study was conducted to see how the effects of aging in hot asphalt mixtures by using slag. There were three types of mixtures in this study with different levels of slag, aging test specimens were conditioned by the AASHTO R30 testing method. The results of testing the slag characteristics with SEM that the slag surface is roughness than the natural aggregate, also the slag has porosity on its surface indicates that the slag has stronger adhesion properties with the asphalt. In hot asphalt mixtures with slags obtained by increasing the slag percentage, the optimum bitumen content will be smaller but if viewed from the optimum Marshall stability value at a slag percentage of 20%. Then the mixture was conditioned for short-term aging with a higher Marshall stability value compared to normal conditions with void in mixture (VIM) values, while for long-term aging the stability value decreased compared to normal conditions with VIM values approaching normal conditions without aging.

1. Introduction
The construction and maintenance of road infrastructure by using waste from by-products of industrial activities has become an important issue in recent years. On the other hand, the limitations of raw materials for development and increasing aggregate demand for road construction that occur in the future cause the need to find alternative materials. The use of natural ingredients continuously in large quantities can consume natural rock materials which are limited. Therefore, using artificial aggregates such as slag is being considered.

Slag waste is the remainder of the steel making process which falls into the category of hazardous and toxic materials. In 2010, slag production in Indonesia was only around 800 thousand tons per year. Meanwhile, in Japan, the slag production reached the number of 20 million tons, where every ton of steel production produced 20% of slag waste [1].

Asphalt mixture using steel slag shows better results compared to the one using natural aggregates, where the slag used as coarse aggregate in the Split Mastic Asphalt (SMA) mixture can improve Marshall stability and decrease the Marshall flow value and has a higher Marshall Quotient (MQ) value, which is an indicator of high stiffness and resistance to permanent deformation [2].
Steel slag has a rough surface and texture compared to ordinary aggregates because of the high surface porosity of the slag, so that the asphalt is absorbed on the surface which results in better adhesion bonds with asphalt compared to ordinary aggregates based on Scanning Electron Microscope (SEM) test [3]. From the results of X-Ray Diffraction (XRD) and X-ray fluorescence (XRF) testing, slag contains aluminium oxide together with other metal elements in the steel slag which is a high abrasive resistance contributor. CaO/SiO2 implies that steel slag is substantially alkaline. This will certainly provide adhesion properties of steel slag in the asphalt mixture [4]. But on the other hand, slag containing Fe is susceptible to corrosion, so it is better that a mixture containing slag is not used on the surface layer that is directly related to the environment.

The use of slag as an aggregate with an increase in the percentage of slag in a mixture resulted in an increase in the Marshall stability and Marshall Quotient (MQ). This is because, according to the Scanning Electron Microscopy (SEM) test, the slag has a rough surface compared to natural aggregates [5]. Although technology that utilizes slag has many benefits, in Indonesia this technology is not widely known. Based on the characteristics of the slag material, it is necessary to evaluate the performance of the asphalt mixture that utilizes slag as an aggregate, both under normal and aging conditions.

2. Materials and Methods
The material used in this study was Pertamina 60/70 asphalt pen, a new aggregate from PT Kadi, and an artificial slag aggregate type EAF from PT Krakatau Steel. Marshall test was conducted to test the performance of asphalt mixture. The design of hot asphalt mixtures starts from testing the characteristics of 60/70 asphalt pen, the new aggregate, and slags with gradations. The reference used is the intermediate Laston gradation (AC-BC) specified in the General Specifications of Roads and Bridges, Bina Marga, Year 2010 Revision 3 [6].

There were three variations of asphalt mixtures based on the percentage of slag. The slag varied with 10%, 20% and 30% of the total mixture volume. This mixture test is carried out in accordance with the test standards for hot asphalt mixtures to obtain the Optimum Asphalt Level (OAL) value in the planning with the Absolute Density Approach method. After obtaining the OAL value, tests were carried out under normal, short-term aging and long-term aging conditions. The details can be seen in Figure 1.

3. Data Analysis
3.1. Material Test
This research used aggregate from PT KADI International obtained from the Klari area, Karawang, which was taken from Gunung Batu, West Java. The test results showed that coarse aggregates and fine aggregates to be used in this study met the aggregate requirements for hot asphalt mixtures specified in the General Specifications of Roads and Bridges, Bina Marga, Year 2010 Revision 3. Meanwhile the asphalt used was the oil asphalt with Penetration grade 60/70 from Pertamina. From the test results, it was found that the characteristics of the 60/70 oil asphalt pen fulfilled the requirements for Hard Asphalt Type 1, 60/70 Asphalt Pen as listed in the General Specifications of Roads and Bridges, Bina Marga, Year 2010. The test of slag aggregate characteristics is referred to the General Specifications of Roads and Bridges, Bina Marga, Year 2010 because until now, the latest slag guideline is the PdT-04-2005-B. The Use of Iron and Steel Slag Aggregates for Hot Asphalt Mixtures so the test results above showed
that the coarse slag aggregate met the General Specifications of Roads and Bridges, Bina Marga, Year 2010. Meanwhile, for the fine aggregate, the specific gravity for filters No.8 (2.36 mm) to 2.00 (0.75mm) was smaller than the requirement of at least 3.3. This was because the fine slag aggregate contains more carbon compared to the coarse slag aggregate [7].

3.2. Design of Mixture Gradation

The design of the slag aggregate used was the same as the new aggregate gradation. Because for aggregate slag all filter sizes were available, AC-BC gradations which referred to the combined aggregate gradations for asphalt mixtures with due regard to the limits set in the General Specifications of Roads and Bridges, Bina Marga, Year 2010 were used, as shown in Figure 2.

![Figure 2. Design of the HMA-Slag Mixture Gradation](image)

In this study, the percentage of slag addition was 10-30%. From this determination, a combined gradation of slag and aggregate was made, where the difference in density between the new aggregate and the slag aggregate would result in a difference in volume with the same weight and the amount of absorption of different water would have an effect on the optimum asphalt level from the result of Marshall test. Based on this, the determination of the weight of Hot Mix Asphalt Slag (HMAS) mixture was made in volume unit so it was expected that it would not affect the characteristics of the HMAS mixture. The calculation of mixture weight with the difference in density was carried out in volume unit, where initially the total weight of the aggregate of 1146 gram was changed to volume unit by dividing the specific gravity on each filter number so that the volume unit was obtained. After that, the weight of each aggregate either slag aggregate or aggregate was multiplied by the specific gravity of each filter number.

3.3. Marshall Test of AC-BC and Slag (HMAS) Mixture

The Marshall test result with the addition of slag levels of 10-30% can be seen in Table 1. Then, from the Marshall test, the optimum asphalt level (OAL) was obtained for the Marshall immersion test, where the test was carried out under normal conditions.

Based on the Marshall test results, it was found that by increasing the slag aggregate content in the HMA slag mixture, the density was greater. This was caused by several things, including: slag can store heat longer, so when in the process of mixing and compaction, the temperature drop occurs more slowly than the mixture of HMA without using slag. This indirectly increased the ease of mixing aggregate and asphalt (workability).

| Percentage Passing The Filter | Filter Size (mm) |
|-----------------------------|-----------------|
| Upper Limit                 | Fuller Curve    |
| Lower Limit                 | Middle Value    |

**Table 1. Result of Mixed HMA Slag Marshall Test in OAL condition**
The details can be seen in progressive oxidation which made the void in the asp compared to the normal conditions. This was because the asphalt contained in the mixture had undergone oxidation was compacted. This resulted in a smaller VIM value because the asphalt in the mixture had been compacted. This was probably due to the decrease in Voids in the Mineral Aggregate (VMA) value. The increase in slag aggregate content in the mixture also resulted in a decrease in the value of the Void in the asp aggregate which had already filled with smaller aggregate particles.

Marshall stability tends to increase at the level of 20% slag aggregate. This is probably due to the friction that occurs in the slag material is greater. This proves that the slag aggregate has a higher stiffness compared to the usual HMA mixture. This is also indicated by an increase in the MQ value, which means that the asphalt that is attached and absorbed into the aggregate can strengthen the mixture so that the mixture is more resistant to deformation. Resistance to changes in water and temperature is indicated by the higher residual Marshall stability value with increasing slag aggregate levels in the mixture. This indicates that the mixture using slag aggregate has a better durability value, although the chemical element of this slag has a weakness against corrosion, it turns out that the asphalt mixture has higher resistance to air and moisture (environment).

3.4. Test of Short- and Long-Term Aging in AC-BC Mixtures with Slag

Further test to find out the Marshall characteristics in the mixture using slag due to aging conditions was carried out by using an oven, where the test referred to AASHTO R30, where the short-term aging test was carried out on the test material with loose / not compacted condition with the test temperatures of 135ºC for 4 hours. While for long-term aging, the test was carried out after compaction with test temperatures of 85ºC for 5 days.

The results of Marshall characteristics test in the STA condition met the requirements of the General Specifications of Roads and Bridges, Bina Marga, Year 2010. However, the VIM value was smaller than the specification by 3-5. This was because after the mixture was conditioned, the new aging mixture was compacted. This resulted in a smaller VIM value because the asphalt in the mixture had been oxidized during the aging process. Whereas in the test in the LTA condition, VIM values increased when compared to the normal conditions. This was because the asphalt contained in the mixture had undergone progressive oxidation which made the void in the asphalt smaller but resulted in an increased VIM value. The details can be seen in Figure 3.
The stability value in STA condition decreased compared to stability value under normal condition. This was because the slag aggregate’s interlocking properties decreased after aging. Whereas, seen from the stability value, the same thing with the STA condition also applied to the LTA condition, which was decreasing compared to the normal condition. Decreasing stability on the one hand is beneficial for mixture resistance to fatigue, because with the reduced stability value, the asphalt oxidation that occurs is not too high which causes the asphalt to not become harder and brittle. This can be seen in Figure 4.

4. Conclusions
Based on the analysis and discussion of the effect of slag material on the performance of hot mixtures in either normal or aging conditions, some results are obtained. First, the increase in the percentage of slag in the AC-BC mixture in normal condition can increase the residual Marshall value which indicates that the mixture has better durability, therefore it has higher resistance to air and moisture. Second, based on the results of the Marshall test for short-term aging condition, there is a decrease in VIM values. This is because the mixture is conditioned by aging under loose test object condition. This results in a smaller VIM value because the asphalt in the mixture has been oxidized during the aging process. In the long-term aging condition, there is an increase in VIM values compared to the normal condition due to the asphalt contained in the mixture has undergone a progressive oxidation which makes the Void Filled in
Asphalt smaller but the Void in Mix value increases. The last, the stability value in STA and LTA conditions decreased compared to the stability value under normal condition. This was because the slag aggregate's interlocking properties decreased after aging. This shows that the mixture using slag in aging conditions will reduce the value of stiffness in the mixture which indicates that the asphalt oxidation that occurs is not too high. This causes the asphalt hard to harden and more brittle.

Acknowledgement
The Author acknowledgement support from Lembaga Pengelola Dana Pendidikan (LPDP)/ Indonesia Endowment Fund for Education, Kementerian Keuangan Republik Indonesia.

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