The effect of using steel slag waste on stability in porous asphalt mixture

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Abstract. The road is an access that connects one place to another in one land. According to Law Number 38 of 2004 concerning roads, the definition of a road is a land transportation infrastructure which includes all parts of the road including auxiliary buildings and equipment. But it often happens that road construction is not accompanied by good maintenance, giving rise to various kinds of problems. One of the road damages that occurred in Indonesia was caused by standing water on the road surface. This is because Indonesia has a high level of rainfall. Therefore, the use of porous asphalt as a road surface layer can be used as an effort to deal with this problem. The use of steel slag waste material is to reduce the use of natural aggregates and to reduce B3 waste, which is increasing day by day. In this study, the coarse aggregate retained on the 3/8” and No. 4 filters in the porous asphalt mixture was replaced with steel slag aggregate with variations of 0%, 25%, 50%, 75% and 100% with variations in asphalt content of 5%, 5, 5%, 6%, 6.5% and 7%. The purpose of this study was to determine the effect of using steel slag waste on the stability level of porous asphalt pavements. The specification used in this study is the Australian Asphalt Pavement Association (2004). The results of the research that has been done, it shows that the use of steel slag as a substitute for coarse aggregate is retained by the 3/8” and No. 4 on porous asphalt mixtures can increase the stability value of porous asphalt for all variations in existing asphalt content.

1 Introduction

Indonesia is a developing country with a wet tropical climate and high rainfall intensity. Damage to roads, especially flexible pavements, is usually caused by a poor drainage system on the pavement, especially coupled with the increasing volume of vehicles. Porous asphalt technology is considered to be able to overcome this problem because it allows water to seep into the top layer (wearing course) vertically and horizontally. Porous asphalt is a new generation in flexible pavement, porous properties are obtained because this mixture uses less fine aggregate than ordinary mixtures so that it has a larger cavity / pore content which is expected to have high roughness and pores can function as drainage channels in the mixture [1]. This porous asphalt layer can effectively provide a higher level of safety, especially when it rains so that aquaplaning does not occur resulting in a rougher surface roughness, and can reduce noise (noise reduction). Porous asphalt pavement has two functions, namely as a management of rainwater runoff and to support traffic loads [2]. Porous asphalt is asphalt that has low stability but has a high permeability value caused by the large number of cavities in the mixture [3]. Porous asphalt is a hot mix of open graded asphalt which is modified with a certain ratio of asphalt mixture. The porous asphalt mixture is spread and compacted on a waterproof pavement surface so that water that falls on the porous asphalt surface seeps into the underlying layer.

Along with the times, the steel industry has experienced growth due to the increasing need for steel itself. This development goes hand in hand with the increase in waste generated by the steel industry. Steel slag is solid waste produced by steel processing which can reach 10-15 tons per day. Waste steel (steel slag) has characteristics that resemble natural aggregates, so it can be used as an aggregate substitute material, this is regulated in SNI 8379: 2017 [4] concerning Specifications for selected materials (selected materials) using slag for road construction. Steel slag is one of the industrial solid wastes with the largest output in the world. Steel slag has good characteristics of wear resistance, particle shape, and porosity. Steel slag when used for asphalt pavements not only solves the problem of insufficient aggregate quality in asphalt concrete mixtures but can also provide increased pavement performance in terms of hardness and wear resistance on asphalt [5].

Asphalt concrete mixtures using steel slag exhibit better mechanical properties and have a better ability to store heat than natural aggregates, thus it can be concluded that steel slag has the potential to replace natural aggregates [6].

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Several studies and research have been conducted to see the effect of steel slag addition on marshall characteristics. The effect of using steel slag waste as a substitute for coarse aggregate of ½ and 3/8 sizes in hot rolled sheet wearing course (HRS-WC) mixtures [7]. Research on the Marshall characteristics of porous asphalt mixtures with the addition of polyurethane and marshall characteristics on porous asphalt [8-9]. The difference between this research and previous research is the use of porous asphalt with a mixture of steel slag waste as a partial replacement for coarse aggregate, while the previous research used a mixture of HRS-WC asphalt with the use of steel slag waste as a partial replacement for aggregate [7].

2 Research method

The implementation of this research was conducted at the Transportation and Highway laboratory, Civil Engineering Department, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta. This research was divided into several stages of research including literature studies, stages of preparation of tools and materials, examination of materials, mix design, manufacture of hot mix specimens and marshall checks. The steps of research can be presented in the flowchart of Fig. 1.

The steel slag used in this study served as a substitute for certain portions of coarse aggregate. The testing steps are presented as below.

2.1 Preparation

Coarse aggregate, fine aggregate, asphalt, and steel slag were the materials used in this study. The maximum nominal size of aggregate used is 1/2 " (12.5mm). The asphalt used was asphalt produced by Pertamina with 60/70 penetration, while coarse and fine aggregates were obtained from Clereng, Kulon Progo. The steel slag used was in the form of steel slag waste from steel processing plants. Preparation of tools used to test materials such as coarse aggregate, fine aggregate, asphalt, and steel slag waste, and testing of Marshall test specimens were confirmed to be in good condition, clean and calibrated.

2.2 Material testing

The material testing phase was carried out with several predetermined testing methods. Natural aggregate and steel slag testing consisted of specific gravity, water absorption, and abrasion testing (Los Angeles) for coarse aggregates. The testing of modified asphalt involved specific gravity, softening point, penetration, ductility, and oil loss at each percentage of asphalt.

2.3 Mixture design

In this study the coarse aggregate retained on the 3/8" and No. 4 filters in the porous asphalt mixture was replaced with steel slag aggregate with variations of 0%, 25%, 50%, 75% and 100% with variations in asphalt content of 5% to 7.5% with a difference of 0.5%.

2.4 Sample making

At this stage, the aggregate was prepared following the grading analysis plan determined according to the AAPA specifications in Table 1. The variations of the steel slag mixture content of 0%, 25%, 50%, 75%, and 100% of the total weight of aggregate that retained by sieve 3/8" and No. 4. After this step, the aggregate was heated to 165 °C. Then the aggregates mixed with asphalt. The next step was to pound the mixture 2 × 75 times in the mold, and each type of mixing has three samples.

2.5 Sample Testing

Marshall Characteristics is a test used as an indicator to find the stability value of a mixture and is a compressive test device equipped with a proving ring, a stability watch, and a flow meter used to measure the flow.

Fig. 1. The steps of research.
3 Result and discussion

3.1 Asphalt test results

The tests consisted of specific gravity, softening point, oil loss, ductility, and penetration tests (Table 2).

<table>
<thead>
<tr>
<th>Testing</th>
<th>Specifications</th>
<th>Result</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration</td>
<td>60-70</td>
<td>65,3</td>
<td>mm</td>
</tr>
<tr>
<td>Softening Point</td>
<td>&gt;48</td>
<td>50</td>
<td>°C</td>
</tr>
<tr>
<td>Oil Loss</td>
<td>Max 0,4</td>
<td>0,145</td>
<td>%</td>
</tr>
<tr>
<td>Ductility</td>
<td>100-200</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>&gt;1,0</td>
<td>1,052</td>
<td>-</td>
</tr>
</tbody>
</table>

3.2 Aggregate test results

The aggregates tested in this study consisted of fine and coarse aggregates. Tests had been carried out in the form of specific gravity, water absorption, and Los Angeles. The results of aggregate testing are presented in Table 3. In a nutshell, the aggregates used in this study had fulfilled the requirements stipulated in SNI 1969-2008 [12], SNI 1970-2008 [13], and SNI 2417-2008 [14].

<table>
<thead>
<tr>
<th>Testing Type</th>
<th>Specifications</th>
<th>Result</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregate</td>
<td>Abrasion LA (%)</td>
<td>≤ 40</td>
<td>27,3</td>
</tr>
<tr>
<td>Bulk Specific Gravity, Sd</td>
<td>≥ 2,5</td>
<td>2,553</td>
<td></td>
</tr>
<tr>
<td>SSD Specific Gravity, Ss</td>
<td>≥ 2,5</td>
<td>2,626</td>
<td></td>
</tr>
<tr>
<td>Apparent Specific Gravity, Sa</td>
<td>≥ 2,5</td>
<td>2,755</td>
<td></td>
</tr>
<tr>
<td>Absorption</td>
<td>≤ 3</td>
<td>2,79</td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>Abrasion LA (%)</td>
<td>≤ 40</td>
<td>2,506</td>
</tr>
<tr>
<td>Bulk Specific Gravity, Sd</td>
<td>≥ 2,5</td>
<td>2,633</td>
<td></td>
</tr>
<tr>
<td>SSD Specific Gravity, Ss</td>
<td>≥ 2,5</td>
<td>2,703</td>
<td></td>
</tr>
<tr>
<td>Apparent Specific Gravity, Sa</td>
<td>≥ 2,5</td>
<td>1,925</td>
<td></td>
</tr>
<tr>
<td>Absorption</td>
<td>≤ 3</td>
<td>2,506</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Steel slag test result

Material steel slag that was used in this study came from Ceper District, Klaten Regency, Central Java Province.

The results of steel slag aggregate testing are presented in Table 4.

<table>
<thead>
<tr>
<th>Testing Type</th>
<th>Specifications</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregate</td>
<td>Abrasion LA (%)</td>
<td>≤ 40</td>
</tr>
<tr>
<td>Bulk Specific Gravity, Sd</td>
<td>≥ 2,5</td>
<td>3,032</td>
</tr>
<tr>
<td>SSD Specific Gravity, Ss</td>
<td>≥ 2,5</td>
<td>3,076</td>
</tr>
<tr>
<td>Apparent Specific Gravity, Sa</td>
<td>≥ 2,5</td>
<td>3,170</td>
</tr>
<tr>
<td>Absorption</td>
<td>≤ 3</td>
<td>1,436</td>
</tr>
</tbody>
</table>

The average value of Abrasion test results steals is 37.1%, this value meets the specifications set by Bina Marga [15], namely 40%. In addition, several other tests were carried out, such as dry bulk specific gravity (Sd) value of 3.032, surface saturated specific gravity (Ss) value of 3.076, apparent specific gravity (Sa) value of 3.170, and water absorption value of 1.436%.

3.4 Results and analysis

3.4.1 Cantabro loss (CL)

The cantabro loss testing was carried out to determine the loss of weight of the test object after an abrasion test with a Los Angeles machine. Before the specimen was inserted into the Los Angeles machine drum, it was first weighed to get the weight before being abrasion (Mo). Then the specimen was inserted into the Los Angeles machine drum without a steel ball. The Los Angeles machine is then run at speeds between 30-33 rpm as many as 300 rounds. After finishing the specimen is removed and weighed after abrasion (Mi). The standard testing refers to ASTM C-131 standard [16]. Cantabro Loss test result can be seen in Fig. 2.

From the graph above it can be seen that the value of Cantabro Loss (CL) will decrease with increasing asphalt content used. With an increase in steel slag substitution from 0% to 100% it will result in a decrease in the value of CL, this is because the density level is greater, the stability is higher and the process of releasing aggregate will decrease. The specimens in the Cantabro Loss test are presented in Fig 3.

3.4.2 Asphalt flow down (AFD)

Asphalt flow down (AFD) is the maximum percentage of asphalt content that is mixed homogeneously with aggregate without asphalt separation.

In this test, a mixture of steel slag asphalt with varying levels of 0%, 25%, 50%, 75%, and 100% was used for 1 specimen for each variation of asphalt flow down. Test result AFD is presented in Fig. 4. The increasing of asphalt content can make the AFD value is decrease, this is because the adhesion and cohesion between aggregate increase.
3.4.3 Marshall stability

The stability value is an important parameter used to assess the resistance of an asphalt mixture to plasticity and ability of the asphalt mixture to withstand deformation due to traffic loads [17-18]. The value of stability will increase with increasing levels of steel slag substitution into the porous asphalt mixture for all variations in asphalt content. This is in accordance with the research, which states that steel slag will increase the level of stability in hot mix mixtures when compared to natural aggregates [19].

Stability will increase with increasing asphalt content, up to 5.5% asphalt content then the stability value will decrease. This condition occurs because there are no more voids to be filled with asphalt. The higher the steel slag substitution, the stability value will increase. This is because the steel slag material has a higher specific gravity than natural aggregate so that the mixture will become denser and the stability will be higher. In conditions of asphalt content percentage of 6.5% and 7% stability will increase until the percentage of steel slag substitution reaches 50% and then decreases. This decrease occurs because some of the asphalt will be absorbed by steel slag which does have larger cavities than natural aggregate (Fig. 5).
3.4.4 Marshall flow

Flow indicates sample deformation value due to the applied load until it achieves the collapse limit expressed in millimeters (mm) on a flowmeter watch. Flow value can be influenced by several factors, including asphalt content, aggregate surface shape, asphalt viscosity, the temperature at compaction, and aggregate gradation. Fig. 6 shows that the Flow value will tend to increase with increasing levels of steel slag substitution. This is in line with Rahmawati's research [7].

3.4.5 Marshall quotient

Marshall Quotient is the quotient between stability and flow values and known as an indicator showing the approach of the rigidity value and the flexibility value of an asphalt porous mixture. The higher the MQ value of a mixture is, the more rigid the mixture becomes. The lower the MQ value of a mixture is, the more flexible the mixture becomes.

MQ has a decreasing trend, this happens because the steel slag substitution will increase the flow value which results in a decrease in the MQ value.

4 Conclusions

The results of tests carried out on porous asphalt mixtures using steel slag waste as a partial replacement for aggregates showed that increasing the level of substitution of steel slag waste from 0% - 100% resulted in a trend of increasing value of asphalt flow down (AFD), marshall stability and flow and decreasing of cantabro loss. The optimum conditions occur in the steel slag content with 5.5% asphalt content and 50% steel slag substitution.
References


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