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# Evaluation of the Use of Steel Slag and Pyrophyllite Materials in the Porous Asphalt Mix

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*Abstract*—**The rapid population growth in some urban areas has caused major changes in land use, in which many productive agricultural lands have been converted into residential or business. These conditions have reduced the land's ability to absorb and be infiltrated by rainwater particularly during rainy season, resulting flooding and decrease of groundwater.**

**The purpose of this study was to develop the optimum porous asphalt mixture design, which should provide a satisfactory level of load carrying capacity and permeability capability. To achieve the objective, three scenarios of asphalt porous mix designs were conducted using: (a) standard material combined with pyrophyllite, (b) standard material combined with steel slag, (c) varied gradations of standard materials. A total of 60 specimens per scenario (180 total of specimens) were prepared in accordance with the Marshall Test procedures. Each sample is then tested to evaluate its permeability capability and its Marshall characteristics performance. The test results showed that: (a) all mix scenarios had a good permeability and Marshall performance but the stability, in which no sample performed above 500 kg, (b) the optimum aggregate proportion to result in a good performance is 65% - 35% both for pyrophyllite and steel slag mixes, (c) samples with steel slag has the highest stability, and (d) mixture with AAPA specification resulted as the best performing. Reviewing the test results further studies are needed in the following areas: (a) the use of asphalt additive to improve the performance of asphalt porous, and (b) investigate the chemical reaction between steel slag asphalt mixture**

Keywords— **asphalt porous, slag materials, pyrophyllite, Marshall stability, and permeability**

## I. Introduction

The rapid population growth in some urban areas has caused major changes in land use, in which many productive agricultural lands have been converted into residential or business. These conditions have reduced the land's ability to absorb rainwater, resulting flooding and decrease of groundwater.

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Since roadways in urban areas can make up to 20% of the lane coverage, it will contribute significantly to the occurring of flooding and the reduced ground water.

Therefore, the use of porous pavement may have some benefits. Porous pavement has actually been practiced since the 1960s in Europe for the construction of airport runway (Zang, et al, 2012). Currently about 90% of the construction of new road network in the Netherlands have adopted porous pavement (Huurman, et al, 2009). The road rehabilitation policy in Japan is directed toward the use of porous pavement (Nakahara et al, 2004).

A study by Collins et al (2009), found that the use of porous pavement reduces peak flow rate of runoff (peak flow rate) from 52% to 81%. In addition, the use of porous pavement has also reduced the volume of tracks that vary from 38% to 78%. Djakfar et al (Djakfar, 2012) studied the base couse gradation scenario that provides the best perfoming for use in the road base material. Raab and Partl (2012), and Cerezo et al (2012) studied the use of porous pavement to increase the safety for driver during rainy season by reducing the splashing effect of water.

Reviewing previous studies, few research on porous asphalt pavement hat have been directed to improve its infiltrating capability. The issue becomes more important in developing countries with large population in which most people live in the urban areas with poor infrastructure and very populated. Therefore, the performance of porous asphalt with regards to its capability to be infiltrated by water during rainy season needs to be investigated. In addition, the use of local and by-product aggregate to contribute to the environment is worthwile to be investigated.

## II. Objective Of Study

The objective of the study is as follows:

a. To investigate the optimum proportion of pyrophyllite and crushed stone for use in the porous asphalt mix
b. To investigate the optimum proportion of the steel slag and crushed stone for use in the porous asphalt mix
c. To investigate the performance of the above materials for use in the porous asphalt mix in terms of Marshall Criteria and permeability capability

# III. Methods

To achieve the above objectives, the following steps were pursued:

a. Prepare materials for all scenarios
b. Test the materials to meet the specification
c. Prepare test samples based on Marshall Procedures for Sample preparation
d. Test each sample for its permeability capability
e. Test each sample based on Marshall criteria to determine the optimum asphalt content for each scenario
f. Prepare Marshall samples based on the determined optimum asphalt content
g. Test specimens to determine its Marshall criteria and permeability capability

Table 1 presents the materials and scenario used in this research. Asphalt contents were varied from 4% to 7%, assuming that the optimum asphalt content will fall between that range. The coarse aggregate, which becomes the focus of this research, were varied not only based on its types but also its gradation. There are 3 types of coarse aggregates used: pure crushed aggregate, combined crushed aggregate with pyrophyllite, and combined crushed with steel slag. The combination is presented in Table 1. The gradation was also varied based on the Australian Standard for porous asphalt (AAPA), California Standard for porous asphalt (CaIAPA), and the Bristish Standard for Porous asphalt (BS).

All materials were tested to meet the specification. Only materials meet the specs were used in the study. For Marshall specimens, there were 3 specimens for each scenario, totaling 180 samples for all test treatments. Before the samples were tested for Marshall characteristic, they were tested for their permeability capability (ASTM, 2007).

**Table 1**. Materials Used in the Research

| No | Materials | Scenarios/Remarks |
|---|---|---|
| 1 | Asphalt | Asphalt Content: 4%, 5%, 6%, and 7% |
| 2 | Mix of Crushed Stone and Pyrophyllite | Combined Gradation: 100/0, 80/20, 60/40, 40/60, 20/80 |
| 3 | Mix of Crushed Stone and Steel Slag | Combined Gradation: 100/0, 80/20, 60/40, 40/60, 20/80 |
| 4 | Crushed Stone using AAPA Gradation | |
| 5 | Crushed Stone using CaIAPA Gradation | |
| 6 | Crushed Stone using BS Gradation | |

Once the permeability test was conducted on specimens, they were then tested using Marshall procedure. After all samples were tested using Marshall apparatus, the next step was to evaluate its characteristics based on stability, flow, void in mineral (VIM), and void in mineral aggregate (VMA). This step was pursued to determine the optimum asphalt content. In this research the optimum asphalt content was determined using graphical method.

Once the optimum asphalt content for each scenario was determined, as many as 3 specimens were prepared again for each scenario using the optimum asphalt content. The Marshall characteristics obtained from the samples become the characteristics of the materials, and evaluations were based on this result.

# IV. Results

Figures 1 to 3 present the permeability coefficient of the mix based on the scenario. As can be seen from the figures, mixtures with steel slag materials have better permeability compared with those with pyrophyllite, and mixtures prepared using AAPA specification provides better permeability capability compared with others.

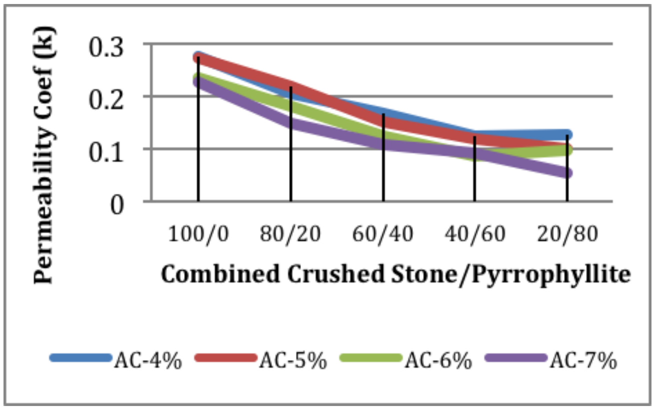


**Figure 1. Permeability Coefficient for Pyrophyllite mix aggregate**

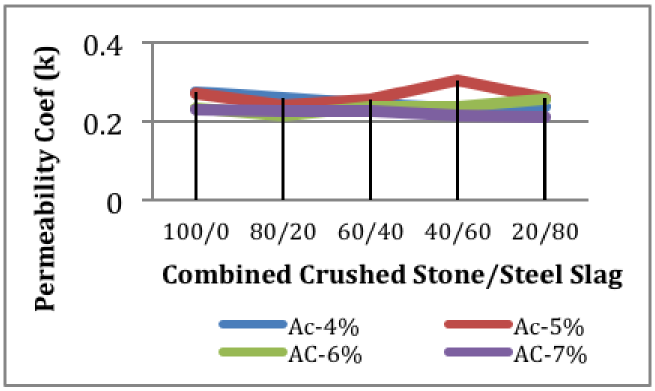


**Figure 2. Permeability Coefficient for steel slag mix aggregate**

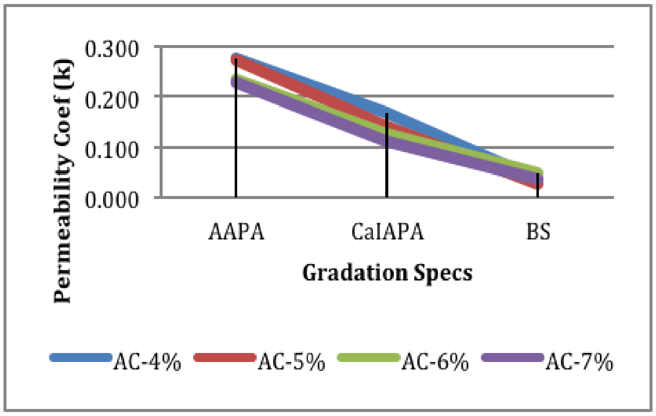


**Figure 3. Permeability Coefficient for specs-based aggregate**

**Table 3**. Marshall Characteristics and permeability capability for each scenario

| Marshall Characteristics | Scenario* | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| VIM | 18.1 | 24.8 | 18.5 | 20.3 | 22.3 |
| Flow | 3.1 | 3.6 | 3.0 | 3.4 | 1.3 |
| Stability | 235.2 | 430.8 | 175.3 | 381.4 | 389.6 |
| Marshall Quotient | 75.2 | 132.1 | 64.9 | 115.1 | 312.9 |
| Permeability Coefficient | 0.125 | 0.254 | 0.235 | 0.157 | 0.040 |

*Notes: A = Porous asphalt with pyrophyllite, B = porous asphalt with steel slag, C= AAPA, D = CaIAPA, E = BS

## A. *Determination of Optimum Asphalt Content*

There are several methods to determine the optimum asphalt content, such as the Asphalt Institute Method (AI, 1990), and others. In this study, a graphical method was used and the results were presented in Table 2.

**Table 2**. Optimum Asphalt Content for each scenario

| No | Scenario | Optimum Asphalt Content (OAC) | Remarks |
|---|---|---|---|
| 1 | Porous asphalt using combined crushed stone and pyrophyllite aggregate | 4.6 % | @66%pyro phyllite |
| 2 | Porous asphalt using combined crushed stone and steel slag aggregate | 4.5% | @ 66% steel slag |
| 3 | Porous asphalt based on AAPA specification | 5.5% | |
| 4 | Porous asphalt based on CaIAPA specification | 4.4% | |
| 5 | Porous asphalt based on BS specification | 4.3% | |

After the optimum asphalt content was determined for each scenario, the next step was preparing 3 specimens each to determine the Marshall characteristics based on this optimum asphalt content. Table 3 and Figures 4 to 6 show the Marshall characteristics for each scenario and its permeability capability.

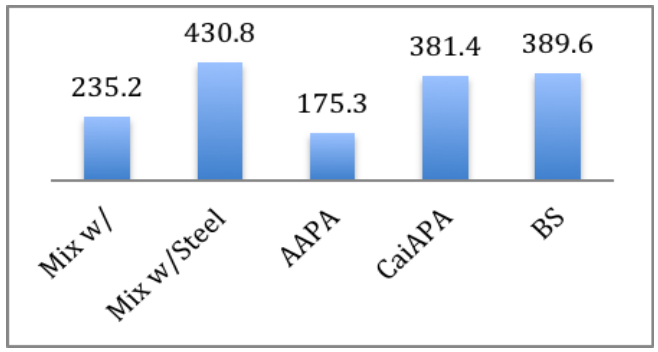


**Figure 4. Marshall Stability for each mixture scenario**

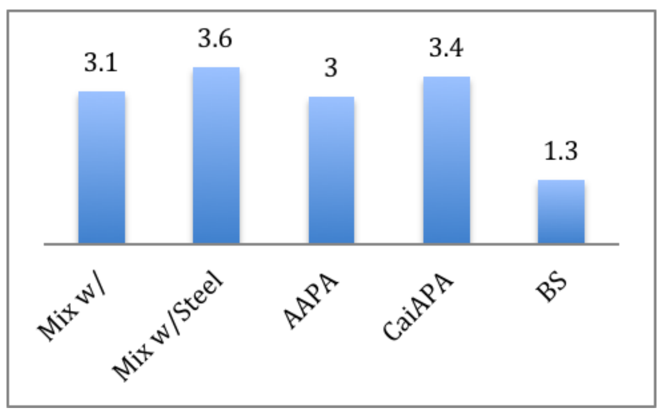


**Figure 5. Flow for each mixture scenario**

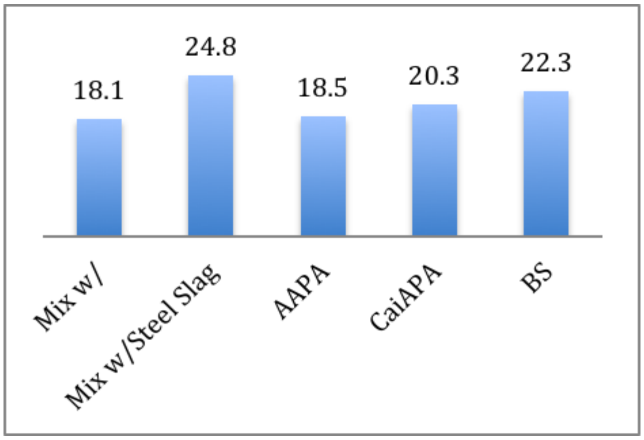


**Figure 6. VIM for each mixture scenario**

## V. Discussions

Figure 4 shows that all mix scenarios produced stability less than 500 kg, which is relatively low compared with the Indonesian standard for asphalt mix requirements of 800 kg. Steel slag mixture, however, produced mix with highest stability, while asphalt mix prepared using AAPA specification produces the lowest stability. The lower stability was expected considering the use of more open gradation in porous asphalt mixture, for the benefit of higher void, which is in the range of 18 to 22% compared with 3 to 5% for standard asphalt mixture.

Another important finding is when one looks at the steel slag material performance. It not only produces the highest stability, but also the highest permeability coefficient, which means that the mix performs not only in terms of strength but also in terms of permeability which is the main purpose of the porous asphalt mix.

The inability of the mixtures to produce higher stability may be due the lack of aggregate internal force action due to the missing of intermediate aggregate size filling among the aggregate, which is encountered in the traditional mixtures. When the load is applied to the mixture during Marshall test, the internal force by aggregate interaction does not fully occur. In addition to the lack of the intermediate aggregate size, the lack of binding among the aggregate, which is supposed to be generated by the asphalt may also be the main cause. In the mixture, asphalt not only functions to glue the aggregate but also to bind together the aggregates. In other words, for the aggregates to produce internal forces, two conditions should exist: the aggregate gradation structure and the binding effort by asphalt. Since the aggregate gradation has been designed to have more open, as in the case of porous mix, then the binding effect of the asphalt should be the last effort. Asphalt used in the porous asphalt should have the binding effort better than the regular mixes. In Indonesia, the commonly used asphalt for mixture is AC 60/70, as in the case of this research. As shown from the result of this study, AC 60/70 seems inadequate to be used in the Porous mix asphalt. It seems lack the ability to glue the aggregate to produce a more massive structure.

Figure 4 above also shows that the hardest the materials the better it is to produce high stability. The steel slag mix aggregate has performed better that that of pyrophyllite mixes since it has better material quality. It also suggests that to produce a better porous asphalt mix, the material requirement should be more stringent.

Evaluating the result of this study, one may be concerned with the stability and VIM produced with the mix. Having large VIM in the mix and low stability will make the mix susceptible to immediate permanent deformation and other future performance. Therefore, one may suggest that the application of the porous mix would be better for low volume roads such as residential or rural roads. Considering that residential areas are where the flooding and water shortage commonly occur, the application of porous mix should be most suitable one.

Future direction of the study, however, should be to improve the performance of the mix in terms of its stability. It may be achieved by either using of better aggregate or improving the performance of asphalt, or both. For improving the asphalt performance it may be achieved by improving the gluing capability by adding some additive to the mix.

## VI. Conclusion

Based on the research result above, the following conclusion can be drawn:

1. Steel slag porous asphalt mix provides the best performing mix, both in terms of stability and permeability capability.
2. Porous mix using BS specification seems to provide better performance compared with those of Australian Standard (AAPA) and California (CaIAPA).
3. For present time, the use of porous asphalt mix may suit for low-volume and residential roads
4. Future research should be directed to improve the performance of the porous asphalt by improving the gluing capability of the asphalt

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