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Impact of Aggregate Gradation on the Performance of Porous Asphalt Mixture

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Abstract – Porous Asphalt Mixture (PAM) is preferred in Singapore due to its water-permeable property and many studies are being conducted to improve its capability. Performance of PAM on pathways under the influence of aggregate gradation was studied in this research, especially in terms of permeability, strength and moisture susceptibility. Three gradations were prepared and each gradation was trialled thrice. PG-76 asphalt binder was used for the study and the properties were tested using Permeability Testing Machine and Marshall Apparatus following the ASTM standards. Subsequently, results from the three gradations were compared to come up with a gradation that gave the optimum properties. It is shown from the results that the gradation with the smallest amount of fines and higher percentage of coarse aggregate with size 2.36-4.75 mm and 9.5-13.2 mm gave the optimum performance for pathways in Singapore. The performance of this gradation may also be further investigated by using different types of asphalt binder.

Keywords – Porous Asphalt Mixture (PAM); Permeability Test; Marshall Stability; Moisture Susceptibility Test

1 INTRODUCTION

1.1 BACKGROUND
Following the recent flooding case in several parts of Singapore due to heavy downpour, use of pervious pavement to manage surface ponding is developing in recent years. Inappropriate surface water drainage becomes a concern as public safety is compromised. Not only public safety, negative impacts are also felt by other sectors e.g. driving conditions.

Porosity of pavement heavily relies on aggregate gradation of the mixture. Open gradation design is used to produce pavemnet, which has a much lower fraction of fines content as compared to dense asphalt mixture. Porous feature of PAM is generated by low content of fine aggregates, while mixture strength is partially compromised. Contradictory effect between these two properties gives a challenge for the study to find an optimum gradation such that the pavement is not only permeable but also desirable in strength.

Besides strength and porosity, moisture susceptibility of a pavement is also a critical factor in tropical countries like Singapore, where rainfall occurs frequently.

Pavement performance must be maintained on rainy days, otherwise pavement becomes moisture-laden. Many road accidents occurred due to slippery roads.

1.2 OBJECTIVES
This study aims to find a suitable gradation in the aggregate blend that can provide pavement with a desirable level of porosity, strength and moisture susceptibility. This study focuses on pavement with low traffic volume (e.g. footway and bicycle way).

1.3 SCOPE
Literature review, methodology adopted in the testing, and the results of the study are covered in the following sections. The research focuses mainly on effect of aggregate fines content on asphalt mixture’s strength, permeability, and moisture susceptibility.

2 LITERATURE REVIEW

Studies done by several researchers showed that aggregate gradation plays a big role on the mixture design properties of PAM. It has been studied that Voids in Coarse Aggregate (VCA) and porosity are affected by the gradation [1]. Furthermore, air voids are suggested to be present in the range 18% - 24% as reported by Xing et al. [2]. On the other hand, strength as one of the important properties is compromised due to a high level of air voids which decreases the binder contact area with the aggregate. Therefore, the conditions and purposes of the pavement must be well understood in order to design a gradation that focuses more either on strength or porosity [3]. It is stated by Ruiz et al. that the gradation must not only contain large portion of coarse aggregate, but also low enough fines to avoid the blockage of air voids [3]. However, there has not been reported in any of the studies regarding how low the amount of fines should be in the gradation, especially under the condition of low-strength pathways in Singapore.

ASTM D7064 standard on Practice of Open-Graded Friction Course (OGFC) was followed and the minimum criteria listed must at least be fulfilled throughout the tests [4]. A permeability value greater than 1.157 mm/s is recommended, while the retained Marshall stability is evaluated as well.
3 METHODOLOGY

Three aggregate gradations were formulated. Three samples were made for each gradation and then put through a permeability test, Marshall stability test and moisture susceptibility test.

3.1 MATERIALS USED

PG-76 binder with a density of 1.01 g/cm³ was used for the study. Crushed granite from Indonesia was used as the aggregate material. The size of the aggregates was selected using standard sieves spanning 19 mm down to below 0.075 mm.

3.2 DESIGN OF GRADATION

The three gradations formulated are shown in Table 1.

<table>
<thead>
<tr>
<th>sieve size (mm)</th>
<th>Gradation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
</tr>
<tr>
<td>Percentage passing (%)</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>100</td>
</tr>
<tr>
<td>13.2</td>
<td>85</td>
</tr>
<tr>
<td>9.5</td>
<td>75</td>
</tr>
<tr>
<td>6.3</td>
<td>60</td>
</tr>
<tr>
<td>4.75</td>
<td>44</td>
</tr>
<tr>
<td>2.36</td>
<td>20</td>
</tr>
<tr>
<td>1.18</td>
<td>17</td>
</tr>
<tr>
<td>0.6</td>
<td>14</td>
</tr>
<tr>
<td>0.3</td>
<td>11</td>
</tr>
<tr>
<td>0.15</td>
<td>8</td>
</tr>
<tr>
<td>0.075</td>
<td>5</td>
</tr>
</tbody>
</table>

3.3 SPECIMEN COMPOSITION AND PREPARATION

The in the specimens for the three aggregate gradations during the sample preparation process are shown in Table 2.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Type</td>
<td>PG-76</td>
<td>PG-76</td>
<td>PG-76</td>
</tr>
<tr>
<td>Binder Content (% of specimen mass)</td>
<td>4.8</td>
<td>4.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Gyration count</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Aggregate Mass (g)</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

All the specimens were hand-mixed to ensure uniform coating of binder to the aggregate. Mixing temperature was maintained at 170 °C and the mixing duration was kept under 15 minutes to minimise aging and maintain binder viscosity.

After each mixing process and placement in the mould, the side and the centre of the specimen were adjusted inside the mould using a spatula to produce a well-shaped product. Gyration compactor was applied to compacting asphalt mixture and reference gyration level was selected, namely each specimen was compacted with the ram pressure of 600 kPa at the speed of 30 gyrations per minute.

3.4 PERMEABILITY TEST

Permeability measures how fast water can pass through an asphalt specimen. A set up from Florida Method of Test was used to test the permeability of each specimen, as illustrated in Figure 1.

![Figure 1 Permeability Test Apparatus](image)

Each specimen was placed in a cylindrical column covered with tubular rubber membrane to ensure water flows vertically through the specimen. Next, the specimen was clamped at the top and bottom while a 2000 cc column tube was set up above the specimen. Water was first poured into the column continuously to saturate the specimen. After it reached a ‘steady-flow’ state, water was then filled until 2000 cc mark and lastly the time taken for the water to reach 0 cc mark was recorded. Faster time indicates higher permeability.

The coefficient of permeability k was then calculated using the formula:

\[ k = \frac{aL}{At\ln(h_1/h_2)}t_e \]

where:

- \( k \) = coefficient of permeability, cm/s;
- \( a \) = inside cross-sectional area of the buret, \((3186.9 \ cm^2)\);
- \( L \) = average thickness of the test specimen, cm;
- \( A \) = average cross-sectional area of test specimen, \( cm^2 \);
- \( t_e \) = elapsed time between \( h_1 \) and \( h_2 \), s;
- \( h_1 \) = initial head across the test specimen, cm;
- \( h_2 \) = final head across the test specimen, cm;
t_c = temperature correction for viscosity of water.

Specimen testing was done at room temperature (25 °C), therefore temperature correction was taken to be 0.89 [5].

### 3.5 MARSHALL STABILITY AND FLOW TEST

Marshall stability is a measure of resistance load obtained while a constant rate of loading is applied on the specimen. On the other hand, deformation of the specimen during the stability test is measured using Marshall flow.

The test procedure is prescribed in ASTM D6927-06. First, the compacted samples were soaked in a 60°C water bath for 30 minutes. Subsequently, they were placed on standard Marshall Test Machine to determine their Marshall stability and flow [6].

### 3.6 MOISTURE SUSCEPTIBILITY TEST

Moisture Susceptibility Test is used to measure the capability of the specimens after they were conditioned in saturated condition.

The procedure is similar to Marshall Stability Test, but instead of 30 minutes, the compacted specimens were soaked in the water bath for 24 hours. Marshall stability and flow were then determined using the Marshall Test Machine [7].

### 4 RESULTS AND DISCUSSION

#### 4.1 PERMEABILITY TEST

The results obtained from the test conducted are shown in Figure 2.

![Figure 2 Permeability Test Result](image)

It is shown that Coefficient of Permeability for Gradations 1 and 2 were below 1.2 mm/s while Gradation 3 reached 1.5 mm/s. Among the three gradations, Gradation 3 had the least fines. Fine aggregate has a property to fill up empty space and consequently, lowers the voids content of the mixture. Low voids content results in lower permeability.

#### 4.2 MARSHALL STABILITY AND FLOW TEST

Marshall Test results are shown in Figure 3.

![Figure 3 Marshall Stability and Flow](image)

On the average, highest stability is given by Gradation 1. However, given low traffic volume (therefore low strength requirements) as the application of this study, the other gradations also gave satisfactory stability. Gradation 3 had the lowest overall stability.

The variability of the flow values is not much across the three gradations, hence the gradations did not appear to give differentiated impact on the deformation of each specimen.

#### 4.3 MOISTURE SUSCEPTIBILITY TEST

The retained stability (in percentage) of Marshall Test of the conditioned specimens relative to that of the normal test is shown in Figure 4.

![Figure 4 Retained Stability of Conditioned Specimens](image)

Most specimens satisfied the requirement of maintaining minimum 80% of its original stability, except for specimens G2-2, G2-3 and G3-1. It appeared that Gradation 2 would not meet the 80% retention.

#### 4.4 DISCUSSION

The average results of the tests are presented in Table 3.
Table 3 Summary of Results

<table>
<thead>
<tr>
<th>Gradation</th>
<th>k (mm/s)</th>
<th>Stability (kN)</th>
<th>Flow (mm)</th>
<th>Retained Stability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.30</td>
<td>9.6</td>
<td>6.6</td>
<td>95.4</td>
</tr>
<tr>
<td>2</td>
<td>1.04</td>
<td>9.4</td>
<td>7.3</td>
<td>78.4</td>
</tr>
<tr>
<td>3</td>
<td>1.61</td>
<td>7.7</td>
<td>6.9</td>
<td>90.5</td>
</tr>
</tbody>
</table>

Gradation 3 had the most favourable performance among the three gradations, as only its permeability number fulfilled the threshold. Although it had a low stability, considering low strength application which is the main focus of this study, it is still acceptable. In terms of moisture susceptibility, it is also satisfactory.

5 CONCLUSIONS

The study was conducted with a purpose to find an appropriate PAM gradation to fulfil the required properties of pathway such as footway and bicycle way. Three gradations were designed and they were tested for their permeability, stability, flow and performance under moisture-laden conditions.

Among the three gradations, permeability requirement was only fulfilled by Gradation 3. Although its stability was the lowest in comparison with others, pathway strength criterion is still acceptable. Under moisture-laden condition, more than 80% of its original strength was retained. Therefore, under Singapore condition (rainy season), Gradation 3 is satisfactory.

Gradation 3 contains the least fines content among the three gradations. High percentage of coarse aggregate is contained in the gradation. Following the result, it is suggested that this type of gradation provides a good stability and porosity for walkway or bicycle way in Singapore.

Only one type of binder (asphalt binder PG-76) was used in this study. Further studies on other types of asphalt binder might also improve the performance of the PAM to withstand Singapore climate.

ACKNOWLEDGMENTS

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