THE INFLUENCE OF FILLER ON THE MARSHALL STABILITY AND VOID IN MIX (VIM) OF ASPHALTIC CONCRETE MIXTURES

By:
Ir. Djoko Murwono, M.Sc.

Abstract

Mineral filler is one of the components in the hot-mix asphaltic concrete, it plays a major role in its workability and practical performance. The influence of the quantity and type of filler on mix properties are fairly well-known, but relatively little information is available concerning the overall effect of filler used in Indonesia.

The aim of the research was to characterize the effect of mineral filler in which commonly used in Indonesia on the Marshall stability and VIM of dense-graded asphaltic concrete mixtures. The effect of filler on the paving mixtures were studied from point of view, design and performance.

It was found that the type and concentration of filler greatly influence the Marshall stability and void in mix of dense-graded asphaltic concrete mixtures.

Stability can be defined as ability of mixture to resist permanent deformation under the load. Dealing with a viscoelastic material such as an asphalt mixture, it is important to define the magnitude and rate of loading, and the temperature spectrum within which the loading occurs.

Various mechanical test have developed by asphalt technologists to measure the stability of mixture and a few of more popular tests are:

(a) Marshall stability test,
(b) Hveem stabilometer,
(c) Wheel-tracking test, and
(d) Gyratory testing machine.

The source of stability in asphalt pavement are the frictional or interlocking resistance developed among aggregate particle and the cohesioness supplied by the bitumen. A proper degree of both internal friction and cohesion in a mix prevents the aggregate particles from being moved pass each other by the forces exerted by traffic.

Because filler is part of what is usually called aggregate, its function, at least by implication, is mechanical. If, however, filler significantly influences the charater and cohesive properties of bitumen, a different function is present.

Introduction

In a hot-mix asphalt paving mixtäre, bitumen and aggregate are blended together in precise portions. The relative proportions of these materials determines the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement.

Mixes are used in practice to provide pavement which can withstand the destructive effects of traffic and climate, and provide acceptable riding qualities. Some mixes are used for wearing courses and are thus exposed to weather and traffic directly but others are used to provide structural strength to the pavement.

In general to ensure good performance, it is desirable that the mix be designed initially to have a certain characteristics or properties although these can not yet be precise quantified, and that these should be maintained during the service life of the pavement. These requirements include stability, durability, workability slip-resistance, flexibility and fatigue resistance.

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Many researchers stated that mineral filler effects the stability of asphaltic concrete mixture. This statement is logical, because the portion of filler with particles thicker than the asphalt film will contribute to the interlocking of aggregate and other portion of filler, with particles smaller than the thickness of the asphalt film will suspended is the asphalt (bitumen) and constitutes the binder in the mixture.

Dukazt, E. L. et al. (3) stated that two types of stiffening effects may result from the volume filling of the filler, and (b) a relatively large stiffening resulting from the physical-chemical interaction between the bitumen and the surface of the mineral filler.

Mineral Filler

Mineral filler is defined as a fraction of fine aggregates with a high proportion (at least 65 percent by ASTM and ASSHTO specifications) of which will pass the No. 200 sieve.

Tunioft, E. G. D., (4) stated that filler should be defined in terms of what is filled, what does the filling, and why the filling is being done. Two such definitions appear to be available. One could be the following: filler is that portion of the mineral aggregate passing the number 200 sieve which occupies void space between coarser aggregate particles in order to reduce the size of the voids and increase the density and stability of the mass. Thus, void space in the coarser mineral aggregate is filled, with mineral particles passing the number 200 sieve, because it is desirable to make the size of these voids smaller and make the density of the mass greater. The other definition is this: filler is mineral material which is in colloidal suspension in the bitumen and which results in a bitumen with a stiffening consistency. Thus, bitumen is filled with colloidal mineral matter because it is desirable to increase its viscosity.

The asphaltic concrete mixture is composed of aggregate cemented together into a solid mass by the bitumen in exact proportion (figure 1). Apart of the bitumen covers the aggregates that can be regarded as "fixed" in inter and intra granular pores of the aggregates, while the remaining parts is "free". The functional volume percentages of "solid", void, and "fluid" phase differ from the compositional volume percentages of coarse aggregate, sand, filler and bitumen. The volume percentages of solid, fluid and void phase are interesting with respect to the workability, densification, and mechanical properties of mixes.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>bitumen</td>
<td>Fluid</td>
</tr>
<tr>
<td>filler</td>
<td>Solid</td>
</tr>
<tr>
<td>coarse agg;</td>
<td></td>
</tr>
<tr>
<td>&amp; sand</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 1: The composition of asphaltic concrete mixture](image)

Experimental Work

Description of materials

Bitumen

Bitumen was used in this study is from a single and uniform source. Physical properties of bitumen was used in laboratory work is given in table 1.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Bitumen AC 40 – 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25°C, 50 kg. 5 sec.</td>
<td>55.6 mm</td>
</tr>
<tr>
<td>Softening Point, Ring &amp; Ball (°C)</td>
<td>52.05</td>
</tr>
<tr>
<td>Specific gravity (kg/m³)</td>
<td>1030.00</td>
</tr>
<tr>
<td>Penetration index</td>
<td>-0.45</td>
</tr>
</tbody>
</table>

Mineral aggregate

Crushed stone aggregate was used in preparation of test specimens. Properties of the aggregate used are summarized in table 2 and below:
Table 2. Gradation of dense-graded AC

<table>
<thead>
<tr>
<th>Filler content, % of mix</th>
<th>Percentage of passing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3%</td>
</tr>
<tr>
<td>Stone size</td>
<td></td>
</tr>
<tr>
<td>19.0 mm</td>
<td>100</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>95</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>59</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>43</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>13</td>
</tr>
<tr>
<td>0.30 mm</td>
<td>3.2</td>
</tr>
<tr>
<td>Bitumen content, % of mix</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Mineral filler

Two types of mineral filler: Duras Filler 15 and Duras Filler 18 were used in this study. Duras filler 15 is composed of 100% limestone with average density 2705 kg/m³, and Duras Filler 18 is composed of limestone 10-20%, slag 40-60%, fly ash 20-30%, and "mineral strewmeter" 10-20%. According to the Dutch guideline (SVC 1990) these kinds of fillers can be categorized as very weak (DF 15) and weak filler (DF 18).

Experimental Procedures

Measurements

Marshall stability test

In the Marshall stability test radial compression was applied to a cylindrical specimen with diameter of 101.6 mm of asphaltic concrete specimen at loading speed of 2 in/min and temperature of 60°C. The force applied to the specimen was recorded as function of compression. The force versus compression curve as recorded during the test went through a maximum. This maximum of the force applied is denoted as the Marshall stability value, and the corresponding compression is called the flow value.

Experimental Results

Marshall Stability and Flow

Asphalt paving mixtures are three-phase systems containing aggregate, bitumen, and air. A general theory relating stability to composition could state that stability is function of the viscosity and proportion of bitumen and type of aggregate. Type of aggregate is a function of numerous aggregate characteristics, which would include at least all of the characteristics as follow:

1. Primarily characteristics of fundamental importance: particle size, size distribution, shape.
2. Primary mineralogical characteristics of less importance: texture, hardness, strength, specific gravity.
3. Secondary characteristics dependent on one or more primary characteristics: void content, surface area.

It is not likely that all these characteristics are controlled by the usual mixture design practices. Whether or not all ought to be controlled is not known.

The function of the two mixture components: aggregate and bitumen are distinctly different for load-bearing purposes. Mineral aggregate resists deformation because of its internal stability, while bitumen, within a mass of aggregate, resists deformation because of its cohesion. Because filler's part of what is usually called aggregate, its function, at least by implication, is mechanical. If however, filler significantly influences the character of bitumen as mentioned in previous section, a different function is present.

Test results of Marshall stability and flow are given in table 3 and plotted in figure 2 and 3.

Table 3. The test results of Marshall stability and flow

<table>
<thead>
<tr>
<th>Filler content</th>
<th>Stability (N)</th>
<th>Flow (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% DF. 15</td>
<td>6883.8</td>
<td>2.72</td>
</tr>
<tr>
<td>6% DF. 15</td>
<td>8451.5</td>
<td>3.15</td>
</tr>
<tr>
<td>9% DF. 15</td>
<td>9306.3</td>
<td>3.48</td>
</tr>
<tr>
<td>3% DF. 18</td>
<td>7855.8</td>
<td>3.23</td>
</tr>
<tr>
<td>6% DF. 18</td>
<td>9002.7</td>
<td>3.83</td>
</tr>
<tr>
<td>9% DF. 18</td>
<td>9161.4</td>
<td>4.08</td>
</tr>
</tbody>
</table>
Reference to figure 2 clearly demonstrates that the
Marshall stability increases with increasing of filler
content for all types of filler. At filler content below
8.5%, mixtures containing of Duras filler 18 have
greater value of stability than mixtures containing of
Duras filler 15. While, filler content more than 8.5%,
Marshall stability of the mixtures containing with
Duras filler 18 are lower. This is most probably due to
the reduction of free bitumen in mixes with Duras
filler 18 are greater than mixes with Duras filler 15. So,
at a high filler content, the free bitumen in mixes with
DF. 18 are smaller than mixes containing with DF. 15.

Reference to figure 3 the following observations are
made:
(a) The Marshall flow increases with increasing of
filler content for all type of filler.
(b) The increase in Marshall flow varies with type of
filler and mixture containing DF. 18 produces
greater Marshall flow compared to the mixtures
containing DF. 15.

*Notes in mix*

Voids in mix (VIM) is defined as the volume of air
in a compacted specimen, expressed as a percentage of
the bulk volume of specimen. The expression for VIM
is:

\[ \text{VIM} (\%) = 100 \left(1 - \frac{C_b}{G_b}\right) \]

where:
- VIM : voids in mix, per cent
- \(C_b\) : theoretical specific gravity of compacted
  specimen
- \(G_b\) : bulk specific gravity of compacted specimen

The relation between voids in mix and stiffness
modulus of mix can be derived by using the
nomograph from shell (see figure 3) as follows:
Table 4. The test results of voids in mix

<table>
<thead>
<tr>
<th>Filler content</th>
<th>VDI</th>
<th>Vbi</th>
<th>Vagg</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% DF 15</td>
<td>10.223</td>
<td>13.776</td>
<td>76.001</td>
<td>2.49</td>
</tr>
<tr>
<td>6% DF 15</td>
<td>6.152</td>
<td>14.609</td>
<td>79.419</td>
<td>3.90</td>
</tr>
<tr>
<td>9% DF 15</td>
<td>5.392</td>
<td>14.514</td>
<td>80.074</td>
<td>4.01</td>
</tr>
<tr>
<td>3% DF 15</td>
<td>7.226</td>
<td>14.196</td>
<td>78.578</td>
<td>3.20</td>
</tr>
<tr>
<td>9% DF 18</td>
<td>5.886</td>
<td>14.370</td>
<td>79.760</td>
<td>4.00</td>
</tr>
<tr>
<td>9% DF 18</td>
<td>4.080</td>
<td>14.642</td>
<td>81.308</td>
<td>4.20</td>
</tr>
</tbody>
</table>

where:
- VDI: voids in mix
- Vbi: volume of binder
- Vagg: volume of aggregate
- V: total volume of mix

Drawn from Table 4, the following observation can be made:

(a) The percentage voids in mix for all type of mixtures decrease with increasing of filler content. The decreasing of VIM is mostly due to the void space between the coarse aggregates is filled with mineral filler.

(b) At 3% of filler content of DF 15 mixture has the highest value of voids in mix. At this level, the voids are usually interconnected and permit the intrusion of air and water throughout the mixture. This graph also shows that the increasing filler content from 3% to 6% has resulted in decreasing in VIM of around 4 percent, while increasing filler content after 6 percent caused small change in VIM. The addition of filler over 6 percent causes increasing binder viscosity, and the mass

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cannot be compacted to low void. Conversely, decreasing in VIM of mixture containing DF. 18 is rather linear as function of filler content.

(c) There are a maximum value of VIM to avoid the risk of raveling, and a minimum value of VIM to avoid the risk of bleeding during service life. Unless some voids we left in mixes, the pavement will flush and tend to become unstable due to the reduction of voids content under traffic and thermal expansion of the bitumen. In order to get better information the risk of flushing, the information of voids filled with bitumen is required. By considering the climate in Indonesia, a range 4.67% to 10% of VIM is preferable to avoid bleeding during service life. While, from the risk of raveling point of view, filler content 3% up to 6% is preferable.

(g) According to the calculation results of stiffness modulus of the mix by using nomograph from Snell (1978) shows that the decreasing of voids in mix has resulted in increasing in stiffness modulus of the mix. On the other hand, the stiffness modulus of the mixture increases with increasing of filler content.

By considering the risk of raveling and bleeding, permanent deformation, and cracking, it can be concluded that dense-graded asphaltic concrete with filler content around 4.67% to 6% is preferable for pavement construction.

Base on the relation between filler content in mix and durability potential a certain mixture, it can be predicted the performance curve for dense-graded asphaltic concrete shows quantitatively as below:

![Figure 4. The predicted performance curve](image)

In the case of filler content in the mixture < 4.67% or higher than 6.0% filler content, the deterioration of the pavement regarded to be more rapidly.

Conclusions and Recommendations

The results of the investigation lead to the following conclusions:

1. Type and concentration of filler greatly influence the Marshall properties both dense-graded AC and open-graded AC mixture. The use of higher filler content results in the high stability and density. However, it appears, particularly at high concentration of filler, the need for higher compactive effort. This probably indicate that at a certain concentration of filler, apart from changing viscosity of the binder, it contributes contact points between coarser mineral particles. In general, increasing of the concentration of filler causes the decreasing in voids in mix. Presumably, filler particles occupy small spaces between coarser aggregate. From raveling of view, the results of the investigation show that the dense-
graded asphaltic concrete mixture containing filler more than 4.67 percent is preferable. Of course, there is a maximum value of filler content to avoid the risk of bleeding or flushing under traffic load and thermal expansion of the bitumen.

(2) By considering the risk of ravelling and bleeding, permanent deformation, and cracking, the filler content of 4.67% to 6% is recommended for dense-graded asphaltic concrete.

(3) The above conclusions and recommendations are still limited on three types of gradation aggregate and two type of filler. Future research, therefore, should include wider ranges of gradation aggregate and types of filler.

References