Study on the Fatigue Behavior of DBM Mix using Crumb Rubber Modified Bitumen by Varying Mixing and Compaction Temperature

M. Shivakumar* & G. Suresh*
*Department of Civil Engineering, Mizan Tepi University, Ethiopia-5160  
Department of Civil Engineering, University Visvesvaraya College of Engineering, Bangalore, Karnataka, India

Abstract: The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical. Bituminous materials are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost. Dense Bituminous Macadam is strong enough to handle years of vehicle traffic, and is relatively easy to repair or refinish. Present study focuses on the design of Dense Bituminous Macadam mix (Grade-II) prepared using Crumb Rubber modified binder (CRMB-55). The Marshall method of mix design was adopted to prepare mix and at optimum bitumen content, Marshall Properties and Indirect Tensile Strength (ITS) test were conducted on Dense Bituminous Macadam Mix at different mixing temperature by varying compaction temperatures. The Indirect Tensile Strength value has been considerably increased from mixing temperature 140°C to 160°C and as further increase in mixing temperature to 170°C there is a hasty reduction. The Fatigue test result shows the maximum number of fatigue cycles and higher resilient modulus value at optimum mixing temperature 160°C and compaction temperature 140°C.

Keywords: Bituminous mixture, Crumb Rubber Modified Bitumen, Compaction temperature, Mixing temperature, Indirect Tensile Strength and fatigue test

I. INTRODUCTION

Dense Bituminous Macadam is a premix widely used in road construction. It is considered as premix with high skid resistance, high comfort ability and low maintenance cost. DBM paving consist of a combination of aggregate uniformly mixed and coated with bitumen. Term of “hot mix” comes from aggregate and bitumen dried and heated for proper mixing and workability and mix together with desired temperature.

The aggregate and bitumen will be combined in a hot mix plant in which it will be proportioned, heated, and mixed to produce the desired paving mixture. After the plant mixing is complete, the mix will be transported to site and spread with paving machine and compacted to desired thickness by using a heavy roller. Bituminous macadam is strong enough to handle years of vehicle traffic, and is relatively easy to repair or refinish.

A. Crumb Rubber Modified Bitumen

Crumb rubber modified bitumen is manufactured from mechanically partial de-vulcanized, chemically treated rubber from heavy vehicular tyres duly admixed with Natural Asphalt & Natural Latex in a high sheared mixing machine at a higher temperature. Rubber used for these products is derived from pneumatic tyres that have been processed by mechanical means and should be substantially free from ground fabric, steel and other contaminants, including moisture. When introduced to the hot binder the rubber swells through absorption of the aromatic fractions of the binder. As a result of the high blending temperature some of the rubber dissolves in the binder and some is de-vulcanized.

B. Temperature and Compaction Characteristics

The binder is heated to enable it to flow so as to achieve proper coating and “wetting” of aggregates. It must not be so fluid as to cause binder drain-down or lead to segregation or inadequate cohesion of the mix. Overheating or extended mixing times can also cause hardening of the binder due to oxidation.

Compaction is defined as the process by which the volume of air in a bituminous mix is reduced through the application of external force. The expulsion of air enables the mix to occupy a smaller space, thereby increasing the unit weight or density of the mix. Compaction plays a vital role in road construction and should not commence unless the mix has sufficient cohesion to support rollers and avoid excessive displacement.

The key objective of this study is to assess the performance and design of Dense Bituminous Macadam mix (Grade-II) prepared using Crumb Rubber modified binder (CRMB-55). The physical properties of aggregates and modified bitumen were tested as per MoRT & H (IV revision) and IRC SP-53 2010 specifications. Using Marshall Method of mix design, the optimum bitumen content for Dense Bituminous Macadam Mix was determined. At optimum
bitumen content, Marshall properties, Indirect Tensile Strength (ITS) and fatigue test were conducted on Dense Bituminous Macadam Mix at 140°C, 150°C, 160°C and 170°C mixing temperature by varying compaction temperatures (90°C, 100°C, 110°C, 120°C, 130°C and 140°C).

C. Need for the study

- Fatigue cracking and permanent deformation is considered as most serious distresses associated with flexible pavements. These distresses reduce the service life of the pavement and increase the maintenance cost.
- To reduce the pavement distresses there are different solutions such as adopting new mix design or by using additives to bitumen.
- The fatigue cracking caused by traffic on the bituminous layer is a very common occurrence and must be given a careful consideration in pavement design and selection of materials to prevent premature cracking of bituminous pavements.
- Therefore there is a need to carryout studies to evaluate the performance of the bituminous mixes with modified binders and to obtain information on the long term benefits over conventional binders.

D. Objective

- To conduct tests on aggregate and bitumen in order to assess the physical properties as per the requirements.
- To determine the optimum bitumen content of the bituminous mix and Marshall Properties of Dense Bituminous Macadam Mix by varying mixing and compaction temperatures
- To conduct Indirect Tensile Strength Test on Dense Bituminous Macadam Mix prepared using Crumb Rubber Modified Bitumen at optimum bitumen content by varying mixing and compaction temperatures.
- To conduct Indirect Tensile Fatigue Test on Dense Bituminous Macadam Mix prepared using Crumb Rubber Modified Bitumen at 25°C keeping constant compaction temperature and varying mixing temperature and stress level.

E. Methodology

- Selection of the aggregate and bitumen
- Selection of aggregate gradation
- Determination Optimum bitumen content
- Evaluation of Marshall properties
- Indirect tensile strength test on mix at different mixing and compaction temperature
- Fatigue test on the prepared mix at fixed stress level
- Analysis and Results

• Conclusions.
• Recommendations.

II. EXPERIMENTAL INVESTIGATIONS

In the present study the aggregate gradation (Grading-II) was adopted for Dense Bituminous Macadam as per Table 500-18 recommended by MoRT&H (IV revision) specifications

A. Constituents of a Mix:

1. Aggregates:

The aggregates acts as the skeleton which transfers the load through the particle to particle contact. This aggregate skeleton determines the overall strength of the mixture. Aggregates properties such as gradation, angularity, soundness etc. effects rutting. Aggregate gradation is responsible for good packing and hence the density of bituminous concrete. A good grading governs the contact and friction between the particles which develops resistance towards shear failure. The coarse aggregates shall consist of crushed rock and shall be clean, hard, durable, free from dust or friable matter, organic or other deleterious substances. Aggregates offer good compressive and shear strength; along with this they provide good interlocking facility with sufficient permeability. Coarse aggregate of 26.5 mm to 2.36 mm and fine aggregates of 2.36 mm to 75 µ were used. The test results are presented in table 1

<table>
<thead>
<tr>
<th>Tests</th>
<th>Test Results</th>
<th>Requirements as per Table 500-17 of MoRT&amp;H Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Impact value (%)</td>
<td>22.42</td>
<td>Max 27%</td>
</tr>
<tr>
<td>Flakiness and Elongation Index</td>
<td>29.07</td>
<td>Max 30%</td>
</tr>
<tr>
<td>(Combined) (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los Angeles Abrasion value (%)</td>
<td>24.2</td>
<td>Max 30%</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>0.6</td>
<td>Max 2%</td>
</tr>
<tr>
<td>Specific gravity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>2.67</td>
<td>-</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>2.68</td>
<td>-</td>
</tr>
</tbody>
</table>

2. Binder:

Bitumen is a binding material. At normal temperature they are in the form of semi-solid, it is heated until liquefied before blending it with the aggregates. The test results are presented in table 2.
### Table 2 Results of Crumb Rubber Modified Bitumen (CRMB)

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Results</th>
<th>Requirements as per IRC SP:53-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25°C, 100gm,</td>
<td>54.67</td>
<td>50-80</td>
</tr>
<tr>
<td>Softening Point (Ring &amp; Ball), °C</td>
<td>55.5</td>
<td>Minimum 55</td>
</tr>
<tr>
<td>Ductility at 27°C</td>
<td>100+</td>
<td>Minimum 60</td>
</tr>
<tr>
<td>Flash point, COC, °C</td>
<td>258</td>
<td>Minimum 220</td>
</tr>
<tr>
<td>Elastic Recovery of Half Thread in Ductilometer at 15°C, %</td>
<td>70</td>
<td>Minimum 60</td>
</tr>
<tr>
<td>Separation, Difference in Softening point (Ring &amp; Ball), °C</td>
<td>2</td>
<td>Maximum 3</td>
</tr>
<tr>
<td>Viscosity at 150°C, Poise</td>
<td>4</td>
<td>2 – 6</td>
</tr>
<tr>
<td>Specific gravity, 27°C</td>
<td>1.02</td>
<td>-</td>
</tr>
</tbody>
</table>

#### Rolling thin film oven test

The rolling thin film test were also carried out for the bitumen sample. The bitumen used was proved to be well within the limit of specified recommendations as per the code. The test results is presented in the table 3 as below

**Table 3. Thin Film Oven Test (TFOT) on Residue**

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Results</th>
<th>Requirements as per IRC SP:53-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss in mass, %</td>
<td>0.52</td>
<td>Maximum 1</td>
</tr>
<tr>
<td>Increase in Softening point, °C</td>
<td>2</td>
<td>Maximum 6</td>
</tr>
<tr>
<td>Reduction in Penetration of Residue, %</td>
<td>29</td>
<td>Maximum 35</td>
</tr>
<tr>
<td>Elastic Recovery of Half Thread in Ductilometer at 25°C, %</td>
<td>60</td>
<td>Minimum 50</td>
</tr>
</tbody>
</table>

### B. Gradation of Aggregate:

The aggregate gradation (Grading-II) was adopted for Dense Bituminous Macadam mix as per MoRT&H (IV revision) specifications presented in table 4.

**Table 4. Aggregate Gradation for Dense Bituminous Macadam Mix (Grading-II) as per MoRT&H (IV revision) Specification**

<table>
<thead>
<tr>
<th>IS Sieve Size, mm</th>
<th>% Passing</th>
<th>% Passing (Mid Limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>13.2</td>
<td>79-100</td>
<td>89.5</td>
</tr>
<tr>
<td>9.5</td>
<td>70-88</td>
<td>79</td>
</tr>
<tr>
<td>4.75</td>
<td>53-71</td>
<td>62</td>
</tr>
<tr>
<td>2.36</td>
<td>42-58</td>
<td>50</td>
</tr>
</tbody>
</table>

### C. Procedure for Mix Design

- Select aggregate grading.
- Determine the proportion of each aggregate size required to produce the design grading.
- Determine the specific gravity of the aggregate, mineral filler and bitumen.
- Prepare the trial specimens with varying bitumen contents.
- Determine the specific gravity of each compacted specimen.
- Perform stability tests on the specimens.
- Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.
- Select the optimum binder content from the data obtained.
- Evaluate the design with the design requirements.

#### 1. Marshall Method of Mix Design

Marshall Stability test of a mix is defined as maximum load carried by a compacted specimen at a standard test temperature of 60 degree Celsius. The flow value is the deformation of specimen that under goes during the loading up to the maximum load in 0.25 mm units. The Marshall Stability test is applicable for hot mix design using bitumen and aggregates with maximum size of 25mm. Marshall Stability test setup is shown in figure 3.1. In this method, the resistance to plastic deformation of cylindrical specimen of bituminous mixture is measurement when the same is loaded.

There are two major features of Marshall Stability method of designing mixes are:

- Density Voids Analysis
- Stability Flow Test.
D. Indirect Tensile Strength Test:

The Indirect Tensile Test is defined as a load applied on a cylindrical specimen with a single or repeated compressive load, which acts parallel to and along the vertical diametric plane and develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametric plane, which ultimately causes the specimen to fail by splitting along the vertical diameter.

The load at failure was recorded and the indirect tensile strength was computed using the relation given below.

Indirect tensile stress:

\[ \sigma_x = \frac{2 \times P}{\pi \times D \times t} \]

Where: \( \sigma_x \) = Horizontal stress, N/mm^2

\( P \) = Failure load, N.

\( D \) = Diameter of the specimen, mm.

\( t \) = Height of the specimen, mm.

E. Indirect Tensile Fatigue Test:

Fatigue is defined as a series of interconnected cracks caused by fatigue failure of the bituminous surface (or stabilized base) under repeated traffic loading. In thin pavements, cracking initiates at the bottom of the bituminous concrete layer where the tensile stress is the highest then propagates to the surface as one or more longitudinal cracks. It is commonly referred to as “bottom-up” or “classical” fatigue cracking. In thick pavements, the cracks most likely initiate from the top in areas of high localized tensile stresses resulting from tire-pavement interaction and binder aging (top-down cracking).

III. DATA ANALYSIS

A. Determination of Optimum Bitumen Content (OBC)

The optimum bitumen content for mix is determined by taking the average values of three bitumen content corresponding to Maximum Stability, Maximum Bulk Density and 4% Air Voids in total Mix. The various properties at OBC are shown in the table 5 below.

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Marshall Properties</th>
<th>Test results</th>
<th>Requirements as per IRC SP 53 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Optimum Bitumen Content, %</td>
<td>5.16</td>
<td>-----</td>
</tr>
<tr>
<td>2</td>
<td>Marshall Stability, kgs</td>
<td>1683.86</td>
<td>1200</td>
</tr>
</tbody>
</table>
B. Marshall Properties of DBM Mix Prepared Using CRMB 55 by Varying Mixing and Compaction Temperatures

Marshall Stability test were conducted on specimens prepared using Crumb Rubber Modified Bitumen by varying mixing temperature (140°C, 150°C, 160°C, 170°C and 180°C) and compaction temperature (90°C, 100°C, 110°C, 120°C, 130°C and 140°C). The comparison of these temperature variations with Marshall Properties are shown in the figures as below.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 3 | Marshall Flow, mm | 3.54 | 2.5 - 4.0%
| 4 | Marshall Quotient, kg/mm | 475.58 | 250-500 |
| 5 | Air voids (Vv), % | 4.32 | 3.0 - 5.0%
| 6 | Bulk density, g/cc | 2.46 | ----- |
| 7 | Voids in Mineral Aggregates (VMA), % | 16.52 | ----- |
| 8 | Voids filled with Bitumen (VFB), % | 78.22 | ----- |

Fig 4 Comparison of Stability V/S Compaction Temperature at different mixing temperature

Fig 5 Comparison of Flow V/S Compaction Temperature at different mixing temperature

Fig 6 Comparison of bulk density V/S Compaction Temperature at different mixing temperature

Fig 7 Comparison of air voids V/S Compaction Temperature at different mixing temperature

Fig 8 Comparison of VFB V/S Compaction Temperature at different mixing temperature
C. Comparison of Indirect Tensile Strength by Varying Mixing and Compaction Temperatures

Comparison of Indirect Tensile Strength v/s Compaction Temperature of Dense Bituminous Macadam Mix prepared using Crumb Rubber Modified Bitumen at mixing temperature 140°C, 150°C, 160°C, and 170°C is shown in figure 10 below.

D. Indirect Tensile Fatigue Test

Indirect Tensile Fatigue Test was conducted at 25°C test temperature on Dense Bituminous Macadam Mix prepared by keeping constant compaction temperature (140°C), varying mixing temperature (150°C and 160°C) and stress levels (10%, 15% and 20%). The figures below shows the relation between fatigue cycles and stress levels.
IV. CONCLUSIONS

- The physical properties of aggregate and bitumen were satisfying the requirements and the Optimum Bitumen Content obtained for Crumb Rubber Modified Dense Bituminous Macadam is 5.16%.

- It was seen that there is a considerable increase in the Marshall Stability as the mixing (140°C to 170°C) and compaction temperature (90°C to 140°C) increases and substantial reduction in the Marshall Stability with further increase in the mixing temperature.

- There is considerable increase in the Indirect Tensile Strength as the mixing and compaction temperature increases and significant reduction in the Indirect Tensile Strength with further increase in the mixing (170°C) and compaction temperature.

- Fatigue Life, Tensile stress and Resilient Modulus of Dense Bituminous Macadam Mix prepared using Crumb Rubber Modified Bitumen increases from mixing temperatures (150°C to 160°C) at constant compaction temperature 140°C and whereas

- Initial Tensile Strain decreases in terms of percentage as the level of the stress increases.

Based on the analysis and experimental results carried out in the present study, an optimum mixing temperature of 160°C and compaction temperature of 140°C is suggested for the preparation of Dense Bituminous Macadam Mix using Crumb Rubber Modified Bitumen.

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