2nd Conference of Transportation Research Group of India (2nd CTRG)

Performance of Low Energy Crumb Rubber Modified Bituminous Mixes

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Abstract

Rising energy costs and increased awareness of emission problems in the production of Hot Mix Asphalt (HMA) have brought attention to the potential benefits of Warm Mix Asphalt (WMA) in India. Warm-mix asphalt is the generic term for a variety of technologies that allow the producers of hot-mix asphalt pavement material to lower the temperatures at which the material is mixed and placed on the road. Crumb Rubber Modified Bitumen (CRMB) is a popular binder in India. CRMB is composed of bitumen binder and tyre rubber. Tyre rubber, at various percentages, is added to the binder, addition of tyre rubber into binder results in a new product, which requires higher mixing temperatures compared to the conventional one, as well as increased mixing time, so as to get the uniformity of the product.

A laboratory study was conducted at CSIR-Central Road Research Institute (CRRI) to investigate, how a commercially available chemical additive can be used to bring down the mixing and compaction temperature of CRMB mix as compared to the hot mix CRMB. Four different temperature ranges were considered in this study viz 100\textdegree C to 105\textdegree C, 110\textdegree C to 115\textdegree C, 120\textdegree C to 125\textdegree C and 130\textdegree C to 135\textdegree C to determine the various performance characteristics. The CRMB bituminous mix was prepared in these four temperature ranges and various mix tests were carried out to indicate how the lower production and compaction temperatures affect the properties and performance characteristics of the mixes. After the laboratory evaluation it was found that CRMB Warm mix can be successfully produced at temperature as low as 110\textdegree C and can be compacted at 80-90\textdegree C as compared to CRMB hot mix (155\textdegree C). Full scale performance study indicate that process is highly energy efficient and environment friendly, warm mixes performed equivalent to “Hot Bituminous Mixes” and indicated encouraging results. After laboratory evaluation, a test track was successfully laid using low energy Crumb Rubber Modified Bitumen.

Keywords: Warm Mix Asphalt; Crumb Rubber Modified Bitumen (CRMB); Performance Characteristics

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1. Introduction

Environmental awareness has been increasing rapidly over the past years. Extensive measures like air pollution reduction targets set by the European Union with the Kyoto protocol have encouraged efforts to reduce pollution. Warm Mix Asphalt (WMA), a new paving technology that originated in Europe, is one of those efforts. It allows a reduction in the temperatures at which asphalt mixes are produced and placed. Its benefits are reduction in energy consumption and reduced emissions from burning fuels, fumes and odours generated at the production plant and the paving site. This paper investigates the potential use of warm mix asphalt to produce Crumb Rubber Modified Bitumen (CRMB) at low temperature to reduce the emissions and to lower the consumption of energy during the production of CRMB bituminous mix.

Bitumen is a useful binder for road construction. The steady increase in high traffic intensity in terms of commercial vehicles, and the significant variation in daily and seasonal temperature demand improved road characteristics. Any improvement in the property of the binder is the need of the hour. The addition of polymers/rubbers typically increases the stiffness of the bitumen and improves its temperature susceptibility. Increased stiffness improves the rutting resistance of the mixture in hot climates and allows the use of relatively softer base bitumen, which in turn, provides better low temperature performance. CRMB is composed of bitumen binder and tyre rubber. Tyre rubber, at various percentages, is added to the binder, addition of tyre rubber into binder results in a new product, which requires higher mixing temperatures compared to the conventional one, as well as increased mixing time, so as to get the uniformity of the product. During construction, the temperature must be high enough to ensure the workability of the mix and yet below the temperature at which excessive binder hardening occur. For little or no improvement in workability, increasing the mix temperature often results in increased plant emissions and fumes at the paving site and binder hardening. All around the globe efforts are being put forward to protect the environment. Currently emphasis is on reducing CO₂ emissions in view of reducing greenhouse effect.

The objective of this paper is to investigate how a commercially available chemical additive can be used to bring down the mixing and compaction temperature of Crumb Rubber Modified Bituminous mix (CRMB) as compared to the conventional CRMB mix. In addition to indicate to how the lower production and compaction temperatures affect the properties and performance characteristics of the mixes.

2. Laboratory Study

2.1 Material

A paving grade Crumb Rubber Modified Bitumen (CRMB-60) and quartzite aggregates of different sizes (13.2mm, 6mm) and stone dust were obtained from the local quarry and was used in this study. CRMB-60 was manufactured at the plant using 10 to 12% of tyre rubber by weight of bitumen. The tyre rubber used to modify bitumen was having gradation size of 600 μ passing and retained on 300 μ. The modified bitumen was tested for physical properties as per IS73:2006 (test results are given in Table 1) and the physical properties of aggregate were studied to determine its performance as per [IS:2386-1963 (Part 1-6)]. The test results are given in Table 2.
Table 1 Physical Properties of CRMB 60

| Sr.No | Test                                      | Grade & Requirement | Results Obtained | Method of Test     |
|-------|-------------------------------------------|---------------------|-------------------|--------------------|
| 1     | Penetration at 25°C, 0.1mm, 100g, 5sec   | <50                 | 52                | IS 1203-1978       |
| 2     | Softening Point, °C, minimum              | 60                  | 58                | IS 1205-1978       |
| 3     | Elastic Recovery at 15°C, minimum %       | 50                  | 60                | Appendix 1         |
| 4     | Flash Point °C, minimum                   | 220                 | 224               | IS1206-1978        |
| 5     | Separation, difference in softening point °C, maximum | 4                  | 2                 | Appendix-2         |

Table 2 Physical Requirements for Coarse Aggregate for Bituminous Concrete

| Property                  | Test                                      | Ministry Specification       | Values Obtained in Lab |
|---------------------------|-------------------------------------------|------------------------------|------------------------|
| Particle size             | Flakiness & Elongation Index              | Max 30% (combined)           | 21.3%                  |
| Strength                  | Aggregate Impact Value                    | Max 24%                      | 21%                    |
| Water Absorption          | Water Absorption                          | Max 2%                       | 2%                     |

A commercially available surfactant based chemical additive was used in this study to lower down the mixing and compaction temperature to prepare warm mixes.

2.2 Viscosity – Temperature Profiles

Viscosity is an important fluid property for bituminous binders as it is a measure of resistance to flow and at the application temperature, this characteristic greatly influences the strength of resulting paving mixes. When any additive is added to the bitumen, it becomes very important to check how the viscosity is getting affected due to that additive. The viscosity profiles of the CRMB-60 bitumen blended with 0.2%, 0.3%, 0.5% and 0.7% of chemical additive were measured using Brookfield Rotational Viscometer. The viscosity of bitumen blends were measured at various test temperatures at a rotational speed of 20 RPM of the Brookfield spindle no. 27. The viscosity plots are shown in figure no. 1
2.3 Mix Design for BC Mix

In this study, design of Bituminous Concrete (BC), grading 2, 30-45mm thick was considered (as per MORTH Specifications for Road and Bridge Works -IV Revision). The Optimum Binder Content (OBC) in hot mix with CRMB-60 was obtained by Marshall bituminous mix design method.

The optimum dose of the additive for the warm bituminous mix determined was 0.5% by weight of the bitumen. The optimum dosage of warm mix additive was determined on the basis of viscosity test. CRMB-60 showed a substantial reduction in viscosity after the addition of 0.2% of the additive and it further reduced to a great extent till 0.5% of addition of the additive. But there was not much reduction observed when the dosage was increased to 0.7% from 0.5%. The optimum reduction in viscosity was observed at the dosage of 0.5% and hence it was selected as the optimum dose of the warm mix additive.

The bitumen-aggregate blended with additive was used and Marshall Samples were prepared at different temperature ranges. The various performance tests of the prepared samples were carried out in the laboratory. The behaviour of the warm bituminous mix asphalt was studied and compared with the conventional bituminous mix through various laboratory performance tests for assessing the properties at reduced mixing and compaction temperatures.

2.4 Performance Characteristics of Bituminous Mix

Samples were prepared at OBC and with 0.5% warm mix additive at various temperature ranges and few samples were made (@155°C) without warm mix additive to compare the results of warm mix with conventional hot mix. Four temperature ranges were considered in this study viz 100°C to 105°C, 110°C to 115°C, 120°C to 125°C and 130°C to 135°C to determine the various performance characteristics.

2.4.1 Retained Stability

Retained Stability tests were conducted on Marshall Samples of conventional mix and warm mix. The stability was determined after placing the samples in water bath at 60°C for half an hour and 24 hours. The test results are given in table 3.

\[
\text{Retained Stability } \% = \frac{\text{Stability after 24 hours in water bath at } 60^\circ\text{C}}{\text{Stability after 30 minutes in water bath at } 60^\circ\text{C}} \times 100 \quad \text{(1)}
\]

| Type of Mix at Various temperatures          | Avg. stability after half an hour in water at 60°C (kg) | Avg. stability after 24 hours in water at 60°C (kg) | Avg. Retained Stability % | Design Requirement                                      |
|---------------------------------------------|--------------------------------------------------------|---------------------------------------------------|---------------------------|---------------------------------------------------------|
| CRMB 60 Bitumen @155°C - 160°C without additive | 1127                                                   | 885                                               | 78.5                      | Minimum 75% (as per MORTH 4th Revision Table 500-17)    |
| Warm mix additive Modified CRMB @ 130°C-135°C | 1196                                                   | 999                                               | 83.5                      |                                                         |
| Warm mix additive Modified CRMB @ 120°C-125°C | 1156                                                   | 962                                               | 83.2                      |                                                         |
| Warm mix additive Modified CRMB @ 110°C-115°C | 1128                                                   | 908                                               | 80.4                      |                                                         |
| Warm mix additive Modified CRMB @ 100°C-105°C | 1119                                                   | 895                                               | 79.9                      |                                                         |
2.4.2 Indirect Tensile Strength (ITS) & Tensile Strength Ratio (TSR)

ITS tests were conducted on Marshall Samples of conventional bituminous mixes and warm mixes at 25°C. The ITS test was performed by loading a Marshall specimen with a single compressive load, which acts parallel to and along vertical diametrical plane. This loading configuration develops a uniform tensile stress perpendicular to the direction of the applied load and along the vertical diameter. The load at which the specimen fails is taken as the indirect tensile strength (also referred as the dry indirect tensile strength) of the bituminous mix.

The tensile strength ratio of the bituminous mixes is used to determine the moisture susceptibility of the mixes. The Marshall specimens were casted at 7% air voids and were placed in the water bath maintained at 60°C for 24 hours and then immediately placed in the environmental chamber maintained at 25°C for two hours. These conditioned samples are then tested for indirect tensile strength. The indirect tensile strength of these soaked samples is called wet indirect tensile strength. The ratio of the wet to dry indirect tensile strength is recorded as Tensile Strength Ratio (TSR) of the bituminous mix.

\[
T = \frac{2\pi p}{\pi t \cdot d}
\]

Where,

- \( P \) = Load at which failure of sample occurred in kg
- \( t \) = thickness of sample in cm
- \( d \) = diameter of sample in cm
- \( T \) = Indirect tensile strength in kg/sq cm

The tensile strength ratio (TSR) is calculated as follows

\[
TSR = \frac{T_2}{T_1}
\]

Where,  
- \( T_1 \) = average tensile strength of unconditioned specimen.
- \( T_2 \) = average tensile strength of conditioned specimen.

### Table 4 Tensile Strength Ratios

| Type of Mix                                      | Avg. Dry ITS (Kg/cm²) | Avg. Wet ITS (Kg/cm²) | Tensile Strength Ratio (%) | Design Requirement                        |
|------------------------------------------------|-----------------------|-----------------------|----------------------------|-------------------------------------------|
| CRMB 60 Bitumen @155°C – 160°C without additive | 9.5                   | 8.4                   | 88.4%                      | Minimum 80% (as per MORTH 4th Revision Table 500-17) |
| Warm mix additive Modified CRMB @130°C – 135°C  | 10.3                  | 9.6                   | 93%                        |                                           |
| Warm mix additive Modified CRMB @120°C – 125°C  | 10.2                  | 9.2                   | 90%                        |                                           |
| Warm mix additive Modified CRMB @110°C – 115°C  | 9.4                   | 8.1                   | 86.1%                      |                                           |
| Warm mix additive Modified CRMB @100°C – 105°C  | 9.3                   | 7.5                   | 80.6%                      |                                           |

2.4.3 Hamburg Wheel Tracking Test

The rutting in bituminous concrete layer is caused by combination of densification (volume change) and shear deformations, both resulting from repetitive application of traffic loads. The rate of permanent deformation accumulation increases rapidly at higher temperatures; thus the laboratory testing was conducted at a higher temperature of 50°C. This test method covers the determination of rut depth of rectangular specimen (slab) of
bituminous mixes. Rutting in the specimen occurs due to repetitive action of wheel subjected to standard axle load. Specimens were prepared for warm mix (120-125°C) and conventional mix (155-160°C) and were conditioned for at least 4 hours at the specified temperature. Wheel tracking apparatus consists of a loaded wheel and a confined mould in which the 300*300*50 mm specimen for BC is rigidly restrained on its four sides. The loaded wheel which bears on a test specimen held on a reciprocating table. The table moves to and fro beneath the wheel in fixed horizontal plane. The test was continued until the wheel-track deformation reaches a depth of 10 mm or for 6 hours, whichever is sooner. Impression depths were recorded for warm mix and conventional hot mix at regular intervals. The behaviour of the two mixes is shown in Figure 2.

From the study it was observed that the warm mix CRMB made at 120°-125°C shows considerably better performance in terms of rutting than conventional CRMB-60 paving grade bituminous mix prepared at 155°-160°C. This increase in rutting resistance in warm mix is due to better stability and bonding between aggregates and binder.

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3. Field demonstration project

The field trial of warm mix was laid over a 500 m section of road at DSIIDC Bawana industrial area in Delhi. The trial was placed using a warm mix surfactant based chemical additive with CRMB-60 produced at site with VG-30 bitumen. The digestion tank capacity was 30 tonnes. Two agitators atop the tank assisted in crumb homogenization and in the solubilisation of the chemical additive. The dosage of warm mix additive was kept around 0.5% by weight of binder. There was no odour of chemical additive emanating from the two tank feed ports during the addition of chemical. After addition, additive-treated CRMB was allowed to stir for 30 minutes prior to transfer to the service tank that fed the pug mill mixer. Conventional CRMB-60 mix was being produced at about 155-160 °C. Warm mix additive treated CRMB-60 mix was produced at 125 °C. At 30-35 °C lower temperature. Warm mix produced excellent coating to the aggregates.

Conventional CRMB-60 was being laid at about 150°C and compaction completed at around 130 °C. Below that, the mix does not remain workable and the roller passes caused hair line cracks on the surface. Warm mix additive-treated CRMB mix was laid at 113°C, and could be compacted at temperature of around 100°C. The workability of the mix could be maintained at that low temperature, which satisfied the paving crew. No sign of crack development was visible. Further, the warm mix generated much less fumes, which is beneficial to environment and health and safety of the workers.
3.2 Energy Consumption

Following parameters were noted down during the plant operations for preparation of CRMB bituminous mix.

Table 5. Plant Configurations

| Item                      | HMA Parameters | WMA Parameters |
|---------------------------|----------------|---------------|
| Pug mill mixing time      | 24 sec         | 16 sec        |
| Burner Opening            | 75-85%         | 45-55%        |
| Average Fuel Consumption  | 3.5-4.5 ltr/ton| 2.5-3.5 ltr/ton|
| Binder Temperature        | 170-180°C      | 170-180°C     |
| Aggregate Temperature     | 170-175°C      | 130-140°C     |
| Mix Temperature           | 170-180°C      | 120-130°C     |

It was observed by plant operation and reduction in burner opening that there was approximately 20-25% of fuel savings in case of WMA CRMB.

4. Results and Discussion

Viscosity tests were performed on blends prepared by mixing 0.2%, 0.3%, 0.5% and 0.7% of warm mix chemical additive in to CRMB-60 bitumen. Results are given in figure 1 and the results show that the addition of warm mix additive reduces the viscosity of CRMB-60. The viscosity of neat CRMB-60 reduced to a great extent when 0.2% of the warm mix additive was added and it further reduced after addition of 0.5% of the warm mix additive, but the decrease was not much significant when 0.7% of the warm mix additive was added. It was observed that optimum reduction in viscosity of CRMB-60 was achieved when 0.5% of warm mix additive was used.

Performance of the Mix: Results given in table 3 indicates that retained stability of the mix increased with the incorporation of warm mix additive. This indicates that the bond between the aggregate and the binder becomes stronger with the addition of warm mix additive. When 0.5% warm mix additive was added the retained stability of the mix increased up to a value of 83.5% from 78.5% of the neat binder at a temperature range of 130-135°C and in the range of 120-125°C the value was 83.2%. Figure 3 shows the variation in the retained stability values when the bituminous mix was made at different temperature ranges after adding warm mix additive. It can be seen that the warm mix modified CRMB gave better retained stability values within the temperature range of 100-105°C as compared to CRMB hot mix values.
The tensile strength ratio of the bituminous mixes determines the moisture susceptibility of the mixes. The values of TSR of CRMB containing warm mix additive are recorded as 93% at 135°C, and 90% at 125°C whereas the CRMB hot mix gave 88.4% at 160°C. Figure 4 shows the variation in TSR values at different temperature ranges after adding warm mix additive to CRMB. This shows that with warm mix additive the CRMB bituminous mix can be prepared at a low temperature of 120°C having similar or better properties than CRMB hot mix made at 160°C. This reduction of 40°C will lead to lot of energy savings.

Rutting is a key factor for design as well as evaluation of the performance of bituminous concrete mixtures. It can be seen from Fig 2 that observed rut depth values for warm mix modified CRMB mixes are much lower than that of CRMB hot mix. Data plotted in Fig 7 indicate that higher resistance to rutting is observed when warm mix additive is added to the binder, indicating better resistance to permanent deformation. The increased rutting resistance is due to the better moisture resistance of the mix containing warm mix additive and also due to the better strength of the mix achieved.

5. Conclusions

Based on the results from the laboratory and from the field trial it can be concluded that:
The addition of warm mix additive of 0.5% by weight of bitumen helps in substantially lowering down the mixing and compaction temperatures.

- The Retained stability for mixes containing warm mix additive were better than the retained stability of CRMB hot mix.
- Better TSR values were observed for warm mixes in temperature range of 110-130°C but MORTH design requirements were met at all the temperatures.
- Warm mix CRMB have indicated improved resistance to permanent deformation as obtained from the wheel tracking tests as compared to the conventional hot mix.
- The Warm mix could be compacted well in field using conventional equipment and rolling patterns, and there was no evidence of the mix agglomerating due to the lower temperature involved. Though it is obvious that there will be an overall reduction in quantity of emission of pollutants when the mix is made at 120°C than at 155°C, in terms of fuel etc., extensive study is required in this area to get better conclusion.

Acknowledgements

The authors are thankful to Dr.S.Gangopadhay, Director, Central Road Research Institute, New Delhi, for his encouragement during the study. The authors are thankful to M/s Mead West Vaco India Pvt. Ltd, for supplying the surfactant based additive, Evotherm, to produce warm mixes in this study. The research sponsoring organization and authors do not endorse any proprietary products or technologies mentioned in this paper. These appear herein only because they are considered essential to the objective of this paper.”
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