Effect of Polymer and Warm mix Modification on Asphalt Mixture Properties

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Abstract. Among various kinds of asphalt binder modification methods, polymer modification and warm mix modification are two of the most popular ones. While polymer modification improves the lower and higher temperature performances of the asphalt mixture, warm mix modification reduces the mixing and compaction temperatures. So, the present study examines the effect of warm mix and polymer modification on the Marshall properties and moisture susceptibility of the asphalt mixes. In order to take advantage of both these popular modification methods, warm mix polymer modified bitumen (WMPMB) was prepared by mixing polymer and warm mix modifier in the conventional binder. The effect of the combined modification (warm mix and polymer) was studied with the help of experiments on the asphalt binders and mixtures. Based on the results it is concluded that using both the modifiers together we can avail the benefits of both the modification methods.

1. Introduction

The increasing traffic, heavier axle loads, and extreme weathering conditions are imposing big challenges in front of the pavement researchers and practitioners. There are different methods which are being adopted to meet these challenges but one of the most common is the modification of asphalt binders. Even though asphalt binder makes 4-6% of the asphalt mixture but its properties affects the performance of the pavement considerably [1]. Among various modification methods, polymer modification and warm mix modification are two of the most widely used. Polymer modification is preferred over others as it has the advantage of improving low temperature performance as well as high temperature performance of the asphalt binders [2, 3, 4, 5]. On the other hand, Warm mix modification reduces the production temperature of the asphalt mixture by 20-40 °C. This reduced production temperature makes the mix economical by reducing the production cost and also making it environment friendly by reducing the fuel utilization in heating the materials [6, 7, 8].

One of the problems associated with polymer modified binder is that it has considerably higher production temperature as compare to the unmodified binder (reference). On the other hand, warm mix modification reduces the production temperature. Polymer modification and warm mix modification has been widely used by the researchers and found to be very beneficial in improving the properties of the asphalt binders and mix (reference) but the use of these two modification method is one area which has not been explored that much. Using these modification methods together may result in the production of mix which has superior performance along with the economic and environmental advantages. So, the current paper explores the prospects of using both the technologies together. In the study polymer modification and warm mix modification methods are used separately and together to produce polymer
modified binder (PMB), warm mix asphalt (WMA) and Warm mix polymer modified binder (WMPMB). The effect of modification examined by using the different experimental procedures on the asphalt binder and mixture. The results obtained from different experiments are compared and based on that conclusions are given.

2. Materials and experimental plan

In the present study viscosity graded VG-10 asphalt binder has been used as the base binder. The binder was modified using styrene butadiene styrene (SBS) polymer modifier and zycotherm a chemical warm mix modifier. By using these modifiers separately and together, three different modified binders were prepared. The optimum modifier content for SBS modification was determined with the help of separation test and fluorescence microscopy [9]. It was found to be 3% by the weight of base binder. The results of these test are not discussed here for brevity. For the preparation of WMA, optimum dosage of zycotherm i.e. 0.1% as suggested by the manufacturers was used. For WMPMB first PMB was prepared using 3% SBS and then 0.1% of zycotherm was added. The preparation details of these binders are given below in the table 1:

| Modified Binder | Base Binder | Modifier | Modifier Dosage | Blending Temp. | Blending Duration | Shear Rate |
|-----------------|-------------|----------|-----------------|----------------|------------------|------------|
| PMB             | VG-10       | SBS      | 3% by wt.       | 180°C          | 60 Minutes       | 1500 RPM   |
| WMA             | VG-10       | Zyrotherm| 0.1% by wt.     | 150°C          | 15 Minutes       | 400 RPM    |
| WMPMB           | PMB         | Zyrotherm| 0.1% by wt.     | 170°C          | 20 Minutes       | 1500 RPM   |

In order to characterise the materials first conventional tests were conducted on the asphalt binders and aggregates. Conventional test results for the asphalt binders is given in table 2:

| Tests                      | VG-10 | WMA | PMB | WMPMB |
|----------------------------|-------|-----|-----|-------|
| Penetration Value, dmm     | 94    | 98  | 44  | 40    |
| Softening Point, °C        | 46    | 42  | 65  | 67    |
| Absolute Viscosity at 60 °C, Poise | 980  | 1165| 20800| 22300 |
| Ductility Value            | >100  | >100| 75  | 74    |
| Elastic Recovery (%)       | -     | -   | 68  | 66    |
| High Temp. PG              | PG 64-XX | PG 64-XX | PG 76-XX | PG 76-XX |

From the above results it can be observed that polymer modification considerably reduced the penetration and ductility values whereas the softening point and viscosity values were increased. This can be credited to the continuous three-dimensional network which polymer additives forms in the base binder during the blending process. This polymer network, at the higher temperatures provides the required rigidity to the binder and on the other hand increases its elasticity at lower temperatures [10, 11]. In case of warm mix modification, the change in conventional properties were similar to that of polymer modification but the extent of changes was much smaller. This may not be the effect of warm mix modifier but these changes can be due to the fact that during the blending process binder is heated and that increases the stiffness of the binder. Polymer modification increased the performance grade (PG) of the binder whereas warm mix modification did not affect it.

The conventional properties of the aggregates are given below in the table 3. All the properties were found to be within the specified limits.
Table 3. Conventional Properties of Aggregates

| Tests                                            | MORTH* Specified Values | Obtained Values |
|--------------------------------------------------|-------------------------|-----------------|
| Specific Gravity (Coarse Agg.)                   | -                       | 2.70            |
| Specific Gravity (Fine Agg.)                     | -                       | 2.712           |
| Water Absorption (IS:2386, Part III)             | Maximum 2%              | 0.85%           |
| Impact Value (IS:2386, Part IV)                  | Maximum 24%             | 15.53%          |
| Los Angeles Abrasion (IS:2386, Part IV)         | Maximum 30%             | 18.97%          |
| Crushing Strength (IS:2386, Part IV)             | -                       | 16.55%          |
| Combined Flakiness and Elongation Index (IS:2386, Part I) | Maximum 35%             | 22.45%          |

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In order to give the clearer understanding of the experimental procedure that has been followed in the study is given in figure 1:

![Experimental flowchart of the study](image-url)
3. Results and discussion
In the study Marshall stability and retained marshall stability tests have been performed. The results of these tests are presented and discussed as follows.

3.1 Marshall Stability Test
The aggregate gradation adopted in the study has been given in the Table 4 and has been visually represented in the figure 2:

**Table 4. Aggregate Gradation Adopted in the Study**

| Sieve Size (mm) | Cumulative % by weight of total aggregate passing | MORTH Specified limits | Obtained Values |
|-----------------|---------------------------------------------------|------------------------|-----------------|
| 26.5            | 100                                               | 100                    |                 |
| 19              | 79-100                                            | 89.5                   |                 |
| 13.2            | 59-79                                             | 69                     |                 |
| 9.5             | 52-72                                             | 62                     |                 |
| 4.75            | 35-55                                             | 45                     |                 |
| 2.36            | 28-44                                             | 36                     |                 |
| 1.18            | 20-34                                             | 27                     |                 |
| 0.6             | 15-27                                             | 21                     |                 |
| 0.3             | 10-20                                             | 15                     |                 |
| 0.15            | 5-13                                              | 9                      |                 |
| 0.075           | 2-8                                               | 5                      |                 |

**Figure 2. Aggregate gradation adopted in the study**

After achieving the required gradation of the aggregates Marshall stability test was performed to evaluate the stability of the asphalt mix. Binder content was varied from 4.5% to 6.5% by weight of aggregate with an increment of 0.5%. About 1200 gram of aggregate (of the desired gradation) was taken and mixed with the different percentage of bitumen. The aggregate and bitumen was heated to the required temperature such that at no time the difference between their temperatures exceeds 14 °C. The mixing was done at a suitable predetermined temperature. The mixing and compaction temperature of WMA mixtures were adopted 20 °C lesser than their hot mix asphalt (HMA) counterparts as prescribed by the zycotherm manufacturers. The compaction and mixing temperatures of different binders is given below in table 5. After mixing the mixture was transferred to a pre-heated Marshall mould having a height of 63.5 mm and diameter of 102 mm. A mechanical hammer of standard weight is used to
compact the sample at a suitable compaction temperature. The preheated hammer was placed in position and the mix was compacted by applying 75 blows on each face. Three identical samples at each binder content were prepared. Prepared Marshall samples are shown in figure 3. The compacted samples were allowed to cool at room temperature overnight. The samples were then transferred to a pre-heated water bath having a temperature of 60 °C for 30 to 40 minutes. Marshall stability test was performed on these samples. The sample were placed below the Marshall testing head. Compressive load is applied at a constant rate of 51 mm/minutes until the failure of the specimen. Marshall stability is the value of the maximum load at failure while the flow value the amount of deformation undergone by the sample as given by the reading of the flow meter.

**Table 5.** Mixing and compaction temperature of different binders

| Binder   | Mixing Temperature (°C) | Compaction Temperature (°C) |
|----------|-------------------------|----------------------------|
| VG-10    | 150                     | 130                        |
| WMA      | 130                     | 110                        |
| PMB      | 172                     | 155                        |
| WMPMB    | 152                     | 135                        |

Figure 3. Marshall test samples

Figure 4 presents the graphical representation of the Marshall stability and flow values obtained in the study. PMB was found to have 23% higher stability values than VG-10. Here warm mix modification was found to improve the stability values of the mix, for both the warm mix asphalt binders WMA and WMPMB, stability values were 8% and 10% (approx.) higher than the VG-10 and PMB respectively. Zycotherm, being a silane-based technology, is reported to be more effective than some other chemical warm mix additives [12]. This improved performance can be credited to the molecular level hydrophobic zone that it creates around aggregate surface. Organofunctional silanes present in the zycotherm forms a covalent bond between an organic and inorganic phase. The inorganic part of this couple forms hydrogen bond with the hydroxylated agent on surface of the stones while the organic part, in the presence of water condenses through the process of hydrolysis and forms hydrophobic siloxanes. So, when the temperature increases, hydrogen bond breaks and produces H₂O and covalently bonded metallosiloxane. This results in the formation of cross-linked siloxane (Si-O-Si) film structure over the aggregate surface. This resulted in better performance of WMA and WMPMB.
Marshall Quotient (MQ) is used as a measure of the permanent deformation; shear stress and rutting of the mix to be used in the road service. Marshall Quotient is estimated as the ratio of stability of the asphalt concrete mix to the flow value. A comparison of Marshall Quotient was done for asphalt concrete mix prepared using different asphalt binders at optimum content. It was observed that polymer modification improved MQ by 23% whereas in case of warm mix modification this improvement was marginal. Marshall quotient values of the different mixes has been given in figure 5.

3.2 Retained Marshall Stability Test

Damage due to moisture is one of the biggest concerns in flexible pavements. The durability of an asphalt mixture can be indirectly assessed by its susceptibility to moisture. Retained Marshall stability test was carried out to examine the susceptibility of the asphalt mixes to moisture. For each type of mix, six different specimens were prepared and divided into two groups having three specimens each. Specimens from the first group were subjected to conditioning by immersing them in a water bath maintained at 60 °C for a period of 24 hours. On the other hand, specimens of group two were kept unconditioned following the normal immersing of specimens for 30 minutes at a temperature of 60 °C. All the samples were tested in a Marshall stability testing machine until failure by application of load at a constant deformation rate of 51 mm per minute. The average stability values for each group was calculated and the retained Marshall stability values were determined using the following equations.
Presence of moisture in a bituminous mix can lead to early failure of flexible pavements and can be a major hazard. The durability of asphalt mixture can also be evaluated by studying the susceptibility of asphalt mixtures to moisture. The loss of adhesion between the bitumen and aggregates was studied by utilising the retained Marshall stability test. A higher value of retained Marshall stability indicates lower moisture susceptibility and vice-versa. Table 6 presents the result of the retained Marshall stability.

\[
\text{Retained Stability} = \frac{\text{Marshall Stability of conditioned specimen}}{\text{Marshall Stability of standard specimen}} \times 100
\]  

Table 6. Retained Marshall Stability of Mixes

| Binder  | Stability (kg) | Retained Stability (%) |
|---------|---------------|------------------------|
|         | Standard      | Conditioned            |              |
| VG-10   | 1374.26       | 1081.64                | 78.71        |
| WMA     | 1491.65       | 1245.61                | 83.51        |
| PMB     | 1689.42       | 1481.25                | 87.68        |
| WMPMB   | 1871.53       | 1711.14                | 91.43        |

Results clearly showed that mixes prepared using modified binders had higher retained Marshall stability than the conventional binder implying that the modified binders are less susceptible to moisture damage. Mix with WMPMB had the best retained Marshall stability. Figure 6 presents the retained Marshall stability values of the mix prepared using different binders. Here also it was observed that mixes containing binder with zycotherm i.e. WMA and WMPMB showed better moisture resistance than their corresponding base binders. This again can be credited to the siloxane (Si-O-Si) film structure over the aggregate surface which being a hydrophobic layer, improves the moisture susceptibility of the mixes [12]. Two major conclusions can be drawn from the results. First, mixtures prepared using modified binders have lower moisture susceptibility as compared to conventional binders and secondly addition of chemical warm mix additive zycotherm improves the moisture susceptibility of conventional as well as PMB.

Figure 6. Retained Marshall Stability of the mix prepared using different binders

4. Conclusions

Present paper studied the use of both polymer modification and warm mix modification together. In order to check the stability of the asphalt mixtures, Marshall stability test was conducted. Retained Marshall stability test was conducted to assess the moisture susceptibility of the mixes. In the study it was found that polymer modification due to their three dimensional polymer network improved the Marshall Properties and moisture susceptibilities of the asphalt mixture considerably. Marshall stability
values increased by 23%, Marshall Quotient was also increased by 23% whereas the retained marshal stability value increased by 10%. Warm mix modification also improved the properties of the mix. It improved Marshall stability by 8% and retained Marshall stability by approximately 5%. Using both the modification method proved helpful in utilising the advantage of both these modification methods. The WMPMB samples showed better performance with increased Marshall stability, retained Marshall stability and Marshall Quotient at 20 °C lower compaction and mixing temperature as compared to PMB. This makes it economic and environment friendly also. So the study concludes that polymer modification and warm mix modification can be used together to obtain better asphalt mixture structurally, economically and environmentally.

References
[1] Singh B, Kumar P 2015 Effect of modifiers on the ageing properties of bitumen: A review proc. of 3rd Conference of Transportation Research Group of India, Kolkata, India.
[2] Lu X, Ekblad UI 1999 Rheological properties of SEBS, EVA and EBA polymer modified bitumens Mater. Struct. 32 131–139.
[3] Sengoz B, Isikyakar G 2008 Evaluation of the properties and microstructure of SBS and EVA polymer modified bitumen Constr. Build. Mater. 22 1897–1905.
[4] Airey GD 2002 Rheological evaluation of ethylene vinyl acetate polymer modified bitumens Constr. Build. Mater. 16 473–487.
[5] Isacsson ULF, Lu X 1999 Characterization of bitumens modified with SEBS, EVA EBA Polymers Journal of Materials Science 4 3737–3745.
[6] Zaumanis M 2010 Warm mix asphalt Investigation PhD Thesis, Riga Technical University, Kgs. Lyngby, Denmark.
[7] Rubio MC, Martínez G, Baena L, Moreno F 2012 Warm Mix Asphalt: An overview Journal of Cleaner Production 24 76–84.
[8] Banerjee A, de Fortier S, Prozzi JA 2012 The effect of long-term aging on the rheology of warm mix asphalt binders, Fuel 97 603-611.
[9] Singh B, Kumar P 2019 Effect of polymer modification on the ageing properties of asphalt binders: Chemical and morphological investigation Constr. Build. Mater. 205 633-641.
[10] Airey GD 1997 Rheological Characteristics of Polymer Modified and Aged Bitumens PhD Thesis, University of Nottingham.
[11] Singh B, Saboo N, Kumar P 2017 Effect of short-term aging on creep and recovery response of asphalt binders Journal of Transportation Engineering, Part B: Pavements 143(4), 04017017.
[12] Mirzababaei P 2016 Effect of zycotherm on moisture susceptibility of Warm Mix Asphalt mixtures prepared with different aggregate types and gradations Constr. Build. Mater. 116 403-412.