Evaluation of Physical Properties of Bituminous Mixtures Modified with Polymer Additives

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Abstract

The road construction industry is concerned with utilizing alternative and sustainable binder materials to aid in the production, placement and increase in the performance of flexible pavements. This research is aimed at evaluating the physical properties of bituminous mixtures modified with PET (Polyethylene Terephthalate), SBS (Styrene-Butadiene-Styrene) and EVA (Ethylene-vinyl Acetate) used as bitumen modifiers. The samples were prepared by heating the base bitumen and each polymers to their respective melting points to facilitate the miscibility of the materials; the base bitumen and each polymers were mechanically mixed together with a blending speed of 2000 ± 10 rpm for an hour. Penetration, ductility, softening point, flash and fire point and water in bitumen tests were performed to relevant standard specifications on bitumen and PMB (Polymer Modified Bitumen) with polymer composition varied from 10% to 50%. The penetration test result showed that polymers have hardening effect on bitumen; this was evidenced by the reduction in the penetration values of PET modified bitumen from 51 to 57 decimillimetre (dmm), 59 to 55 dmm for SBS modified bitumen and 68 to 59 dmm for EVA modified bitumen for all the percentage compositions. The PMB showed improved stiffening which was demonstrated by increase in the softening point of the PMB, the softening point of PET modified bitumen increased from 540C to 670C. Likewise, the softening point of SBS modified bitumen increased from 560C to 700C and the softening point of EVA modified bitumen also increased from 550C to 600C for all the percentage polymer compositions. The improvement in the water resistant capability of the PMB was confirmed by the reduction of moisture content of bitumen on addition of polymers from 3% for bitumen to 1.1% which is the least moisture content recorded at 50% composition of SBS modified bitumen.

Keywords: Physical properties, polymer additives, bitumen, bituminous mixture

1. Introduction

Bitumen is an important low-cost thermoplastic material, which has applications as a building, and engineering material; however, bitumen has poor mechanical properties, as it is hard and brittle in cold environments, soft and fluid in hot environments [1].

The use of bitumen in road pavement and airfield runway applications has been satisfactory but in recent time, the increase in amount and weight of vehicles had very severe effects on the performance of asphalts produced with bitumen. Two main alternative ways to tackle this problem and to construct more durable pavement is by applying thicker asphalt pavement and the second is by constructing asphalt mixture with modified characteristics. The first solution does not offer a proper solution because it causes higher construction costs [2]. Utilization of alternative and sustainable binder materials to aid in the production, placement and increase the performance of flexible pavements is fast gaining acceptability in the road paving industry. For the materials to be considered sustainable, they must be technically, economically and environmentally viable. Technically, these materials should be compatible with other materials and the existing production and paving equipment can be used for it [3]. Economically, a sustainable material should be available in large quantities that is appropriate for the application. In addition, to justify its use, this material adds value to a product in an affordable manner while environmental viability ensures that the environment is not affected in a negative way. The use of modified bitumen is an important solution to reduce the frequency of maintenance and sustain the pavement’s durability. According to practical needs and requirements on site, different modifiers are available to improve properties of the bitumen [3]. More recently, researchers have focused on the use of reactive polymers to modify the morphology, rheological properties and storage stability of bitumen. In particular, low molecular weight isocyanates have been shown to react with the asphaltene fraction and alter the mechanical and other properties of bitumen, although the composition and source of the bitumen will play a major role in the extent of these reactions [4]. For example, one of the many ways of toughening bitumen is by blending it with synthetic polymers, which can be either virgin or waste polymer, improvements in deformation resistance can be achieved using thermoplastic polymers and rubbers, as well as some chemicals, such as Sulphur. Thermoplastic elastomers could improve the thermal cracking and fatigue resistance [5]. Rising from the foregoing, this research is therefore aimed at evaluating the physical properties of bituminous mixtures modified with PET, SBS and EVA polymer additives.
2. Materials and Method

2.1. Materials

In this research, bitumen was modified with Styrene-butadiene-styrene (SBS), Ethylene-vinyl acetate (EVA) copolymer and Polyethylene Terephthalate (PET). The price of these polymers per kilogram (kg) is small compared to bitumen, they are readily available and some of them like PET are generated in large quantities as waste.

Materials: materials used for this research are:

1. 60/70 penetration grade bitumen
2. Bitumen modifiers:
   a. Polyethylene Terephthalate (PET) in Fig. 1 is the most common thermoplastic polymer resin of the polyester family.
   b. Ethylene-vinyl Acetate (EVA) in Fig. 2 is the copolymer of ethylene and vinyl acetate.
   c. Styrene-butadiene-styrene (SBS) in Fig. 3 is a family of synthetic rubbers derived from styrene and butadiene.

2.1. Sample Preparation

The percentages of each polymer, which is aimed at partially replacing bitumen to improve their properties, was weighed in 10%, 20%, 30%, 40% and 50% percentage compositions of the weight of bitumen and heated to their respective melting points; bitumen was also heated to a temperature of 120°C. This temperature guaranteed that both polymers and bitumen were always over their softening point temperature. Temperature, blending speed of 2000 ± 10 rpm and mixing time of an hour were picked according to conditions detailed by past researchers [6] [7]. After heating, each percentage compositions of polymer were added to bitumen and mixed thoroughly with a mechanical stirrer Heidolph display RZR 2020 to ensure that the resulting solutions were homogeneous.

2.2. Methods

Physical properties of bitumen and PMB were determined by carrying out the following tests:

1. Penetration test (ASTM D5 / D5M-13) [8].
2. Ductility test (ASTM D113 - 86) [9].
3. Softening point test (ASTM D36 / D36M) [10].
5. Water in bitumen test Dean and Stark Method (ASTM D95) [12].

3. Result and Discussion

The results of penetration test, ductility test, softening point test, flash and fire point test and water in bitumen test analysed for PET, SBS and EVA modified bitumen are presented in Fig. 4 – 9 respectively. The results are expected to comply with the paving grade bitumen specification ASTM/EN 12591 [11] in Table 1.

3.1. Penetration Test

Penetration test is an empirical test that measures the consistency (hardness) of an asphalt at a specified test condition and makes it possible for bitumen to be graded. The result of penetration of bitumen and PMB in Fig. 4 showed that there is decrease in penetration of PMB from 66 dmm to 51 dmm with increasing polymer content. The indication of the decrease in the penetration values of PMB is that there is increase in binder hardness, as showed by the decrease in penetration. This can be attributed to a
hardening effect caused by the addition of polymers to base bitumen. PET modified bitumen reduced the penetration of bitumen well.

Table 1: Standard Test Method and Limit (ASTM/EN 12591)

<table>
<thead>
<tr>
<th>Test</th>
<th>Unit</th>
<th>Limit</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration @ 25°C</td>
<td>dmm</td>
<td>60-70</td>
<td>ASTM D5</td>
</tr>
<tr>
<td>Softening Point</td>
<td>°C</td>
<td>49-56</td>
<td>ASTM D36</td>
</tr>
<tr>
<td>Ductility @ 25°C</td>
<td>cm</td>
<td>100 Min.</td>
<td>ASTM D1113</td>
</tr>
<tr>
<td>Flash Point</td>
<td>°C</td>
<td>280 Min.</td>
<td>ASTM D92</td>
</tr>
<tr>
<td>Fire Point</td>
<td>°C</td>
<td>320 Max.</td>
<td>ASTM D90</td>
</tr>
<tr>
<td>Water in Bitumen test</td>
<td>%</td>
<td>5 Max.</td>
<td>ASTM D95</td>
</tr>
</tbody>
</table>

3.2. Ductility Test

The result of ductility test which measures the distance a standard bitumen sample will stretch without breaking under a standard testing condition (5 cm/min at 25°C) shown in Figure 5 indicated that bitumen and PET modified bitumen have high ductility values which is an indication of good adhesive properties and good performance in service. However, 40% and 50% percentage compositions of SBS and EVA modified bitumen have ductility values which are less than the 100 cm minimum ductility value of bitumen.

3.3. Softening Point Test

Ring and ball softening point test result, which measures the temperature at which an asphalt reaches a certain softness in Fig.6, showed that PMB exhibited increase in hardness or stiffness; this is responsible for the increase in softening point values from 50°C to 70°C. The standard required softening temperature for 60/70 bitumen is 49-56°C.

3.4. Flash and Fire Point Test

The result of flash and fire point test to determine the temperature to which a bitumen can be safely heated in the presence of an open flame before its gives a flash of fire and later fire is contained in Fig. 7 and 8 respectively.

The result indicated that flash points of the bitumen, PET modified bitumen and SBS modified bitumen are all within the specified limit of 280 - 300°C in ASTM/EN 12591 [11]. However, EVA modified bitumen at 40% and 50% modifications have a flash point which is lower than the specified range. The fire point of bitumen, PET modified bitumen and EVA modified bitumen are all within the specified range of 300 – 320°C, but SBS modified bitumen displayed fire point values that are more than the specified range for all the percentage modifications.

3.5. Water in Bitumen Test (Dean & Stark Method)

The result of water in bitumen test in Fig. 9 showed that the water content of base bitumen reduced from 3% to 1.1% as the percentage compositions of each polymers increases. SBS modified bitumen with 50% SBS composition reduced the water content to the lowest value of 1.1%.
4. Conclusion

The results of physical properties tests carried out on bitumen and PMB confirmed that polymers have hardening effect on bitumen; this was demonstrated by reduction of the penetration of PET modified bitumen from 51 to 57 dmm, 59 to 55 dmm for SBS modified bitumen and 68 to 59 dmm for EVA modified bitumen. The stiffening effect of polymers on bitumen was confirmed by increase in the softening point of the PMB; the softening point of PET modified bitumen increased from 54°C to 67°C. Likewise, the softening point of SBS modified bitumen increased from 56°C to 70°C and the softening point of EVA modified bitumen followed the same trend as it increases from 55°C to 60°C for all the percentage polymer compositions. The result of water in bitumen test confirmed that PMB has a reduced water content compared with bitumen. The results of all the physical properties tests conforms to the values in ASTM EN 12591. The research output suggested that polymers could be used to improve the hardness, stiffness, water resistance and ductility of bitumen.

References