Modification of Malaysia Bituminous Binder Using Waste Polystyrene

Olufemi A. Johnson, Ibrahim Kamaruddin and Ibrisam Akbar

Abstract Waste Polystyrene is a principal component of urban litter and marine debris. Proper management of waste as become a major concern. Waste Polystyrene is non-degradable and environmentally unfriendly. This study explores the economical use of waste polystyrene as polymer modifier in bitumen. Modified bitumen were prepared by adding 1, 2, 3% waste polystyrene in Malaysia bituminous grades (60/70 and 80/100). The characteristic properties and storage stability of the modified bitumen was evaluated and compared with conventional bitumen and results show a significant increase of 35 and 29% softening point values for 60/70 and 80/100 gradation respectively. There is a 20% reduction in the penetration values for both 60/70 and 80/100 gradation which is an improvement in characteristics of the modified bitumen and there is no significant change in the phase of the modified bitumen after storage. The utilization of waste polystyrene will not only improve bitumen performance but also create a friendly and sustainable environment by creating alternative reuse of the waste.

Keywords Bituminous binder · Modifier · Bitumen · Modified binder · Polymer · Polystyrene

1 Introduction

Polymer modified binder (PMB) have proved to be useful in various application of road constructions, by improving reflective cracking in pavement [11]. In asphalt concrete, polymer modified binders are active in decreasing rutting and may also

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improve fatigue crack resistance. The higher the shear resistance the better the performance of the pavement at high-stress locations. In full depth pavements, polymer modification increases the stiffness of the load-bearing layer thus increasing pavement fatigue life, this is also in thinner layers [8].

Chemical composition of Polymers is made up of large molecules of similar units. Polystyrene comprises of numerous styrene molecules connected together in sequential order. They can be of similar molecular units in a unique block pattern. The properties of a polymer depend on the properties of the molecular units that made up the polymer and their interaction with other molecular types [10].

Polystyrene is manufactured through a process whereby monomer molecules reacts together to form larger molecules. Polystyrene contained carbon and hydrogen as it only atoms in chemical structure. The polystyrene chemical structure bonds indicate interconnectivity of the carbon atoms. There is no evidence of chemical reactions between the polymer addictive and the bitumen. However, it does affect its physical properties, thus leading to an improved softening point, brittleness, and elastic recovery. The aim of this study is to explore the effect of waste polystyrene on the characteristic properties of the selected bitumen grades.

Nassar et al. [9] investigated the effect of waste polystyrene (WPS) on the modified bitumen performance using expanded polystyrene (EPS), the result shows that the addition of wastes polymer significantly influenced the mechanical properties of the base bitumen.

Xiaohu and Isacsson [7] carried out a study evaluating the influence of SBS modifier application on viscosity of modified bitumen, the results indicates that the SBS polymers were very active agents, though there is no defined proper proportionality in the influence of the modifier content on the values of kinematic and dynamic viscosities, the viscosities increases as the polymer content increases by weight of the blend. Kumar et al. [6] explored the effect of using elastomer as bitumen modifier over elastomers. The results show that elastomers modified bitumen displayed enhanced properties compared to plastomer modified bitumen.

Asim et al. [2] explored the application of rubber crumb as bitumen modifier considering the rheological properties of the modified bitumen. They recorded an improved aging resistance in the rubber crumber modified bitumen. Mahrez et al. [1] investigated the viscoelastic properties of waste plastic modified bitumen. The result shows an enhanced viscoelastic properties of waste plastic modified bitumen compared to the conventional bitumen (80/100).

PMB has been proven to significantly improve the properties of bitumen binder. However, the optimum mixing temperature, time, and % content of WPS have not been established. This study explores the optimization in the use of WPS in bituminous binder modification of Malaysia bitumen.

2 Material and Method

2.1 Bitumen

The selected bitumen are 60/70 and 8/100-pen grade Malaysian bitumen supplied by PETRONAS. The properties of the bitumen are shown in Tables 1 and 2.

2.2 Waste Polystyrene

Waste Polystyrene from food and drink containers shredded fibers was used as a modifier in this study. The waste container was shredded into fibers of size 20 and 30 mm. The properties of the polystyrene are shown in Table 3.

3 Preparation of Modified Binder

About 600 g of the bitumen was heated at 170 °C to a fluid condition. The mixing was done in the laboratory with a high shear mixer at 600 rpm. High shear was used to attain higher levels of fine particle dispersion. This fine dispersion assists the association of the polymer with the base bitumen, allows easier absorption of the maltene fraction into the polymer particles and minimizes the propensity for the modifier to settle out during storage. After the mixing temperature is reached, the molten bitumen were divided into five small empty cylindrical containers of

Table 1 Properties of 60/70 grade bitumen

Specific gravity @ 25/25 °C (g/cm^3)	Penetration @ 25 °C (0.1 mm)	Softening point @ °C	Viscosity @ 60 °C (Poises)	Viscosity @ 135 °C (cSt)
1.01–1.06	62	46	175	0.22–0.45

Table 2 Properties of 80/100 grade bitumen

Specific gravity @ 25/25 °C (g/cm^3)	Penetration @ 25 °C (0.1 mm)	Softening point @ °C	Viscosity @ 60 °C (Poises)	Viscosity @ 135 °C (cSt)
1.020	81	42	125	0.15–0.4

Table 3 Properties of waste polystyrene

Specific gravity (g/cm^3)	Apparent density (g/cm^3)	Water absorption (%)		
1.03–1.06	0.60–0.65	0.30–0.10		

250 mL volume. The net weight of bitumen in each small tin was 120 g. Polymer content by weight of binder in 1, 2, and 3% was introduced into the hot bitumen in a gradual manner to ensure a homogeneous mixture and the typical mixing time was 1 h. at 180 °C temperature [9]. After the preparation of the blend, the sample was allowed to cool for 1 h. and the same process was repeated for other samples.

3.1 Testing

The conventional tests were used for the rheological characterizations of the original bitumen and the modified bitumen. Basic bitumen tests were carried out on the original bitumen and the modified bitumen to measures its consistency and the influence of storage on the modified binder.

3.1.1 Penetration Test

Penetration test was used to examine the consistency of samples of neat bitumen and modified bitumen by determining the distance in tenths of millimeter that a standard needle vertically penetrates the bitumen specimen under known conditions of loading, time and temperature.

Penetration test specimens were prepared in accordance with the standard [5], dimensioned needle loaded to 100 g was brought to the surface of the specimen the right angle, then allowed to penetrate the bitumen for 5 s, while maintaining the temperature at 25 °C, the penetration was measured in tenths of millimeters. Three determinations were made on each specimen and the mean was calculated.

3.1.2 Softening Point Test

This test was conducted to evaluate the temperature at which the bitumen begins to flow. The specimens were prepared in accordance with Standard [3] and maintained at a temperature of 10 °C below the expected softening point for 30 min before the test. The rings and assembly, and two ball bearings were placed in a liquid bath filled to a depth of 105 mm and the whole maintained at a temperature of 5 °C for 15 min. The steel ball bearing was placed on the specimen and then heat is applied to the beaker to raise the temperature. The temperature at which each bitumen specimen envelop the bearing ball and touches the base plate was recorded.

3.1.3 Storage Stability Test

Effect of storage on the modified bitumen was evaluated in the highway laboratory on the 60/70 and 80/100 modified bitumen with 3% modifier of the bitumen weight.

The sample was poured inside a carefully made aluminium foil tube with 30 mm diameter and 20 cm height, which was stored at 163 °C for 48 h. After 48 h the sample was cooled at room temperature and the sample was divided into three equal parts and samples were taken from the top and bottom sections of it to determine the temperature at which the sample will begin to flow and the difference in the temperatures at which both samples flow was compared, if more than 2.5 °C, the sample is not having a good storage stability but otherwise, it can be said it has good storage stability [4].

4 Results and Discussion

This chapter discusses the laboratory results from the preliminary tests conducted. Some of the tests carried out to confirm the feasibility of the proposed project are the one that are used in the characterization of binders and these involve penetration-test, softening point-test, and storage stability test.

4.1 Penetration Test

Penetration measures the consistency of bitumen. Figure 1 shows the variation of penetration value with the different percentage of bitumen modified WPS and it indicates that consistency decreases with increase in WPS content. The penetration values for the modified binders decrease as the WPS content in the mix increases. There is a significant decrease of 20% in the penetration value for both 60/70 and

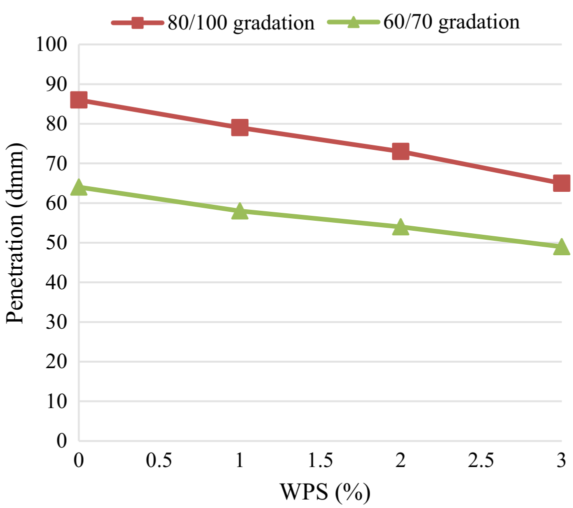

Fig. 1 Penetration grade versus different percentage of WPS for 80/100 and 60/70 gradation

80/100 gradation. This means that the presence of WPS in the binder makes it harder n consistent which invariably increase the rutting resistance of the binder [5].

4.2 Softening Point Test

The Softening point test measures the temperature at which bitumen begins to show fluidity. Figure 2 show that softening point increases with increase in WPS content thus reduces the temperature susceptibility of the binder. There is a significant increase of 30 and 29% in the softening point temperature for 60/70 gradation and 80/100 gradation respectively. This improves the resistance of binders to permanent deformation. The use of WPS in the bituminous mix will help reduce rutting due to the increase in softening point value.

4.3 Storage Stability Test

Effect of storage on the modified bitumen was carried out on the samples with 3% WPS considering that this is the optimum modifier content and the results are shown in the table; since the difference between the softening point of the top section and the bottom section is not more than 2.5 °C, it can be said that WPS modified bitumen is storage stabled. Table 4 shows that the difference in the softening point temperature of the top and bottom of the modified bitumen with 3% WPS is less than 2.5 °C for both 60/70 and 80/100 grade, which indicates good

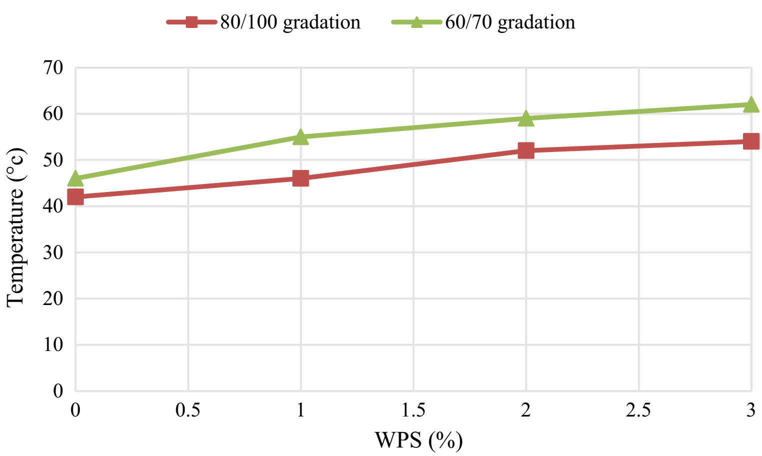

Fig. 2 Softening point temperature versus different percentage of WPS for 80/100 and 60/70 gradation

Table 4 Storage stability test results for 60/70 and 80/100 grade bitumen

Sample	80/100 (top section)	80/100 (bottom section)	60/70 (top section)	60/70 (bottom section)
Ball 1	54.5	53	79.6	79.5
Ball 2	54	53.4	79.8	80
Mean value	54.3	53.2	79.7	79.8

storage stability. Though it was discovered that there is a drop of 5–7% in the value of the softening point temperature compared to the value obtained before storage, this may be further investigated.

5 Conclusions

Based on the results, it can be deduced that WPS increases the resistance of binder to temperature changes, while the resistance to flow also increases thus improved the rutting resistance of the modified bitumen. It can be seen from the results that the application of WPS can significantly change the bitumen gradation, from 80/100 to 60/70 and from 60/70 to 40/50. It is also discovered that the modified bitumen will exhibit high resistance to fatigue and rutting compare to virgin bitumen, though all the three had the same performance grade, the use of WPS in polymer modification of bitumen will not only help in improving binder properties and performance but also help reduce the environmental problem caused by WPS.

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