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Modification of Bitumen Characteristic by Using Recycled Polyethylene

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The aim of this study was to evaluate the effect of recycled polyethylene on physical and rheological properties of polymer modified bitumen. Four type of analysis consist of rheological, mechanical, thermal and surface morphology was conducted to study the effect of polyethylene content on bitumen binder. Dynamic shear rheometer was used to study the rheological properties of the composite binder. Thermogravimetric studies showed that the thermal stability of polyethylene modified binder was improved compared to unmodified binder. Gradually increase in the polymer contents has increased the complex shear modulus, storage modulus and loss modulus of the bitumen binder.

Keywords Bitumen binder; recycled polyethylene; rheological; cracking; ductility; morphology

Introduction

Bitumen is known as residue produced from the process of petroleum fractionation. It is widely used for road pavement comparing with another material called tar. Nowadays, many researches have been carried out to find the most suitable mixture of bitumen with other material to improve its rheological properties. Recently, waste material is used for various purposes such as in road making, as fill beneath building, in brickmaking and others [1]. Abdel Aziz Mahrez et al. [2] had conducted rheological evaluation on bituminous binder containing plastic waste of polyethylene terephthalate (PET). It's an environmental friendly solution as we can reduce the amount of polymer waste without reducing the production of polymer itself. Besides, the use of modified bitumen is economically and financially viable. Modified bitumen requires less thickness, longer life and less maintenance cost [3].

Garcia-Morales et al. [4] have conducted rheological studies for four different types of waste polymers which are crumb tire rubber, ABS, EVA and lastly EVA/LDPE blend

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Table 1. Typical properties of 80/100 grade bitumen

Test	Standard method	Value
Penetration at25°C (1/100cm)	ASTM D5	98
Softening point (°C)	ASTM D36	50
Ductility at 25°C (cm)	ASTM D113	99
Viscosity at 135°C (MPas)	ASTM D4402	320

as bitumen modifying agent. By mixing the recycled polymer with bitumen, it is expected that polymer modified bitumen composite with better performance and properties will be resulted. In studies conducted by Yue Huang et al. [5], recycled plastic claimed to substitute part of aggregates or act as binder modifier. Overall, the substitution of aggregates with low density polyethylene improved the water resistance, rutting, tensile strength and Marshall Stability. Construction industry has taken up the challenge to apply the plastic scrap in their building material to reduce their material cost and creating friendlier environment [6].

Experimental

In this study, bitumen with penetration grade of 80/100 was used as the binder. The conformance of the bitumen grade was done referring to the Manual on Pavement Design for penetration grade 80/100 which includes penetration test, softening point test, ductility test and viscosity test. The properties of bitumen were given in Table 1.The waste polymer used is polyethylene (PE) obtained from Recycled Petchem (M) Sdn. Bhd. The recycled polyethylene used has a melting point ranging from 105°C to 115°C.

Polyethylene (PE) scrap in pellet shape was used to mix with the bitumen. In this study, five different concentration of polyethylene which range from 1 wt% to 10 wt% by weight were mixed using high shear mixer at RPM of 1000-2000. Before mixing, the bitumen was heated at 100°C for 1 hour to ease up the mixing process with the polymer. The temperature during the mixing using high speed shear mixer was monitored to be in the range of 140°C – 160°C using thermometer. Four type of analysis consist of rheological, mechanical, thermal and surface morphology was conducted to study the effect of polyethylene content to bitumen binder. Characterization test on the polymer modified bitumen samples were conducted according to ASTM method. The rheological test includes penetration test (ASTM D-5), softening point (ASTM D-36), viscometer test (ASTM D-4402), ductility (ASTM D-1113), dynamic shear rheometer (DSR) (ASTM D-4 P246).Thermal degradation analysis was observed using thermogravimetric analyser (Mettler Toledo TGA/SDTA). The surface morphology was monitored using optical microscope Olympus BX61.

Results and Discussion

Figure 1 shows that the softening temperatures of the bitumen only slightly increased when >7 wt% of recycled polyethylene was added in bitumen. This result indicates that the polymer modified bitumen with >7 wt% of polyethylene can resist higher temperature before deformation. Penetration test was used to measure the hardness and softness point of the bitumen binder after modification by adding recycled polyethylene at different composition. Figure 2 illustrates that the penetration value decreases as the polyethylene

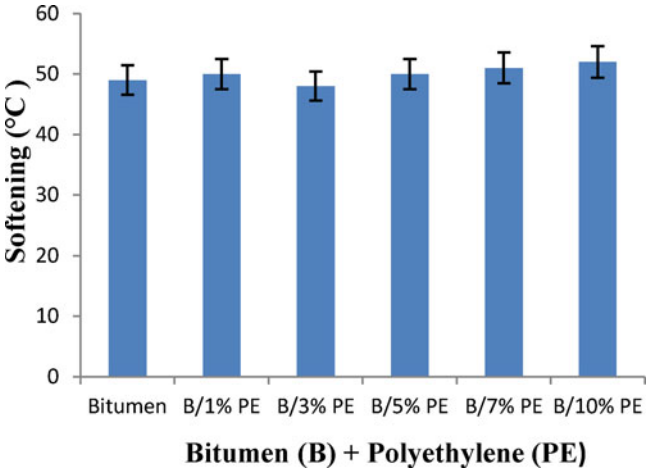

Figure 1. Effect of addition of recycled polyethylene to softening point of bitumen binder.

content in bitumen increase. Pure bitumen used in this study has the value of penetration at 98 dmm. After polymer modification, the penetration value declined to 52 dmm at 10 wt% of polypropylene content. The lower the penetration value, the harder the polymer modified bitumen. The increase of the stiffness would contribute to the higher resistance to rutting and less temperature susceptibility of the polymer modified bitumen composite [7].

Viscosity test is used to measure the resistance to flow and its internal friction. The viscosity of asphalt binder at high manufacturing and construction temperatures is generally above 135°C due to three factors which are ability to pump, ability to mix and workability [2]. Figure 3 shows that the viscosity of the polymer modified bitumen binder increased as the polyethylene addition increased. Structural changes happened when viscosity increased resulting higher stiffness. It is stated in ASTM D3673 that bitumen binder is practicable at value below 3000 mPas, thus polyethylene modified binder does satisfied the criteria as the

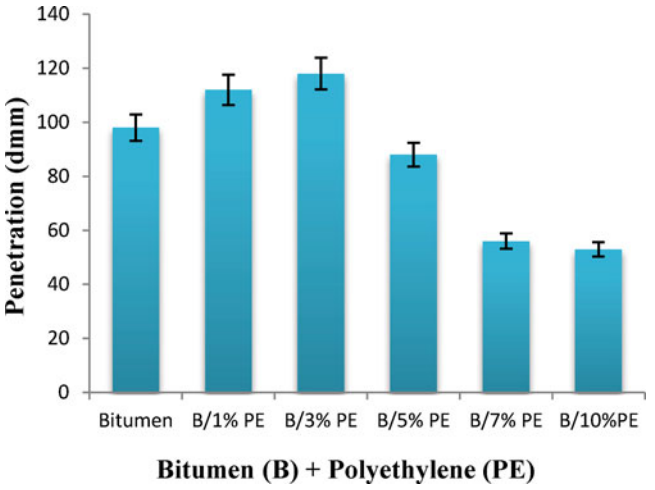

Figure 2. Effect of recycled polyethylene content to penetration properties of bitumen binder.

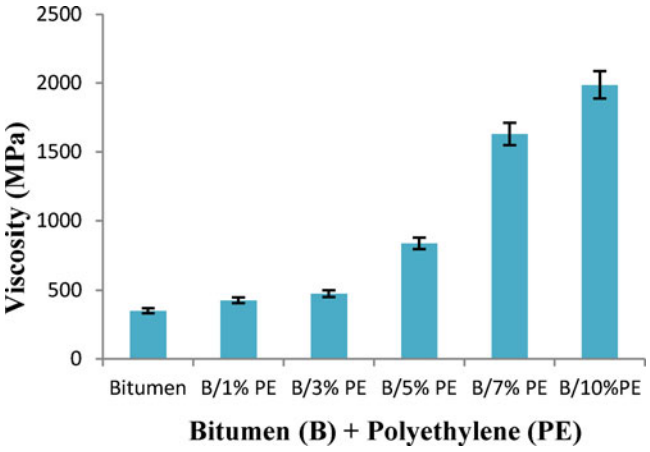

Figure 3. Effect of recycled polyethylene content to viscosity of bitumen binder.

highest viscosity value is 1987 mPas for component with 10 wt% of recycled polyethylene content. The increment on this viscosity property must be controlled since too high viscosity will create complexity in mixing, laying and compaction of the mixture [8].

Ductility test used to evaluate the anti-cracking performance of asphalt at low temperature [9]. Referring to the result shown in Fig. 4, the ductility values decreased as the polyethylene addition increased to the binder. Generally, bitumen with 80/100 penetration grade has the ductility value of ∼100 cm. As the polyethylene modified binder get harder and stiffer, the reduction of ductility values is predictable. Addition of polyethylene to viscous bitumen tends to reduce the ductile characteristic of the material. According to ASTM D113, the ductility value is less than 100 cm, thus the addition of <10 wt% of recycled polyethylene to bitumen composite binder fulfills the requirement and can be applied for pavement usage.

Mechanical characteristic of recycled polymer modified bitumen has been carried out at temperature of 76°C. The complex shear modulus (G^*) is defined as the ratio of the

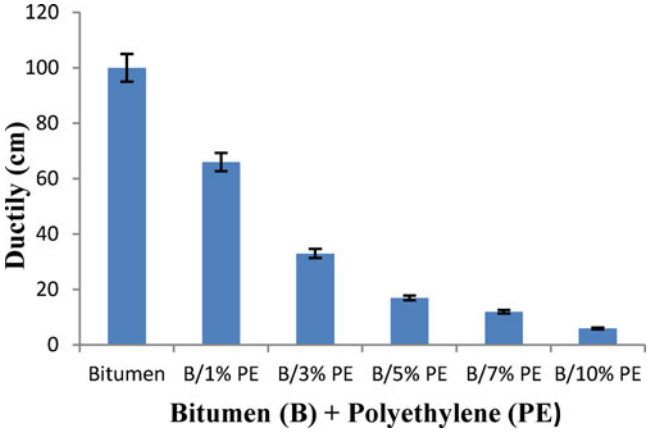

Figure 4. Ductility properties of recycled polyethylene modified bitumen binder.

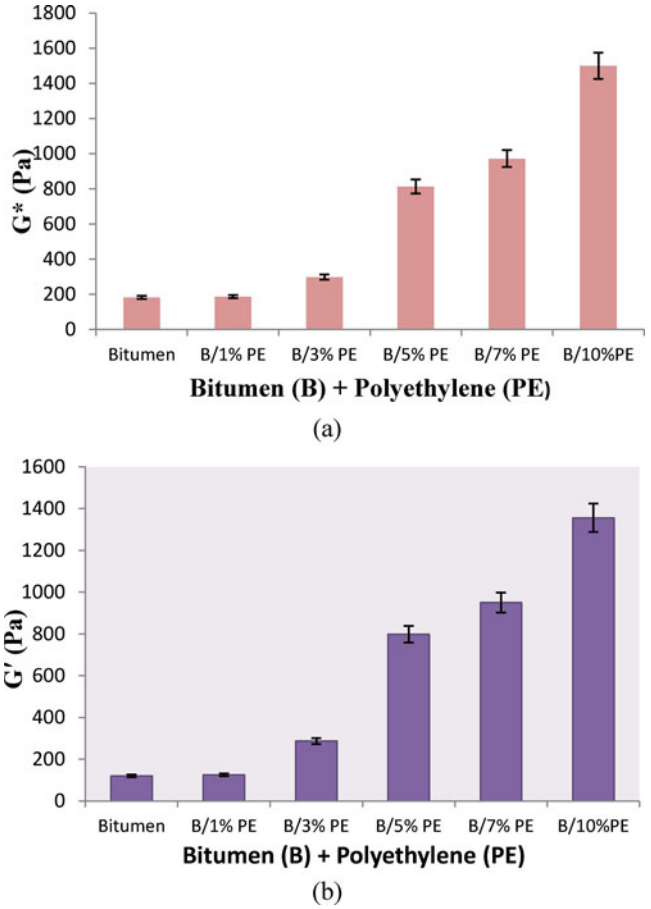

Figure 5. Effect of polyethylene content to complex shear modulus, G* and elastic modulus, G' of bitumen binder at 76°C temperature.

peak stress to the peak strain which measure the overall resistance to deformation of a material when repeatedly sheared. With the increase of recycled polyethylene addition to the bitumen, the elastic modulus, G' showed significant increments as shown in Fig. 5(a). Figure 5(b) illustrates that the value of elastic modulus increased from 125 Pa to 1574 Pa when 10 wt% of polyethylene content was added into neat bitumen. With lower elastic modulus and higher tan δ, higher energy will be released [10]. The thermal cracking will occur when additional impact from traffic loadings. According to Read and Whiteoak [11], thermal cracking will occur when the bitumen becomes too stiff to withstand the thermally induced stress and it is related to the coefficient of thermal expansion and the relaxation characteristic of the mixture.

Thermal degradation behavior of polyethylene modified bitumen and base bitumen is reflected in Fig. 6. Thermal stability of neat and modified bitumen binders is one of the most important properties for production, application, and service [12] (Fig. 7). Averagely, polyethylene addition to the bitumen binder from 1 to 10 wt% showed thermal stability until 400°C. Modified bitumen with 5 wt% plastic was found to have the highest thermal stability compared to other binders investigated [13]. It can be said that, polyethylene modified bitumen binder is safe to be used up to 400°C before it loses its characteristic.

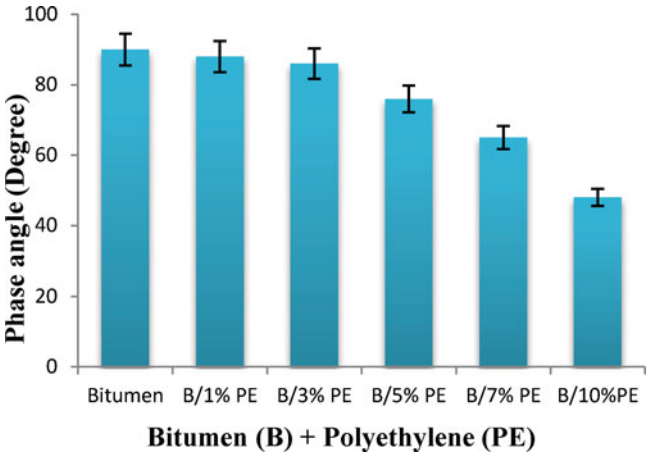

Figure 6. Changes of phase angle value for bitumen binder after modification with various composition of recycled polyethylene.

The mutual effect of polymer and bitumen can result in the morphology as it is affected by the bitumen content and polymer content itself [14]. Optical microscope has been used to investigate the state of polymer dispersion within the base of bitumen. Figure 8 illustrates that the image of polyethylene modified binder at different composition. At lower polyethylene content of 3 wt% and 5 wt% (Fig. 8(a) & 8(b)), the blend was in homogenous state. Dispersion of polymer globules was not seen. This result indicates that the addition of small amount of 3 wt% of polymer addition can mix well with the bitumen at 180°C mixing temperature. As the polyethylene content was increased to 7 wt% and 10 wt%, continuous bitumen phase with a dispersed polymer globules were observed as shown in Fig. 8(c) and Fig. 8(d) respectively. The dispersed polymer globules became bigger in size

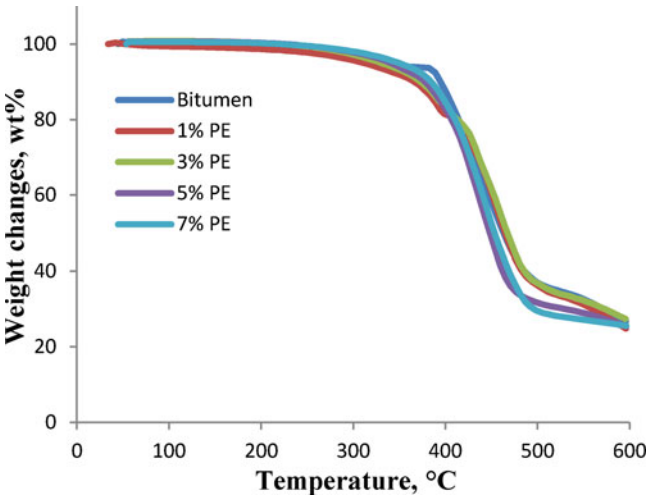

Figure 7. Thermal stability study of recycled polyethylene modified bitumen binder.

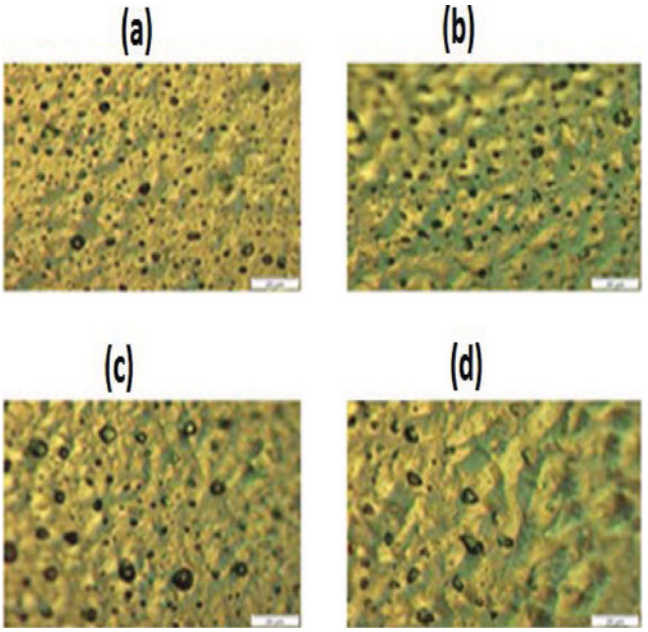

Figure 8. Images of polyethylene modified bitumen binder with (a) 3 wt%, (b) 5 wt%, (c) 7 wt% and (d) 10 wt% polyethylene content.

when the polyethylene content increased from 3 wt% to 10 wt%. This indicated that as the polymer content in bitumen increased, the bitumen/polymer composite blend became more heterogeneous.

Conclusion

Recycled polyethylene in pellet form added to the bitumen binder at low concentration producing homogenous textures. With the increase of softening point and decrease in penetration values, the viscosity and deformation resistance of the bitumen/polymer blend was enhanced rapidly. Based on the softening and penetration test result, polyethylene modified binder can resist higher temperature before deformation and improved the resistance to fatigue cracking due to the increase of stiffness. Polyethylene modified binder have higher elastic modulus, G' which give positive impact and reduce possibilities of thermal cracking during application. Thermogravity also revealed that thermal stability has been achieved with the addition of polyethylene from 3 wt% to 10 wt%. Thus, the recycled polymer modified bitumen binder is better compared those unmodified bitumen binder.

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