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Effects of Waste Polypropylene Additive on the Properties of Bituminous Binder

Perviz Ahmedzade^{a*}, Kadir Demirelli^b, Taylan Günay^a, Fatih Biryan^b, Omar Alqudah^a

Ege University, Civil Engineering Department, Izmir, 35100, Turkey

Firat University, Department of Chemistry, Elazığ, 23000, Turkey,

Abstract

In this study, a polymer which have a content of 80% wasted polypropylene and other materials, such as maleic anhydride and styrene known as compatible with bitumen was synthesised and employed as a modifier in bitumen. After the polymer (PP_r) synthesizing, base and polymer modified bitumens were investigated by means of florescent microscope, penetration, softening point, rotational viscometer (RV) and dynamic shear rheometer (DSR) tests. The results indicated that PP_r modifier provides an increased stiffness for bitumen. For instance, the binder having %6 PP_r has a penetration of 27 dmm, softening point value of 76 °C, viscosity of 687.5 cP whereas base bitumen has a penetration of 62dmm, softening point of 50.5 °C and viscosity of 412 cP. Stiffening effect of the PP_r was also approved by complex modulus (G*) values in DSR tests. Better viscoelastic behaviour was observed by means of DSR test after the modification. In addition to importance of employing waste polymers in pavements in terms of economic and environmental care, the results indicate the positive effect of the waste polymer on the performance of bitumen and against of rutting in asphalt concrete.

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Keywords: Bituminous materials; Modification; Waste polypropylene; Polymer synthesis; Performance of bituminous binders

1. Introduction

Bitumen, used in many engineering applications especially in flexible highway pavements, is a product from crude oil distillation and a complex material basically composed of hydrocarbons. Due to its viscoelastic and

* Corresponding author. Tel.: 90 232 311 51 79; fax.

E-mail address: perviz.ahmedzade@ege.edu.tr

thermoplastic properties, bitumen behaves like an elastic solid at low temperatures or under rapid loading and like a viscous fluid at high temperatures or under slow loading [1]. Polymer modification is a common method to provide enhanced performance of bitumen by decreasing its temperature susceptibility [2]. Although the polymer modifiers such as styrene-butadiene-styrene (SBS), ethylene-vinyl-acetate (EVA) are used satisfactorily in flexible pavement applications, the tendency of the most recent studies in this field has been to employ wasted polymers as modifier in terms of cost effectiveness and environmental awareness [3].

In this study, a waste polymer (PP_R) that could possibly be compatible with bitumen was synthesised and employed as a modifier in bitumen. The polymer has a content of 80% wasted polypropylene and other materials, such as, maleic anhydride and styrene which are known as modifier of bitumen. After polymer synthesizing, base and polymer modified bitumens were investigated by means of florescent microscope, penetration, softening point, rotational viscometer (RV) and dynamic shear rheometer (DSR) tests. In addition to importance of employing waste polymers in pavements in terms of economic and environmental care, the results indicate that the positive effect of the waste polymer on the performance of bitumen and against of rutting in asphalt concrete.

2. Experimental

2.1 Materials

In this study, the bitumen of 50/70 penetration grade was selected as a binder for all tests. The waste polypropylene used in the synthesis has a specific density of 0.95 g/cm³, melting point of 145 °C. The preparation of waste polymer modifier (PP_R) was carried out as shown in Fig 1. 6.66 mol of wasted polypropylene, 0.061 of maleic anhydride and 0.0123 mol of styrene was selected as initial component for polymer synthesis. All these components and 250 ml 1,2,4-trichlorobenzene (as solvent) were added into reaction flask immersed in oil bath adjusted to 180 °C. Polymerization was done at 24 hours under constant temperature and inert gas atmosphere.

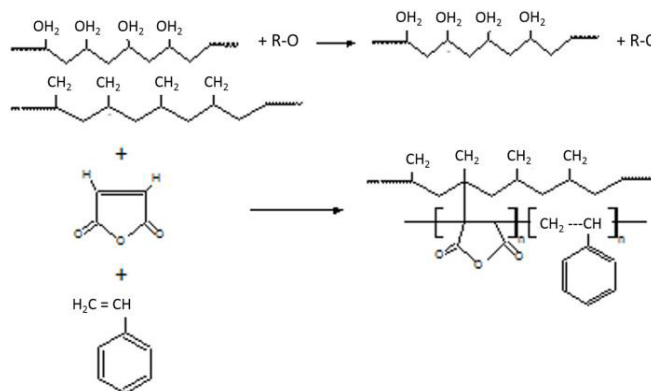


Fig. 1. Synthesis of PP_R polymer.

2.2 Preparation of samples

After polymer synthesis, PP_R additive was used as modifier in bitumen amount of wt. %: 3, 4, 5, and 6 by total weight of the binder which is enough to measure employability range of polymer additive. The bitumen of 50/70 grade was heated for 90 minutes at 180 °C, and then poured into the flask of the high shear mixer (Silverson LSM) adjusted to 1200 rpm. Subsequently the (PP_R was added to bitumen by portions) in 15 minutes at certain intervals and then the mixing rate was increased to 4000 rpm and mixing was continued for 45 minutes. After the end of the mixing process, the samples were removed from the flask and divided into small containers, covered with aluminium foil and stored for various testing. The binders used in this study were coded as below;

base bitumen – “B”;

base bitumen + 3% PP_R – “B-3- PP_R”;

base bitumen + 4% PP_R – “B-4- PP_R”;
 base bitumen + 5% PP_R – “B-5- PP_R”;
 base bitumen + 6% PP_R – “B-6- PP_R”;

3. Testing program

3.1 Morphology of base and PP_R bitumens

The quality of the dispersion of PP_R modifier in the bitumen at different proportions was examined by means of fluorescent microscopy, Leica DM750, magnifying up to 200X. Florescent microscopy uses a blue light for excitation whereas the fluorescent yellow light for the swollen polymer phase [4]. Hence, two different phase (bitumen and polymer) can be discerned.

3.2 Conventional tests

Penetration (ASTM D5), softening point (ASTM D36), ductility (ASTM D 113), rotational viscosity (ASTM D4402) tests were applied to base and PP_R modified bitumens to investigate the effects of the modifier on physical properties of bitumen. Conventional tests were all conducted in accordance with ASTM given in the parenthesis. Penetration index was also calculated in order to investigate the temperature susceptibility of the binders.

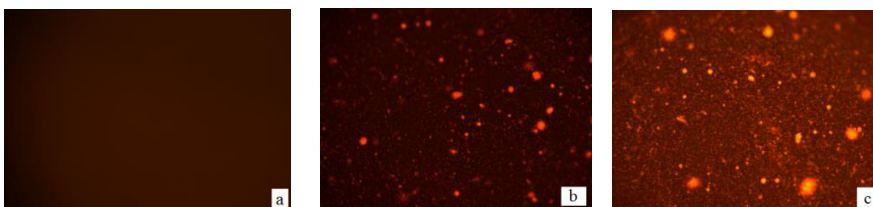
3.3 Dynamic mechanical test

Dynamic shear rheometer test is used to investigate rheology of bitumen by utilizing for a range of test temperature and frequencies. Thus, shear rate dependency of the binders can be analyzed at different temperatures. After the DSR tests the principal viscoelastic parameters such as G^* and δ were determined for base and PP_R modified bitumens. Tests were conducted using frequency sweeping with 3 different frequency points (0.1, 0.71 and 1.94 Hz) and at 10 different testing temperatures between 25 and 75 °C. One type of plate with a diameter of 25 mm and 1 mm gap between the plates was selected as test geometry throughout the testing program.

4. Results and discussion

4.1 Morphology of base and PP_R bitumens

The surface images of B, B-3-PP_R and B-6-PP_R binders taken by florescent microscope at magnification of 200X were given in Figs.2 (a,b,c) which is sufficient to obverse dispersion of polymer modifier content in bitumen according to different polymer proportions. As can be seen from Fig. 1a, base bitumen (B), without PP_R modifier has only one phase (in dark brown) which presents bitumen. At low modification levels (B-3-PP_R), the polymer modifier (in yellowish) almost homogenously dispersed in bitumen phase with a particle size not exceeding 10 micron. In this case, content of PP_R polymer are not enough to form a matrix in bitumen. In this way, bitumen is still the only one phase having dispersed polymers. However, at high modification levels (B-6-PP_R), as can be seen, brown coloured bitumen matrix (in background) starts to fade away as yellowish polymer phase become to dominant phase appearing a distinct phase from bitumen matrix. Thus, at higher polymer content, mechanical behavior of binders are controlled by not only bitumen matrix but also polymer phase which can provide an increase in elastic deformation of bitumen.



Figs.2. The surface images of B (a), B-3-PP_R (b), B-6-PP_R (c) at magnification of 200X

4.2 Conventional test results

The results of the physical tests performed on base and PP_R modified binders were given in Table 1. It can be seen that penetration of PP_R modified binders are lower than that of the base bitumen whereas softening point of PP_R modified binders are higher than base bitumen's. Besides, there is a gradual decrease in penetration and increase in softening point as PP_R modifier content in bitumen increases. These trends in penetration and softening point clearly point out that PP_R modifier provides an increased stiffness for bitumen. As for penetration index which indicate temperature susceptibility of bitumen, as can be clearly seen, this parameter is greater than 0 for all PP_R for all modified binders while penetration index of base bitumen was -0.57. This result is evidence of declining in temperature susceptibility by modification which means bitumen can be applied in a wider range of temperature after PP_R modification.

According to ductility test results, as PP_R modifier slightly decreases bitumen's ductility that means elongation ability of bitumen without break was limited after the modification. Viscosity of bitumen are increased progressively with increasing PP_R polymer content in bitumen that signifies the stiffening effect of PP_R modifier.

Table 1. Physical test results

Properties	Binder type				
	B	B-3- PP _R	B-4- PP _R	B-5- PP _R	B-6- PP _R
Penetration (dmm)	62	48	41	31	27
Softening point (°C)	50.5	65.5	68	72.5	76
Penetration index	-0.57	1.96	2.00	2.07	2.28
Ductility (cm)	90	88	88	85	84
Viscosity (cP) 135 °C	412.5	590	645	672.5	687.5

4.3 Dynamic shear rheometer test results

Plots of log-complex modulus and phase angle (two axes) versus temperature were depicted in Figs. 3-5. Each isochronal plot was drawn at 3 different frequencies which represent different traffic speeds (low-middle-high) in service. As seen in Fig. 3, represent low traffic speeds, complex modulus of PP_R modified binders is greater than that of the base bitumen at all temperature regions. Therefore, it must be noted that in low traffic speeds where the permanent deformation occurs mostly, PP_R modifier improves complex modulus of binders that leads to decrease in deformation. Another parameter, phase angle, generally regard as elasticity of bitumen [5], as can be seen tends to decrease as PP_R modified in bitumen increases which is more evident in high temperature region. Hence, binder of B-6- PP_R has the lowest phase angle compare with rest of the binders. Decrement in phase angle is a clear evidence of improved elasticity of bitumen by means of PP_R modification. The tendencies in Figs. 4 and 5, represents behaviour of binder under middle and high traffic speeds, are very similar to that of given in Fig. 3. Consequently, it can be said that, PP_R modifier provide better complex modulus and lower phase angle at all frequencies and temperature region which lead to decrease in permanent deformation such as rutting.

The positive results obtained from DSR test can be attribute to two distinct phases of modified binders (bitumen and polymer), which was revealed in the surface images, providing better viscoelastic properties especially at high temperatures where bitumen becomes completely viscous whilst polymers phase maintains its viscoelastic behavior [6].

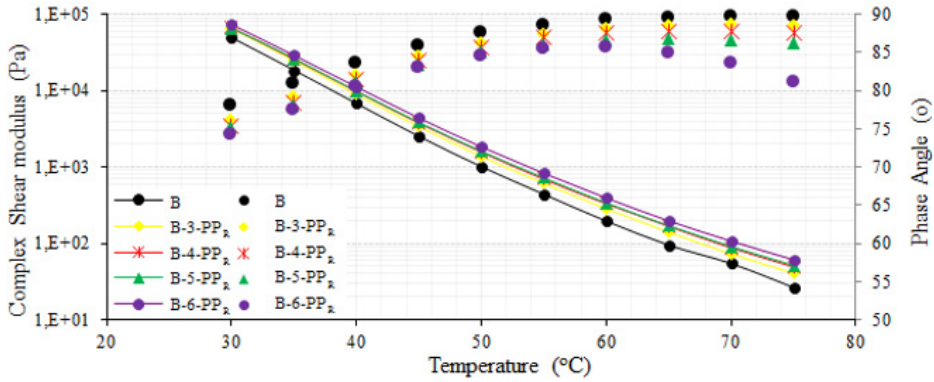


Fig 3. Complex shear modulus and phase angle at 0.1 Hz for base and PPR modified bitumens.

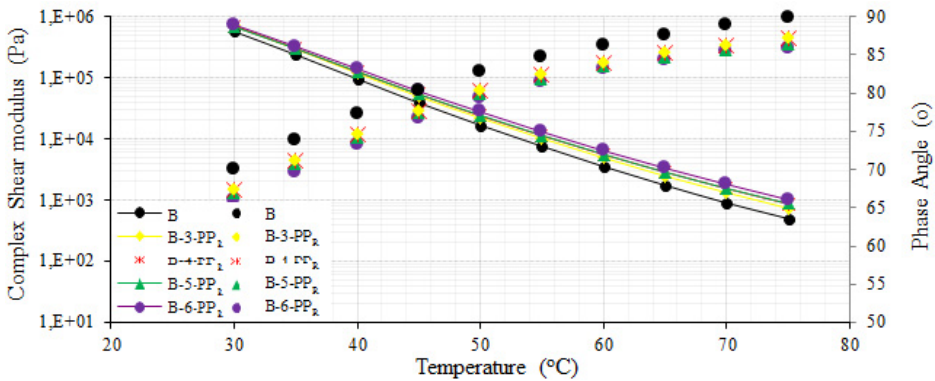


Fig 4. Complex shear modulus and phase angle at 0.72 Hz for base and PPR modified bitumens

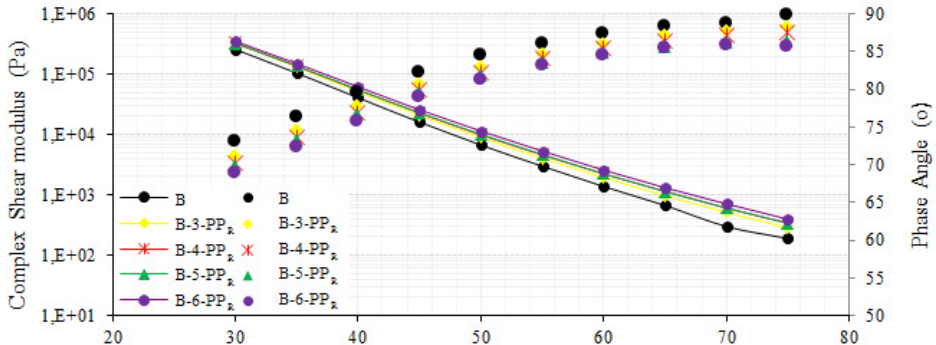


Fig 5. Complex shear modulus and phase angle at 1.94 Hz for base and PPR modified bitumens.

5. Conclusion

Effects of the PPR modifier on properties of bitumen grade of 50/70 were evaluated by several tests. Dispersion of PPR modifier in bitumen is almost homogenous and two distinct matrixes namely bitumen and polymer phase was observed at high modification levels according to surface images of the binders. This observation indicates that at

higher polymer content, mechanical behavior of binders are controlled by both bitumen and polymer phases which could induce an enhanced deformation behavior of bitumen under load.

PP_R modifier produces significant increment in stiffness of binder which evidenced by penetration and softening point tests. Besides, the binders having PP_R modifier is more viscous than that of the base bitumen which also signifies the stiffening effect of bitumen. Complex modulus obtain from DSR frequency sweep tests signifies that increasing content of PP_R modifier in bitumen enhances thermo-mechanical properties of bitumen whilst decrease in phase angle is a clear evidence of improved elasticity of bitumen by means of PP_R modification especially at low frequency and high temperature region.

Acknowledgements

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