Effect of the Waste Plastic bottles on properties of asphalt

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Abstract*:* The purpose of this research is to investigate the possibility of using waste Polyethylene Terephthalate as polymer additives in Bituminous binder. The characteristics of PET-modified binder obtained by fix mixing temperature, was investigated. The binders were prepared by mixing the PET in 2%, 4%, 6%, 8% and 10% (by the weight of optimum bitumen) with 80/100 penetration grade bitumen at temperature of 150 ºC. It may be inferred that PET-modified bituminous binders provide better resistance against permanent deformations due to their higher G*/sin d and . their higher softening point when compared to conventional binders. Using PET-modified binders also contribute to the recirculation of plastic waste, as well as to the protection of the environment.

Keywords: *Polyethylene Terephthalate, modified bitumen, binder test.*

INTRODUCTION

For the past two decades significant research has been conducted on polymer modified asphalt (PMA) mixtures. Polymers can successfully improve the performance of asphalt pavements at low, intermediate and high temperatures by increasing mixture resistance to fatigue cracking, thermal cracking and permanent deformation (Aflaki & Tabatabaee, 2008). The addition of polymers to enhance service properties over a wide range temperature in road paving applications was considered a long time ago and nowadays has become a real alternative. Addition of natural or synthetic polymers to bitumen is known to impart enhanced service properties. By adding small amounts of polymers to bitumen, the life span of the road pavement may be considerably increased. The purpose of bitumen modification using polymers is to achieve desired engineering properties such as increased shear modulus and reduced plastic flow at high temperatures and/or increased resistance to thermal fracture at low temperatures and decreased permanent deformation under load (rutting). Other benefits include greater adhesion to the aggregate and increased tire traction (González Uranga, 2008).

Improvement in rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility have led polymer modified binders to be a substitute for asphalt in many paving and maintenance applications, including hot mix, cold mix, chip seals, hot and cold crack filling, patching, recycling, and slurry seal. They are used wherever extra performance and durability are desired. In many cases, they are selected to reduce life cycle costs (Yuonne *et al*., 2001). Polymer modified binders also show improved adhesion and cohesion properties (Awwad & SHbeeb 2007).

Polymer modification of asphalt binders has increasingly become the norm in designing optimally performing pavements. Mixing polymers into bitumen has important consequences on the engineering properties of bituminous binders. Thus, structural and chemical changes may be observed during processing of polymer-modified bitumen (Pe´rez-Lepe,A *et al*., 2003).

Polyethylene has been found to be one of the most effective polymer additives (Hinisliglu & Agar 2004). Polyethylene is the most popular plastic in the world. Polyethylene is semi-crystalline materials with excellent chemical resistance, good fatigue and wear resistance and a wide range of properties. It has a very simple structure. A molecule of polyethylene is a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom They are light in weight; provide good resistance to organic solvents with low moisture absorption rates (Awwad & Shbeeb 2007). Polyethylene terephthalate (PET) is a linear, aromatic polyester (Bing Sh *et al*., 2006).

2. MATERIALS AND METHODS

2.1 polymers

There are several kinds of polymers that can be recycled in bitumen (Murphy et al., 2001). These include low and high density polyethylene (LDPE, HDPE), widely used in packaging and plastic bottles; polypropylene (PP) often used in straws, sweet wrappings, textile, automobile industries and furniture industries (Zheng et al. 2009), polyvinyl chloride (PVC), used in plumbing pipes and fittings; polyethylene terephthalate (PET), widely used in water and soft drink bottles and acrylonitrile butadiene styrene (ABS), used in electronic devices such as laptops and mobile phones. Some of these materials would be unsuitable for use in manufacturing recycled polymer-modified bitumen. Although the above recycled polymers are available in sufficient quantities so as to be commercially feasible, not all are suitable for the proposed use (Casey et al., 2008).

In this investigation, waste PET in the powdered form in 2%, 4%, 6%, 8% and 10% (by the weight of bitumen) was used as a modifier. Hundreds of waste mineral water bottles were crushed and then were sieved. The properties of PET are as follows: density 1370 kg/m^3 and melting point 260°C.

2.2 Bitumen

The selected bitumen was 100/80-pen grade Malaysian bitumen with a softening point of 46◦C. The properties of asphalt binder, which are presented in Table 1, are within the specification of penetrated bitumen grade 80/100.

Table1 the results of tests performed on bitumen

Test	Test result
Ductility (cm)	< 100
Penetration (0.1 mm)	84-100
Softening point (C°)	46
Specific Gravity (g/cm3)	1.03

2.3 Mixing Method

Dry mix is used in this study. The bitumen, contained in a 1-liter cylindrical container, was put into the oven and heated until it became liquid. The molten bitumen was poured into six small empty cylindrical containers with a volume of 250 ml. The net weight of bitumen in each small tin was 120 gr. Before mixing the waste PET with bitumen in small tins, bitumen would have to be heated up to about 160°C first. To achieve this, small tins of bitumen were heated into the oven for about 1 hour. After that, waste PET in percentage of 2%, 4%, 6%, 8% and 10% was added into the tins and were mixed manually for about 2 minutes. Immediately after mixing, the mixture was placed in softening point rings, penetration cups, viscosity sample chambers and then DSR test specimens were prepared. After having cooled in room temperature for 1 day, samples were tested.

3. RESULTS AND DISCUTION

3.1 Penetration Test Results

Penetration test is the most widely used method of measuring the consistency of a bituminous material at a given temperature. It is a means of classification rather than a measure of quality. The engineering term consistency is an empirical measure of the resistance offered by a fluid to continuous deformation when it is subjected to shearing stress. The consistency is a function of the chemical constituents of bitumen, viz. the relative proportions of asphaltenes (high molecular weight, responsible for strength and stiffness), resins (responsible for adhesion and ductility) and oils (low molecular weight, responsible for viscosity and fluidity). The type and amount of these constituents are determined by the source petroleum and the method of processing at the refinery.

The results are very sensitive to test conditions and bitumen specimen preparation and the requirements of the appropriate standard must be rigidly adhered to. The maximum difference between highest and lowest readings is reported in Table 2.

Table 2 The Maximum Difference Between Penetration Test Results

Penetration (d-mm)	0-49	50- 149	150 - 249	250-500

Maximum Difference	2	4	12	20

It appears clearly from figure 1 that the penetration value of modified bitumen is lower than unmodified one and also they show with increasing the portion of PET in bitumen the penetration value decreases. The decrease is 2.4%, 4.9%, 8.5%, 11% and 14.6% with the addition of 2%, 4 %, 6%, 8% and 10% of PET, respectively, as compared to the original bitumen. This means that the addition of PET makes the modified bitumen harder and more consistent.

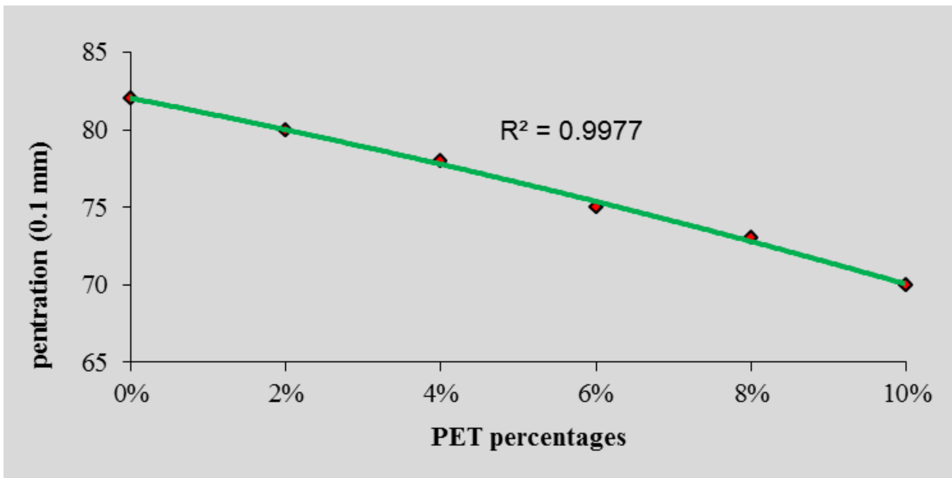

Figure 1 Penetration Vs. Different Portion of PET

3.2 Softening Point Test Results

The softening point is a measure of the temperature at which bitumen begins to show fluidity. It is also defined as the temperature at which a bitumen sample can no longer support the weight of a 3.5-g steel ball. Basically, two horizontal disks of bitumen, cast in shouldered brass rings are heated at a controlled rate (5°C per min) in a liquid bath while each supports a steel ball.

Figure 2 shows that softening point increases with increasing PET content. The results clearly show that the addition of PET to bitumen increases the softening point value, and as the PET content increases the softening point also increases. This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of PET the modified binder will be less susceptible to temperature changes.

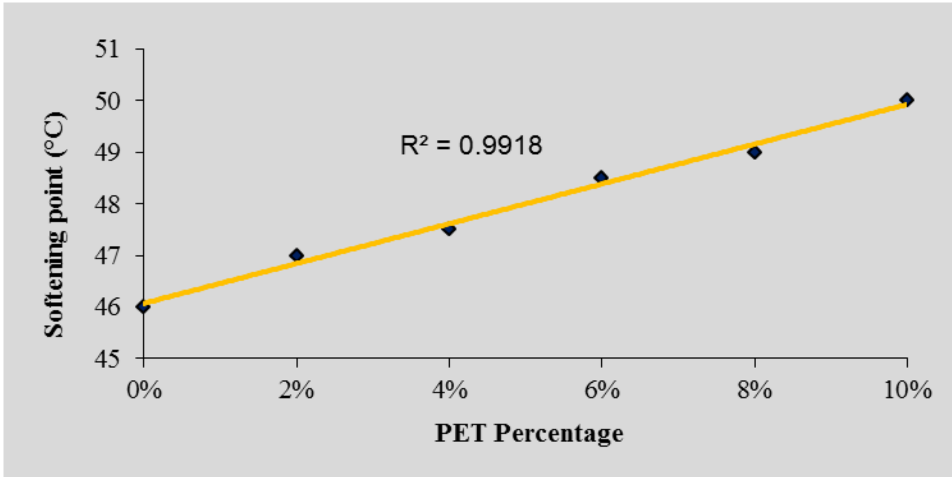

Figure 2 Softening Point Vs. Different Portion of PET

3.3 Penetration Index (PI)

In addition, the temperature susceptibility of the modified bitumen samples has been calculated in terms of penetration index (PI) using the results obtained from penetration and softening point tests. Temperature susceptibility is defined as the change in the consistency parameter as a function of temperature.

A classical approach related to PI calculation has been given in the Shell Bitumen Handbook (Zhang *et al.* 2009) as shown with the following Eq.

$$PI = \frac{1952 - 500\log(\mathrm{Pen25}) - 20 \times \mathrm{SP}}{50\log(\mathrm{Pen25}) - \mathrm{SP} - 120}$$
$$PI = \frac{1952 - 500\log(\mathrm{Pen25}) - 20 \times \mathrm{SP}}{50\log(\mathrm{Pen25}) - \mathrm{SP} - 120}$$

(1)

Where Pen25 is the penetration at 25 ◦C and SP is the softening point temperature of polymer modified bitumen (PMB).

The nomograph as given in figure 3 enables the PI to be deduced approximately from the penetration at 25°C and the softening point temperature. Typical values of PI are presented in table 3.

Table 3 Typical Values of PI

Bitumen type	PI
Blown Bitumen	>2
Conventional Paving Bitumen	-2 to +2
Temperature Susceptible Bitumen (Tars)	<-2

To deduce the PI from figure 3 draw a line between the softening point (line 'A') and penetration (line 'B') values. The intercept on line 'C' is the PI of the bitumen.

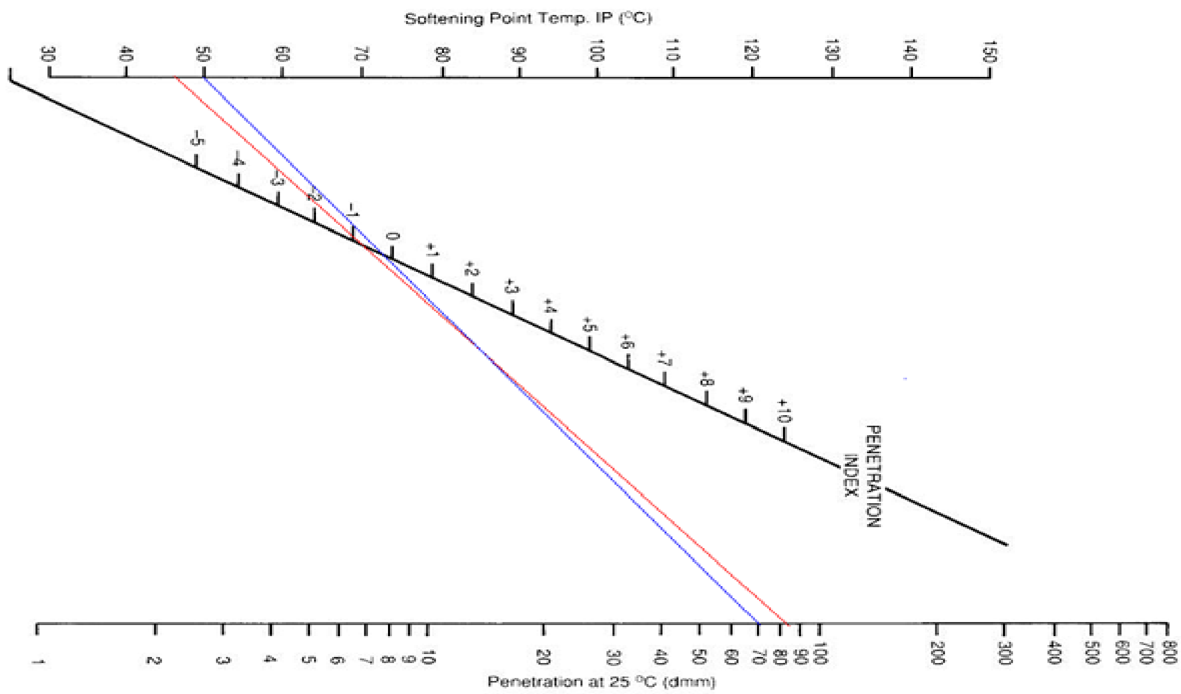

Figure 3 Nomograph for the IP of Bitumen (Whiteoak, 1990)

From figure 3 we can see that PI for all kind of binder in this study is between -1 and +0 therefore the bitumen type is conventional paving bitumen. The intercept on line C and the red line is the PI of original bitumen which is 0 and the intercept on line C and the blue line is the PI of modified bitumen with 10% PET. As we can see PI of modified bitumen is less than PI of unmodified one. It means that Polymer modification reduces temperature susceptibility (as determined by the penetration index-PI) of the bitumen. Lower values of PI indicate higher temperature susceptibility. As reported in the Journal of Testing and Evaluation, asphalt mixtures containing bitumen with higher PI were more resistant to low temperature cracking as well as permanent deformation.

PI values can be used to determine the stiffness (modulus) of bitumen at any temperature and loading time. It can also, to a limited extent, be used to identify a particular type of bituminous material. One drawback of the PI system is that it uses the change in bitumen properties over a relatively small range of temperatures to characterise bitumen; extrapolations to extremes of the behaviour can sometimes be misleading.

1. **Rotational Viscosity**

Modified asphalt binders are usually more viscous than unmodified ones (Aflaki & Tabatabaee, 2008). Figure 4 shows the viscosity curves of Modified bitumen and Figure 5 shows the viscosity of a modified binder at135°C. From test result is obtained that the ratio of viscosity of the modified asphalts binders to the viscosity of the base binder at 135°C varies between 1 and 2 for the modifiers used in this study. In the extreme case of adding 10 % PET to the base binder, the viscosity increased from 275 mPas to 538 mPas. This value is less than 3000 mPas and therefore satisfies the ASTM D6373 criterion for asphalt binder workability (Aflaki & Tabatabaee, 2008).

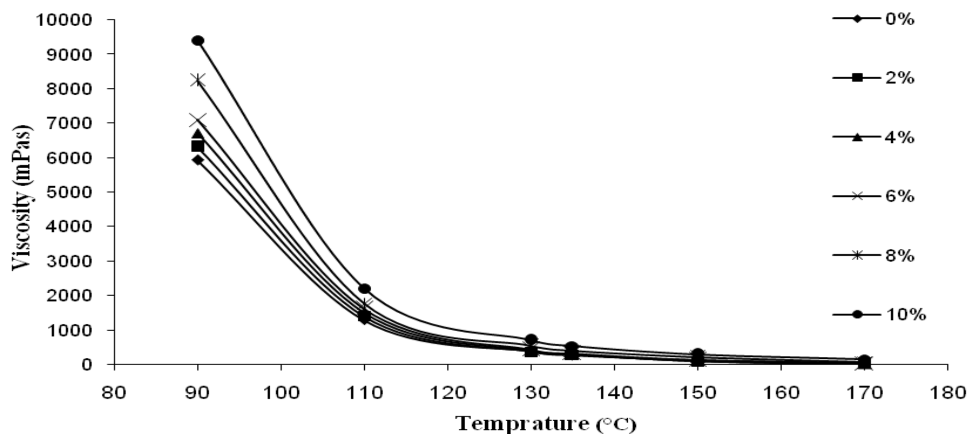

Figure 4 Viscosity vs. Temperature

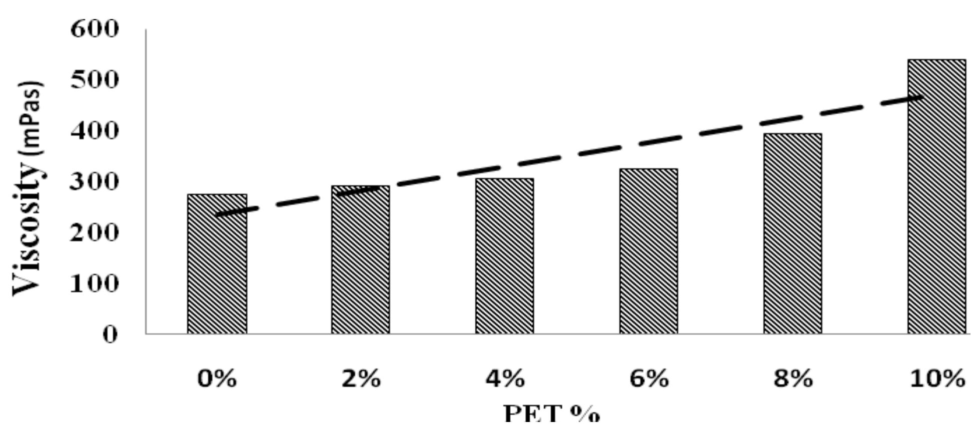

Figure 5 Viscosity vs. PET% @ 135°C Temperature

3.5 Complex shear modulus

The temperature dependence of G* is lowest for the unmodified bitumen compared to modified bitumen. It is observed that in all samples (unmodified and modified bitumen) the complex shear modulus G* decreases as the temperature increase (Figures 6 and 7).
From the graphs we can also see that as PET content increases the complex shear modulus *G**

increases. This can be clearly seen from the figures since the graphs of G* follow a certain order.

It can be seen that the lowest graph is for the original sample (without PET) and the highest one is for the sample with 10% of PET.
The lower slope of the complex shear modulus G* means that the asphalt is softer, and can deform without developing large stresses. Also, a higher complex shear modulus G* have are beneficial since it reduces rutting problems (deformations) in the asphalt.

1. **Phase angle**

Figure 8 shows that the phase angle δ for the unmodified bitumen is higher than modified bitumen. Generally as PET content increases the phase angle δ decreases and we can verify this by doing the same comparison as before concerning the order of the graphs for the samples.
We can also see from the unmodified and modified samples that as the temperature increases the phase angle δ also increases.

The lower slope of phase angle δ means that the asphalt is more elastic than viscous, and will recover to its original condition without dissipating energy. Also, at high temperatures, a low phase angle δ is desirable since this reduces permanent deformation.

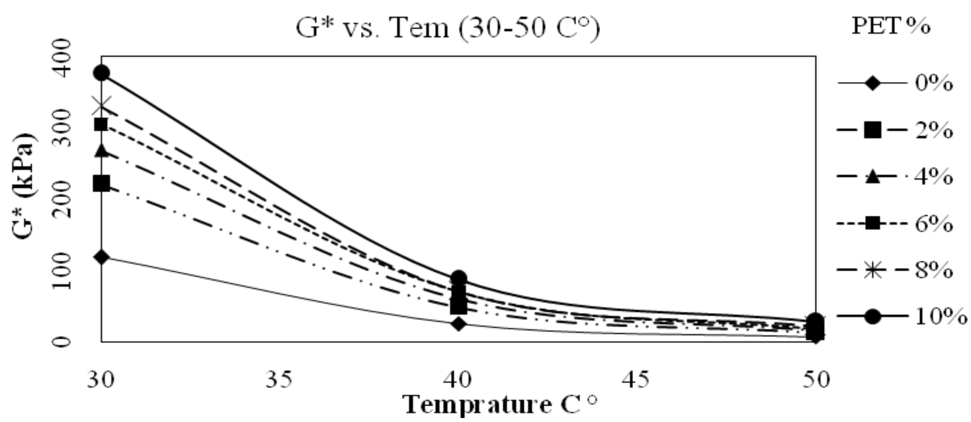

Figure 6 G* vs. Temperature (30-50 °C)

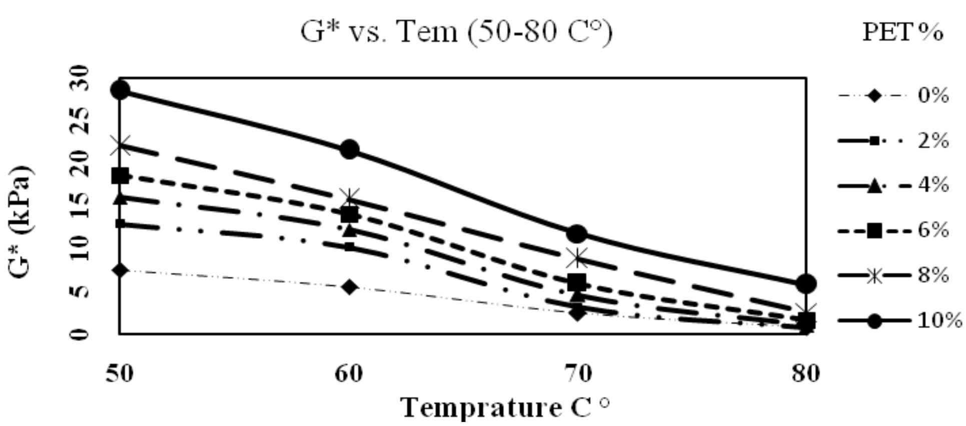

Figure 7 G* vs. Temperature (50-80 °C)

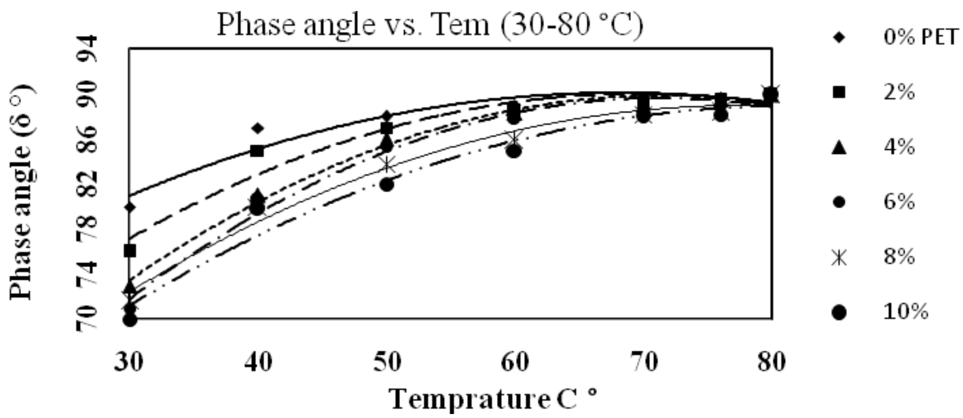

Figure 8 Phase angle vs. Temperature

4. CONCLUSION

Based on the laboratory test results, the mixture containing PET resulted in higher resistance to rutting. It appears that polyethylene Terephthalate (PET) decreases the consistency and increases the resistance of the material to temperature changes, while the resistance to flow also increases. It may be inferred that PET-modified bituminous binders provide better resistance against permanent deformations due to their higher phase angle when compared to conventional binders. The properties of road bitumen are improved by means of PET polymer modification. This result has been reached by the conventional test methods such as penetration and softening point. PET modification causes increases in softening point and reductions in penetration. Since, the decreased penetration, and increased softening point temperature indicate increased stiffness (hardness) of the PMBs, the results demonstrate that the asphalt mixtures prepared with the PET PMBs may be less sensitive to permanent deformation. Along with the parameters related to penetration and softening point test; increased viscosity values and indices also indicate the stiffening effect of PET modification. PET polymer modified bitumen display reduced temperature susceptibility than base bitumen. The reduced temperature susceptibility may be attributed to the resistance of PET asphalt mixtures to cracking with the temperature change.

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