Influence of Polyethylene on Fatigue Parameters of Bitumens

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ABSTRACT

The use of polymer modified bitumen has become a very important part of pavement construction due to its superior performance, including less ageing, enhanced rutting resistance and lower fatigue cracking properties. The polyethylene is a type of product normally not used as additive to bitumen, generally showing a congealing point of 92-100°C. Areas where it has been used are for instance in plastics and polishes, as thickener for lubricating oils and petrolatum and as paraffin wax improver/up-grader. Although the many significant researches which have been carried out related to the polymer modified bitumen in road applications, more studies should be undertaken on the compatibility, in the interaction between polymer and the different sources bitumens according to the needs of refineries in different countries. The main purpose behind this study is to minimize the fatigue damage of waxes within bitumens obtained from different sources. For this purpose; bitumen samples were modified by recommended content of polyethylene polymer (at concentration of 1.5% by weight of the bitumen). The intermediate temperature performance levels of polyethylene polymer modified bitumens were determined by fatigue parameters.

Keywords: Polyethylene, modification, polymer, fatigue parameter, wax.

INTRODUCTION

Polymer modified bitumen (PMB) has been developed by asphalt industry to fulfill the needs for making better pavements that exhibit better performance under loads due to high traffic applications. Polymer modifications are becoming important factors in paving industry due to their proven effects such as better resistance to rutting, fatigue damage, stripping, and thermal cracking in asphalt pavements (Wekumbura, Stastna & Zanzotto, 2007; Punith, 2005; Chen, Liao & Shiah, 2002).

Inspite of the above mentioned advantages of PMB, the production and placement temperatures at site which in turn brings concerns about the continuous exposure of workers to high temperatures during paving operations which may yield significant health problems; health issues that will arise from high level of toxic fumes.

Almost all bitumen obtained from crude oil by refining process but only certain crude oils contain good quality bitumen for asphalt pavement (Lyne, Wallqvist & Birgisson, 2013). Naphthenic-base crude oils often give a large amount of bitumen that may be in good quality, while paraffinic crude oils may give bitumen of good quality or yield bitumen that are not suitable for asphalt pavement (Edwards & Redelius, 2003).

Based on literature, the high content of paraffin affects the properties of bitumen in different ways. The low melting point of paraffin decreases resistance of asphalt mixtures against fatigue at middle temperatures as well as the crystallization of paraffin causes cracking at low temperatures (Lu & Redelius, 2006). Physical hardening, poor ductility and poor bitumen adhesion can be listed as the outcomes caused by the high content of paraffin (Edwards & Redelius, 2003).

The polyethylene (PE) is a type of product normally not used as additive to bitumen, generally showing a congealing point of 92-100°C. Areas where it has been used are for instance in plastics and polishes, as thickener for lubricating oils and petrolatum and as paraffin wax improver/upgrader. PE is manufactured from natural gas derived feedstock by two basic polymerization processes.

The low pressure polymerization process results in linear polymer chains with short side branches. The high pressure polymerization process results in polymer chains with more highly developed side branches. The physical properties of PE polymers are specific to each grade or type, and can be modified by both variations in density, and in the molecular weight distribution. PE modified bitumen is less expensive as well as shows more resistance to ultraviolet aging and rutting (Zhu, Birgisson & Kringos, 2014).

The main purpose behind this study is to minimize the fatigue damage of waxes within bitumens obtained from different sources. For this purpose; bitumen samples were modified by recommended content of polyethylene polymer (at concentration of 1.5% by weight of the bitumen). The intermediate temperature performance levels of polyethylene polymer modified bitumens were determined by fatigue parameters. The results have been compared with base bitumen and PMB samples.

MATERIALS AND METHODS

Two bitumens were used in this study. The bitumen samples are identified as Bit-TR1 and Bit-TR2 respectively. Bit-TR1 was manufactured from crude oil deposited in the east part of Turkey. Bit-TR2 was produced by the blending of crude oil from various sources by a manufacturer in Middle Eastern countries. The general description of samples together with penetration grades are depicted in Table 1.

Table 1. The general description of samples.

Source of Bitumens	**Abbreviation**	**Sample No**	**Penetration Grades**
Turkey	Bit TR	Bit-TR1	50/70
		Bit-TR2	40/60

The used PE (polyethylene)) was Titan® 7686 in white pellet form obtained from Honeywell company, USA. Titan® 7686 is created through the polymerization of ethylene. Titan® 7686 has low molecular weight and semi-crystaline structure. Addition of PE significantly improves the mechanical properties of bitumens, especially at high temperature ranges. The concentration of PE used was 1.5% by weight of the bitumen. The mixer was set at 800 rpm during 1 hour (mixing period). The mixture's temperature was maintained at 150±5°C during the mixing process.

The dynamic shear rheometer is used to test bitumens and measure their rheological properties, including complex shear modulus (G*) and phase angle (delta), at intermediate to high test temperatures. Theses parameters can be used to characterize both viscous and elastic behavior of bitumens. The complex shear modulus, G*, is a measure of the total resistance of a material to deformation when exposed to a sinusoidal shear stress load. G* consists of both elastic (recoverable) and viscous (non-recoverable) components.

The phase angle, delta, is an indicator of relative amounts of viscous and elastic components. The values of G* and delta for bitumens are highly dependent on the test temperature and frequency of loading. At high temperatures, bitumens behave like viscous fluids with little capacity for recovering or rebounding. In this case, the bitumen could be represented by the vertical axis (there would be no elastic component of G*, since delta = 90°). At very low temperatures, asphalts behave like elastic solids, which rebound from deformation completely.

The dynamic shear rheometer (DSR) is used to describe the viscous and elastic behaviour of asphalt bitumen at medium to high temperatures. This characterization is used in the Superpave PG asphalt bitumen specification. The basic DSR test uses a thin bitumen sample sandwiched between two circular plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample at 10 rad/sec (1.59 Hz) (or any other set frequency) to create a shearing action. DSR tests are conducted on unaged, RTFOT aged and PAV (pressure aging vessel) aged bitumen samples (ASTM D 2872-12, 2012; ASTM D6521-05, 2005).

The DSR measures a specimen's complex shear modulus (G*) and phase angle (δ). The complex shear modulus (G*) can be considered the sample's total resistance to deformation when repeatedly sheared, while the phase angle (δ), is the lag between the applied shear stress and the resulting shear strain. G* and δ are used as predictors of rutting and fatigue behaviours. Early in pavement life rutting is the main concern, while later in pavement life fatigue cracking becomes the major concern. G*⁄sinδ is described as rutting indicating parameter and G*. sinδ as fatigue cracking indicating factor (Asphalt Institute, 2001).

In order to evaluate the performance of the bitumen samples at moderate temperatures, PAV Binder Grade (Fatigue cracking test) test has been performed on the base and PMB samples using DSR apparatus. All of the samples used in this test were PAV aged residues. The test geometry was of 8 mm parallel plates and the gap between the plates was set at 2 mm. Each sample was subjected to oscillating shear in the DSR at the frequency of 10 rad/s (1.59Hz). Each test was set to start at 40°C as moderate temperature.

RESULTS AND DISCUSSION

In order to determine the performance of the PMB samples at moderate temperatures, PAV Binder Grade test (Fatigue cracking test) has been performed on them using DSR apparatus.

Fatigue properties of bitumen can be evaluated by the fatigue factor at intermediate temperatures. The fatigue behaviour was investigated by applying continuous oscillatory shear loadings with using DSR. Temperature sweep test is performed under the strain controlled mode at a frequency of 10 rad/s (1.59 Hz.). The temperature cycles were set to start at 40°C within the PAV aged samples a run up in 3°C decrements. During the test procedure, an 8 mm diameter plate with a 2 mm gap between parallel plates was used for each PAV aged bitumen sample. There is a limiting maximum stiffness at the intermediate temperature to mitigate fatigue cracking. G*.sinδ values of PAV aged bitumen samples does not exceed 5000 kPa and low values of these parameters are considered good indicators of fatigue cracking resistance (Asphalt Institute, 2003). Variation of the fatigue parameters (G*.sinδ) for PAV aged PE modified bitumens at different intermediate temperatures are illustrated in Figure 1. Beside, based on the Superpave fatigue cracking requirement the following conclusions can be made as presented in Table 2.

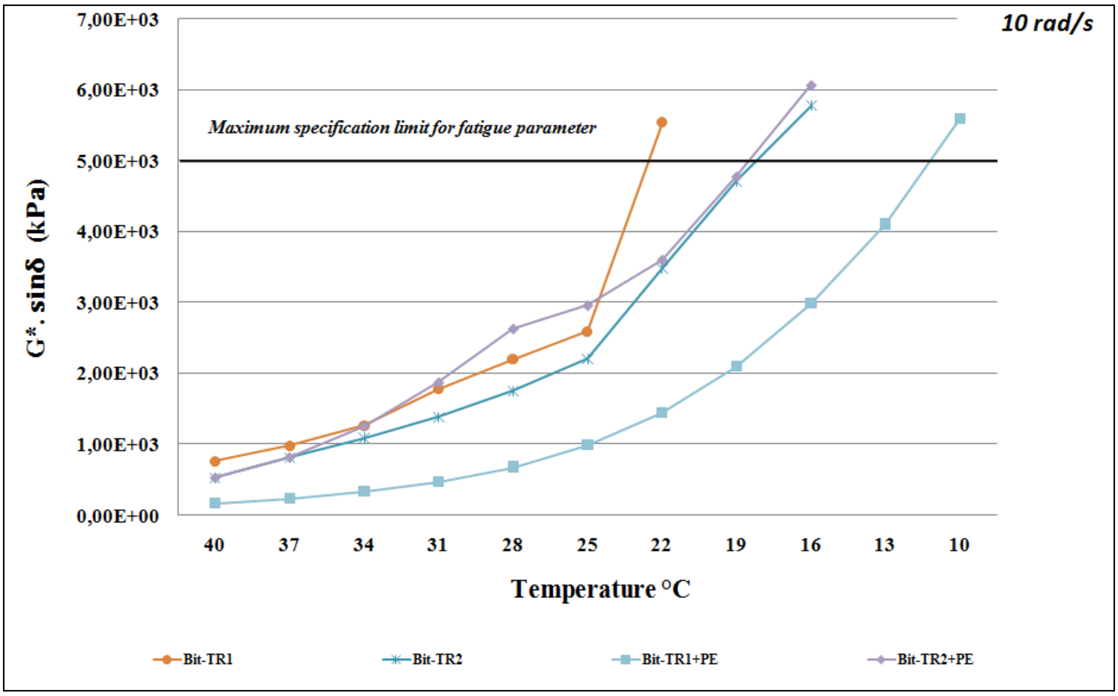

Figure 1. G*.sinδ values for PE modified bitumen samples.

Table 2. Temperature at which G*sinδ reaches 5000 kPa for each bitumen sample.

Bitumen sample	Temperature (°C)
Bit-TR1	25
Bit-TR2	19
Bit-TR1+PE	13
Bit-TR2+PE	19

As depicted in Figure 1 and Table 2, regarding all of bitumen samples, G*.sinδ values increase with decrease in temperature at 10 rad/s. Owing to the aging, the lower G*.sinδ value indicates less shearing energy loss and better ability of the fatigue resistance. Bit-TR1 samples manufacturing from crude oil deposited in the east part of Turkey exhibit the highest G*.sinδ value at all intermediate temperatures. Higher G*.sinδ values is not preferable since the samples with higher G*.sinδ values exhibit fatigue cracking.

The addition of PE polymer into Bit-TR2 producing by the blending of crude oil from various sources did not make any significant effect on the fatigue cracking properties on the samples.

The limitation of 5000 kPa value is reached at Bit-TR1+PE which occur at the test temperature 13 ^{o}C as well as Bit-TR2+PE meets with specification limit at the temperature 19 ^{o}C.

Hence, modification process with PE depicted slightly improved fatigue cracking properties of Bit-TR1 samples manufacturing from crude oil deposited in the east part of Turkey that expresses the ability of the material to resist cracking at intermediate temperatures.

CONCLUSIONS

Polymer modified bitumen (PMB) has turned into a very significantportion of pavement industrydue to its superior performances including less aging, better rutting resistance, and lower fatigue cracking properties.

Although the many significant researches which have been carried out related to the PMB in road applications, more studies should be undertaken on the compatibility and in the interaction between polymers and the different sources bitumens according to the needs of refineries in different countries.

The scope of the research is to reduce the fatigue cracking parameters within the different sources bitumens. For this purpose, modified bitumen samples were prepared by using polyethylene (PE) polymer additive. The values found in the study can be considered as useful parameters in determining which type of polymer would be better for the needs of refineries in different countries in terms of fatigue cracking.

Oscillation test was performed on PAV aged bitumen samples using DSR so as to determine the Superpave fatigue cracking parameter (G*sinδ). Lower values of G*sinδ are desirable attributes from the stand point of resistance to fatigue cracking. In the Superpave asphalt binder specification, in order to resist fatigue cracking, G*sinδ is limited to 5000kPa. The test results indicate that for each bitumen sample the fatigue cracking parameter increases when the temperature decreases. When the fatigue cracking factor reaches 5000kPa, Bit-TR1+PE indicates the lowest temperature of 13°C while Bit-TR2+PE indicates the highest temperature of 19°C.

In the light of findings from fatigue test, modification process with PE depicted slightly improved fatigue cracking properties of Bit-TR1 samples manufacturing from crude oil deposited in the east part of Turkey that expresses the ability of the material to resist cracking at intermediate temperatures.

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