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How Thermal Fatigue Cycles Change the Rheological Behavior of Polymer Modified Bitumen?

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Abstract

The paper deals with the problem of thermal fatigue cycles phenomenon, which affects the performance of flexible pavement. The purpose of the paper is to extent the knowledge on the rheology of polymer modified bitumen which was affected by cycles of thermal fatigue. The aim of this research is to determine the rheological components and their evolutions under thermal fatigue with freezing - thawing cycles. To represent thermal fatigue cycles phenomenon of polymer modified bitumen in laboratory, both freezer and controlled temperature room were used to produce the real cycles of freeze - thaw of winter season. The results suggest that thermal fatigue cycle is more complicated on rheological behavior of polymer modified bitumen. It is shown that thermal fatigue cycles influenced the behavior of polymer modified bitumen. It is concluded that thermal fatigue cycles reduce the performance of binder and accelerate the degradation of pavement.

*Keywords :*Polymer modified bitumen, rheology, thermal fatigue cycles, freeze-thaw, creep-recovery, behaviour

1. Introduction

The resistance of road asphaltic pavements to destructive operation of external factors depends significantly on the properties of bitumen used. Results of many investigations showed that there is a

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strong relationship between the rheological properties of asphalt binders and the asphalt mixture behavior in pavements. The influence of properties of binders on the operating parameters of a pavement is estimated at 40÷50% at high temperatures and at 90% at low temperatures [1].

The temperature has a great influence on the performance of pavements. Thermal cracking is one mechanism that accelerates the degradation of asphalt concrete [2]. Thermal cracking is a serious problem that results in both structural and functional problems in asphalt concrete pavements [3].

The asphalt concrete pavements are constantly subjected to temperature fluctuations, and the physical properties of asphalt concrete are highly temperature dependent. This thermal loading results in the development of thermal stresses in the pavements [4]. Thermal fatigue is among distresses developed in flexible pavements due to temperature variation. Tensile stresses tend to increase in the pavement as the temperature decreases, and at very low temperatures cracking occurs once the developed stresses exceed the tensile strength [5], [6].

A lot of researches have been studies the complexity of thermal fatigue phenomenon. Until now, it does not available a standard test method for evaluating mixture and binder resistances to thermal fatigue. The bitumen binder is the first factor that participates in the degradation of asphalt concrete.

The present study focuses on thermal fatigue cycles of polymer modified bitumen binder. In this research, the objective is to determine the evolution of rheological behavior of EVA polymer modified bitumen under effects of the thermal fatigue with freezing – thawing cycles.

2. Materials and Methods

2.1. Materials used

The bitumen binder used in this study is 40/50-penetration grade. Usually, it is used in aerodrome and road pavements in hot regions in Algeria.

The polymer was used as a modifying agent; thermoplastic material of Ethylene Vinyl Acetate (EVA) copolymer with 18% Vinyl Acetate contents.

The polymer modified bitumen was manufactured at the laboratory of LCPC (Central laboratory of bridges and pavements ((((France)) by mixing during 02 hours the bitumen with 5% of polymer under moderate shear stirring (about 1000 tours/minute) at 160°C temperature.

2.2. Methodology of test

This study focuses on the fundamental rheological properties of two binders:

- The unaged polymer modified bitumen is: 40/50 bitumen modified with 5% of EVA polymer.
- The aged polymer modified bitumen with thermal fatigue cycles; which is resulted from the same origin of unaged polymer modified bitumen binder.

The experimental method of thermal fatigue cycles in this study is as below:

Firstly, using a freezer to regulate the low temperature wanted and controlled temperature room. Then, putting the polymer modified bitumen inside the freezer. After that, getting out the modified bitumen, and putting inside a controlled temperature room to produce the thaw of this binder. The repeating thermal cycles on modified binder leads to produce a phenomenon of thermal fatigue.

The aged polymer modified binder was submitted to thermal fatigue with freezing – thawing cycles. The temperatures of the study tests were: -10°C for freezing and 25°C for thawing. The specimen was exposed to 100 cycles of thermal loading. Figure 1 illustrates one cycle of temperatures in 24 hours. As shown in this figure, the duration of freezing and thawing was the same: 12hours. For each applied thermal solicitation, it is assured 08 hours constant duration during the test.

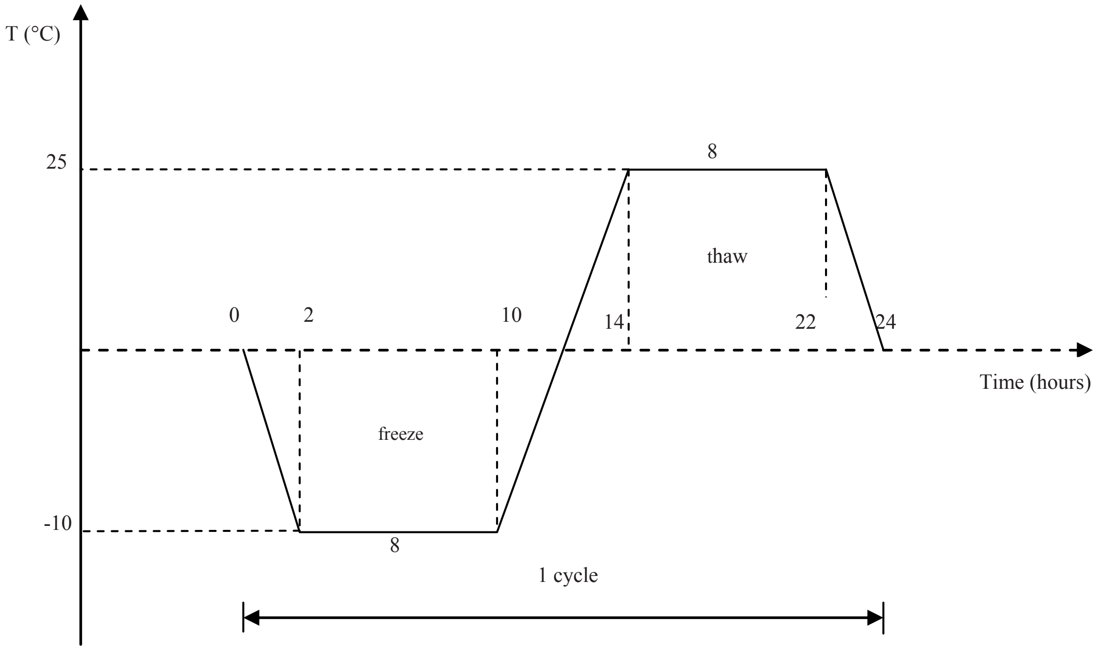

Fig. 1. one cycle of thermal loading.

2.3. Complex modulus test

The study of rheological behaviour of polymer modified bitumens was carried out at laboratory of Road and Railway engineering (TU Delft, Netherlands).
The fundamental characterization was done using the Dynamic Shear Rheometer (DSR).

The Dynamic Shear Rheometer (DSR) was used to perform frequency sweeps on aged and unaged binders at different temperatures -5, 0, 20, 30, 40, 50 and 60°C. Also, DSR was used to do static creep and recovery tests at temperatures 20 and 40°C.

Measurements were taken at different temperatures. The 8-mm spindle was used for measurements at the temperature -5, 0, 20 and 30°C. The 25-mm spindle was used for the temperatures 40, 50 and 60°C. The gap width of 2 mm and 1 mm was used for the small spindle (8 mm) and the large spindle (25 mm) respectively.

2.4. Creep – recovery test

The creep - recovery test was carried out to characterize binders. Measurements were performed using the rheometer DSR. The device is used in controlled stresses with different diameter of spindles according the temperature of test (table 01).

Table 1. Conditions of creep – recovery test

Test	Temperature (°C)	Diameter (mm)	Stress (kPa)
Creep	20	8	100
Creep	40	25	10
Recovery	20	8	0
Recovery	40	25	0

3. Results and discussion

3.1. Effects of thermal fatigue cycles

a. Black curve

The determination of rheological behaviour of binder from rheological parameters (complex modulus, phase angle,...), can be a good indicator to evaluate the performance in front of the risk of rutting and cracking under extreme temperatures of service.

The bituminous binder is a material, which is more susceptible to the variation of temperature. The latter produces thermal stresses that accelerate the degradation at extreme temperature.

Figure 2 shows black curves of aged polymer modified bitumen submitted to thermal fatigue with freeze - thaw cycles, and unaged polymer modified bitumen. The thermal fatigue cycles change the binder behaviour by increasing the complex modulus and decreasing phase angle. The slope rate of aged polymer modified bitumen is decreased for each temperature, i.e. a little variation in the phase angle. The effects of thermal fatigue cycles on modified binder reduce the performance and the durability of pavements. At low temperatures (-5 and 0°C), a little change is observed a slight increase in the complex modulus and slight decrease in the phase angle. These changes are not favourable since it makes the binders stiffer and more elastic, as mentioned in the research of [7]. So, thermal fatigue leads the modified binder to behave unfavourably concerning thermal cracking.

At intermediate temperatures (20 and 30°C), the rate of variation of the phase angle is smaller than virgin binder. There is a decrease in the curve slope of aged polymer modified bitumen. Increasing of the complex modulus and decreasing in variation of phase angle appears the changes. In this case, the increasing in the complex modulus is not favourable for fatigue cracking, especially for thin pavements [7].

At high temperatures (40 and 50°C), the direction of the curve slopes of aged polymer modified bitumen is changed. The phase angle decreases when the complex modulus increases. This indicates an increase in rigidity and in elasticity, which results in better resistance to permanent deformation [7]. In this case, the EVA polymer reduces the thermal susceptibility [8], which means a better behaviour concerning the permanent deformation resistance. However, at 60°C, the phase angle is observed to be higher for the aged modified bitumen and it remain constant during this temperature. Thermal fatigue with freezing - thawing cycles makes polymer-modified bitumen softer, and this change is not favourable for permanent deformation resistance.

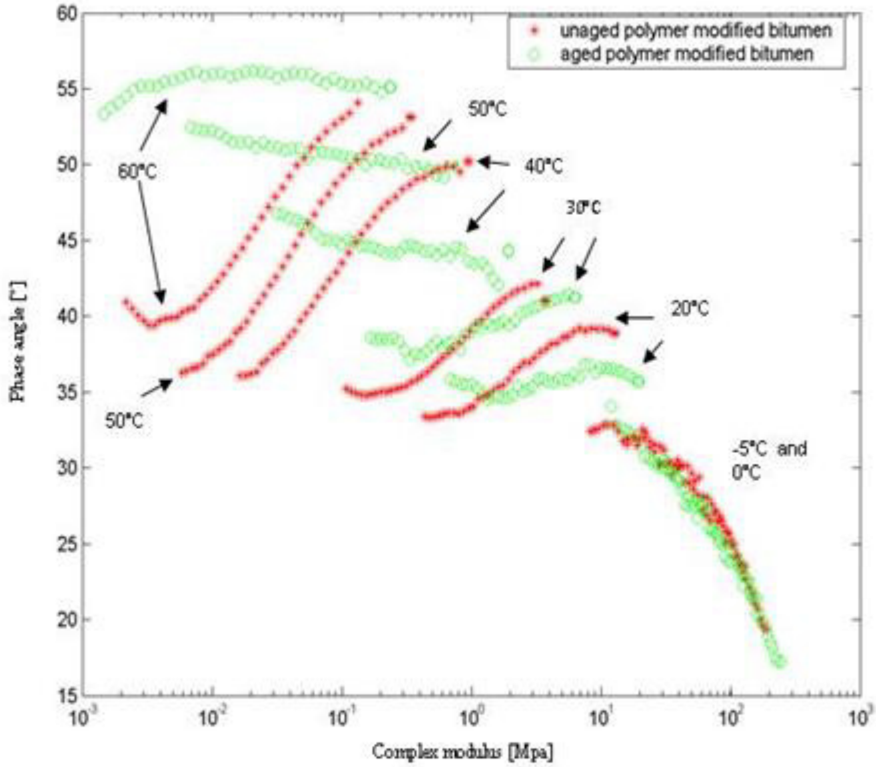

Fig. 2. comparison between origin and aged polymer modified bitumen binders.

b. Static creep – recovery

Effect of freezing – thawing cycles on the evolution of behavior of binders is rarely cited in the literature.

The pavement design is based on bituminous binder behavior at constant extreme temperature without taking into account the thermal history (effects of thermal cycles) and the evolution of its initial characteristics.

From the figure 3, it appears that the polymer modified bitumen which is exhibited to thermal fatigue cycles has big strains in front of origin modified binder [9]. The creep strain of aged polymer modified bitumen is the higher with a value around 10%. Also, strain which is not recovered is somewhat the higher around 9% (increase in the slope of the creep curve and therefore the total strain increases). So, thermal fatigue with freeze – thaw cycles produces the susceptibility to permanent deformation of polymer modified bitumen [10].

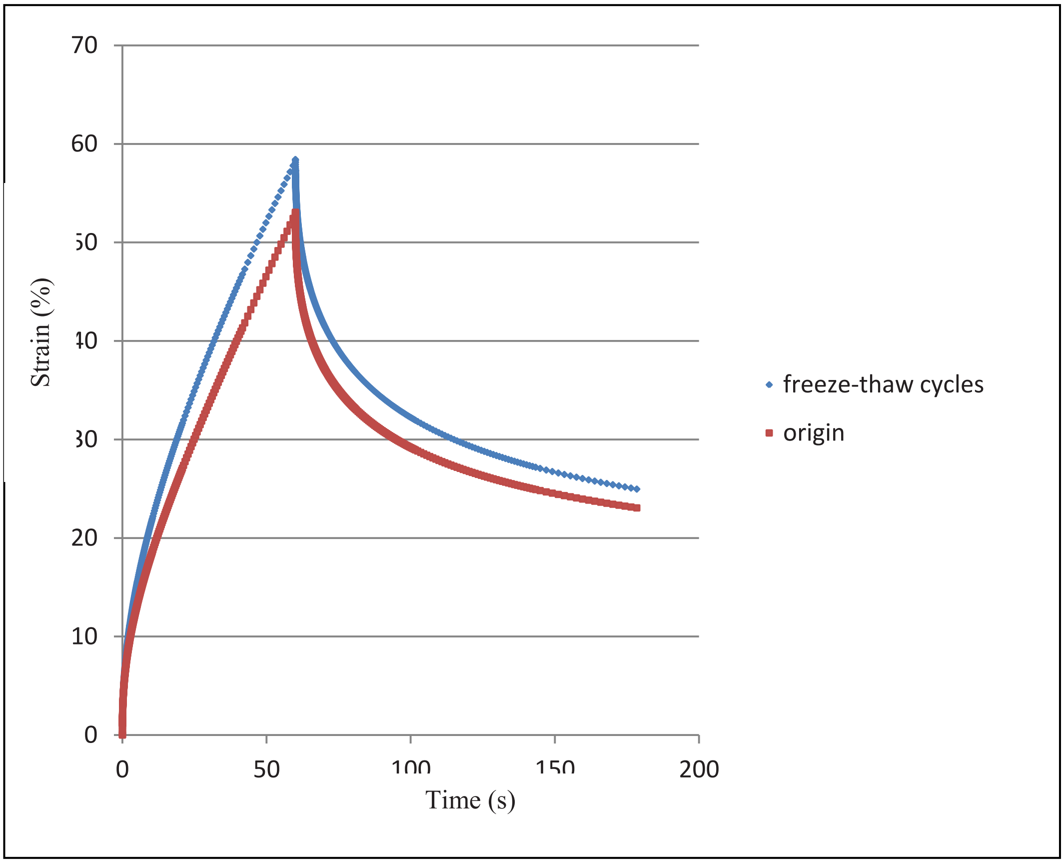

Fig. 3. **c**reep recovery of polymer modified bitumen at 20°C.

Figure 4 presents creep recovery test of aged and origin polymer modified bitumen at 40°C. The effect of thermal fatigue with freeze – thaw cycles is appeared by increasing the both creep strains and strains which are not recovered. The strain of creep is increased around a value 57%, and also strain which is not recovered is increased with a percentage of 78%. In this case, the aged binder is more deformable at the temperature 40°C, which is more susceptible to deformation permanent [9].

The rate of change the strains between binders is increasing with temperature (from 20 to 40°C). The freeze – thaw cycles lead the binder more deformable at high temperature [10].

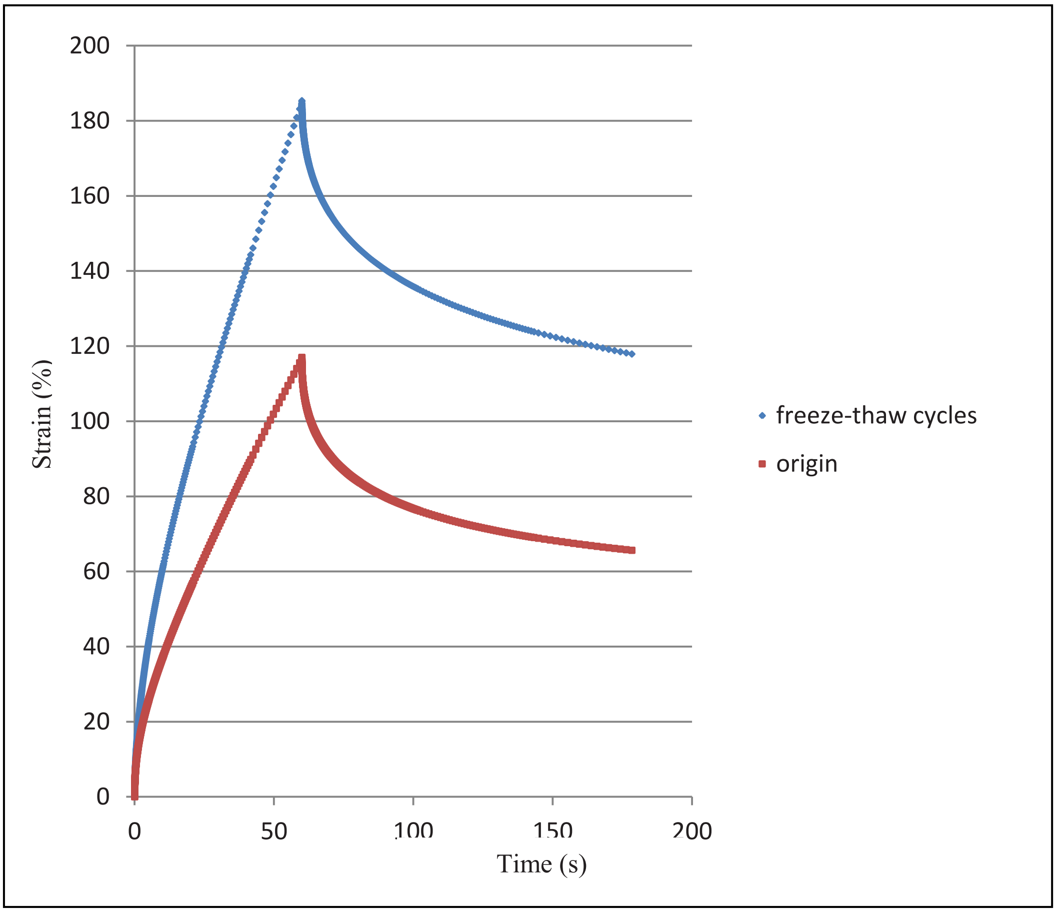

Fig. 4. creep - recovery of polymer modified bitumen (with and without thermal fatigue cycles) at 40°C.

4. Conclusion

The objective of this study was to determine evolution of complex modulus, phase angle, creep recovery of polymer modified bitumen which was submitted to thermal fatigue with freeze – thaw cycles. Allowing the procedure in laboratory to experiment the real of thermal fatigue cycle phenomenon, and although the modified binder was exhibited only to 100 cycles of thermal loading (freezing – thawing); the results of experimental indicated that thermal fatigue cycles were changed the rheological behavior of polymer modified bitumen. At low temperatures, complex modulus was slightly increased and phase angle was slightly decreased, which are not favorable for thermal cracking. Within intermediate temperatures, increasing of complex modulus and decreasing in variation of phase angle appears the changes. These changes are not good for fatigue cracking. At high temperatures 40 and 50°C, there is a decreasing of phase angle and an increasing of complex modulus. In this case, the polymer-modified bitumen has an increase in rigidity and in elasticity, which results a better behavior in front of permanent deformation resistance. However, the results of creep recovery at temperatures 20 and 40°C explain that the aged polymer modified bitumen has a bad behavior to permanent deformation resistance. At 60°C, the higher of phase angle was not favorable for permanent deformation resistance. Thermal fatigue with freeze – thaw cycles makes the modified binder softer and more deformable.

From test of creep – recovery, it appears that freezing – thawing cycles increase the susceptibility and accelerate the risk of rutting. Degradation by freeze - thaw cycles produce a loss of consistency.

The pavement performance is affected by thermal fatigue cycles (influencing thermal cracking, fatigue cracking and permanent deformation resistance).

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