BUILDING MATERIALS AND PRODUCTS

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University of Béchar,
Laboratoire de la Fiabilité des Matériaux et Structures en Régions Sahariennes (FIMAS)
Bachir Glaoui , M'hamed Merbouh, Mahdjoub Bendjima
Algeria, Béchar; e-mail: glaoui_bachir@yahoo.fr
Delft University of Technology (TU Delft)
Laboratory of Road and Railway Engineering
Martin Van de Ven
Delft, South Holland, Netherlands

B. Glaoui, M. Merbouh, M. Van de Ven, M. Bendjima

IMPACT OF FREEZE-THAW CYCLES ON THE PERFORMANCE OF POLYMER MODIFIED BITUMEN

Problem statement. In seasonal frozen region, the performance of asphalt pavement is affected severely by the freeze-thaw cycles. The binder is the first factor that affected by these cycles. The objective of this study is to evaluate the performance of EVA polymer modified bitumen after freeze-thaw cycles.

Results and conclusions. Before and after thermal cycling, the complex modulus and phase angle, creep and recovery, also m-value and creep stiffness, were experimentally determined by the rheometers DSR and BBR. Results obtained indicate that freezing-thawing cycles change the rheological behavior of polymer modified bitumen, which translated in reducing the performance of this binder.

Keywords: polymer modified bitumen, freeze-thaw, temperature, complex modulus, phase angle, creep-recovery, m-value, creep stiffness.

Introduction

The asphalt layers of roads are designed by the concept of average climate of year, which is average temperature equivalent. However, the change in temperature due to day-night makes thermal cycles, which accelerate the degradation of asphalt by increasing the rigidity, fragility or rutting.

During the winter, temperatures can reach negative values at night, or even -10 °C or less in cold regions and highlands. The temperature difference is similar to that experienced in the summer. In Europe, according to the French National Group Bitumen [1], this phenomenon is crucial in the south than in the north, a difference of 5 °C can delay or accelerate the risk of cracking a period of about three years.

The flexible pavements are subjected to deterioration from seasonal freezing and thawing [2]. In the winter, the pavement structures modulus increases because of ice segregation in the unbound base or subgrade and because of the influence of temperature on the viscosity of the asphalt concrete.

During spring thaw, the pavement foundation can become saturated with water from the thawing ice lenses, thus reducing the structural adequacy of the base or subgrade. With a weakened structure, the pavement cannot support the load it was designed for; therefore, one can expect most of the damage to a pavement to occur during the spring thaw.

Damage to the pavement structure will reveal itself on the surface in the form of fatigue cracking and rutting [3].

However, current methods of pavement design traffic and aircraft do not take into consideration the specific climatic conditions and thermal history of bituminous materials, for each region. In reality the effect of this phenomenon adds to the effect of traffic and it is not considered when standard tests to characterize fatigue [4].

This study focuses on the impact of freeze-thaw cycles on the performance of binder. In this research, the objective is to determine the evolution of rheological behavior of EVA polymer modified bitumen under effects of the thermal cycles with freezing – thawing.

1. Materials

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. Experimental program

2.1. Simulation of freeze-thaw cycles. This research 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 cycles; which is resulted from the same origin of unaged polymer modified bitumen binder.

The experimental method of freeze - thaw 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. Table 1 illustrates one cycle of temperatures in 24 hours. As shown in this table, the duration of freezing and thawing was the same: 12 hours.

Table 1

Condition of freeze/thaw cycles

Sample	Extreme temperature, °C	Nombre of cycles	Duration of cycle, hours
Nine	–	–	–
Freeze/thaw	T- = -10, T+ = +25	100	12

2.2. Complex modulus test. The study of rheological behavior 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.

2.3. 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 2).

Table 2

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

2.4. Creep stiffness and m-value. The Bending Beam Rheometer (BBR) was used in this research, to measure the creep stiffness and m-value which were taken at low temperature -20°C.

3. Results and discussion

3.1. Effects of thermal cycles with freeze/thaw

3.1.1. Complex modulus and phase angle. The determination of rheological behavior 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.

Fig. 1 presents black curves of aged polymer modified bitumen submitted to freeze - thaw cycles, and unaged polymer modified bitumen. These cycles change the binder behavior 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 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 favorable since it makes the binders stiffer and more elastic, as mentioned in the research of [5]. So, freeze-cycles lead the modified binder to behave unfavorably 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 favorable for fatigue cracking, especially for thin pavements [5].

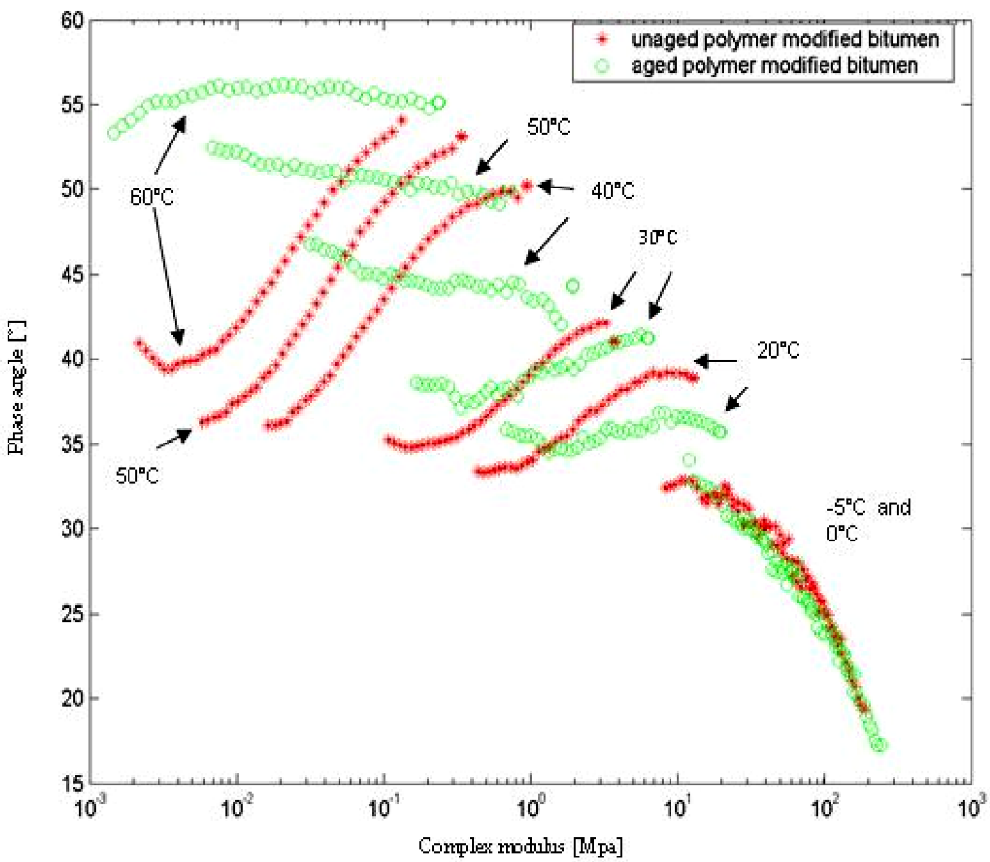

Fig. 1. Comparison between origin and aged polymer modified bitumen binders

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 [5]. In this case, the EVA polymer reduces the thermal susceptibility [6], which means a better behavior 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. Freezing - thawing cycles make polymer-modified bitumen softer, and this change is not favorable for permanent deformation resistance.

3.1.2. 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 Fig. 2, it appears that the polymer modified bitumen which is exhibited to freeze - thaw cycles has big strains in front of origin modified binder [7].

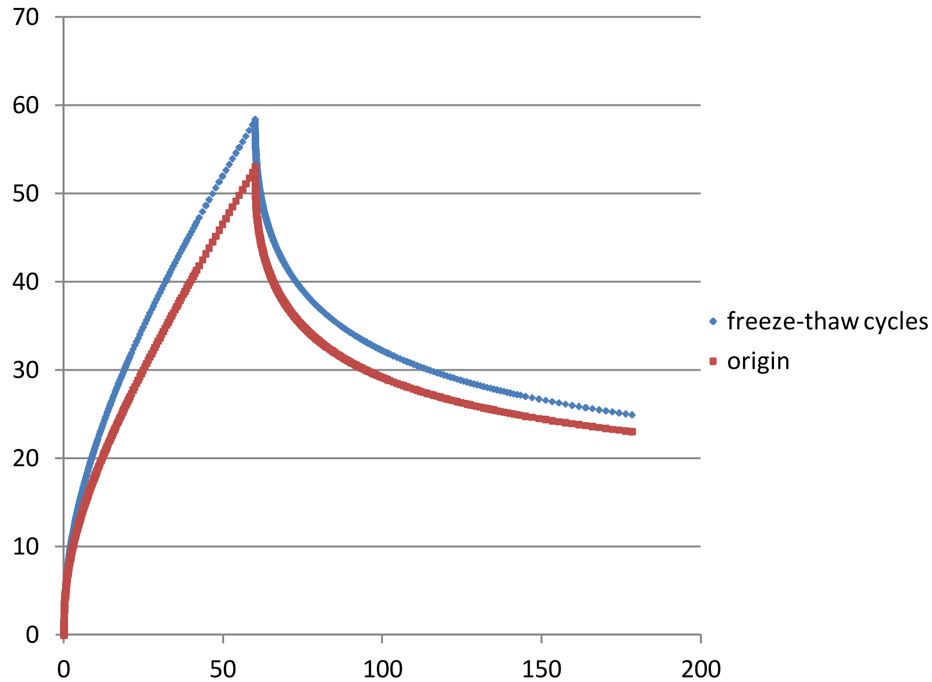

Fig. 2. Creep recovery of polymer modified bitumen at 20°C

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, freeze-thaw cycles produce the susceptibility to permanent deformation of polymer modified bitumen [8].

Fig. 3 presents creep recovery test of aged and origin polymer modified bitumen at 40°C. The effect of 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 [7].

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 [8].

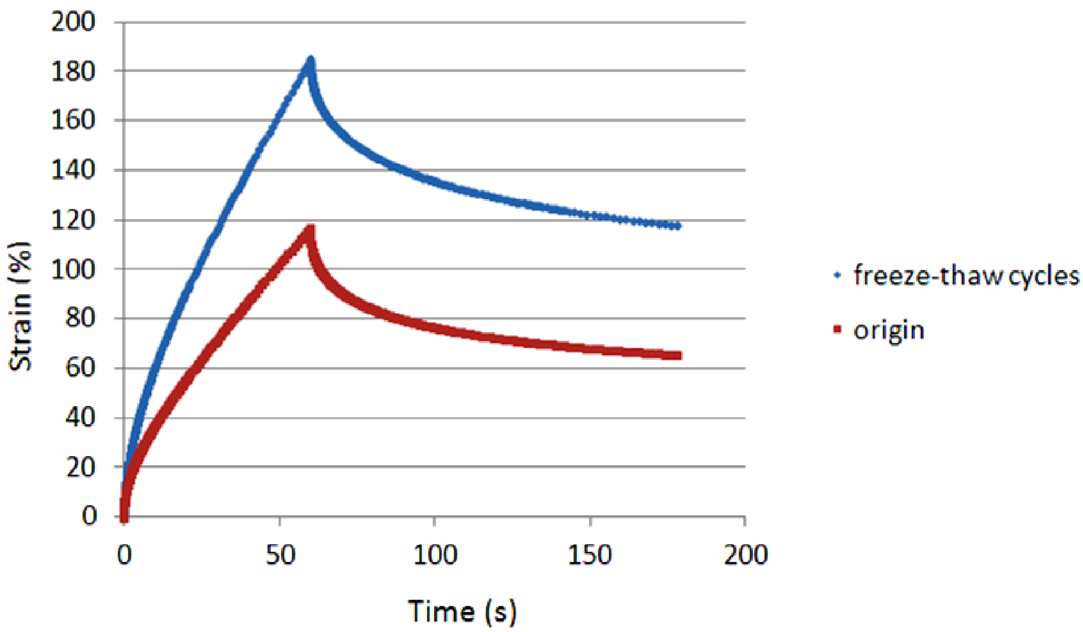

Fig. 3. Creep/recovery of polymer modified bitumen
(with and without thermal fatigue cycles)
at 40°C

3.1.3. Stiffness and m-value. The creep stiffness at 60 sec of origin polymer modified bitumen is higher than aged polymer modified bitumen. By the recommendation of SHRP, the specific maximum creep stiffness value at 60 sec is 300 Mpa [9].

The results of the two binders are within the limited value (Fig.4).

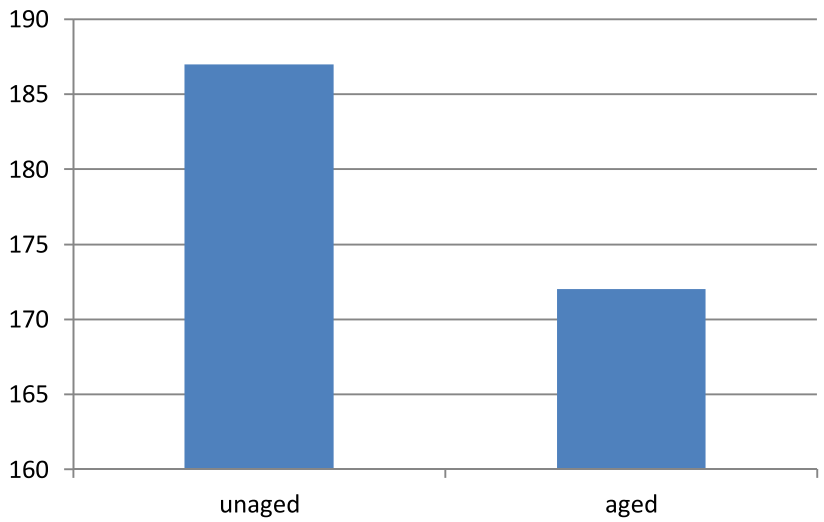

Fig. 4. Creep stiffness of aged and unaged of polymer modified bitumen

The m-value of origin polymer modified bitumen is higher than aged polymer modified bitumen, which [9] represents the viscosity of origin binder is higher than aged binder with freeze-thaw cycles. Considering the recommended minimum m-value, 0.3 by SHRP, the test results are within the limited (Fig. 5) [9].

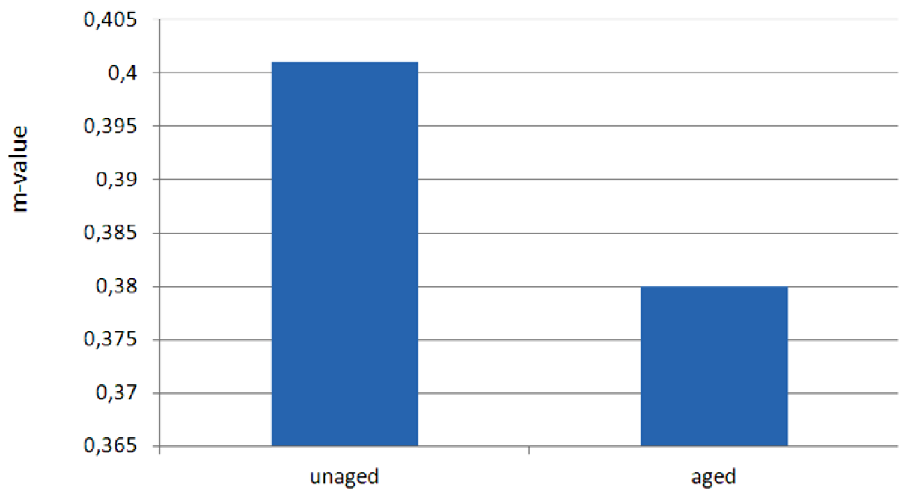

Fig. 5. M-value of aged and unaged of polymer modified bitumen

From these results of creep stiffness and m-value, it appears that thermal freeze-thaw cycles weaken the quality of polymer modified bitumen. So, the modified binder becomes more deformable when it submitted to freezing-thawing cycles. In cold regions, the bituminous mixes are exhibited, under effect of freeze-thaw cycles, to quick degradations.

Conclusions

Allowing the procedure in laboratory to experiment the real of thermal cycle phenomenon, and although the modified binder was exhibited only to 100 cycles of thermal loading of 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. Freeze – thaw cycles make 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.

Also from results of the lower values of creep stiffness and m-value, which indicate that the modified bitumen becomes more deformable.

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

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