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Effect of Thermal Cycles on Creep Behavior of Bituminous Binder in Hot Regions

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Abstract: This research is devoted to the study of creep behavior of asphalt binder in hot region. This binder was subjected to thermal cycles due to the variation of temperature from day to night. These cycles produce a heating-cooling phenomenon. To evaluate the effect of climate change in laboratory, the DSR (dynamic shear rheometer) was used, and the results found with the nine samples were compared. These thermal cycles led to aging and therefore hardening of the binder. Thus, a rheological model was proposed that can represent the curves obtained experimentally, where it is able to describe the creep behavior of binders tested. A new model is proposed that correlates well with the experimental curves, which is called A + 2 K.

Key words: Bitumen, temperature, heating/cooling, DSR, BBR, model.

1. Introduction

Bitumen is an important construction material with many applications; however, this binder is used mainly for the construction of roads and airfields. Nowadays, asphalt pavements have to sustain increasingly large loads. When these loads are combined with adverse environmental conditions, the distress modes in pavements lead to the rapid deterioration of road structures

The knowledge of viscoelastic properties of binders represents a means of improving the durability of road and airport infrastructures.

Several research works have been done on the phenomena of evolution in time of the performance of bituminous materials, under the effect of extreme stresses, whether they come from thermal or mechanical, join on a common point: the intensity and shape of the solicitation have a significant role causing damage on the strength and durability of asphalt.

The temperature of the road varies according to weather conditions. In warm and hot regions, summer is very severe. The surface temperature in these regions often exceeds 60 ℃. The difference in temperature between day and night is very important. The climate is often unstable, associated with sudden changes in temperature, which leads to a phenomenon of heating/cooling due to sunlight and ventilation caused by the flow of air. These thermal gradients cause internal stresses and changes in the viscoelastic properties of the surface layers. During operation, the structure of the surface layer suffers under the effect of these thermal cycles phenomena and gradually deteriorates. The surface layer loses the viscoelastic character, making the latter to a behavior, which tends to be rigid than flexible. Therefore, poor performance is developing in the bituminous material

Bitumen is the element most sensitive to variations in climatic conditions. The properties of this binder, such as other organic substances, may be influenced by variations in temperature and the presence of oxygen [1].

Our study is a contribution to the characterization and rheological modeling in static creep, for the behavior of nine binders and those who were suffered

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to thermal cycling with heating-cooling.

2. Materials and Methods

The study was carried out on two types of binders, the first is a pure bitumen nine (without thermal cycle), the second is the result of the stress of this binder by thermal cycles in heating-cooling. To evaluate the effect of thermal cycles on the viscoelastic properties of the material, creep tests are performed using a DSR (dynamic shear rheometer).

The bitumen used is Class 40/50 (penetration: 43 (1/10 mm) and softening temperature: 52 ℃), often used for the realization of surface layers of roads and airfields in Algeria.

2.1 Simulation of Thermal Cycles (Heating/Cooling)

Test temperatures for a cooling-heating cycle are: 60 ℃ to perform the heating during 8 h and 25 ℃ for cooling for 8 h. These temperatures represent the temperatures of the summer. The sample was exposed to 100 cycles of thermal load.

2.2 DSR Creep Test

This type of experiment is intended to highlight the influence of time on the rheological behavior of bituminous binders. The binder is submitted from $t = 0$ to a constant stress for a while, and then it follows the evolution of deformation.

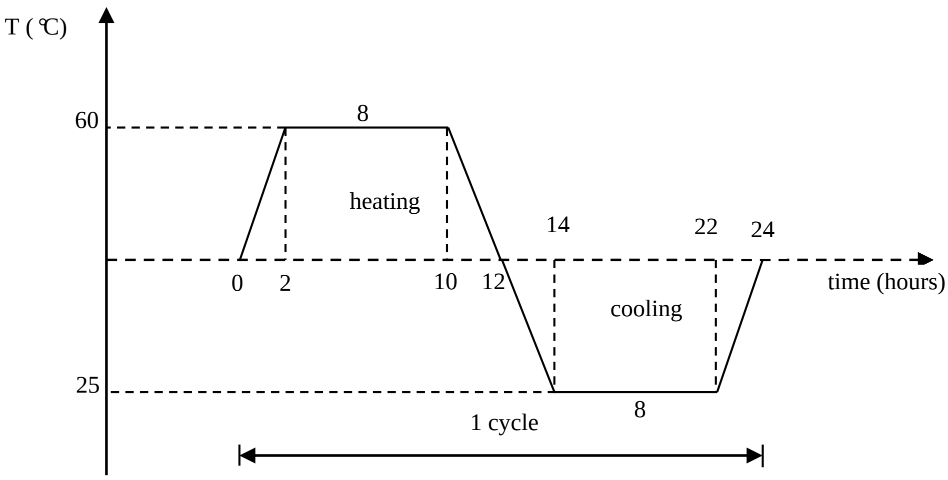

Fig. 1 Heating-cooling thermal cycle.

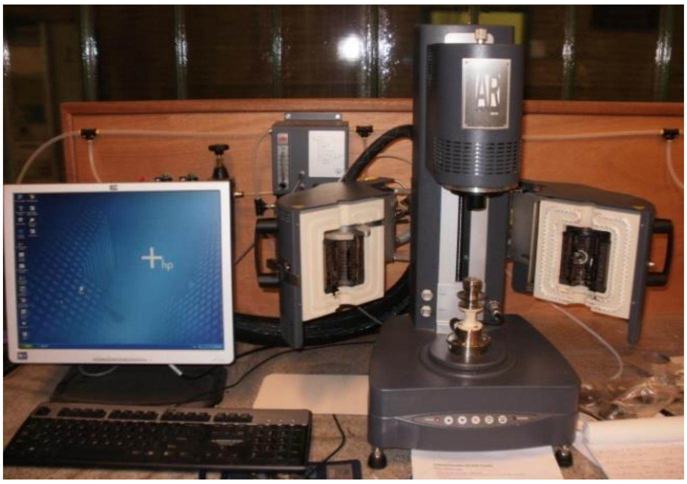

Fig. 2 DSR.

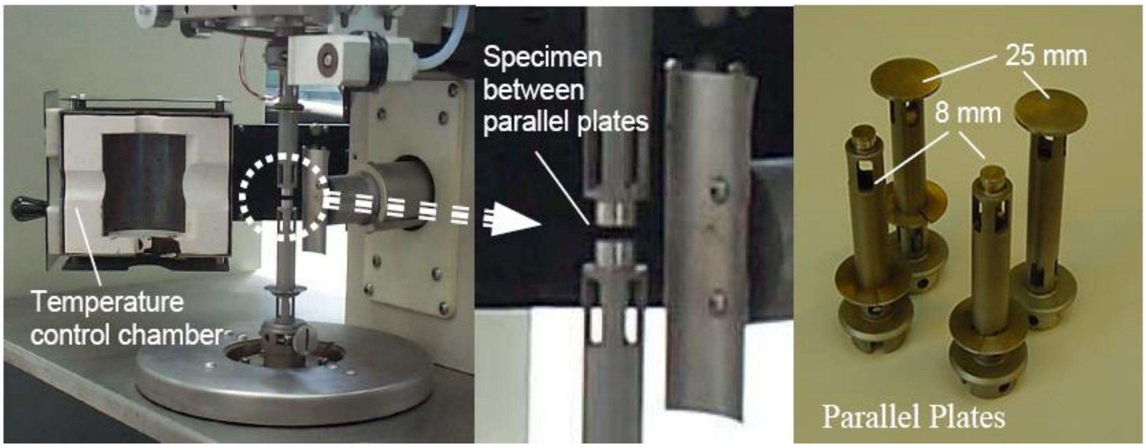

Fig. 3 Diameters of plates (DSR).

The geometry of the apparatus is such that the diameters of the plates 8 and 25 mm are used depending on the temperature used, with a fixed lower plate and a movable upper plate.

The apparatus is used in mode constant stress of 100 kPa at the temperature of 20 ℃ and 10 kPa at the temperature of 40 ℃. These temperatures were taken as the average temperature of the service road, they represent average temperatures of the seasons of spring and summer. For each temperature, the constant stress is applied for 60 s to measure the creep deformation.

3. Results and Discussion

With time, the air, the high temperatures during storage and in thin layers, the binder subjected the risk of oxidation. In service, asphalt pavements suffer from weather and age more rapidly [2].

From Fig. 4, it appears that the rate of creep of binder at 40 ℃ is almost equals to ten (10) times that at 20 ℃, although the stress at the latter is equal to ten (10) both the first (100 kPa at 20 ℃ and 10 kPa at 40 ℃).

The creep curves are almost linear. We know that the bitumen under high temperature or under load for a time becomes viscous and therefore it becomes deformed. Stress tests are relatively high. We can say that the test conditions creep used were severe.

The slope of the creep curve decreases with the thermal treatment by heating-cooling cycles. There has been a decrease in creep rate by 58% and 56% at 20 and 40 ℃ respectively. This means that the viscous flow rate decreases and consequently decreases the deformability of the binder. This decrease is translated by the increase in stiffness and consistency of the binder.

The phenomenon of heating/cooling cycles causes aging of bitumen and hardening [3].

Tests were developed by SHRP to simulate aging of the binder (hardening) during the production of hot asphalt mix, construction and service life. The binder becomes harder when its viscosity increases by aging. It loses ductility and becomes brittle [4].

It has been shown that aging is responsible for an increase in the content of heteroatoms (S sulfur, N nitrogen and O oxygen), mainly oxygen, which leads to a decrease in sensitivity to creep bitumen [5].

The decrease in the creep rate is due to the aging of bitumen. Indeed, when aged bitumen tends to harden, from a certain stage of hardness, the binder has nothing to gain by further hardening the contrary, it can become brittle under the effect of traffic or lowering of temperature and therefore the risk leads to cracking and degradation of coatings [6].

The ventilation air leads to rapid oxidation of the binder, especially at high temperature, therefore, the aging of the binder. The binder acquires a hardness that reflects in terms of performance vis-à-vis the rutting resistance (creep strain) [7].

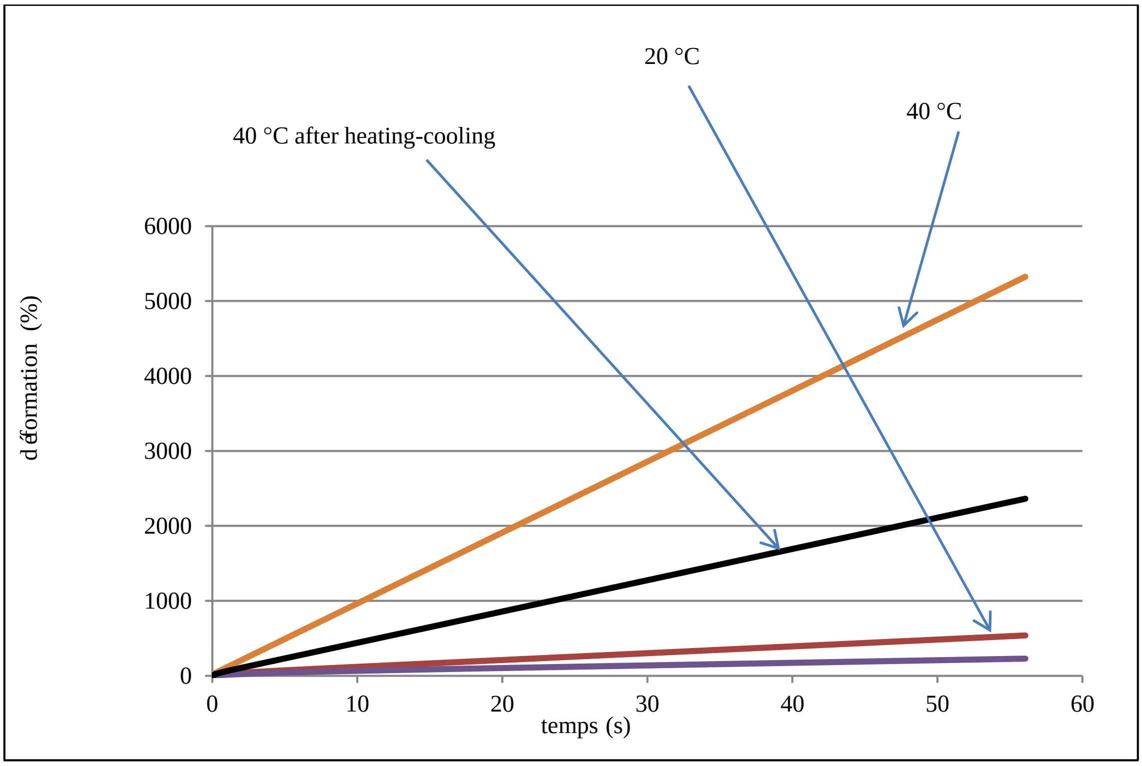

Fig. 4 Creep of bitumens before and after heating cooling cycles at 20 and 40 ℃.

4. Rheological Modeling

Any combination of springs (elastic elements) and linear dampers (viscous Newtonian elements) is an analog linear viscoelastic model [8, 9]. Many models combining linear springs and dampers have been employed to describe the linear viscoelastic behavior of bituminous binders and mixtures. The simplest combinations are the models of Maxwell and Kelvin-Voigt [10].

The analog models Maxwell (viscoelastic liquid) and Kelvin-Voigt (viscoelastic solid) cannot adequately describe the complex behavior of bituminous materials [8, 9], but they can be the basic elements for more complex associations [10].

It applied several rheological models on bitumens, which subject to thermal cycles, to find the rheological behavior the most appropriate to creep model.

In this article, we present only the most appropriate model. We propose a new model which consists of a damper (A) plus two elements of Kelvin (2K) in series is called: A + 2 K.

This model allowed us to remedy the curves of models Burger and Jeffrey, to have a good fit with those obtained experimentally. The modeling on the set of curves is good from Fig. 5.

It follows an expansion of the creep curves at the beginning (after a very short time about 2 s), there is a good coincidence between the experimental curves and those of model A + 2 K as it appears in Fig. 6.

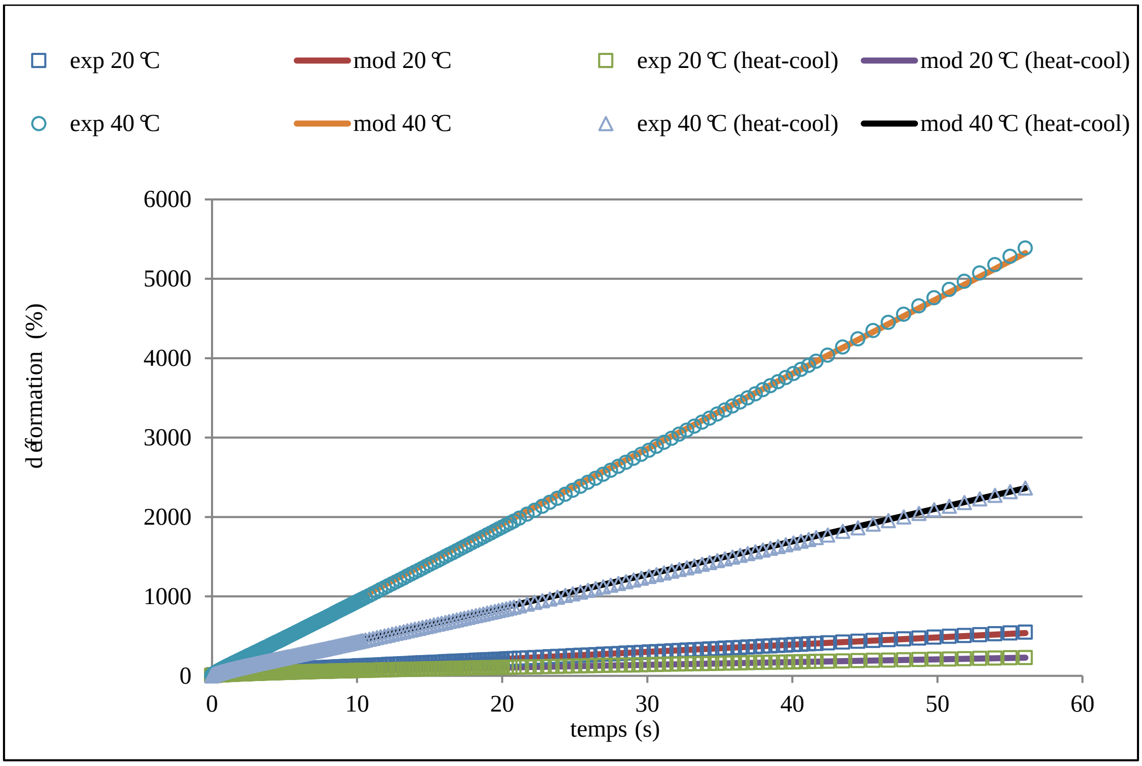

Fig. 5 Comparison between creeps of experimental and modeling curves.

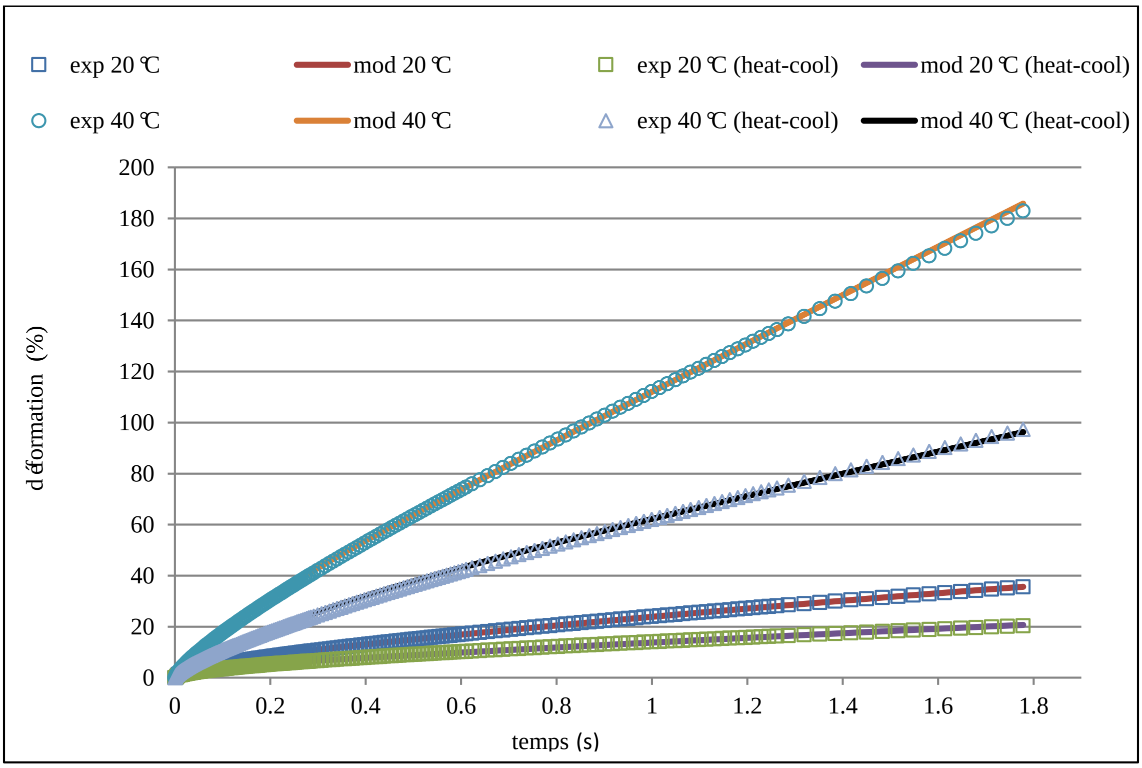

Fig. 6 Experimental and modeling curves of creep at the beginning (about 2 s).

5. Conclusion

This study was conducted in the laboratory to evaluate the effect of heating/cooling cycles on the creep behavior of bituminous binders.

It is interesting to note that the heating/cooling phenomenon causes aging of bitumen resulting in changes in the chemical structure. These changes engender shifts in the viscoelastic properties of binders and their rheological behavior. The viscoelastic behavior of the nine bitumen gives it a character of strength and flexibility. When the material loses this character it is non-deformable, rigid and fragile.

The search for a suitable rheological model has allowed us to propose a new model (A + 2 K), which significantly improves the rheological modeling of bitumens.

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