

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

Bachir Glaoui^{1*}, Mahdjoub Bendjima¹, M'hamed Merbouh¹ and Martin Van de Ven²

¹Laboratoire de la Fiabilité des Matériaux et Structures en Régions Sahariennes (FIMAS)-Université de Béchar B.P. 417, Béchar, 08000 Algeria

²Laboratory of Road and Railway Engineering-TU Delft- P.O. Box 5048 2600 GA Delft, The Netherlands

Abstract

This research is devoted on 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, it was used the rheometer DSR, and compare the results found with the nine sample. These thermal cycles led to aging and therefore hardening of the binder. Thus, the proposal of a rheological model that can represent the curves obtained experimentally, where it is able to describe the creep behavior of binders tested. It is proposed a new model that correlates well with the experimental curves, it is called A+2K.

Keywords: Rheometer; Climate change; Temperature

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 on weather conditions. In warm and hot regions, summer is very severe. The surface temperature in these regions often exceeds 60°C. 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 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 [1-3].

Our study is a contribution to the characterization and modeling rheological in static creep, for the behavior of nine binders and those who were suffered to thermal cycling with heating-cooling.

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 rheometer.

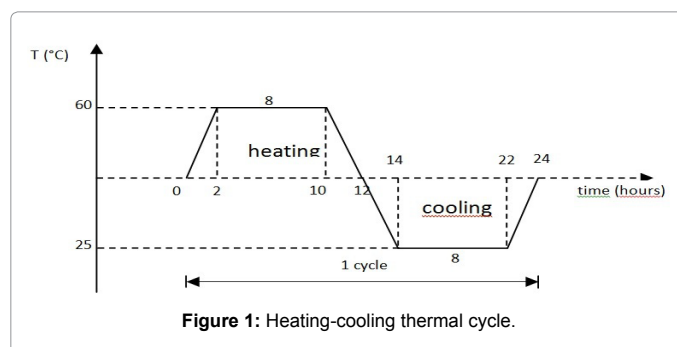
The bitumen used is Class 40/50 (penetration: 43 (1/10 mm) and softening temperature: 52°C), often used for the realization of surface layers of roads and airfields in Algeria.

Simulation of thermal cycles (heating/cooling)

Test temperatures for a cooling-heating cycle are: 60°C to perform the heating during 8 hours and 25°C for cooling for 8 hours. These temperatures represent the temperatures of the summer. The sample was exposed to 100 cycles of thermal load (Figure 1).

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 (Figure 2).



***Corresponding author:** Bachir Glaoui; 1Laboratoire de la Fiabilité des Matériaux et Structures en Régions Sahariennes (FIMAS)-Université de Béchar B.P. 417, Béchar, 08000 Algeria, Tel: +213-660-329; E-mail: glaoui_bachir@yahoo.fr

Received April 05, 2014; **Accepted** October 09, 2014; **Published** October 16, 2014

Citation: Glaoui B, Bendjima M, Merbouh M, de Ven MV (2014) Effect of Thermal Cycles on Creep Behavior of Bituminous Binder in Hot Regions. J Civil Environ Eng 4: 159. doi:10.4172/2165-784X.1000159

Copyright: © 2014 Glaoui B, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

The geometry of the apparatus is such that the diameters of the plates 8 and 25mm are used depending on the temperature used, with a fixed lower plate and an upper plate movable (Figure 3).

The apparatus is used in mode constant stress of 100 kPa at the temperature of 20°C and 10 kPa at the temperature of 40°C. 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 seconds to measure the creep deformation.

Results and Discussion

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 aging more rapidly [4].

From Figure 4, it appears that the rate of creep of binder at 40°C is



Figure 2: DSR Rheometer.

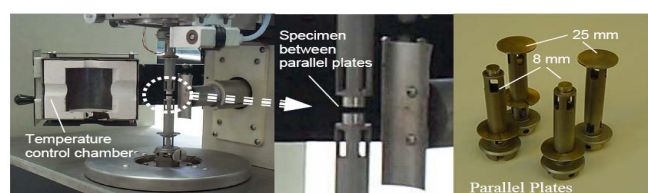


Figure 3: Diameters of plates (DSR).

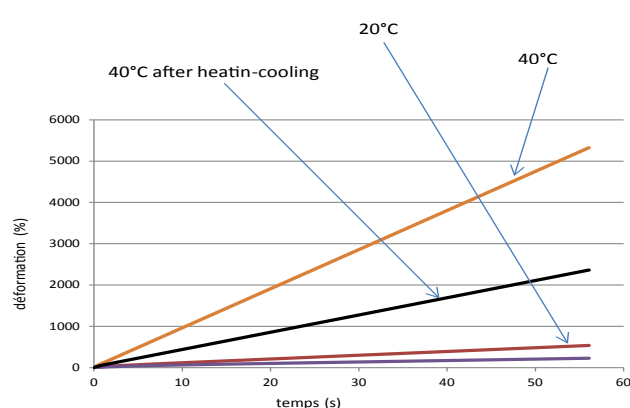


Figure 4: Creep of Bitumens before and after heating cooling cycles at 20 and 40°C.

almost equals to ten (10) times that at 20°C, although the stress at the latter is equals to ten (10) both the first (100 KPa at 20°C and 10 kPa at 40°C).

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°C 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 [5].

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 [6].

It has been shown that aging is responsible for an increase in the content of heteroatoms (S Sulfur, Nitrogen and Oxygen O N), mainly oxygen, which leads to a decrease in sensitivity to creep bitumen [7].

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 cracking and degradation of coatings [8].

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) [9].

Rheological Modeling

Any combination of springs (elastic elements) and linear dampers (viscous Newtonian elements) is an analog linear viscoelastic model [10,11]. 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 [12].

The analog models Maxwell (viscoelastic liquid) and Kelvin-Voigt (viscoelastic solid) cannot adequately describe the complex behavior of bituminous materials [10,11], but they can be the basic elements for more complex associations [12].

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+2K.

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 Figure 5.

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

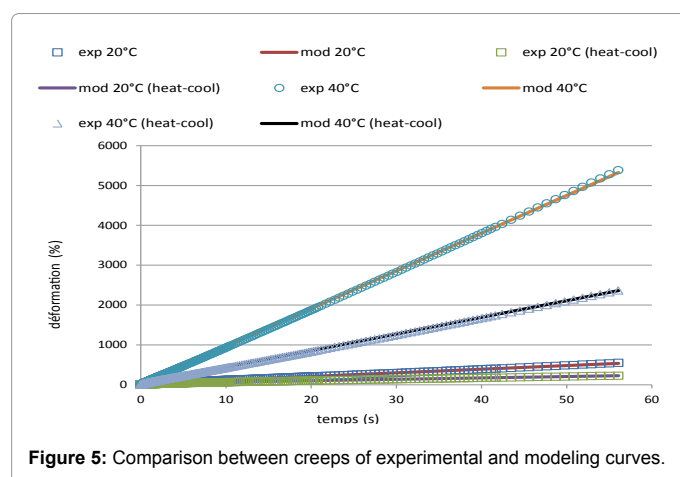


Figure 5: Comparison between creeps of experimental and modeling curves.

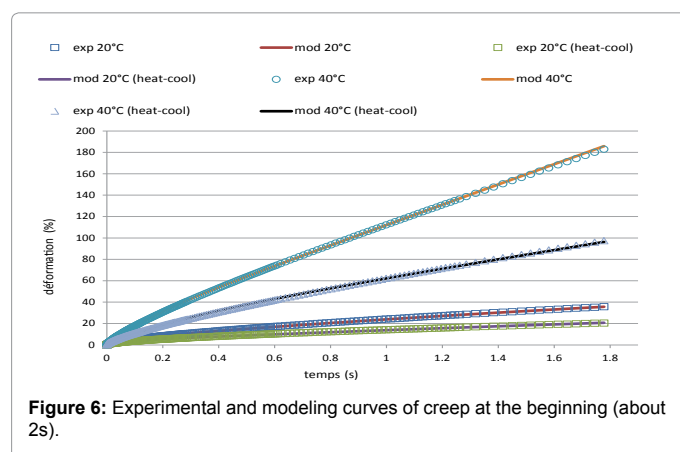


Figure 6: Experimental and modeling curves of creep at the beginning (about 2s).

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+2K), which significantly improves the rheological modeling bitumens.

References

- Dickinson EJ (2000) Prediction of the Hardening of the Bitumen in Pavement Surfacing by Reaction with Atmospheric Oxygen. TRB 1: 255-279.
- Glaoui B (2012) Contribution à la Caractérisation des Liant Modifiés et non Modifiés par l'Analyse Vibratoire, Effet des Cycles Thermiques sur les Liant Modifiés, Thèse de Doctorat, USTO, Oran, Juillet 2012.
- Merbouh M (2010) Contribution à la Modélisation du Comportement Rhéologique des Enrobés Bitumineux, Influence des Conditions Extrêmes de Température et de Trafic en Fatigue, Thèse de Doctorat, U-Bordeaux-I, France.
- Little, Dallas N, Jon Epps (2001) The Benefits of Hydrated Lime in Hot Mix Asphalt-Report for National Lime Association.
- Merbouh M, Laradi N, Aek Youcefi (2002) Comportement Rhéologique des Bitumes Routiers, la Relation Viscosité-Consistance aux Hautes Températures de Service. SIGC1 1er Séminaire International de Genie Civil, USTHB, Alger.
- Glaoui B (2005) Etude Expérimentale du Comportement Rhéologique des Bitumes Modifiés, Mémoire de Magistère. CUB-Bechar, Algérie.
- Michalica IB, Kazatchkov J, Stastna L, Zanzotto (2008) Relationship Between Chemical and Rheological Properties of two Asphalts of Different Origins. Fuel 87: 3247-3253.
- Ghomari F (2003) Science des Matériaux de Construction, DGC-FSI. Université A B Tlemcen, Algérie.
- Glaoui B, Merbouh M, Van de Ven M, Chailleux E, Youcefi A (2012) Thermal Fatigue of Polymer Modified Bitumen. Journal of Thermoplastic Composite Materials 25: 469-478.
- Di Benedetto H, Corte JF (2004) Matériaux Routiers Bitumineux 1 : Description et Propriétés des Constituants. Hermès.
- Olard F (2003) Comportement Thermomécanique des Enrobés Bitumineux à Basses Températures. Relations entre les Propriétés du Liant et de l'Enrobé. Thèse de Doctorat INSA de Lyon, France.
- Saoula S (2010) Approche Modéliste et Valorisation des Enrobés Modifiés par Ajout de Polymères - Impact sur l'Environnement. Thèse de Doctorat USTHB-Alger, Algérie.