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Evaluation of the influence of water and temperature on the rheological behavior and resistance to fatigue of asphalt mixtures

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HIGHLIGHTS

- Complex modulus and fatigue tests with and without immersion in water.
- Degradation of asphalt mixtures during cycles of immersion and drying.
- The effect of water and temperature on the rheological-mechanical performance of asphalt mixtures.
- Introduction of the damage factor (D) into the Huet-Sayegh model.

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ABSTRACT

Damage caused to asphalt layers by the action of traffic load, along with water and temperature, is the main factor responsible for the progressive deterioration of pavement structures. Although many studies have been carried out and the effect of water on asphalt mixtures has been reported, this phenomenon is not yet taken into consideration in models for dimensioning the thickness of asphalt layers. This paper reports the results of a study on the effect of water and temperature on the rheological behavior, complex modulus and fatigue resistance of an asphalt mixture formulated with a conventional asphalt binder with a penetration grade of 30/45. This evaluation was carried out through 2-point bending (2PB) tests, where trapezoidal specimens were submitted to wetting-drying cycles at 60 °C and then tested with immersion in water at different temperatures. On comparing the results with those obtained from specimens tested without conditioning and immersion and employing Huet-Sayegh's rheological model with the introduction of the damage factor (D), it was possible to evaluate the effect of the action of water and temperature on the graphical representation of the complex modulus and on the reduction in the fatigue life of the asphalt mixture. The results obtained highlight the need to take into account the action of water and temperature on the dimensioning of the thickness of the asphalt layers as well as on the prediction of the lifespan of these coatings, mainly in regions with a tropical climate.

1. Introduction

The effects of the action of water on the behavior of asphalt mixtures have been studied for many years. As a result, tests have been designed to predict this deleterious action, for instance, the moisture-induced damage test. The moisture factor is associated with the sensitivity of asphalt mixtures to water, directly affecting their constituent materials and chemical binders and the adhesiveness between them. Thus, the degradation of asphalt pavements due to the effect of the action of water and temperature is a common cause of damage to asphalt layers.

In countries with a warm and humid climate, characterized as tropical, the degradation of asphalt mixtures in the structures of road pavements due to the deleterious action of water along with the temperature gradient and the action of traffic are factors that affect the functional and structural conditions throughout the lifespan of the pavement structure [15]. The phenomenon of cycles of rain and dry conditions with high temperature increases the level of damage to the pavement, generating a need for the costly maintenance and restoration of highways.

Two tests are generally employed to evaluate the water sensitivity of asphalt mixtures: The modified Lottman test [2], an American methodology, and the Duriez test [9], a French methodology, are used to evaluate the influence of water on asphalt concrete during the preparation stage of asphalt mixtures when mixtures can be rejected or used in the formulation depending on the

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acceptability limit. Although the action of water and cycling affect the behavior of asphalt concrete in the dimensioning of the pavement, they are not considered as parameters in the dimensioning design.

Water does not only affect the surface layer of the pavement but also the asphalt mixtures in the pavement structure. These effects generally occur through the condensation of moisture and infiltration of water. Due to the volume of voids present in asphalt concretes, damage can be caused by the action of water and when combined with the effects of temperature variations and traffic the damage can be significant.

In this study, the mixtures designed are intended for use in the structural layer of the pavement and therefore it is appropriate to carry out complex modulus and fatigue tests, with alternating flexion, in order to approximate the real conditions observed in the field. Based on the evaluation of the effects of the action of water and cycling in the complex modulus and fatigue tests, intrinsic parameters of the complex modulus and admissible strain of asphalt mixtures are obtained, which can be considered in the dimensioning of the asphalt concrete layer.

The fatigue and complex modulus tests are indispensable for the determination of the admissible strain in the lower fiber of the asphalt concrete layer, the formula for which is expressed in Eq. (1) [22]:

$$\varepsilon_{t,ad} = \varepsilon(NE, \theta_{eq}, f).k_r \cdot k_s \cdot k_c = \varepsilon_6 \cdot (10^{\circ}C, 25Hz) \cdot \sqrt{\left[\frac{E^*(10^{\circ}C)}{E^*(\theta_{eq})}\right]} \cdot \left(\frac{NE}{10^6}\right)^b \cdot k_r \cdot k_s \cdot k_c \quad (1)$$

where:

$\varepsilon(\mathbf{NE}, \theta_{\mathbf{eq}}, \mathbf{f})$ = is the admissible strain of the asphalt mix related to a given number of loading cycles (NE), the equivalent temperature (θ_{eq}) and the load frequency;

$\varepsilon_6(10^{\circ}\mathbf{C}, 25\,\mathbf{Hz})$ = is the strain level at 10^6 cycles at a given temperature (θ) and loading frequency (f), based on the fatigue curve obtained for the material;

$\mathbf{E}(10^{\circ}\mathbf{C})$ = complex modulus for a temperature of 10 °C and frequency of 10 Hz;

$\mathbf{E}(\theta_{\mathbf{eq}})$ = complex modulus for a temperature of 15 °C and frequency of 10 Hz;

b = slope of fatigue curve;

$\mathbf{k_c}$ = adjust coefficient;

$\mathbf{k_s}$ = coefficient for the reduction in the effect of the heterogeneity of the support capacity;

$\mathbf{k_r}$ = risk coefficient (k_r) which is fitted to the calculated value for the risk of admissible strain.

The complex modulus test is particularly important with regard to effectively considering the viscoelastic behavior of asphalt concrete in the dimensioning of pavement layers, which is carried out introducing parameters of the Huet-Sayegh model in the Viscoroute software program.

This paper reports the results of a study aimed at evaluating the action of water and temperature on the rheological and mechanical behavior of asphalt mixtures. An asphalt mixture was formulated with a conventional binder with a penetration grade of 30/45, which was evaluated in the complex modulus test and in the resistance to fatigue test. The trapezoidal specimens were tested in 2-point bending (2PB) tests [11], and submitted to two conditions to investigate the action of water: in one case, the specimens were tested dry and immersed in water; and in the other the specimens were previously conditioned through submitting them to cycles of water immersion at 60 °C for 18 h followed by drying in oven at 60 °C for 6 h, over a period of 120 h (5 cycles). The aim of the conditioning was to increase the asphalt mixture degradation resulting from the action of water and temperature. In the second case, the conditioned mixtures were also tested dry and immersed in water.

In the fatigue tests, the specimens were tested at the reference temperature of 10 °C [12] and also at the temperature, determined from the graphical representation of the complex modulus in a Cole-Cole plot, where the greatest imaginary part, known as the critical temperature (20 °C), occurs. The test was carried out with controlled deformation with the application of a loading frequency of 25 Hz [12].

2. Literature review

2.1. Complex modulus

The complex modulus (E^*) is a complex number defined as the relation between the amplitude of the force with pulsation (ω) applied to a specimen and the complex amplitude of deformation in a stable regime. Due to viscoelastic characteristics of the asphalt mixture the deformation as a response to the stress imposed on the specimen is out of phase, the complex modulus can be determined through Eq. (2).

$$E^*(t) = \frac{\sigma_0}{\varepsilon_0} e^{-i\varphi} = |E*|e^{i\varphi} \quad (2)$$

where:

σ_o, ε_o – stress and strain amplitudes, respectively;

$\omega = 2\pi f$, the pulsation with f being the load frequency;

φ – phase angle;

i – complex number ($i = \sqrt{-1}$).

The complex modulus can be obtained as shown in Eq. (3).

$$E^*(i\omega) = E_1 + iE_2 \quad (3)$$

where:

$E*$– complex modulus;

E_1 – elastic modulus or real part (recovered energy);

E_2 – loss modulus or imaginary modulus (lost energy); and

2.2. Huet-Sayegh model

The Huet-Sayegh rheological model represents the behavior of the asphalt mixtures via the complex modulus through the constitutive equation derived from the parabolic damper (springs and dashpots) and compares their theoretical and experimental impedances, graphically represented on the Cole-Cole plot and in the Black Space, in the domain of the test frequencies and temperatures. This model is represented by two parallel parts, the first

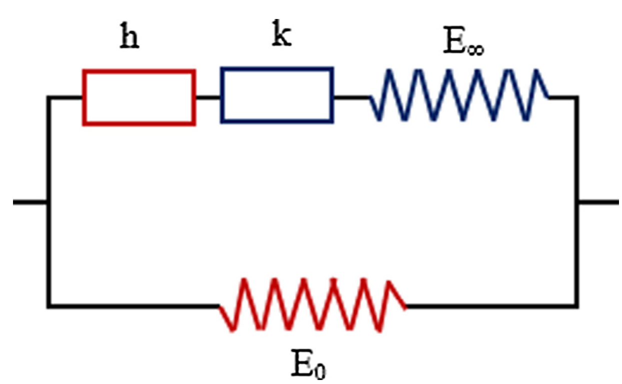

Fig. 1. Huet-Sayegh's rheological model.