EVALUATION OF THE VISCO-ELASTIC PROPERTIES IN ASPHALT RUBBER AND CONVENTIONAL MIXES

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Abstract: Flexible pavements are subjected to a set of degradations on the pavement surface, such as cracks and other specific types of distress which arise from traffic and temperature variations and which are responsible for the users’ unsafety and discomfort. The occurrence of temperature variations in the pavement leads to a severe aggravation of the reflective cracking phenomenon which implies a premature distress of the overlays. In this way, a theoretical study about the influence of temperature variation in the reflective cracking overlay behaviour was performed. To this end, a thermo-mechanical characterization of bituminous materials was made through a set of tests performed with an asphalt rubber mix and a conventional mix. It is intended to study the relaxation behaviour for four different temperature cases, 25ºC, 15ºC, 5ºC and -5ºC, which is a range of temperature variations similar to those that occur in the pavements located in the Northeast of Portugal. This paper presents a study in which the viscoelastic properties of asphalt rubber and conventional mixes, related with long-time loading and thermal loading, were determined through static relaxation tests using different test configurations. It also describes the material used, the test configurations applied to evaluate the viscoelastic properties and it finally establishes a comparison between the two mixes studied.

INTRODUCTION

The study of the influence of temperature variations in the behaviour of bituminous mixes requires a simulation of the relaxation effect subjected to long-time loading, such as thermal shrinkage associated to temperature variations (Minhoto et al, 2005).

For that purpose, a set of tests was performed in bituminous mixes samples to obtain relaxation capability evaluation, expressed by relaxation properties estimated for a set of temperatures. A constant strain was applied to a sample during a loading time under constant temperature conditions (Figure 1).

The definition of relaxation models must be developed for its integration in finite elements models used for calculate stress and strain states. The establishment of these models is based on the adjustment of representative curves of the experimental results to the generalized expressions which describe this type of behaviour (Minhoto et al, 2005).
Figure 1 – Relaxation test scheme

The stress function of a viscoelastic material is given in an integral form. In the context of small strain theory, the constitutive equation for an isotropic viscoelastic material can be written as:

\[
\sigma = \int_0^t \left[ 2G(t-\tau)\frac{de}{d\tau} d\tau + I \cdot \int_0^t K(t-\tau)\frac{d\Delta}{d\tau} d\tau \right]
\]  

The viscoelastic properties of the material for what respects to relaxation, used in the numerical simulation through finite elements methodology, had been expressed in an integral form using the kernel function of the generalized Maxwell elements, \(G(t)\) and \(K(t)\), representing the shear and bulk relaxation modulus, respectively, through the following equations:

\[
G(\xi) = G_\infty + \sum_{i=1}^{n_G} G_i e^{-\xi/\tau_i} \\
K(\xi) = K_\infty + \sum_{i=1}^{n_K} K_i e^{-\xi/\kappa_i}
\]

The kernel functions are represented in terms of Prony series which assumes the formulation indicated by the following expressions:

\[
G = G_\infty + \sum_{i=1}^{n_G} G_i \exp\left( -\frac{t}{\tau_i} \right) \\
K = K_\infty + \sum_{i=1}^{n_K} K_i \exp\left( -\frac{t}{\kappa_i} \right)
\]

As the viscoelastic property of materials depends strongly on temperature, the so called thermo-rheological simplicity is an assumption based on the observation of many glass-like materials, the relaxation curve of which, at high temperature, is identical to that at a low temperature if the time is properly scaled. Thus, the characterization of viscoelastic properties of the mixtures must be expressed in function of the temperature. The consideration of the temperature dependence in the previous models is guaranteed through the adoption of shift factors. For this purpose, the principle of thermo-rheological simplicity is considered as applicable and it is expressed by the shift factor \(X=A(T(t))\), defined through the expression of William-Landel-Ferry (WLF):
\[
\log_{10} \left( A(T(\tau)) \right) = \frac{C_1(T - T_r)}{C_2 + T - T_r}
\] (6)

In this work the relaxation behaviour of two bituminous mixes types were analysed: Asphalt Rubber gap-graded mix (ARHM) and conventional dense asphalt mix (CM). The material used to obtain the test specimens was extracted from a road pavement after construction.

**TEST DESCRIPTION**

The relaxation tests were performed using prismatic core specimens of 90 mm long by 65 mm thick by 45 mm wide. Each sample was fixed to a shear machine device support, as shown in Figure 2.

![Figure 2 –Sample used in relaxation tests](image)

Each sample is subjected to a constant vertical axial strain through an induced constant displacement. The constant test strain applied a range from 1E-3 to 2E-3 and the test temperatures were -5, 5, 15 and 25 °C. The time loading for each test was 7200 seconds.

**TESTING RESULTS**

For each test, the values of the three controlled parameters are obtained periodically: temperature, displacement and load. From these parameters only load presents a variation over the time and it is the parameter used for the characterization of the relaxation behaviour of the mixtures. The temperature and deformation were kept constant during the test. The calculation of the bulk relaxation modulus and the shear relaxation modulus was obtained with the parameters measured in the test.

The representative curves of each observed modulus type were obtained and were used as a basis for the adjustment to the functions kernel, in the form of Prony series. The Prony series obtained must be representative of the viscoelastic behaviour of the studied mixtures.
In Figure 3 a representative graph of the curves obtained for each test (or for each sample) is presented, involving the asphalt rubber hot mix. In Figure 4 the same type of representation is presented for the conventional mixture.
FITTING BEHAVIOUR CURVES

The adjustment of curves to the experimental results is made through the establishment of the Prony’s series constants (of Bulk and shear) and of the order of the series, which characterize the models of no-linear materials. These constants were established to guarantee the best approach to the experimental results. Three elements of the Prony series to represent the behavior of the studied mixtures were adopted.

Thus 17 parameters of the Prony-series were defined, seven related to the shear expression, $G(t)$, seven related to the bulk expression, $K(t)$, and three related to the WLF expression.

The Prony constants for a representative relaxation curve, relative to a reference temperature, $T_r$, and associated to the function WLF parameters, were defined from the curves established for the four test temperatures, establishing a relaxation law which shows a temperature dependence (Table 1).

The obtained parameters constitute a behaviour data set of the studied mixtures which can be considered as input data for the numerical modelling of the overlays behaviour, under thermal loading conditions.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>AR-HMA</th>
<th>CM</th>
<th>Parameters</th>
<th>AR-HMA</th>
<th>CM</th>
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</table>

In Figure 5 the relaxation modulus curves for the asphalt rubber mix are presented, compared with the representative points of the laboratorial tests results in which the testing results and the developed models largely match.

CONCLUSIONS

The characterization of the relaxation modulus was made for an asphalt rubber mixture and for a conventional dense hot mixture, through a set of one cycle long duration load. The tests results were fitted in the kernel function of the generalized Maxwell elements, $G(t)$ and $K(t)$, representing the shear and bulk relaxation modulus, respectively. The kernel functions were represented in terms of Prony series resulting four relaxation modulus relationships for the considered temperatures.
The curves obtained were used as the basis for the definition of the Prony constants for a representative relaxation curve, relative to a temperature of reference and associated to the function WLF parameters. Thus, a relaxation law which shows temperature dependence can be established.

It was observed that, the asphalt rubber mixture shows a relaxation modulus less than the conventional mixture. The relaxation modulus in an asphalt rubber mixture, for a loading time of 7200 seconds and for a temperature of -5ºC, is 2 times less than the relaxation modulus of conventional mixtures. Thus, the residual thermal stresses in asphalt rubber mixtures at low temperatures are lesser than in conventional mixture.

REFERENCES
