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Complexity of the behaviour of asphalt materials in cyclic testing

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ABSTRACT

This paper compares the results obtained in two types of cyclic tension-compression tests, a time sweep test, constant strain amplitude, and a strain sweep test, increasing strain amplitude every 5000 cycles, called EBADE (standing for the Spanish words for strain sweep test). This comparison has shown that the rapid loss of stiffness during the initial part of cyclic testing is recoverable in bituminous materials. It has been found that reversible phenomena dominate in asphalt binders, while in mixtures are as important as damage. A damage equation has been proposed to describe the evolution of the material distress during the phase II in time sweep tests. In addition, a new methodology to estimate the fatigue law of bituminous mixtures is proposed.

1. Introduction

One of the most frequent current failures of bituminous mixtures and which is prioritised when designing flexible pavements is the cracking of the asphalt layers. This can be due to various deterioration mechanisms, especially the failure of bituminous mixtures at low temperatures due to thermal stresses and their failure due to fatigue cracking as a result of load repetition over the lifetime of the pavement. The latter type of failure has to be especially considered during the design of the pavement, and this property of the mixture has been studied for many years. Until now, the laws and models that govern the cracking of the pavement over time and passing of loads have not been clearly defined. There are many factors that have an impact on this failure that must be taken into consideration, in addition to traffic loads. Firstly, there is the viscoelastic or thixotropic behaviour of the mixture and the variation of its mechanical properties with temperature. These properties also undergo changes with the passage of time and aging of the binder.

Given the complexity of the problem due to the amount of the variables involved, failure due to fatigue cracking has been analysed at the intermediate temperature of the pavement. Not at the lowest temperature with which the most fragile response of the bitumen and mixture is associated, nor at the highest temperatures when the fracture mechanisms are associated with the settling and plastic deformations of the mixtures and granular layers and subgrade. Thus, the average temperature of the location of the mixture and the response of the bitumen to fatigue at this temperature is one of the criteria used in the Superpave [1] for the selection of the type of bitumen.

The tests for the evaluation of resistance to fatigue failure of the bituminous mixtures are also usually carried out in the average temperature range, normally between 10 and 20 °C, and most frequently at 20 °C. The variation of the properties of the mixture over time is not normally taken into consideration, and the tests are usually made on unaged mixtures.

The conventionally employed tests are the flexural tests on beams with 2, 3 or 4 support points, or tension-compression tests on cylindrical or prismatic specimens, Fig. 1. In these tests, either the cyclic force applied (testing at constant stress) or the applied strain (testing at constant strain) is kept constant. From these tests, the number of cycles (N) is obtained that the mixture can withstand for a given stress or strain (ε, σ). Also, the dynamic modulus of the mixture is determined at the start of each test. The procedure is repeated with different stresses or strains and, based on these results which require several days to obtain, the fatigue law of the mixture and its average dynamic modulus are determined for the range of tested loads.

However, it should be borne in mind that the conducting of these tests is not a simple and straightforward task given the complex behaviour of the bituminous mixtures. When fatigue tests are carried out on metals and concrete, a more or less continuous loss of the mechanical properties of the materials is observed until the failure occurs. There is very little difficulty in defining the mechanical characteristics of the material at the start of the test and when

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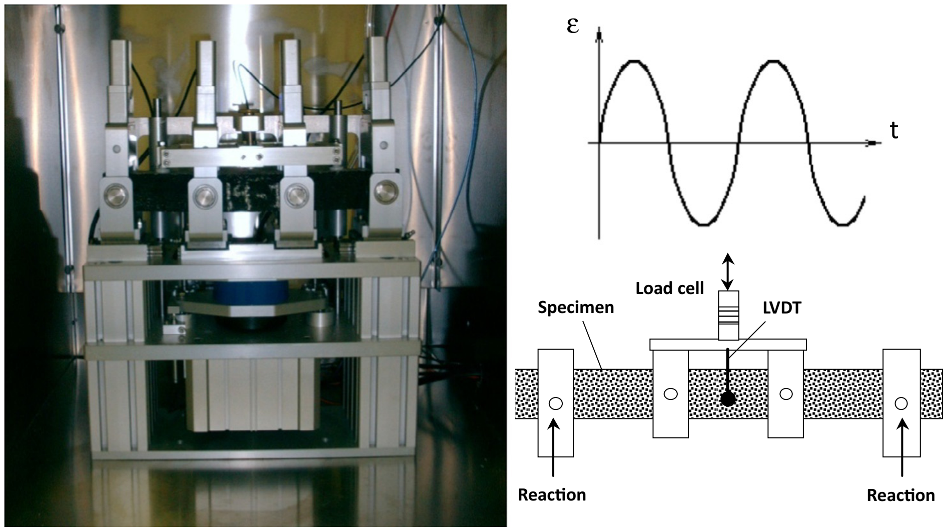

Fig. 1. Four points bending beam fatigue test.

the failure occurs. In the case of bituminous mixtures, Fig. 2, there is a first phase in which there is a rapid loss of stiffness (phase I), then the trend changes and there is a linear and more moderate loss (phase II), and finally there is again a more rapid and continuous deterioration (phase III). For the evaluation and quantification of these results, guidelines have been established that associate the initial properties of the mixture with those that are present at cycle 100, and its failure with the cycle in which the property that is being measured (normally the load or the modulus) is reduced to 50% of the value measured at cycle 100. This does not correspond to a defined and specific state of the specimen (initial/failure); it is totally arbitrary and can lead to errors when the fatigue laws obtained in this way are applied to the design of pavements by analytical methods. Fig. 2 shows how the failure of the specimens would be associated to a smaller number of cycles, and the actual number when failure occurs (phase III). This fact has been highlighted by a number of authors [2–4].

The response of bituminous mixtures during the deterioration processes due to load repetition has also been analysed based on the application of thermodynamic principles, which relate the deterioration of the material with the dissipated energy. For bituminous materials, Schapery and Park [5] propose the following expression for the deterioration equation:

$$\dot{S}_m = (-\partial W^R / \partial S_m)^{\alpha} \quad (1)$$

where $\dot{S}_m$ is the change of the variable that represents the material damage, W^R is the pseudo-energy dissipated in each load application and α is a coefficient related to the viscoelastic response.

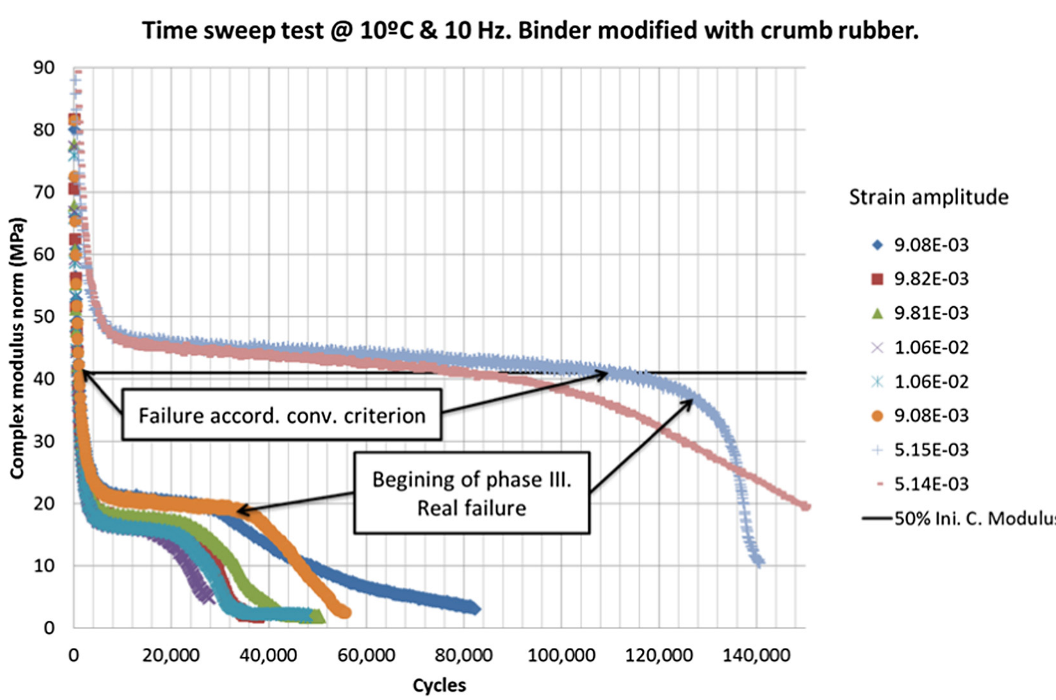

Fig. 2. Time sweep test (tension-compression) on asphalt binder. Conventional criterion of fatigue failure.