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Investigating cohesive healing of asphalt binders by means of a dissipated energy approach

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Abstract

The paper reports the results of an experimental investigation in which the cohesive healing properties of different types of asphalt binder were evaluated by means of the dissipated energy ratio approach. A specifically designed testing methodology was proposed which involves comparing the response of binders subjected to continuous oscillatory shear loading carried out without rest periods and with single rest periods introduced at predefined levels of damage A rheological parameter (Healing Ratio) was introduced to quantify the magnitude of healing occurring during rest time and to rank the consequent healing potential of binders. Obtained results indicate that the investigated binders did not completely recover their original fatigue resistance after rest time, confirming the existence of some intrinsic irreversible damage, the amount of which depends on the total damage experienced before load removal. Experimental results also indicate that healing performance of binders can be significantly enhanced by polymer modification.

Keywords: Healing; Fatigue; Dissipated energy ratio; Asphalt binder; Polymer modification

1. Introduction

The evaluation of fatigue resistance of asphalt concrete mixtures employed in road pavements is traditionally carried out by subjecting them to continuous cyclic loading until failure in controlled temperature and stress/strain conditions. Such an approach does not reproduce what happens in the field, where, due to the intermittent nature of traffic, rest periods exist between each axle load application. It has been widely demonstrated that asphalt concrete mixtures have the capability to recover stiffness or strength during rest time [1–11]. This capability, commonly referred to as healing, is responsible for the significant difference between fatigue life predicted by means of traditional laboratory tests and actual fatigue life observed in the field, with the first one being considerably shorter than the second one. To overcome such a limitation, laboratory-to-field shift factors, the values of which can range from 3 to about 100, are commonly used in pavement design [12].

Two types of healing exist in asphalt concrete mixtures: adhesive healing at aggregate binder interface and cohesive healing within the asphalt binder at microcrack surfaces [5,7]. The study of adhesive healing is out of the scope of this paper which focused on cohesive healing only.

A number of research works has been carried out to investigate cohesive healing of asphalt binders. The Dynamic Shear Rheometer (DSR) has been generally employed in these works and different methods and criteria have been proposed.

In the majority of cases researchers used cyclic stress or strain at a predefined frequency and temperature,

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interrupted by the inclusion of a single long rest period [13–20] or of multiple short rest periods [21–25]. In these studies healing behaviour of binders was quantified in terms of complex modulus recovery and/or increase in load repetitions to failure due to rest time.

Other authors used the so called two-piece bitumen healing setup [26–28] in which two specimens of asphalt binder are attached to the upper and bottom plates of a DSR. The surfaces of the two specimens are brought into contact with each other and during the test the change in complex shear modulus is recorded by applying small strain cyclic loading at different time intervals.

Despite the remarkable efforts made by researchers worldwide, more work is needed in order to fully understand cohesive healing mechanisms and to develop scientifically sound procedures to assess and rank performance of materials.

This paper presents the results obtained from an experimental investigation in which the cohesive healing characteristics of three types of asphalt binder were analysed. A novel approach, based on the concept of dissipated energy, was used in the analysis and a healing index was introduced to quantitatively evaluate and compare healing potential of materials. The effectiveness of the proposed method in capturing the effects of polymer modification on binder response was also discussed.

2. Experimental investigation

2.1. Hypothesis

Cohesive healing is believed to be the results of several processes which take place at crack interfaces, such as wetting (which depends on surface energy of the material), interfacial cohesion and interdiffusion and randomization of molecules between wetted surfaces [29–31]. Such processes contribute to cracks to be repaired and original internal structure of the asphalt binder to be restored.

It can be stated that any change occurring in the internal structure of materials due to damage reflects in a change in their energy dissipation processes. Moving from this basic assumption, the study described in this paper introduces a methodology based on the comparison of dissipated energy measured under continuous oscillatory shear loading without rest periods (fatigue tests) and after single long rest periods introduced at fixed values of complex modulus loss (healing tests). In such a context, the Dissipated Energy Ratio (DER) concept originally proposed by Pronk and Hopman [32] is used to analyse fatigue and healing test data.

The DER parameter after N loading cycles is calculated by means of the following expression:

$$\mathrm{DER} = \frac{\sum_{1}^{N} W_i}{W_N} \tag{1}$$

where W_i and W_N are the energy dissipated per unit volume in the generic i-th and in the N-th cycle which are calculated by means of the following general expression:

$$W_i = \pi \cdot \tau_{0,i} \cdot \gamma_{0,i} \cdot \sin(\delta_i) \tag{2}$$

in which $\tau_{0,i}$ and $\gamma_{0,i}$ are respectively the stress and strain amplitudes, while δ_i is the phase angle value.

In the case of stress-controlled tests, the plot of DER as a function of the number of loading cycles N is of the type shown in Fig. 1. It can be observed that after an initial phase of testing with no damage accumulation, the experimental data points gradually deviate from the equality line (with 45° horizontal slope). A peak value is reached, after which DER values decrease until complete failure of the specimen.

Several fatigue life indicators can be derived from the DER function obtained from continuous oscillatory loading test data [33,34]: N_p, which identifies the onset of crack propagation and corresponds to the intersection between the equality line and the horizontal line passing through the maximum DER value; N_{p20}, which is associated with 20% deviation of DER from the equality line; N_{max}, which corresponds to peak DER.

For the purpose of healing evaluation, the DER function obtained from fatigue tests is considered as a reference point, since it is representative of the response of the material in its original state. Its comparison with the DER function obtained after a certain amount of damage has been induced in the binder may provide information on the healing capability of the material.

2.2. Materials and methods

The materials employed in the experimental investigation included one unmodified bitumen (50/70 penetration grade), indicated as “Neat”, and two commercially available polymer modified binders containing styrene-butadienestyrene (SBS), indicated as “Soft” (45/65 penetration grade) and “Hard” (50/70 penetration grade). The terms “Soft” and “Hard”, commonly used in Italy, refer to products prepared with a low and high polymer dosage,

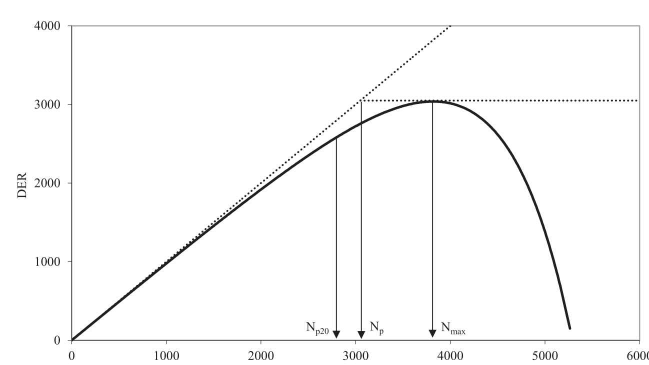

Fig. 1. Example of a typical DER function obtained from a stress-controlled fatigue test.