

Testing methods to assess healing potential of bituminous binders

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Abstract. Despite the fact that ability of bituminous materials to heal damage has been largely studied and that a wide literature is available on this topic, there is still no consensus in the research community on actual factors governing healing process and methods to be used to quantitatively assess healing performance of bituminous materials. In such a context, one of the main objectives of the RILEM Technical Committee 278-CHA is to evaluate the different test methods proposed by various research teams to characterize healing in bituminous materials and come up with clear and concise recommendations regarding the evaluation of healing behavior of bituminous materials in the laboratory. To this regard, an inter-laboratory experimental program has been recently started with the specific purpose of testing a common set of selected bituminous binders by using three different protocols. This paper describes the protocols adopted in the experimental program and reports some preliminary results obtained to date.

Keywords: Bituminous binders, Healing, Damage, Dynamic Shear Rheometer

1 Introduction

Bituminous binders are recognized to have the interesting ability to restore their strength or stiffness lost due to external loading when allowed to rest for a given time interval [1-2]. This ability is generally referred to as healing. Despite such a phenomenon has been widely studied for long time and a number of testing methods have been proposed, there is no consensus among the scientific community on a possible standardized protocol to be used for the evaluation of binders healing potential. In fact, the development of a reliable testing procedure is not a trivial task due to many effects coming into play in laboratory measurements, including reversible materials effects (non-linearity, local heating, thixotropy) not related to micro-damage [3-4]. However, the research community would benefit from the adoption of a single recommended methodology for material's evaluation and classification purposes. This is the main challenge of the Task Group TG2 of the Rilem Technical Committee TC 278-CHA (Crack-Healing of Asphalt Pavement Materials), that launched an inter-laboratory testing program in which a common array of bituminous binders has been

evaluated by means of different protocols with the purpose of comparing the aptitude of such protocols in discriminating and ranking material healing response. This paper describes the protocols selected for the inter-laboratory experimentation highlighting the different rationales underlying various testing approaches. Moreover, some preliminary results are presented and discussed.

2 Materials

A set of three bituminous binders of different type and provenience was used in the inter-laboratory experimentation, including two neat bitumen and one SBS polymer modified binder (PMB). Description of investigated materials is given in Table 1.

Table 1. Bituminous binders used in the experimental investigation

Binder	Type	Provenience	Pen Grade
B1	Neat	Italy	70/100
B2	Neat	Ireland	40/60
B3	SBS PMB	France	30/45

3 Testing methods

The three selected protocols used by different laboratories involved in the activities of TG2 to evaluate healing potential of the bituminous binders are based respectively on:

- 1) Time sweep tests with single rest period (TS-SRP)
- 2) Time sweep tests with multiple rest periods (TS-MRP)
- 3) Linear amplitude sweep test with single rest period (LASH)

For all protocols, measurements were carried out by means of DSR equipped with 8 mm parallel plates and 1 mm gap. For comparison purposes, a common temperature of 20 °C and frequency of 10 Hz were adopted by all laboratories. Three replicates were performed for each type of test and average results were considered in the subsequent analysis.

3.1 TS-SRP

TS-SRP test consists of two oscillatory shear loading phases separated by the interposition of a single long rest period (2 h), with the purpose of evaluating the kinetic of recovery process over time [5]. The first loading phase, preceded by a conditioning phase of 30 minutes, is interrupted at specific levels of damage reached by the material, corresponding to the reduction of the norm of the complex modulus $|G^*|$ equal to 15, 35 and 50%. Oscillatory loading is applied in the strain-controlled mode at a strain amplitude belonging to the non-linear viscoelastic domain of the material. Based on preliminary strain amplitude sweep tests performed on all selected binders, a strain amplitude value of 3% was chosen. During both the conditioning phase and the rest

period, a low strain amplitude ($\leq 0.1\%$) was also applied to monitor the evolution of G^* as a function of time. With the aim of evaluating and subtracting reversible material effects occurring during rest period and not related to micro-damage repair, binders were also subjected to TS-SRP tests in which the first loading phase is substituted with a dummy phase, characterized by a few loading cycles during which a negligible damage is induced in specimens.

A schematic representation of TS-SRP tests with effective and dummy first loading phase is depicted in Fig. 1.

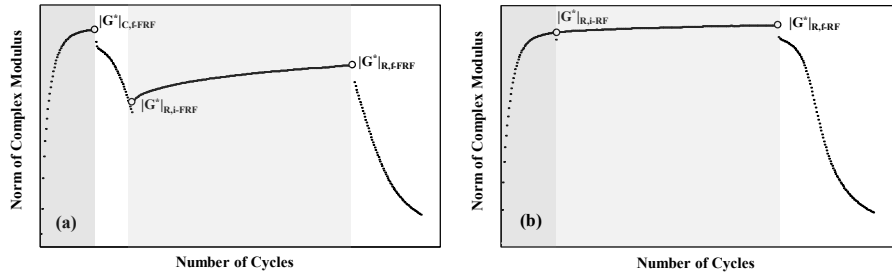


Fig. 1. Schematic representation of TS-SRP test with effective (a) and dummy (b) first loading phase.

The self-healing response of binders was assessed by introducing a healing index HI_{TS-SRP} , calculated as indicated in Eq. 1:

$$HI_{TS-SRP} = \frac{\Delta|G^*|_{R-RRF} - \Delta|G^*|_{R-RF}}{\Delta|G^*|_{F-RRF}} \cdot 100 \quad (1)$$

where $\Delta|G^*|_{R-RRF}$ is the difference between the final value $|G^*|_{R,f-RRF}$ and the initial value $|G^*|_{R,i-RRF}$ of the norm of the complex modulus recorded in the rest period of effective TS-SRP tests, $\Delta|G^*|_{R-RF}$ is difference between the final value $|G^*|_{R,f-RRF}$ and the initial value $|G^*|_{R,i-RRF}$ of the norm of the complex modulus recorded in the rest period of dummy TS-SRP tests, and $\Delta|G^*|_{F-RRF}$ is the modulus loss imposed during the first loading phase of effective TS-SRP tests, given by the difference between the value of the norm of the complex modulus at the end of the conditioning phase $|G^*|_{C,f-RRF}$ and the value of the norm of the complex modulus at the beginning of rest period $|G^*|_{R,i-RRF}$.

3.2 TS-MRP

TS-MRP tests consist of time sweeps interrupted by multiple rest periods, aimed at mimicking real loading conditions occurring in the field [6-7]. The evolution of the loss modulus ($|G^*| \cdot \sin \delta$) is continuously monitored during the entire test as representative of damage accumulation. Each loading phase is interrupted when the $|G^*| \cdot \sin \delta$ drops down to 65% of its initial value (selected damage level) and is resumed after 30 minutes. A strain amplitude belonging to the non-linear viscoelastic domain of the material was applied. During each rest-period a low strain amplitude ($\leq 0.1\%$) is

applied in order to monitor the recovery of loss modulus. A minimum number of 12 load-rest phases are recommended in all test conditions. The test data analysis provides the identification of numerical parameters to quantify the overall fatigue endurance limit of material as follows:

$$N_{Fat} = N_0 + N_{fH}; N_{fH} = \lim_{n \rightarrow \infty} N_H(n); N_H(n) = \sum_{i=1}^n \Delta N_H(i); \Delta N_i = \Delta N_H(i) + \Delta N_{\infty} \quad (2)$$

where N_{Fat} is the effective number of loading cycles that the material withstands before failure considering the “ n ” rest periods, N_0 is the number of loading cycles in the first loading phase, N_H is the overall self-healing contribution after “ n ” rest periods, ΔN_i is the number of loading cycles after each “ i -th” rest period which are necessary to reach the selected level of damage, $\Delta N_H(i)$ is the self-healing contribution (variable depending on the “ i -th” rest-period considered) and ΔN_{∞} is the thixotropy contribution (constant for each rest/load phase). It is observed that $\Delta N_H(i)$ decreases with the number of rest periods applied and vanishes after a certain number of rest periods. Thus, after a high number of rest periods (virtually infinite) N_H , defined as the self-healing potential, converges to a finite asymptotic value N_{fH} that represents the cumulative self-healing capability for infinite number of rest periods (Fig. 2).

A healing index HI_{TS-MRP} is then introduced, calculated with Eq.3:

$$HI_{TS-MRP} = \frac{N_{Fat} - N_0}{N_0} \cdot 100 = \frac{N_{fH}}{N_0} \cdot 100 \quad (3)$$

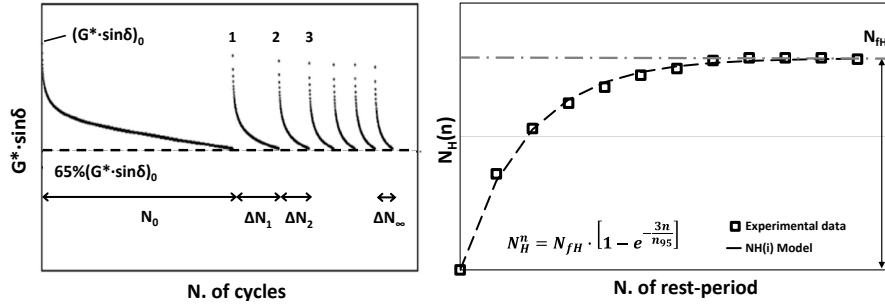


Fig. 2. Loading-recovery sequence used in TS-MRP tests (a). Modelling of self-healing parameter $N_H(n)$ (b).

3.3 LASH

LASH test consists in a Linear Amplitude Sweep (AASHTO TP101-12) with the inclusion of a rest period at a fixed level of damage [8]. LASH test data can be interpreted with the Simplified-Viscoelastic Continuum Damage (S-VECD) model approach to identify the damage characteristic curve, which is described in terms of pseudo stiffness (C) versus damage intensity (S). The details of the S-VECD model application on bituminous binder are available elsewhere [9]. The key concept of LASH procedure is to take the S_f as a critical damage parameter, which represents the damage intensity of S up to failure occurrence. The analyzed damage states are defined at

25% S_f , 50% S_f , 75% S_f , and 125% S_f and include values above and below the critical damage parameter. For each S_f -based damage level, multiple rest periods of 60, 300, 900, and 1800 s are introduced to characterize the healing behavior.

An example of results obtained from LASH test is given in Fig. 3, which shows typical damage characteristic curves of the material before and after rest period. A healing index HI_{LASH} is defined based on the damage recovery as expressed in Eq. 4, in which the S_1 and S_2 represent the measured S values immediately preceding and after the rest period, respectively:

$$HI_{LASH} = \frac{S_1 - S_2}{S_1} \cdot 100 \quad (4)$$

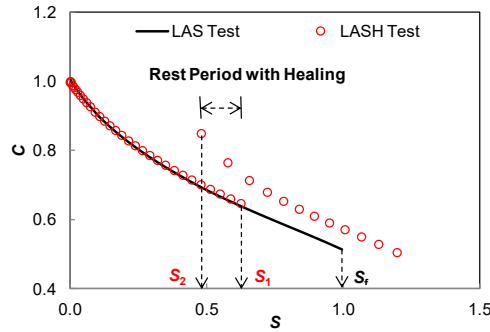


Fig. 3. Damage characteristic curve before and after rest period from LASH test.

4 Preliminary results and concluding remarks

With the only purpose of providing a preliminary comparison of the healing ranking obtained adopting different experimental approaches (TS-SRP, TS-MRP, and LASH protocols), a summary of healing indicators is displayed in Fig. 4 for the three investigated materials. In the case of TS-SRP tests the healing indicator is represented by HI_{TS-SRP} (Eq. 1), calculated at a level of damage corresponding to a reduction of the norm of the complex modulus $|G^*|$ of 35 % and a single rest period of 2 h; for TS-SRP tests the healing indicator is HI_{TS-MRP} (Eq. 3) corresponding to a 35 % drop in dissipated energy and multiple rest periods of 1800 s; for LASH tests the indicator is HI_{LASH} (Eq. 4), obtained at a level of damage of 50% S_f and a single rest time of 1800 s. It is observed that, even if all the tests were performed in oscillatory shear strain mode at common values of temperature and frequency (set at 20 °C and 10 Hz, respectively), a univocal ranking was not achieved. When comparing neat binders B1 and B2, a similar ranking was obtained according to TS-SRP and LASH methods, opposite to that highlighted using TS-MRP. On the other hand, the polymer-modified bitumen B3 revealed the highest healing capability when tested using the TS-MRP method, it showed a similar healing capability to B1 when TS-SRP was used, while it exhibited the worst healing properties with the adoption of LASH protocol.

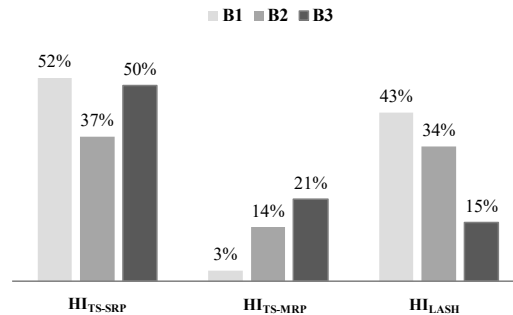


Fig. 4. Healing indicators according to TS-SRP, TS-MRP, and LASH methods.

Such unexpected findings bring to light the non-negligible role played by the choice of testing parameters and analytical approach used to assess healing.

From these preliminary results, it can be stated that there is an urgent need to converge towards a standardized laboratory protocol capable of providing accurate and reliable description of the healing ability of bituminous materials, representative of a wide spectrum of prevalent environmental and loading conditions in the field.

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