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Self-healing capability and thixotropy of bituminous mastics

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ABSTRACT

Fatigue resistance of bituminous materials is related to time-dependent phenomena, such as damage accumulation, hardening, viscoelasticity, thixotropy and healing.

In bituminous mixtures, damage related to fatigue processes mainly involves bitumen and its combination with filler (i.e. mastic).

Currently, there is no consolidated method for the determination of the fatigue endurance limit of bitumens that takes into account also the above-mentioned phenomena, while limited work has been done on mastics.

To bridge this gap, the experimental investigation described in this paper provides a comparison between bitumens and corresponding mastics in terms of fatigue, self-healing and thixotropy. Long term aged materials were also taken into consideration in order to identify potential detrimental effects on self-healing due to oxidation phenomena, evaluating the possible inclusion of Reclaimed Asphalt (RA) for the production of bituminous mixtures. The data analysis was based on an innovative test method which had previously been implemented for bitumens and was carried out using a Dynamic Shear Rheometer (DSR). Moreover, the influence of morphological properties of filler on filler-bitumen interactions was assessed by means of a Scanning Electron Microscope (SEM).

Results show that the above-mentioned analysis method is also suitable for analysing bituminous mastics and is able to identify the role of filler as well as the influence of ageing on the self-healing process of bituminous materials. The investigation confirms that a certain amount of aged bitumen added to a virgin bitumen/mastic is able to considerably improve the overall fatigue performance suggesting significant benefits when dealing with recycled mixtures including RA aggregates.

1. Introduction

Bituminous materials are extensively used for the construction of road pavements. These materials are subjected to a wide range of thermo-mechanical stresses that cause premature failure if not properly addressed during their entire service life. Fatigue is one of the main failure modes for flexible pavements. It consists in the formation of micro-cracks due to repeated loading cycles which leads to the appearance of macro-cracks by coalescence. Nevertheless, once a crack is opened in the pavement, it starts healing and, if there is enough time for the process to be completed, it may even close [1]. However, the complete closure of an existing crack due to the ability of bitumen to flow is not proven. Studies conducted by several authors [2] suggest that, even when bitumen flowing could re-link two crack surfaces, this link would be extremely weak. It is evident that fatigue resistance is the result of several mechanisms, which are both time and temperature dependent. In particular, thixotropy and self-healing occur simultaneously when a bituminous material is subjected to an external stress [2].

Thixotropy, an intrinsic property of a viscoelastic material, represents the material capability to recover its microstructure from the un-cracked part of the sample [3]. In particular, thixotropy represents the tendency of material viscosity to decrease over time during loading conditions and to recover during rest periods thanks to molecular rearrangement in the bituminous phase [4].

Self-healing is the ability of bituminous materials to recover their initial properties by wetting and interdiffusion [5] and mainly occurs during rest periods. There exist two main types of healing in bituminous mixtures: adhesive healing at the bitumen-aggregate interface and cohesive healing within the bitumen [6]. Researchers have mainly focused on the analysis of the bituminous phase (e.g. cohesive healing), because it is well known that healing depends on the material surface energy and is mainly related to the interdiffusion among bitumen components [7]. In fact,

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self-healing consists of three main phases: consolidation of stresses and flow of bitumen, wetting (adhesion developed between the crack surfaces depending on surface energy) and interdiffusion (responsible for the complete recovery of mechanical properties) [8–10]. However, few investigations have dealt with the simultaneous interaction of fatigue, self-healing and thixotropy [11–13] and the lack of standardised procedures and test protocols to characterise such phenomena is still to be solved [2,14].

In literature, many experimental studies aiming at evaluating the fatigue performance of bituminous mixtures [15,16] can be found. In bituminous mixtures, the damage related to fatigue process mainly involves bitumen and its combination with filler (i.e. mastic). The latter has an intermediate behaviour between bitumen and mixture and is the real binder in bituminous mixtures, which should be considered as mastic-coated aggregates rather than pure bitumen-coated aggregates [17]. Consequently, experimental studies on mastics have the potential to represent a more reliable tool to properly evaluate the fatigue behaviour of bituminous mixtures. Although many researchers have studied the fatigue and healing characteristics of bitumens [18–21,13,22], limited work has been done about the assessment of mastic behaviour. Recent studies have shown that the fatigue response of mastics differs from that of the associated bitumens, as fatigue life is affected by filler type and concentration [23]. Underwood [24] developed an analytical model for the mechanical degradation of bitumen and mastic under repeated loading and found, however, that fatigue is mainly due to physical damage occurring in bitumen. Garcia [1] studied the self-healing processes of open cracks in mastic: a series of mastic beams were broken and healed at different temperatures and the time required for complete recovery was used to calculate the healing activation energy.

Further implications are due to the increasing reuse of Reclaimed Asphalt (RA) for the production of new and environmental friendly bituminous mixtures which involves the need to understand the influence of reactivated bitumen from RA on the final behaviour of mastic. As it is well known, the exposure of RA to high temperature during mix plant production causes the reactivation of a certain part of the bitumen contained in it, which is, in turn, subjected to extra oxidation and undergoes changes in its chemical and mechanical properties. Hence, it is also important to analyse the interaction among aged reactivated bitumen from RA, new virgin bitumen and filler, investigating the related repercussions on fatigue, thixotropy and self-healing capability.

2. Objectives

The main objective of this paper is to assess the self-healing capability of mastics. To this aim, an innovative experimental approach previously implemented for bitumens was applied in order to discriminate self-healing capability from other simultaneous contributions due to viscoelastic phenomena, such as thixotropy [13].

The experimental study is based on time sweep tests with multiple rest periods (strain controlled mode) inserted at a damage level selected so as to involve the second phase of the fatigue curve, where the role of fatigue is predominant [15]. The model adopted for the data analysis is able to identify the true self-healing potential and its impact on the overall fatigue resistance, taking into account also the thixotropic phenomenon that concurrently occurs. Based on the results obtained on bitumens, the aim of this study is to assess if the same approach can be reliably extended also to mastics in order to evaluate possible effects on thixotropy and self-healing capability due to the presence of filler. To this purpose, as suggested by Antunes et al. [25], the influence of filler morphology in the filler-bitumen interaction was also considered by means of SEM imaging.

3. Materials

Different materials were analysed and compared considering SBS (Styrene Butadiene Styrene) modified bitumens, which are those usually employed for Italian motorway bituminous mixtures. In particular, three mastics and four bitumens were investigated.

An SBS polymer was adopted to modify a base bitumen (coded as BB) in order to produce a high modified bitumen (coded as H) by adding 3.8% of SBS by bitumen weight. The other three bitumens were obtained by blending bitumen H to different percentages of a same SBS modified artificial reclaimed bitumen (coded R). Three types of mastic were then produced by adding limestone (L), the most commonly used filler for bituminous mixtures, to each of the above-mentioned bitumens.

A constant filler/bitumen ratio equal to 1 by weight (corresponding to a filler/mastic ratio equal to 28% by volume) was selected in accordance with Superpave specifications [26], which recommend a ratio by weight within 0.6 and 1.2 and a maximum filler concentration by volume of total mastic equal to 28%.

Moreover, in order to account for the effects due to the addition of RA, a certain percentage of the artificial reclaimed bitumen R, which simulates the presence of the reactivated bitumen released by RA during the in-plant production of HMA, was also evaluated for both bitumens and mastics. The artificial reclaimed bitumen R was obtained by subjecting virgin bitumen H to long-term ageing by means of Rolling Thin Film Oven Test and Pressure Aging Vessel testing procedure, in accordance with European Standards EN 12607-1 and EN 14769.

The mastics were prepared following an optimised protocol so as to obtain homogeneous bitumen-filler mixes [27]. At first, the limestone L and bitumens H and R were heated in the oven at 165 °C until the consistency of the bitumens became sufficiently fluid. Then bitumen H was blended with the set percentage of bitumen R using a low shear mixer operating at 60 rpm and 165 °C for five minutes; finally, the filler was gradually added to the bitumen and blended using the same mixer. The rotation speed was progressively increased in proportion to the amount of the material and the addition of the filler was completed in about 10 min. The parameters of the blending procedure were selected so as to prevent bitumens from severe processing conditions and to minimise additional ageing effects. Moreover, during the preparation of the mastics, further aspects were carefully taken into account in order to avoid inhomogeneities in the materials studied:

- segregation (due to different specific weights of mastic components);
- hardening (steric hardening was controlled by standardising all sample preparation times before testing);
- heterogeneity (all the components in the samples comply with the percentages selected).

The materials investigated in this study are summarised in Table 1.

Table 1
Materials investigated.

Material	Code	SBS polymer content by bitumen weight (%)	Artificial reclaimed bitumen, R, by bitumen weight (%)	Filler/Bitumen ratio by weight
BITUMEN	BB	0	0	0
	BH_0R	3.8	0	0
	BH_45R	3.8	45	0
	BH_100R	3.8	100	0
MASTIC	MHL_0R	3.8	0	1
	MHL_45R	3.8	45	1
	MHL_100R	3.8	100	1