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Fatigue, self-healing and thixotropy of bituminous mastics including aged modified bitumens and different filler contents

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HIGHLIGHTS

- Fatigue, self-healing and thixotropy of mastics are analysed using a new approach.
- Effects of different percentages of filler and aged modified bitumen are considered.
- Filler inhibits bitumen interdiffusion reducing cohesive self-healing potential.
- The presence of 45% of aged modified bitumen improves overall fatigue response.
- An optimum filler/bitumen ratio is determined with respect to fatigue performance.

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ABSTRACT

Bituminous mastic is a self-healing viscoelastic material. Recoverable phenomena, such as thixotropy and self-healing capability, are recognised as an important resource for the development of sound road pavements.

The experimental investigation described in this paper and carried out through a Dynamic Shear Rheometer (DSR) provides a comparison among mastics blended with different percentages of aged polymer modified bitumen, new virgin polymer modified bitumen and filler in terms of fatigue, self-healing and thixotropy.

Data analysis is based on a model adopted in previous studies for polymer modified bitumens in order to calculate the fatigue endurance limit.

Results show that the presence of increasing percentages of filler causes detrimental effects on mastic fatigue performance which can be offset by the addition of a certain amount of aged polymer modified bitumen. In fact, regardless of the filler content considered, a percentage of aged polymer modified bitumen (up to 45%) added to mastics enhances the fatigue endurance limit suggesting significant benefits when dealing with sustainable recycled mixtures containing Reclaimed Asphalt (RA) aggregates.

1. Introduction

Fatigue cracking represents the major cause of failure for asphalt pavements. Hence, it is fundamental to identify reliable fatigue parameters in order to estimate the pavement service life under traffic loading conditions.

Nowadays, pavement-engineering strategies aim at performance improvement, resources conservation (e.g. recycling techniques) and environment protection (e.g. reduction of harmful emissions). In this sense, it should be emphasised that fatigue resistance is the result of several mechanisms, such as self-healing which can be classified among environmentally sustainable strategies designed to decrease maintenance costs, extend service life and reduce greenhouse gas emission as well [1]. In fact, when exposed to damage, some materials (e.g. metals, polymers, concrete or bituminous mixtures) have the intrinsic ability to repair small cracks and partial restore their original properties through thermo-mechanical or induced mechanisms. However, other recoverable phenomena of viscoelastic materials, such as thixotropy and heating, can permanently recover material properties. In order to avoid misleading-analyses, it is important to distinguish between recovery due to real healing and recovery due to intrinsic responses, especially with respect to thixotropy since the latter does not contribute to the fatigue life.

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Over the last years, many studies focused on the determination of the self-healing capability of bituminous mixtures since this property can constitute an important future for the development of long lasting asphalt pavements [2,3]. The healing process of bituminous materials consists of a three-step-mechanism: (1) surface approach due to the consolidation of stresses and flow of bitumen; (2) wetting (adhesion of two crack surfaces driven together by surface energy) and (3) the complete recovery of mechanical properties due to diffusion and randomisation of asphaltene structures [4].

Although previous researches demonstrated that self-healing is mainly related to the interdiffusion of bitumen components [5] and, consequently, the majority of experimental studies mainly focused on bitumen analyses, mastic is the real binder phase in bituminous mixtures, which should be considered as mastic-coated aggregates rather than pure bitumen-coated aggregates [6].

Mastic self-healing response differs from the associated pure bitumen behaviour because of the presence of filler which determines a discontinuity within the material, as result of volume filling and physicochemical interactions with bitumen [7,8]. In fact, fatigue process of mastics involves chemical and mechanical phenomena due to the interaction between the bituminous phase and the lytic component (i.e. filler). In particular, the presence of filler particles within the continuous bituminous phase further complicates crack propagation by altering the overall cohesive potential of the real binder component of a mixture (i.e. mastic) [9].

Because of the combination of two main mechanisms (adhesive healing at the bitumen-aggregate interface and cohesive healing within the bitumen [10]), self-healing of bituminous materials has an impact on asphalt pavements service life.

Various internal and external factors influence the self-healing capability of asphalt pavements. Chemical and mechanical characteristics of bituminous materials are identified as the most important internal factors, whereas high air temperatures and long rest periods are the major external factors.

In literature, self-healing capability was studied using different methods, but a specified protocol has not been yet standardised to examine this issue [11,12]. This phenomenon was investigated at the bitumen, bituminous mastic and bituminous mixture level using fatigue, fracture or non-destructive tests. Fatigue tests with the insertion of rest periods represent the main method for self-healing capability evaluation in laboratory. This test method was performed on bituminous mixtures by means of Four Point Bending Test (4PBT) or Indirect Tensile Test (ITT) [13,14] and diffusely on bitumens by means of Dynamic Shear Rheometer (DSR) [15–20]. Besides, fatigue tests with rest periods were carried out on mastics on limited scale by means of Three Point Bending Test (3PBT) or DSR [21,22,9]. Moreover, most investigations were characterised by the lack of discrimination between real healing and other recoverable phenomena in bituminous materials, such as thixotropy. In addition, few of them dealt with the simultaneous interaction among fatigue, self-healing and thixotropy [23,24,19,9]. It should be noted that there is a basic difference between self-healing capability and thixotropy in bituminous materials properties recovery during rest periods. In fact, as previously mentioned, self-healing is regarded as an effort to recover initial properties by wetting and interdiffusion, whereas thixotropy occurs due to molecular rearrangement in the bituminous phase [25,26].

Given this background, there is a need to bridge the lack of an analytical consolidated approach to determine self-healing potential and thixotropy of bituminous mastics, concurrently identifying useful insights for filler types and contents. In fact, it is expected that the prediction of field performance of bituminous mixtures is closely linked to mastic self-healing properties. Moreover, the increasing reuse of Reclaimed Asphalt (RA), containing polymer modified bitumen, for the production of new, more performing and environmental friendly bituminous mixtures, leads to a further need of understanding the influence of aged polymer modified bitumen from RA on the final mastic behaviour. Thus, it is fundamental to analyse interactions among aged polymer modified bitumen from RA, new virgin polymer modified bitumen and filler, investigating the related effects on fatigue, thixotropy and self-healing capability.

2. Objectives

The main objective of this study is to assess the effect of different filler and aged SBS polymer modified bitumen contents on mastic self-healing capability and thixotropy. To this aim, an innovative experimental approach previously implemented for bitumens [18,19] and then found suitable also for mastics [9] was applied to discriminate self-healing capability from other simultaneous contributions, such as thixotropy.

The experimental study is based on fatigue analyses characterised by strain-controlled time sweep tests including multiple loading phases alternated with rest periods. In particular, each rest period is inserted at a specific damage level selected so as to involve the second stage of the fatigue curve, where fatigue is actually occurring [27], but the damage level is still quite low. In fact, during the stage in which macro-cracks appear (third stage), it becomes difficult to recover material properties through self-healing phenomena [28]. The model adopted for the data analysis is able to identify the real self-healing potential and its impact on the overall fatigue resistance taking into account also the thixotropic phenomenon that concurrently occurs.

3. Materials

Nine mastics were obtained by combining three percentages of bituminous blends with three percentages of filler.

Filler contents were set according to a filler/mastic ratio equal to 14%, 28% and 42% by mastic volume (corresponding to 0.4, 1.0 and 1.9 filler/bitumen ratio by bitumen weight, respectively). The

Table 1
Mastics investigated.

	Code	SBS polymer content, by weight %	Artificial aged bitumen R, by weight %	Filler/bitumen ratio, by weight	Filler/mastic ratio, by volume %
MASTIC	14L_0R	3.8	0	0.4	14
	14L_45R	3.8	45	0.4	14
	14L_100R	3.8	100	0.4	14
	28L_0R	3.8	0	1.0	28
	28L_45R	3.8	45	1.0	28
	28L_100R	3.8	100	1.0	28
	42L_0R	3.8	0	1.9	42
	42L_45R	3.8	45	1.9	42
	42L_100R	3.8	100	1.9	42