Comparison of the Effects of Hydrated Lime on the Moisture-Induced Damage of Stone Mastic Asphalt (SMA) Mixtures

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Abstract. Moisture-induced damage is one of the most prominent distresses affecting pavement structures worldwide. As a consequence, various strategies for mitigating this phenomenon have been proposed, including the use of additives to improve bitumen-aggregate bonding, engineered to mitigate/counteract the moisture damage effects. Among these, the reported benefits of various lime forms, such as hydrated lime (HL), have propelled its use (mainly in the United States from the early 70's) as widely reported in scientific literature. However, very few studies have been conducted in the United Kingdom with locally available materials, specifications and testing methods suitable for that purpose. Therefore, this study investigates the effects of HL on the moisture damage resistance of stone mastic asphalt (SMA) mixtures designed, produced and tested under local UK conditions. A set of asphalt slabs with a target 4.0% air voids content and two bitumen contents (5.6% and 6.2%) using granite aggregates were manufactured using a roller 'slab' compactor consisting of control mixtures (0% HL) and those with 1%, 2% and 3% HL by weight of total mixture. Characterisation of the mixtures was done via the saturated ageing tensile stiffness (SATS) test to account for both the effects of ageing and moisture damage. The SATS test results showed a positive effect of the addition of HL on the moisture damage resistance, however increasing HL contents only produced marginal additional improvements. The influence of the reduction in bitumen content was negligible. Furthermore, the results indicated an optimum dosage of 1% HL for enhanced moisture damage resistance.
Keywords: Hydrated Lime, Moisture Damage, Stone Mastic Asphalt, Ageing.

1 Introduction

Moisture-induced damage represents one of the main distresses affecting bituminous pavement structures worldwide due to its detrimental effects on the surface layers that turn into the deterioration of the ride quality, reduction of road safety, and also compromising the aesthetic features of the bituminous layers [1]. By definition, moisture-induced damage relates to the loss of strength, stiffness and durability in a bituminous mixture as the result of the presence of moisture, which turns into adhesive and/or cohesive failure of the bitumen-filler mastic [2]. Both cohesive and adhesive failure are key factors in assessing the susceptibility of a given bituminous mixture to the detrimental effects of water [3]. Similarly, moisture-induced damage is a very complex process that involves mechanical, physicochemical and thermodynamic features that pose a challenge for the comprehensive analysis of its causes and implications in pavement performance [4]. The former relates to the quality of the bonding between the aggregates and the bitumen and the nature of their physical interaction, whereas the later relates to the quality of bonding of the bitumen chemical components within the bitumen matrix and hence a physicochemical process.

Although the topic is widely researched and published, the scarcity of studies done with regards to stone mastic asphalt (SMA) mixtures with incorporated hydrated lime motivated this research study. Considering the complex nature of the moisture-induced damage phenomenon, various approaches have been considered to study its mechanisms and effects on bituminous mixtures, which include but are not limited to: (i) mechanical characterisation of virgin or recycled mixtures [5, 6], (ii) correlation with field performance [7], and the most recent efforts which have focused on the fundamental characterisation of the mixture components that include surface free energy, fracture characteristics [8, 9], modelling and simulation [10, 11].

Recent research in the United Kingdom refers to the advancement in the characterisation of moisture-induced damage in bituminous mixtures through accelerated testing methods. Among these, the Saturated Ageing Tensile Stiffness (SATS) has gained acceptance due to its simplicity, ease of use, being relative quick and the ability to distinguish the effects of: materials characteristics, water and ageing, filler type and content, bitumen-specific responses, and to allow for ranking-criteria for mixture performance [12-14]. In consequence, it is currently used as a screening test for adequate selection of materials combinations, included as part of the standard test methods for bituminous mixtures [15].

As a result of research efforts from the early 80's [16], the current knowledge of the moisture-induced damage phenomenon is gaining a deeper understanding of the mechanisms for different materials combinations and mixture design types. Vast sources of literature are available for dense-graded hot mix asphalt, warm mix asphalt and cold mixtures. Nevertheless, some gaps still remain in terms of assessing the effects of recycled materials, innovative materials, new testing methods and other mixture design types that satisfy specific requirements for the specific geographical locations. Therefore, this research focuses on the study of the moisture-induced damage of Stone Mastic Asphalt (SMA) with incorporated hydrated lime (HL) via the SATS test protocol with local materials produced in the United Kingdom.

2 Materials and Methods

2.1 Materials

The SMA mixtures that were subjected to SATS protocol were produced with one conventional bitumen type at two contents (6.2% and 5.6%), granite aggregates, addition of hydrated lime (HL) as a partial replacement of limestone filler (LF) at contents of 0%, 1%, 2%, and 3% by weight of total mixture.

2.2 Mixture Design

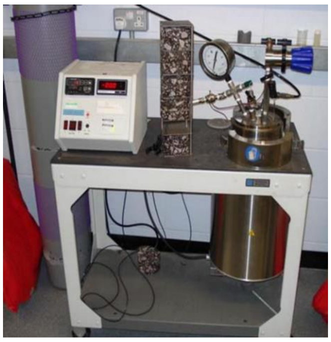
All mixtures were manufactured with a target air voids content of 4%. The bitumen to filler ratio was kept as 1:1 for all the mixtures manufactured in order to have comparable mastic responses. The protocol for mixture manufacturing comprised the specifications for SMA10mm following the British Standard BS EN 13108-5:2016/PD 6691:2007. The aggregates and bitumen were heated for 8h and 3h as a minimum, respectively. HL was added to the aggregates directly in the drum (dry method) and these were subjected to 30s mixing time, after which the bitumen was added and mixed using a mechanical mixer for a period of 3min. A roller compactor was used to achieve the desired density in the slabs with dimensions (306x306x60 mm^3) for simulating compaction of wearing courses in the field. After sufficient time for cooling down of the slabs, 5 cylindrical specimens were cored from these and subjected to trimming of the upper and lower portions to obtain more homogeneous air voids' distribution and smooth surfaces. The final specimen geometry was set as 100-mm diameter and 40-mm thickness. Table 1 presents the details of the mixtures subjected to the SATS conditioning protocol (BS EN 12697-45:2012). Each of the mixtures was run in the SATS with a set of five samples from which the average retained stiffness ratio and retained saturation values were calculated. The codes presented in Table 1 are used in the manuscript to refer to each of the mixtures shown therein.

Table 1. Mixture characteristics and testing parameters considered.

Mixture Type	Code	Air voids (%)	Bitumen content (%)	Aggregate Type	HL Content (%)	LF Content (%)	Testing Temperature $ITSM_c$ and $ITSM_u$ (°C)
SMA10mm	BitA1	4.0	6.2	Granite	0	6.2	20
	BitA2		5.6		0	5.6	20
	BitA2+1%HL		5.6		1	4.6	20
	BitA2+2%HL		5.6		2	3.6	20
	BitA2+3%HL		5.6		3	2.6	20

2.3 Saturated Ageing Tensile Stiffness (SATS)

The combined effects of moisture and ageing were evaluated on the asphalt cores by means of the Saturation Ageing Tensile Stiffness (SATS) test. Test configuration consists of a temperature controlled pressurized vessel (metal cylinder), in which a set of five asphalt cores (100-mm diameter and 40 mm-height) were conditioned for a period of 24h at a temperature of 85°C and 2.1 MPa confining pressure (Fig. 1a.). These testing conditions were selected based on recommendations from previous research studies [12]. The test evaluated the changes in stiffness of the cores for a certain mixture design (i.e., control mixtures and those with incorporated HL): Stiffness modulus prior to conditioning ($ITSM_U$) and after conditioning in SATS ($ITSM_C$) were determined for all tested cores at an intermediate temperature (20 +0.5°C). From these, an ITSM ratio ($ITSM_c/ITSM_U$) was calculated. Higher ratios indicate a higher resistance of the mixture and therefore improved performance against the combined effects of water intrusion and age hardening. A minimum value of 0.55 for the ratio was used as a reference for acceptable mixture performance. As a consequence, those mixtures falling below this range were considered unacceptable. Further details regarding the SATS methodology and theory can be found elsewhere [12-14]. Stiffness test was carried out using the Indirect Tensile Stiffness Modulus (ITSM) set up (Fig.1b), following the British Standard [17].



(a)

(b)

Fig. 1. (a) Saturation Ageing Tensile Stiffness (SATS) conditioning equipment [12]. (b) Indirect Tensile Stiffness Modulus (ITSM) setup in Nottingham Asphalt Tester (NAT) machine.

3 Test Results and Discussion

The results in this section are presented and discussed in terms of the effects of bitumen content, filler type and content, ranking of mixtures resistance to moisture-induced damage, and determination of optimum HL content.

Considering the change in bitumen content from 6.2% to 5.6% in the control mixtures, the SATS parameters provided evidence regarding the negligible impact on the resistance of the mixtures to the moisture damage (Fig.1a). As shown in Fig.1a, the filler-type effects indicated that the partial replacement of LF for HL positively influenced the moisture-ageing performance of the mixtures under study. The control mixtures (with 0% replacement of LF by HL) had the worst performance than that of mixtures with HL. The circled-dashed samples shown in Fig.1 are expected to have higher retained stiffness and final saturation due to the fact these were under water during the whole length of conditioning, whereas the other samples were above the water level. This fact explains the reduction in stiffness after SATS (i.e., lower retained stiffness) of the non-submerged samples and their lower saturation values. These findings about the combined effects of bitumen, filler type and content, and saturation are consistent with previous research by [2, 12-14].

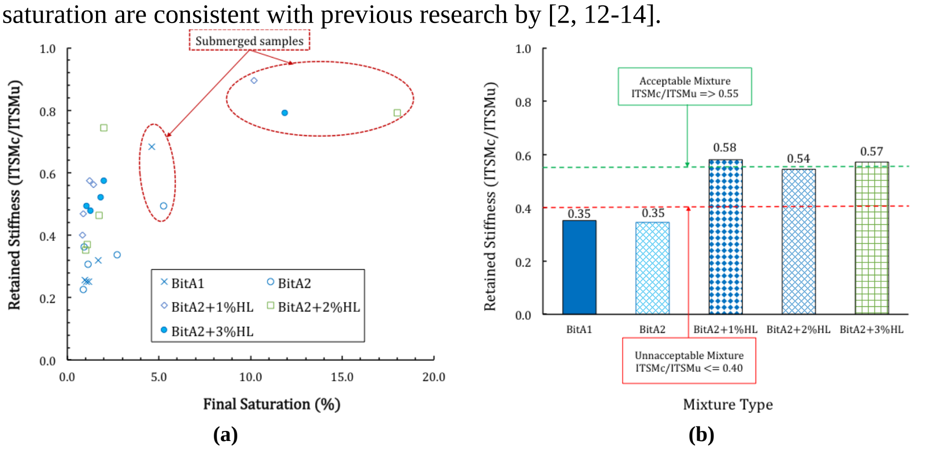


Fig. 1. (a) Comparison of the ageing/moisture effects. (b) Ranking of mixture performance.

Based on the performance criteria proposed (*$ITSM_c/ITSM_u \geq 0.55$, acceptable mixture*), and (*$ITSM_c/ITSM_u \leq 0.40$, unacceptable mixture*), a ranking of the mixtures subjected to SATS is presented in Fig.1b. It is observed that the control mixtures (BitA1 and BitA2) had the lowest retained stiffness of the whole set of mixtures which fell below the acceptable mixture category. Overall, the ranking is as follows: (BitA2+1%HL as best combination followed by 3%HL and 2%HL, and BitA1=BitA2 as worst combination). By using these data, an optimum HL content is proposed: all mixtures with HL improved the resistance to moisture-damage at a similar extent in contrast to both control mixtures but considerations of cost-effectiveness and practicality of the three contents suggests that 1%HL would provide adequate resistance to the moisture-induced damage.

4 Conclusions

This research investigated the moisture-ageing resistance of Stone Mastic Asphalt (SMA) mixtures manufactured with incorporated hydrated lime (HL) and subjected to the Saturated Ageing Tensile Stiffness (SATS) procedure. Based on the results, the following conclusions are drawn: (*i*) The partial replacement of LF by HL induced a positive improvement of the moisture damage resistance. (*ii*) Overall, the mixtures with HL added showed a lower moisture/ageing sensitivity in contrast to the control bitumen. (*iii*) An optimum of 1% HL is suggested based on the cost-effectiveness and the fact higher contents didn't have a major effect on the retained stiffness of the studied mixtures.

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