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Influence of rest period on asphalt recovery considering nonlinearity and self-heating

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HIGHLIGHTS

- Temperature sensors were embedded in the mix specimens during compaction.
- The effect of nonlinearity on complex modulus recovery is relatively low (8.5%).
- The effect of self-heating accounts up to 17% of the overall modulus recovery.
- The effect of self-heating contributes more rapidly to recovery than other effects.

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ABSTRACT

This paper presents investigation on the recovery potential of hot mix asphalt (HMA) mixture using cyclic uniaxial tension-compression test in stress-controlled mode. The recovery potential and its dependence on rest period duration were investigated taking into consideration nonlinearity and self-heating effects observed during cyclic loading. In order to preserve the internal specimen's structure a small-size temperature sensor was embedded into asphalt mixture during compaction. It is found, that the effect of nonlinearity on complex modulus recovery is relatively small and that it is not affected by increasing duration of the rest period. The effect of temperature variation in the core of the specimen occurring during cyclic excitation and rest periods has a significant influence on HMA recovery properties. Self-heating results in a much more rapid recovery of complex modulus than other eventual side effects, such as thixotropy, self-healing and strain relaxation. This effect vanishes when temperature reaches its original value, leaving to the other biasing phenomena dominant in terms of complex modulus recovery.

1. Introduction

Road pavement structures are susceptible to fatigue cracking which initiates in the asphalt material due to repeated heavy traffic loading. The rest periods between each traffic loading repetition may induce the recovery of the material mechanical properties and the partial reversibility of progressive cracking effects. This phenomenon is commonly referred as a self-healing. Such a property can significantly enhance the fatigue life of asphalt pavements and should be taken into considerations during materials selection and pavements design [cf. 1–3].

In order to address fatigue and self-healing properties of asphalt mixtures, accelerated cyclic laboratory tests are commonly performed. Thereby, damage and self-healing are usually related to the decrease and increase in the complex modulus, respectively. During laboratory cyclic excitation, some biasing effects can appear together with fatigue and self-healing; this is not consistent with field loading conditions [4]. Biasing effects such as nonlinearity, self-heating, thixotropy and strain relaxation (for stress-controlled tests) can significantly affect the complex modulus evolution and consequently lead to inaccurate fatigue results and erroneous interpretation of the fatigue characteristics [2,5]. Since all these effects are completely reversible during rest period, they cannot be accounted for self-healing and have to be separately considered. If observed together the term material recovery should be used.

2. Objective and research approach

In this work an investigation on the recovery properties of an hot mix asphalt (HMA) mixture and its rest period duration dependency is performed with the objective of including nonlinearity and self-heating effects in the analysis. For this purpose, uniaxial

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tension-compression tests on prismatic specimens in stress-controlled mode were conducted. Amplitude sweep tests, temperature sweep tests, and discontinuous fatigue tests with single rest periods of different duration (recovery tests) were performed to investigate the evolution of complex modulus. The contribution to the recovery of material properties of effects such as nonlinearity and self-heating together with the combined influence of thixotropy, strain relaxation and self-healing is evaluated and, finally, quantified. Fig. 1 provides the flow chart of the selected research approach.

3. Experimental study

3.1. Material composition and specimen preparation

The investigation of HMA recovery properties was carried out using a standard asphalt mixture for surface courses, i. e. AC 11 D S. This mixture was prepared with aggregates having maximum grain size of 11 mm and with a bitumen having penetration grade 50/70 [6] in percentage of 5.6% by total mixture weight.

Asphalt mixture was compacted using a segmented steel roller compactor (see Fig. 2), able to produce HMA slabs (320 mm × 200 mm × 50 mm) with similar characteristics (air voids distribution, particle distribution, particle orientation and performance properties) compared to those in the field [7].

The compactor uses a steel roller cylindrical sector to induce a kneading action and to apply a downward force to the specimen in both displacement-controlled pre-compaction and stress-controlled main compaction phases [8]. The pre-compaction phase is intended to simulate the compaction effort of the road paver and the main compaction phase is assumed to simulate the compaction by the road roller. Temperature sensors were placed in the loose mixture within the compaction mould and then compaction was performed. Finally, prismatic specimens $(50 \times 50 \times 160\ \text{mm}^3)$ were cut from the slabs (see Fig. 2). Further details are presented in the next section.

3.2. Test equipment and procedure

Evaluation of the recovery properties of HMA was performed using uniaxial tension-compression test (UTCT) under stress-controlled mode. This type of test leads to the highest change in material's mechanical properties compared to other stress-controlled fatigue tests [9]. UTCT provides a satisfactory experimental mean for reliable investigations on the recovery properties of a material, since it induces homogenous stress and strain fields in the test specimen. The test equipment is shown in Fig. 3, left.

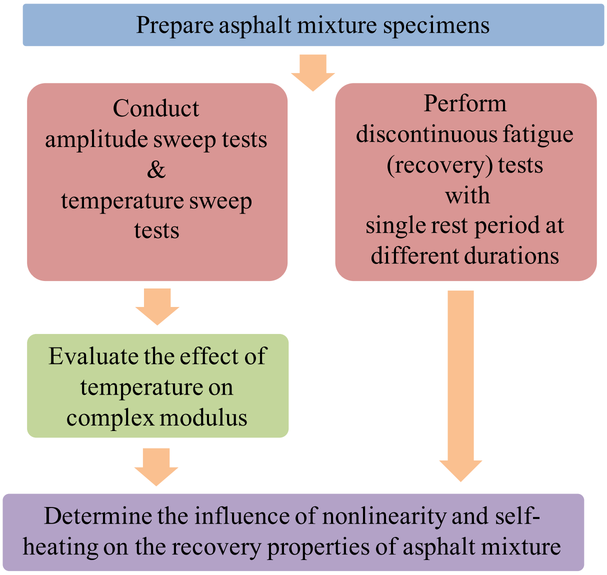

Fig. 1. Flow chart of the selected research approach.

In order to monitor the temperature variation inside the specimen during cyclic loading, a temperature sensor PT100 was embedded in the middle part of the sample (see Fig. 3, right). This was done during compaction. The relatively small size of the temperature sensor (5 mm in length and 2 mm in width) and its robustness through ceramic housing, represent two critical advantages of the selected type of internal temperature detectors. These properties guarantee a good integration of the sensors in the asphalt mixture. This is because the temperature probe is directly embedded in the mixture during compaction, limiting potential distortion of the material microstructure. This procedure also avoids the introduction of a (relatively large) point of weakness in the specimen, as it is usually the case, when the sensor is placed after compaction by drilling a hole in the specimen [cf. 5]. Such solution may result in a substantial deviation of the stress field during the tensile phase [10], due to the binder used to fill the hole's gap between sensor and mixture. The sensor installation proposed in the present research, may significantly limit the distortion of the stress field while providing a consistent continuity of material in the specimen.

Evaluation of HMA recovery properties were performed using three types of test modes: (i.) amplitude sweep tests, (ii.) temperature sweep tests, and (iii.) discontinuous fatigue tests with single rest periods of different durations (recovery tests).

All tests were performed in stress-controlled mode in tension and compression at a fixed frequency of 10 Hz. The most important parameters for material analysis, such as stress amplitude, strain amplitude, temperature, etc., were monitored and recorded during the entire test duration.

In order to obtain the viscoelastic properties and the complex modulus-temperature dependence of the selected HMA, amplitude sweep tests at different temperatures were performed. This was done with the purpose of quantifying the influence of temperature variation within the asphalt sample during cyclic loading on the complex modulus evolution. This type of test was designed with a stepwise increase of the stress amplitude from 0.3 MPa to 1.9 MPa, with increment of 0.1 MPa. In total, 17 loading sequences were applied each consisting of 50 cycles. This number of loading cycles was sufficient in order to achieve the specified stress amplitude. Three test repetitions were performed at each temperature: 15 °C, 17.5 °C, 20 °C, 22.5 °C and 25 °C.

Taking into consideration that the progressive loading applied during amplitude sweep tests can generate a certain degree of damage, the viscoelastic properties measured in the progress of the loading sequence (steps) could be underestimated, which would lead to erroneous results. This can be proved by conducting one loading sequence with selected stress amplitude at the observed temperature. In order to cover the temperature range from the amplitude sweep tests, one loading sequence (50 cycles) with specific stress amplitude is applied to the sample at the following temperatures: 15 °C, 17.5 °C, 20 °C, 22.5 °C and 25 °C. The test starts at 15 °C and ends at 25 °C, with 7200 s of conditioning time between each temperature. A single stress amplitude of 0.7 MPa is applied; this stress level is also used for the discontinuous fatigue tests (recovery tests). The stress amplitude of 0.7 MPa was selected in pre-testing procedure in order to achieve fatigue life between 80,000 and 100,000 loading cycles for discontinuous fatigue test.

In order to provide better assessment and to determine the influence of the rest period duration on the recovery properties,