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Fatigue comparisons of mortars at different volume concentration of aggregate particles

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ABSTRACT

Fatigue cracking is one of the primary failure mechanisms in asphalt pavements and it predominantly occurs within the mortar phase. For this reason, in recent years, a number of studies were carried out by various researchers to better understand the fatigue mechanism in such a critical mixture phase. In the present work, time sweep tests were performed in strain control mode on asphalt mortars prepared with three volume percentages of fine aggregate at different aging conditions. In particular, two different asphalt mortars were used: one containing Recycled Asphalt Pavement (RAP) materials and the other one composed of the same RAP aggregate skeleton without the aged binder. The influence of the different aging conditions, the presence of the aged binder and the addition of fine aggregate particles on the fatigue resistance of the mortars were evaluated. Moreover, a relationship between the parameters of the obtained fatigue laws and the different aging and mix design conditions was found. The proposed relationship can be easily used to predict the fatigue resistance of a mortar composed of a specific volume concentration of aggregate particles and recycled material. The potential extension of the proposed relationship to mixtures may eventually result in the implementation of a simple analysis tool for practitioner limiting the need for more sophisticated and expensive fatigue tests on asphalt mixtures.

1. Introduction

Asphalt mixture is commonly described as a composite material consisting of different components: asphalt binder, aggregates and air voids [16]. Conventionally, a number of phases are identified within the mixture depending on the size of the aggregate considered: asphalt mastic, asphalt mortar, fine aggregate matrix (FAM) [24]. Within these phases, mortar, which consists of binder, fine aggregate particles (smaller than 0.15 mm) and entrapped air [18,21], plays a major role in the behavior of asphalt mixtures. This is because the finest particles fill the voids between coarse aggregates in the mixture and positively affect the properties of the binder, as they act as an integral part of the mortar, which can be analyzed as a composite material to predict its rheological properties [22]. Therefore, the properties of the mortar influence the overall mechanical performance of asphalt mixtures. For this reason, a number of research efforts were performed in the past and more recently to better understand the actual contribution of the filler components on the mechanical response of asphalt mixtures [1,3,7,19].

Fatigue damage is one of the primary failure mechanisms that occurs in asphalt pavements and it predominately appears within the mortar phase. Several research studies on fatigue performance on binders and mortars [4,23] confirm that fatigue damage is strongly related to binder characteristics, filler properties and to the interaction between binder and filler. In addition, it may be hypothesized that the fatigue behavior of mortar, rather than that of plain binder, is more appropriate to establish a correlation with the fatigue behavior of the corresponding asphalt mixtures. This is because fatigue cracking takes place in the material film coating the larger aggregates; this is not only consisting of asphalt binder, but it is rather a mix of binder and fine aggregate particles [14].

The addition of fine aggregates to asphalt binder influences the overall rheological and fatigue behavior of the material since particles have a stiffening effect and they interrupt the crack growth in the mortar [19]. Therefore, a fatigue failure criterion based on asphalt mortar, rather than on asphalt binder alone, would be much more effective in discriminating mixtures with good fatigue behavior. This is especially true since the current Superpave parameter, $G*sin\delta$, used in the last decades, has arisen a number of concerns. Several authors [6,2,14] have experimentally shown that $G*sin\delta$ is not well correlated to the fatigue response of asphalt

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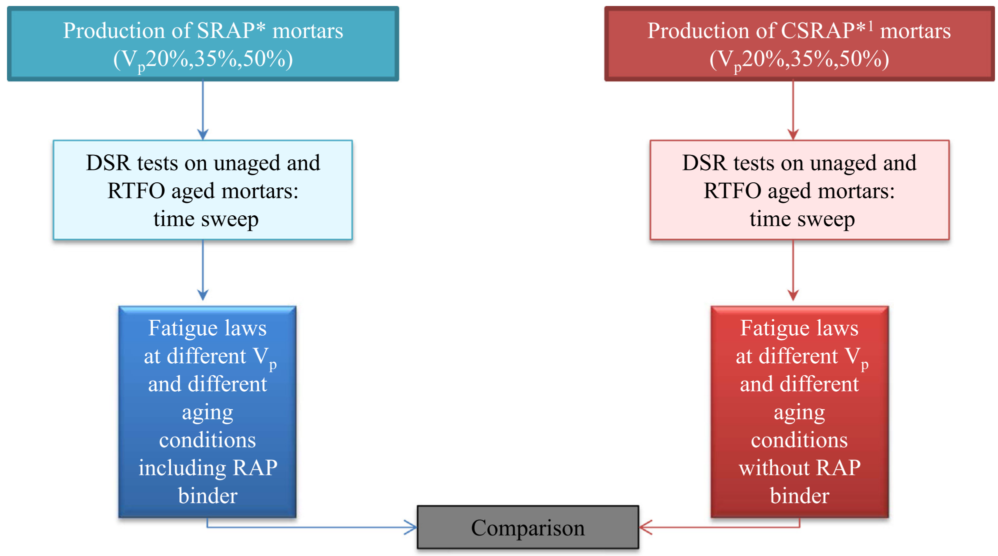

Fig. 1. Flow chart of the research approach.

mixture, and it does not take into account the non-linear behavior of asphalt binder under fatigue.

2. Scope and methodology

The main objective of the present work is to evaluate the effect of fine particles, aging conditions and of the presence of aged binder on the fatigue performance of mortars. In order to achieve this goal, time sweep tests in strain control mode were performed with the dynamic shear rheometer (DSR) [13] on mortars composed with different volume fractions (V_p = 20, 35, 50%) of fine aggregate particles smaller than 0.15 mm. Mortars were short term aged according to the rolling thin film oven test (RTFOT) [11] procedures, with the aim of evaluating the effect of aging on fatigue performance. Two different types of mortars were produced, one containing Reclaimed Asphalt Pavement and virgin binder, identified as Selected Reclaimed Asphalt Pavement (SRAP) mortar and the other composed with the same aggregate skeleton of the previous one, but without RAP binder, called Cleaned Selected Reclaimed Asphalt Pavement (CSRAP) mortar. In such a way, the effect of the aged binder on fatigue could be also addressed. Finally, a relationship between the parameters of the obtained fatigue law at different aging and mix design conditions was found. The research approach used in this study is summarized in the flow chart reported in Fig. 1.

3. Fatigue behavior

At intermediate service temperature, the repeated strains and stresses, caused by traffic loading, induce an incremental damage in the asphalt material. The damage accumulates and leads to fatigue cracking consisting in a crack initiation at the bottom of the asphalt layer which propagates to the top of the surface layer (bottom-up cracking) [25]. According to Bahia et al. [5], the characterization of the fatigue behavior has to be performed on asphalt binder through the analysis of the evolution of viscoelastic properties during cyclic shear loadings imposed with a DSR. However, it is quite complex to identify the actual failure initiation associated to fatigue phenomena based on laboratory testing. Therefore, in the present work, fatigue life is measured in accordance with two different conventional failure criteria [2]. The first one defines fatigue life as the number of loading cycles (N_{f50}) required to reach a reduction of 50% of the complex modulus, $|G^*|$; the other one considers the number of cycles (N_{p20}) to achieve 20% deviation from the initial linear trend of the Dissipated Energy Ratio (DER) calculated by Eq. (1):

$$DER = \frac{\sum_{i=1}^{n} W_i}{W_n} \quad (1)$$

where W_i is the dissipated energy at cycle ith equal to $\oint \pi.\sigma_i(t).\varepsilon_i(t).\sin\delta_t dt$, $\sigma_i(t)$ and $\varepsilon_i(t)$ are stresses and the strains at cycle ith respectively and δ_i is the phase angle at cycle ith.

In Fig. 2, the complex modulus $|G^*|$ versus time, for a time sweep test in strain control mode on asphalt binder, is reported. Three different stages can be observed: at the beginning, the curve of $|G^*|$ is characterized by a horizontal plateau which is identified as the non-damage stage; this is followed by the damage propagation, where a rapid decrease in modulus occurs due to crack propagation and, finally, the failure stage. The same three stages can be observed also when plotting DER versus the number of loading cycles, as shown in Fig. 3.

Fatigue data are typically plotted against initial strain or initial stress. The straight fatigue lines for bituminous materials are used

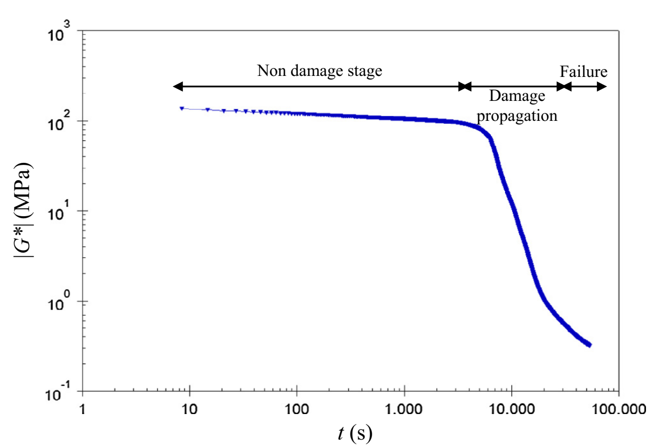

Fig. 2. Complex modulus $|G^*|$ versus time during a time sweep test in strain control mode.