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DUSST: Development of a new stress sweep fatigue test for asphalt mixtures

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HIGHLIGHTS

- A new stress sweep fatigue test for asphalt mixtures is proposed (called DUSST).
- The new fatigue test is done in a shorter time than classical fatigue tests.
- DUSST shows a good sensitivity of the main parameters evaluated.

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ABSTRACT

Fatigue cracking is one of the main damage mechanisms that take place in asphalt pavements. However, its evaluation during the design asphalt mixtures is not usually considered due to the complexity of the tests required, their high costs and the long time required to perform them. As a consequence, several research teams are working on developing new test procedures to reduce the time related to fatigue characterization of asphalt mixtures. In this context, this paper presents the development of a new test procedure consisting of a cyclic uniaxial tension-compression test in which the stress applied increases every 5000 cycles. In this manner, it is possible to evaluate a mixture's response under cyclic loading at different stress levels in one test. Also, failure of the mixture takes place in a shorter time period than that required by classical time sweep fatigue tests. This paper presents results obtained in the application of this new methodology to a mixture frequently used in Chilean pavement structures (type IV-A-12 by Chilean standards) with three different asphalt binders: a conventional binder (CA-24), a high modulus binder (CA-HM) and a polymer-modified binder (CA-PM). We evaluated three different types of aggregates obtained through two different shredding processes. Results achieved in the development of our Direct Uniaxial Stress Sweep Test (DUSST) show that it is an experimental method with great potential. This test can characterize fatigue behaviors of asphalt mixtures in a shorter time by using important parameters such as initial strain, failure strain, complex modulus and dissipated energy. In addition, we obtained a good sensitivity of the DUSST main parameters to variables evaluated.

1. Introduction

The most basic form of travel between two points in a country is to roads and highways, which are key for a country's economic and social development [1,2]. As a reference, approximately 95% of road and highway pavements around the world correspond to asphalt pavements [3]. Pavement structure is the part of the road infrastructure which requires the highest economic investment, both in the construction and maintenance stages [4]. Furthermore, pavement state directly influences a majority of indirect highway costs. These costs increase when the pavement state is not optimal, mainly due to increases in travel times, fuel consumption, and deterioration of vehicles, among others [5,6]. In the case of asphalt mixtures, the main performance properties that should be considered during dosage and design phases are: 1) resistance to plastic deformations, 2) resistance to raveling due to damage caused by moisture, 3) resistance to thermal stress cracking and 4) resistance to fatigue cracking. The latter refers to the resistance that an asphalt mixture must present when subjected to repetitive dynamic solicitations caused by traffic loads. In this aspect, it is important to highlight that distress caused by fatigue cracking of the asphalt mixture layers is one of the main damage mechanisms for asphalt pavements [7,8]. An accelerated progress of fatigue

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cracking involves serious economic implications, given the need to rehabilitate or rebuild the pavement structure ahead of time, thus increasing the cost of infrastructure at the time of use. Additionally, this distress has an aesthetic effect when rehabilitation is not carried out in the indicated period, or when only minor maintenance is done. Finally, there is an effect on comfort for road users, which affects their safety due to possible structure detachments with greater deterioration [5,9]. Fatigue cracking is caused by tensile and compressive forces produced by traffic loads on the pavement, leading to progressive reduction of the stiffness modulus in asphalt mixtures [10]. In a pavement structure, when vehicle wheel loads are relatively far from the considered cross section, a tensile force is produced at the top of the layer and a compressive force is produced at the bottom (Fig. 1a). When the load is on top of the considered section, the stress state changes, and a compressive force is produced at the top of the layer, and a tensile force is produced at the bottom. After the load passes, the stress state reverses again [11]. This effect is continuously repeated with the passing of each vehicle over the pavement. In this context, asphalt mixtures work as a dual system of mechanical resistance: during compression effect, friction between the mineral particles opposes its relative displacement; but during tension effect, the binder and interlocking of aggregates resist the stresses. For these reasons, good adhesion between the aggregates and binder (even in the presence of water) and sufficient internal cohesion in the mixture are the properties desired for a good performance of the asphalt mixtures [12].

The traditional approach to fatigue cracking in asphalt mixtures considers bottom-up cracking. That is, micro-cracks are caused by deformations from tensile stresses originated in the lower part of the asphalt layer, causing the beginning of the crack and its propagation towards the surface. In this scenario, the repetition and accumulation of loads generate cracking and the consequent failure due to pavement fatigue, even though stresses generated are lower than the tensile stress limit of the material [13,14].

As a consequence of traffic loads, asphalt mixtures accumulate damage, resulting in a gradual cracking process rather than a sudden process of brittle failure. From this point of view, the validity of Miner's Law is often supported for fatigue analysis, establishing that each applied load generates fatigue consumption, and these consumptions are accumulated until the fatigue resistance of the mixture is exhausted [15–17]. In this context, Kanitpong and Bahía pointed out that during the fatigue process, continuous loss of resistance and degradation of the asphalt mixture is caused by the formation of initial micro-cracks and the consequent accumulation of damage that results in total degradation of the material [18].

Nowadays, an asphalt mixture's resistance to fatigue cracking is determined in the laboratory by applying repeated loading to specimens [8,19]. These procedures consist of conducting cyclic tests at constant stress or strain amplitude, using the classic failure criterion. This failure criterion, as described in the European standard UNE-EN 12697:24, establishes as failure of the specimen when its stiffness reduces half of the initial value. In the case of displacement or strain-controlled tests, failure of the specimen is assumed when the initial load (F_0) is reduced by half ($F_0/2$); in the case of force or stress-controlled tests, failure of the specimen is assumed when strain (ε_0) is equal to double the initial strain ($2\varepsilon_0$) [20]. However, one disadvantage that arises in these procedures is that their failure criteria provide erroneous results when testing highly flexible asphalt mixtures, or those manufactured using a high content of asphalt binder or modified binders. These flexible mixtures can experience a 50% reduction in stiffness only due to reversible phenomena, and therefore do not fail if the solicitation is reduced or completely stopped [21]. This is explained by a readjustment of the materials into the mixture, mainly due to viscoelasticity of the material. A combined effect of thixotropy and heating may exist due to the application of dynamic loads; once the application of these dynamic loads has finished, the material partly recovers its condition or original state [22–25]. It has also been observed that when stress-controlled determination tests are carried out, fatigue failure takes place at the same strain level regardless of the applied stress level [26]. This indicates that there is a strain level at which each asphalt mixture fails under cyclic loading in stress-controlled tests. This strain would correspond to the strain amplitude that would cause failure in few cycles in cyclic strain-controlled tests. Moreover, below a certain stress level, the mixture does not present damage and the applied loads do not produce any distress process [15,27,28]. In this context, in to characterize the behavior of a material under cyclic loading, it is important to identify two strain levels: 1) that which does not produce damage, and 2) that which causes total failure in few load applications.

Procedures used to characterize resistance to fatigue cracking in asphalt mixtures present some drawbacks which cause that the fatigue property is not usually considered in asphalt mixture design. The main drawback is that these tests require numerous tests (and specimens) and extended time periods to characterize the material. For example, the UNE EN 12697-24 standard requires 6 replicates to be tested at three strain amplitudes; a total of 18 replicates [29]. To overcome this, novel testing procedures or prediction models have recently been developed to predict fatigue behavior of asphalt mixtures in shorter times [8,30–32]. An example is the Fenix procedure by which a fatigue law can be estimated by using parameters obtained from this test [33]. Another procedure that provides a faster method to estimate an asphalt mixture's fatigue law is the EBADE test [34,35], which is based on a strain sweep imposed on a notched prismatic specimen. This procedure

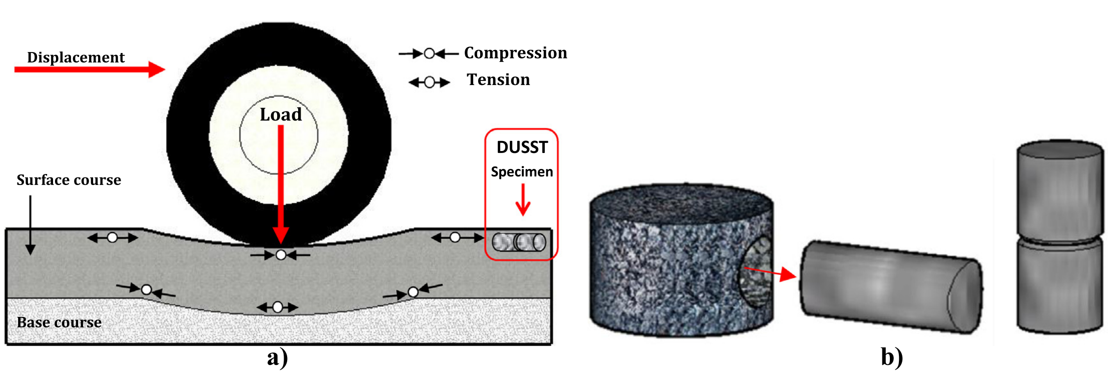

Fig. 1. a) Stress state of the asphalt layers on a pavement and b) DUSST specimen manufacture scheme.