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Analysis of the mechanical behaviour of bituminous mixtures at low temperatures

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HIGHLIGHTS

- Fénix is a new monotonic test to assess fracture energy during cracking of bituminous mixtures.
- EBADE is a new strain sweep test to evaluate fatigue resistance of bituminous mixes.
- Failure Strain is defined from dissipated energy density obtained through EBADE test.
- Variation of mechanical behaviour with temperature has been analyzed.
- Master curve that provides information about mixture response has been defined.
- Mixture properties at low temperatures must be considered during design phase.

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ABSTRACT

The assessment of the mechanical properties of bituminous mixtures at low and intermediate temperatures is of great interest because it is in this temperature range that cracking failure due to mechanisms associated with fatigue failure from repeated load applications, thermal stress fracture or a combination of both occurs. Both distresses are complex and difficult to simulate in laboratory, especially fatigue failure, which requires expensive and time-consuming equipment set-up. For this reason, these mechanisms are hardly considered in asphalt mix design.

This paper describes two procedures for mix design and assessment developed at the Road Research Laboratory of the Technical University of Catalonia: Fénix and EBADE tests. Fénix is a Semi-Circular Single-Edge-Notched Tension (SENT) test while EBADE is a cyclic fatigue test on a prismatic specimen in Double-Edge-Notched Tension (DENT).

The aim of this work is to analyze the ability of these tests to assess changes in the cracking resistance of binder-containing mixtures with test temperature. A "master curve" or curve of mixture property variation with temperature is drawn from test results to determine bituminous mix response, especially at low temperatures where cracking resistance is more critical.

1. Introduction

Bituminous mixtures show significant variations in mechanical properties with load application speed and temperature due to differences in thermal susceptibility and viscoelastic behaviour of bitumens.

Mixture behaviour has mainly been studied at high temperatures and low load application speeds because one of the most common types of failure, i.e., plastic deformation, occurs under these conditions. A variety of experimental procedures, such as Marshall test, Hveem test, simulation methods like wheel tracking test, or fundamental procedures like cyclic load compression tests, have been developed to analyze resistance of bituminous mixtures to plastic deformation. They are commonly used together with clear specifications about the values to be considered for each parameter in the bituminous mix design. As a result, plastic deformation has been almost entirely eliminated in many countries.

Current concerns focus on the assessment of mix mechanical properties at low and intermediate temperatures, i.e., from 20 °C to −15 °C or −30 °C, because it is in this temperature range that failure by cracking due to mechanisms associated with fatigue failure by repeated load applications, thermal stress fracture or a combination of both occurs [1–3]. Since load application speed in these distress mechanisms is significantly different, two types of tests have been designed: those where specimens are subjected to monotonic loading at low application rates (associated with thermal stress cracking and fracture) [4–9] and those where specimens are tested under cyclic loading at frequencies of 10–30 Hz (related to traffic load fatigue) [1,10–12].

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Among monotonic tests, semi-circular bending test, SCB test, disk-shaped compact tension test, DC(T), and Fénix test stand out [5,6]. The three procedures measure the effort required to split the specimen into two parts from a crack on the fracture surface. However, in SCB test fracture results from flexural-tensile stresses while in DC(T) and Fénix test tensile stresses are applied perpendicular to the crack tip. In the latter case, load is applied at a constant deformation rate, allowing visualization of the crack propagation process. Fénix test can be applied for a wider temperature range than DC(T) and SCB, where the load application area undergoes deformation at intermediate temperatures (10–20 °C).

It is worth pointing out that load application speed, which is different in the three tests, affects the results. Therefore, conversion factors must be considered if results are used to model pavement crack propagation under given temperature conditions. This is the case of DC(T) test, whose results are used in the AASHTO method to calculate thermal cracking in surface layers [13].

The above tests also evaluate and compare the fracture energy in mix design in order to select the gradation and bitumen type and content which most increase mixture resistance to cracking. Additionally, they could be used to assess resistance to fatigue. To this end, correlations were obtained between the parameters calculated by Fénix test (tensile stiffness index and fracture displacement) and those defining the fatigue laws of mixtures (a and b coefficients in equation $\varepsilon = a \cdot N^{-b}$) [14].

Procedures for evaluating mixture fatigue resistance, called "time sweep tests, are usually based on cyclic load application under stress or strain controlled conditions until fatigue cracking occurs, which is laborious and time-consuming [15]. To reduce the time to determine the fatigue laws of bituminous mixtures, simple cyclic load tests like EBADE are now carried out in strain sweep mode where cyclic loading is applied with increasing strain amplitude until fracture [16].

The present paper describes the ability of two new tests, Fénix and EBADE, to assess changes in the fracture resistance of mixtures depending on test temperature and bitumen type. The purpose of this study is to determine the relationship between fatigue and fracture properties of binder-containing mixtures at low temperatures.

2. Study

The study was conducted on a semi-dense mixture with maximum aggregate size of 16 mm and aggregate gradation within the specified Spanish grading envelopes (AC16D). Moreover, this gradation also passes through the Superpave control points and avoids the restricted zone, as can be seen in Fig. 1.

Four different bitumens, i.e., two conventional 50/70 penetration grade bitumens, B 50/70 (1 and 2), a polymer-modified bitumen, BM3c, and a crumb rubber modified bitumen, BC 35/50, were tested. Their main characteristics are summarized in Table 1.

Marshall specimens were prepared with a constant bitumen content of 5% by weight of mixture, that is, slightly higher than the minimum specified percentage used in Spain for wearing course bituminous mixtures.

Fénix test belongs to the category of Semi-Circular Single-Edge-Notched Tension (SENT) tests. It was developed by the Road Research Laboratory of the Technical University of Catalonia to evaluate cracking resistance of asphalt concrete mixtures by calculation of the dissipated energy during the cracking process. The test is named after a previous research work: FENIX Project ("Strategic Research on Safer and More Sustainable Roads").

EBADE test is a cyclic fatigue test on a prismatic specimen in Double-Edge-Notched Tension (DENT). The name EBADE stands for the Spanish words "strain sweep test" (*Ensayo de BArrido de DEformaciones*).

The samples used in Fénix and EBADE tests were obtained from Marshall specimens (shape and dimensions are given below). Test temperatures were 20 °C, 5 °C, −5 °C and −15 °C. A description of the two tests is provided in the following section.

3. Test procedures

3.1. Fénix test

The Fénix test [4] procedure consists of subjecting one half of a 101.6 mm diameter cylindrical specimen prepared by Marshall method or gyratory compaction to a tensile stress at a constant displacement velocity (1 mm/min) and specific temperature. A 6 mm-deep notch is made in the middle of its flat side where two steel

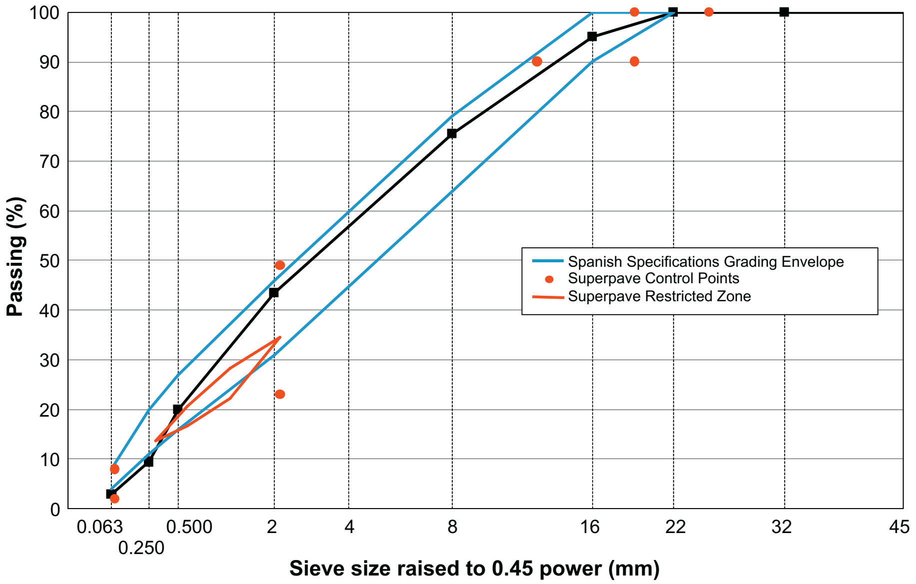

Fig. 1. Aggregate gradation of the AC16S mixture.