Construction and Building Materials 26 (2012) 372–380

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Approach to fatigue performance using Fénix test for asphalt mixtures

Félix Pérez-Jiménez [a], Gonzalo A. Valdés [a,b], Ramón Botella [a], Rodrigo Miró [a,c,*], Adriana Martínez [a]

[a] Technical University of Catalonia, Barcelona, Spain
[b] Universidad de La Frontera, Temuco, Chile
[c] Jordi Girona 1–3, Módulo B1, 08034 Barcelona, Spain

ARTICLE INFO

Article history:
Received 17 March 2010
Received in revised form 3 June 2011
Accepted 18 June 2011
Available online 20 July 2011

Keywords:
Asphalt mixture
Fatigue
Fracture
Dissipated energy
Direct tensile test
Fénix test

ABSTRACT

Fatigue is one of the most common causes of damage in bituminous pavements. However, since fatigue characterization requires complex cyclic tests, this property is not usually taken into account when designing bituminous mixtures. The present study introduces a new methodology to assess fatigue behavior of bituminous mixtures by means of a simpler procedure based on a new fracture test called Fénix. Several bituminous mixtures were tested at the Road Research Laboratory of the Technical University of Catalonia using the Fénix test and the three-point bending beam fatigue test, which complies with the new European standard UNE-EN 12697-24:2006. Results show that this new methodology assesses fatigue behavior of bituminous mixes by correlations between both tests. In addition, the procedure can be used to relate stiffness and dissipated energy parameters obtained in the cracking process, which allows the choice of mixtures with better fatigue performance considering the thermal conditions to which mixtures will be subjected during their service life.

1. Introduction

Fatigue distress in bituminous mixtures is a complex phenomenon that depends on several variables like component characteristics, pavement layer thickness and fabrication process, among others. Furthermore, external agents such as traffic and environmental conditions also have a strong influence in mixture behavior under fatigue conditions [1–3].

This distress is considered one of the most important problems in bituminous mixtures. It occurs when pavement is stressed to the limit of its service life by repetitive load applications [4]. The ability of bituminous mixes to accumulate damage allows gradual failure instead of fragile failure [5]. During the fatigue process, resistance decreases and material undergoes continuous degradation, resulting in the formation of microcracks and eventual complete failure [6–8].

Cyclic tests to determine fatigue performance of bituminous mixtures are usually complex and time consuming. This property is not usually considered in mixture design. However, fatigue behavior is important enough to be defined in detail in order to know the actual performance of the mixture as a layer in the pavement structure.

On the other hand, the complex microstructure of asphalt concrete is related to aggregate gradation, properties of the aggregate–binder interface, rheological behavior and bitumen type, bitumen film thickness, thermal sensitivity of mixtures, void size distribution, and interconnectivity of voids. Consequently, the fatigue property of asphalt mixtures is very complicated and sometimes difficult to predict [9].

In recent years some research has addressed the prediction of fatigue behavior of bituminous mixes using fewer assays or simpler test procedures which correlate the obtained mechanical properties with the fatigue properties of mixtures. However, results have not been fully satisfactory as no specific methods have been established, either because of the need for long, complex tests or the impossibility of obtaining correlations between the evaluated methodologies and fatigue procedures [10,11].

A previous study conducted at the Road Research Laboratory of the Technical University of Catalonia investigated fatigue failure of bituminous mixes by subjecting prismatic specimens to sinusoidal loading. The authors of the present work have used the results of that investigation, where correlations between modulus and fatigue law slope, and between failure strain and ordinate at the origin of the fatigue law were obtained [12]. The work hypothesis of this paper is that fatigue law parameters can be estimated using a new direct tensile test called Fénix test [13,14] since this method determines parameters related to both stiffness and strain. These relationships are shown in the paper.

Moreover, the Fénix test can determine dissipated energy in the cracking process. Many investigations have established this parameter, obtained by monotonic tests, as a useful indicator for mixture characterization according to crack resistance [14–17]. Other

* Corresponding author at: Jordi Girona 1–3, Módulo B1, 08034 Barcelona, Spain. Tel.: +34 934017085; fax: +34 934017264.
E-mail address: r.miro@upc.edu (R. Miró).

0950-0618/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2011.06.036

researchers have also assessed dissipated energy from cyclic (fatigue) tests [18–21]. However, the relationship between dissipated energy obtained from monotonic tests and mixture fatigue behavior has not been analyzed in detail and deserves further study [22,23]. For this reason, this paper presents dissipated energy as a new parameter for the design of fatigue resistant mixtures by the Fénix test.

Two different tests were used during the development of this work, the three-point bending beam fatigue test (UNE-EN 12697-24:2006) and the new direct tensile test at constant displacement rate, the Fénix test.

2. Experimental programme

The experimental program was conducted in two phases.

The first focused on establishing a correlation between the new direct tensile test, the Fénix test, and the three-point bending beam test. Another objective was to relate the fatigue behavior of bituminous mixes with the crack dissipated energy parameter, as obtained by the Fénix test.

In the second phase, the relationship between dissipated energy and fatigue behavior of bituminous mixes was studied on a larger number of different types of mixtures and at a wider temperature range by the Fénix test.

In order to meet the objectives of the first phase, bituminous mixtures commonly used in Spain containing soft and hard binders (B60/70 and B13/22) were tested and their behavior at 5 °C and 20 °C was compared. Asphalt mixtures with a high percentage of Reclaimed Asphalt Pavement (RAP) were also tested and their behavior at 20 °C was compared. Recycled mixtures were chosen because of their brittle performance. In this first stage, fatigue and Fénix tests were carried out over six different mixtures. Four of them were Spanish standardized mixtures and were tested at 5 °C and 20 °C while the other two were recycled mixtures and were tested at 20 °C.

In the second experimental stage, 13 different mixtures were tested by the Fénix test at −10 °C, 5 °C and 20 °C.

Fatigue life of the mixtures was estimated on prismatic specimens by the three-point bending beam test, Fig. 1, whereas dissipated energy, stiffness and displacement parameters were determined using the Fénix test, Fig. 2.

2.1. Mixture characteristics

In the first stage, four different gradations were used.

- Two were standard gradations, named G-20 and S-20, respectively.
- Two were also based on standard gradations but had a different percentage of RAP (S-20R60 and S-12R40 with 60% and 40% of RAP, respectively).

The number after G and S refers to the maximum aggregate size in millimeters. The average gradation of the aggregates is illustrated in Fig. 3.

Two mixtures, G-20 and S-20, were manufactured with a 5% content of binders B60/70 and B13/22, thus obtaining four different mixtures. The binders of S-20R60 and S-12R40 mixtures had penetrations of 250 and 200 dmm, respectively. Test temperatures were 5 °C and 20 °C (the mixtures with RAP were only tested at 20 °C).

In the second stage, the Fénix test was performed on specimens prepared with G-20 and S-20 gradations at three temperatures (−10 °C, 5 °C and 20 °C). Three different binders (B60/70, B40/50 and B13/22) and three different contents in aggregate mass (3.5%, 4.5% and 5.5%) were studied using G-20 gradation. The same three binders and a polymer-modified binder, BM-3c, were studied using S-20 gradation. The characteristics of the binders are shown in Table 1.

2.2. Test description

Fatigue laws of the mixtures were determined by the three-point bending beam test under controlled displacement conditions, in compliance with the European Standard UNE-EN 12697-24:2006. This test consists in subjecting a prismatic specimen to a time-varying displacement, according to a sinusoidal function. The specimen is clamped to a support mechanism through the two metallic tubes glued to one of its faces and to the piston rod through the tube glued to the opposite face, Fig. 1. The support mechanism can move and swing to avoid flexural or torsion stresses on the specimen, which could modify its tensional state. An extensometer is fixed to the face of the specimen where the two metallic tubes are glued. Once the assembly is finished, all elements must reach the specified testing temperature. To conduct the present study, five prismatic specimens of 300 × 50 × 50 mm were obtained by sawing a specimen of approximately 300 × 300 × 50 mm.

The initial maximum deformations and the number of cycles necessary to reduce the applied load to 50% were recorded to represent pairs of values from different tests, which can be plotted to define the fatigue law under controlled displacement.

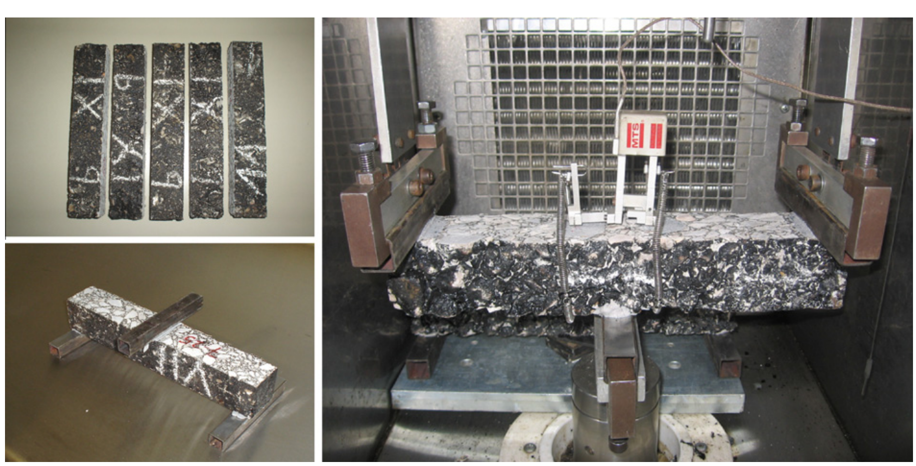

Fig. 1. Three-point bending beam test set up.