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Differences in cracking resistance of asphalt mixtures due to ageing and moisture damage

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HIGHLIGHTS

- The effect of ageing and moisture damage on cracking resistance has been analyzed.
- A direct tension test (Fénix) and a cyclic strain sweep test (EBADE) were applied.
- The action of water apparently improves mixture response due to slight ageing.
- Composition and design are decisive in mixtures cracking response to external factors.

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ABSTRACT

The ageing phenomenon and moisture damage become key factors to evaluate mixture cracking resistance. In this paper, the effect of ageing and water on cracking resistance and fatigue behavior in a bituminous mixture is studied. Specimens were tested by a direct tensile test (Fénix test) to obtain fracture energy values whereas variation of complex modulus and dissipated energy density was obtained by a strain sweep fatigue test (EBADE test). Results show a significant reduction in cracking resistance and fatigue life of the mixture after ageing (failure strain is reduced approximately by 35%). Water in standard conditions has very little influence.

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1. Introduction

Pavement distress is mainly caused by asphalt mixtures cracking [1]. From the mechanical point of view, asphalt mixture cracking mechanisms can be analyzed under monotonic loading at low application rates or under repeated cyclic loading lower than pavement maximum resistance. The former is associated with thermal stress cracking and fracture while the latter is related to failure of the surface due to traffic loading (fatigue).

Asphalt mixture ageing is considered one of the most important factors affecting cracking resistance [2]. This phenomenon brings about changes in bitumen properties [3]. In particular, it is known to increase binder stiffness due to the convergence of various processes during the life of asphalt mixtures [4]. These processes can be attributed to chemical ageing and physical ageing or steric hardening [5,6].

Chemical ageing is primarily associated with loss of volatiles, but more particularly, to an oxidation process. The sum of these chemical processes leads to mixture hardening and higher brittleness because of ageing of bitumen [7]. The oxidation and volatilization processes, slow at ambient temperature, are accelerated when the bitumen is subjected to high temperatures, such as during the manufacturing process, transportation and laying of the mixture. The surface layer of asphalt mixtures has been shown to age faster than the lower layers of the pavement [8]. This is because of a constant supply of oxygen on the surface due to the high temperatures and UV photo-oxidation.

Steric hardening results from a molecular reorganization process over a long period of time by which asphalt hardens at ambient temperature as time elapses. Thus, steric hardening is a physical process because it changes the rheological properties of bitumen without altering its chemical composition. For this reason, steric hardening is a reversible process. Steric hardening is associated with slow crystallization of waxes at room temperature [9]. Wax crystallization refers to the crystallization of linear alkanes present in asphaltene fractions [7]. This phenomenon causes an

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increase in viscosity without chemical modification of the constituents. Steric hardening can be reversed by exposure to heat or mechanical work [10].

Bitumen hardening processes result in higher mixture stiffness. This tends to increase load bearing capacity and resistance to permanent deformation of bituminous mixtures. Nevertheless, brittleness increases because of decreased bitumen ductility, causing premature pavement damage and, ultimately, cracking or total failure [11,12].

From a mechanical standpoint, ageing can be categorized in two stages [13]: short term ageing and long term ageing. Short term ageing takes place during manufacturing and laying of bituminous mixtures [14]. Long term ageing is associated exclusively with deterioration due to environmental factors during the service life of pavement.

Most laboratory bituminous mixture ageing methods are based on maintaining the mixture (compacted or loose) in an oven at a certain temperature for a certain period of time. The ageing procedure established by SHRP is one of the most common methods [15]. It includes short term ageing, STOA (Short Term Oven Ageing), and long term ageing, LTOA (Long Term Oven Ageing). STOA consists in ageing the loose mixture in an oven for four hours at 135 °C whereas during LTOA, the mixture, previously aged by STOA, is compacted and kept in an oven for five days at 85 °C. In 2009, a new ageing procedure was established by the RILEM Technical Committee. It consists in maintaining the loose mixture for 4 h at 135 °C for short term ageing and for nine days at 85 °C for long term ageing [16].

Another phenomenon associated with deterioration due to environmental factors affecting asphalt mixture durability is moisture damage [17]. It is generally caused by loss of adhesion between the bitumen and aggregate interface (adhesive failure) and/or loss of cohesion in the mixture (cohesive failure). Moisture damage mechanisms in asphalt mixes start with water transport mechanisms by which water reaches the interior of the material structure and culminate with the various manifestations of this deterioration. Obviously, problems only occur if water penetrates into the mixture. There are three main water transport mechanisms in asphalt pavement mixtures [18–20]: permeability, capillarity and diffusion. Permeability can be defined as the ability of a porous material to allow the flow of water through its voids [21]. Capillarity is defined as the elevation of a liquid above the level zero of pressure due to the total ascending force produced by the attraction of the liquid molecules to a solid surface. These factors depend on environmental conditions and the structure of voids in the mixture. Lastly, diffusion is the process where water particles (liquid and/or vapor) move through the constituent components of the mixture.

A necessary condition for good behavior of asphalt pavement mixtures is that the binder maintains good adhesion with the aggregate in order to prevent debonding. The following pavement mechanisms, acting individually or together, can produce debonding [22,23]: detachment, displacement, spontaneous emulsification, pore pressure, hydraulic scouring and pH instability. Detachment consists in microscopic separation of the bitumen film from the aggregate surface by a thin layer of water without any apparent break in the bitumen film. During the displacement phenomenon, the presence of water affects the aggregate-bitumen bond. The debonding rate depends on mixture viscosity and compactness, as well as on the chemical forces and stresses between aggregate and binder. This rate may be very low or even zero [24]. Spontaneous emulsification results from the formation of an inverse emulsion of water droplets in the binder, for example when clay minerals or other additives are present in the mixture [25]. Pore pressure occurs when water is trapped in the air voids of the mixture. Increases in temperature and traffic loads lead to water evaporation, eventually generating sufficient pressure to cause the rupture of the binder film [26]. Hydraulic scouring is due to the action of vehicle tires on a saturated road surface [18,26,27]. Finally, pH instability affects the adhesion between aggregate and binder. PH stabilization in the aggregate-binder interface minimizes bond rupture, provides strong and durable links and reduces loss of coating [28].

The most common manifestation of moisture-induced distresses in bituminous mixtures is called stripping or loss of bitumen coating on the aggregate surface produced by adhesion failure. The action of water is also involved in the progressive detachment of aggregates from the mastic caused by the wheel path on the asphalt layer. This kind of distress, known as raveling, includes both adhesive and cohesive failure [29].

Laboratory analysis of asphalt mixture moisture damage tipically consists in placing specimens in a water bath at a certain temperature for a certain period of time. In some procedures, such as the one set out in the old Spanish standard NLT-162 [30], specimens are immersed in a water bath at 60 °C for 24 h or at 49 °C for 4 days. Currently, and according to standard UNE-EN 12697-12 [31], samples previously subjected to vacuum are placed in a bath at 40 °C for a period of time between 68 and 72 h.

Quantifying the influence of ageing and moisture on the behavior of bituminous mixtures is not easy. Normally, it is evaluated separately on the mechanical and chemical properties of mixtures. However, both factors are dependent on each other. Lu and Harvey [32,33] showed that pavement ageing has a strong influence on moisture damage.

The present paper studies the effect of ageing and moisture damage on bituminous mixture cracking resistance. Two new tests are used: a direct tension test, i.e. Fénix test, and a cyclic strain sweep test, i.e. EBADE test. The former determines monotonic load cracking resistance whereas the latter studies fatigue. The aim of this work is to show the suitability of both tests to evaluate the effect of ageing and moisture damage on cracking resistance due to monotonic and cyclic loading. The study also provides insights into the cracking resistance behavior of bituminous mixtures under different environmental conditions.

These two tests (Fénix and EBADE) were developed to eliminate deficiencies found in other tests in the literature. One of the main advantages of the Fénix test is that it gives a realistic simulation of crack propagation in bituminous mixtures subjected to thermal and traffic stresses. Moreover, the test is very easy to perform both Marshall specimens and samples extracted from the pavement. As regards the EBADE procedure, advantages over other fatigue tests include shorter test duration, use of prismatic specimens to facilitate the estimation of material parameters, wide range of test temperatures, realistic simulation of fatigue behavior under thermal and traffic stresses and good test sensitivity to variation in parameters.

2. Methodology

Two tests developed by the Road Research Laboratory of the Technical University of Catalonia, i.e. Fénix and EBADE tests, were applied on a dense mixture to evaluate its fracture resistance and fatigue behavior under slow monotonic loading and fast cyclic loading, respectively. Furthermore, the effect of ageing and moisture damage on these two properties was determined.

The Fénix test [34] is a monotonic tensile test at constant displacement rate. A tensile effort is applied on a semicylindrical specimen which is fixed in its diametral plane by two steel plates attached to a loading platen (Fig. 1). The specimen has a notch in the middle of its flat side to facilitate cracking in that area. The test was conducted at a constant displacement velocity of 1 mm/min and 20 °C (although it can be done at other temperatures). The force applied as a function of the imposed displacement was recorded throughout the test.

The three parameters related to mechanical and resistance characteristics of the mixture tipically defined from the load-displacement curve of the Fénix test are tensile stiffness index, fracture energy and toughness index.

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