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New approach to characterize cracking resistance of asphalt binders

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HIGHLIGHTS

- A new binder characterization methodology based on cracking resistance is proposed.
- Several types of asphalt binders with a wide stiffness range were characterized.
- Fénix test was used to characterize binder performance.
- The effect of temperature and ageing on cracking resistance has been analysed.
- Binder ageing leads to a sharp reduction of the work undergone during cracking.

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ABSTRACT

Asphalt binder characterization is a complex and difficult task due to its rheological behaviour. Indeed it has been traditionally realized by means of simple tests at an established temperature. An added challenge is that low temperatures, as well as binder aging, lead to significant changes in the viscoelastic behaviour of binders. This study aimed to characterize asphalt binders, not through the traditional procedures, but through the ductility and tenacity that they provide to a mixture, being these two properties directly related to the cracking response of the binder. To this end, a new approach for asphalt binder characterization was proposed based on the application of the Fénix test on a standard mixture with a defined aggregate gradation and composition, without fines or filler, manufactured with different types of binders and tested at different temperatures, as well as subjected to accelerated aging in laboratory. The obtained results showed the thermal susceptibility of binders, which evidence the need to characterize binder performance at different temperatures to obtain a reliable cracking response. In addition, binder aging results in a more brittle cracking fracture, being the aging effects more pronounced in high penetration binders.

1. Introduction

Asphalt binder characterization has always presented some complexity due to the rheological behaviour of the tested material. Bituminous mixtures show significant variations in mechanical properties with load application speed and temperature due to the thermal susceptibility and viscoelastic behaviour of asphalt binders [1]. At low temperatures and short load application times, binder response is elastic, while at high temperatures and long periods of load application the response is viscoplastic. Likewise, binder aging also changes its rheological behaviour [2].

Due to the complexity of such a study, characterization of asphalt binder behaviour has been classically realized by means of simple tests, which partially assess the binder properties at an established temperature (penetration, softening point, ductility, fragility point, viscosity, among others).

However, the aim of this research is to characterize asphalt binders, not by these traditional procedures, but through those characteristics that are directly related to the properties that binders have to provide to the asphalt mixture for an appropriate performance of the pavement. And probably, the most representative characteristic of asphalt binders' performance, which differentiates them from other binders such as cement, is their rheological properties, such as ductility and tenacity that represent the ability to withstand tensile stresses that can lead to cracking failure and fracture of pavement [3].

Therefore, this paper evaluates the ductility and tenacity that different types of asphalt binders provide to a mixture under different environmental conditions by applying the Fénix test [4,5]. This test, developed by the Road Research Laboratory of the Tech-

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nical University of Catalonia, evaluates the crack resistance of asphalt mixtures by calculating the dissipated energy during mixture cracking [6].

However, the cracking resistance of a mixture, as most mechanical properties, is not only influenced by the binder type and content, but also by a wide range of factors such as the type and content of filler that constitutes the mastic or the amount and nature of the fines.

Recently, numerous researchers have investigated the influence of asphalt binders on the cracking resistance of mixtures by establishing a correlation between the rheological properties of the binders using conventional tests, e.g. elastic recovery test, bending beam rheometer or dynamic shear rheometer, and the cracking performance of asphalt mixtures at a defined temperature, e.g. overlay tester or indirect tension test [3,7]. Others have tried to establish a correlation between the critical cracking temperature for both asphalt binders and mixtures at low temperatures [8,9]. However, relationships between binder tests and mixtures tests have not been fully established due to significant differences in the test temperature. Based on the encountered discrepancies, this study aims to directly characterize the cracking resistance that different asphalt binders withstand by applying a direct tensile stress under different test temperatures.

In order to isolate the effect of the asphalt binder, the cracking resistance provided by the asphalt binder has been evaluated on a standard mixture with a defined gradation and composition, without fines or filler, where only the binder content is providing the cohesion of the mineral skeleton. This test methodology, which consists of isolating the effect of asphalt binder through a defined standard mixture, has attracted significant researchers' attention who have used it to evaluate the bonding ability provided by the binder in the aggregate-asphalt matrix, as well as the effect of temperature, moisture damage and aging of binder on the adhesion mechanism [10]. This methodology was named the UCL method (Universal Binder Characterization) [11]. Under these conditions, the cracking performance of the mixture will be exclusively influenced by the type of binder. In other words, the role of the mineral skeleton is to become a holder to characterize the performance of the binder type.

It is worth pointing out that cracking resistance may become critical at low and intermediate temperatures due to the thermal susceptibility and viscoelastic behaviour of asphalt binders [9,1]. Under this temperature range, asphalt binder hardening process results in higher mixture stiffness; thus, brittleness increases due to the decreased binder ductility. Similarly, this change in binder properties may also occur due to the long term aging of the binder [12]. This process can be attributed to chemical aging, mainly explained by the thermal-oxidation and photo-oxidation, or steric hardening [13].

Generally, the aging process brings about mechanical and chemical changes in binder properties, leading to an increase in asphalt binder stiffness, impoverishing its adhesive capacity and reducing its coating properties [14]. If this loss of ductility is combined with the effect of low temperatures, consequences can be even more severe.

Therefore, in order to fully characterize cracking resistance of asphalt binders, the test will be performed under a wide range of working temperatures to evaluate their thermal susceptibility, especially under low temperatures when asphalt binder becomes significantly more brittle, as well as the consequences of the aging process.

Hereafter, a description of the followed methodology and Fénix test applied on five different asphalt binders, under a wide range of temperatures, as well as the influence of aging, is provided.

2. Methodology and materials

The aim of this research is to characterize asphalt binders by evaluating the ductility and tenacity that they provide to a mixture through the application of the Fénix test. In particular, two aspects have been considered: (1) the effect of binder typology and (2) the effect of binder aging.

It is worth noting that the Fénix test is a direct tensile strength test that evaluates the cracking resistance of asphalt mixtures, a property that is influenced by many other factors beside the type of binder. Therefore, in order to isolate the effect of the binder, the cracking resistance provided by the asphalt binder has been evaluated on a standard mixture with a defined gradation and composition, without fines or filler, the same type of aggregate and characterized by a high void content. Then, the only variable was the type of binder, so the differences observed in the cracking response of the standard mixture were due entirely to the binder type.

To this aim, five asphalt binders covering a large portion of the current market were evaluated: four conventional binders, B15/25, B35/50, B70/100 and B160/220, and a polymer modified binder, PMB 45/80-65. Thus, a wide spectrum of binder consistencies is covered and conventional binders can be compared to the modified binder. Binders' specifications are shown in Table 1.

The standard mixture had a defined composition, without fines or filler, a fixed binder content of 4.5% (by weight of the aggregate) and a gradation composed of 80% of aggregated size between 2.5 and 5 mm and a 20% of aggregate size between 0.63 and 2.5 mm (Table 2). Only porfidic aggregates were used. Marshall specimens were manufactured with 50 blows per side and the air voids content was around 28%. This aims to minimize the effect of any other factor on the cracking response of the mixture other than the binder type.

In order to evaluate the cracking resistance that, in these conditions, the different asphalt binders provide to the mixture, the Fénix test was applied. The Fénix test procedure consists of subjecting one half of a 101.6 mm diameter cylindrical specimen prepared by the Marshall method to a tensile stress at a constant displacement velocity (1 mm/min) and specific temperature [6]. A 6 mm-deep notch is made in the middle of its flat side where two steel plates are fixed. The specimen is glued to the steel plates with an adhesive mortar containing epoxy resins. Each plate is attached to a loading platen so that they can rotate about fixing points (Fig. 1).

Stress and displacement data are recorded throughout the test, and based on this output curve, the parameters involved in the cracking process are obtained: tensile stiffness index, fracture energy and toughness index.

The Tensile Stiffness Index (IRT) represents the slope of the stress-displacement curve between 25% and 50% of the peak load, and it is related to the mixture modulus. It is obtained using the following Eq. (1):

$$IRT = \frac{0.5F_{max} - 0.25F_{max}}{d_{0.5F_{Fmax}} - d_{0.25F_{Fmax}}} \quad (1)$$

where

- IRT: tensile stiffness index (kN/mm)
- F_{max}: peak load (kN)
- $d_{0.25Fmax}$ and $d_{0.5Fmax}$: displacement before peak load at 25 and 50% of the peak load (mm), respectively

Fracture energy (G_F) during cracking is calculated by Eq. (2):

$$G_F = \frac{\int_0^{d_f} F(u) \cdot du}{S} \quad (2)$$