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Effect of warm additives on rutting and fatigue behaviour of asphalt mixtures

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HIGHLIGHTS

- Study of rutting deformation and resistance to fatigue of warm mix asphalt.
- Reducing the manufacturing temperature provoked an increase in rut depth in all asphalt mixtures manufactured.
- The use of tensoactives and zeolites led to lower WTS values than wax asphalt mixtures.
- The waxes and zeolite additives in asphalt mixtures manufactured at 140 °C showed a similar fatigue life to HMA's.

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ABSTRACT

This paper studies the rutting deformation and resistance to fatigue of warm mix asphalt with different additives (tensoactives, waxes and zeolite). Warm-mix type Asphalt Concretes were manufactured at different manufacture and compaction temperatures. Wheel tracking and four-point bending tests were carried out according to the European standard. The tensoactive and zeolite mixtures led to better results under permanent deformation than waxes, but all modified asphalt mixtures showed higher values of rutting than hot mix asphalt. In the fatigue test, the asphalt mixtures with waxes and zeolite displayed similar behaviour to hot mix asphalt, but the asphalt mixtures modified with tensoactives showed less fatigue life.

1. Introduction

Numerous studies have been done to study the different mechanical properties of warm mix asphalts (WMA). Cooper et al. [1] studied the use of the additive Thiopave (a sulphur additive). They measured the permanent deformations of modified asphalt mixtures under wet conditions (submerged in water at 50 °C and 20,000 cycles) and the fatigue life using three-point bending in a strain-controlled mode at 10 Hz and 20 °C. The use of this additive improved the rutting resistance and led to better fatigue life.

De Visscher et al. [2] performed a study of mechanical properties of asphalt mixtures manufactured at different temperatures using zeolites. They concluded that asphalt mixtures modified with zeolites may be manufactured at a temperature of 120 °C without worsening the rutting performance compared to an HMA but below 120 °C the compactability and resistance to water of the asphalt mixtures diminished.

Xiao et al. [3] carried out a study of the rutting resistance in WMA with different types of wet aggregates, using three additives (Aspha-Min®, Sasobit® and Evotherm®). The WMAs were compacted with a gyratory machine. The wheel-trucking test conditions were 8050 cycles at 64 °C. The results showed that the rutting resistance is related to the type of aggregate and not to the moisture content and also that the asphalt mixtures with Sasobit® showed lower permanent deformations that those using Aspha-Min® or Evotherm®.

Goh and You [4] analyzed the fatigue life with the four-point bending test and the dynamic moduli in asphalt mixtures manufactured and compacted at various temperatures, using the wax Sasobit® and the zeolite Advera®WMA. The dynamic moduli of WMA were lower than those of HMA at most temperatures and frequencies tested, and the asphalt mixtures with zeolite were less stiff than those manufactured with wax. The fatigue life of WMAs was similar or even longer than HMA, except in the case of the WMA manufactured and compacted at 130 °C.

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Su et al. [5] studied the rutting performance and fatigue life of asphalt mixtures manufactured with three different aggregate gradations, a polymer modified bitumen and a synthetic wax created by a Japanese company. The wheel-tracking test conditions were at a temperature of 60 °C and a contact pressure between wheel and sample of 1.38 MPa. The four-point bending fatigue test was done under controlled strain with a strain level of 400 με, applied at a frequency of 10 Hz and a test temperature of 20 °C. The results showed that decreasing the working temperatures improved the rutting performance, independently of the aggregate gradation used, and also that the use of wax additive increased the rut depth. Reducing 30 °C the manufacture temperature, the fatigue life of additivated asphalt mixtures were similar to HMA; instead of decreasing 50 °C, the fatigue life of asphalt mixtures with synthetic wax were reduced in the three gradations used between 27% and 33%.

Zhao et al. [6] analyzed the rutting resistance with an Asphalt Pavement Analyzer (APA) in asphalt mixtures manufactured with three different types of bitumen (two PG 62-22s of different origin and a PG 58-28), adding four warm additives: two waxes in solid state and two viscous liquid chemical products. The test conditions were: hose pressure at 700 kPa; cylinder load of 445 N on each wheel; 8000 loading cycles and the test temperature was 64 °C for PG 62-22 and 58 °C for PG 58-28. The results showed that decreasing manufacture temperature and using additives decreased the resistance to rutting due to lower aging of the bitumen. The use of chemical additives showed similar results compared to the reference mixture; nevertheless the use of waxes increased the rutting resistance, since these additives stiffen the bitumen.

Morea et al. [7] used two tensoactives, one liquid and the other solid, in asphalt mixtures to check their rutting behaviour. They employed an aggregate gradation and two types of bitumen (a Pen 70/100 binder and modified bitumen AM3-C), and two manufacturing and compaction temperatures. The temperature of the wheel-tracking test was 60 °C, with a loaded wheel of 520 N. The results showed that reducing the manufacture and compaction temperatures in asphalt mixtures mixed with a Pen 70/100 bitumen lowered the rutting resistance. The addition of additives did not improve the behaviour of the asphalt mixtures with Pen 70/100 bitumen. In contrast, the use of AM3-C bitumen did not show significant differences reducing the working temperatures and/or adding additives.

This paper is the second part of a previous study in which the compactability, water sensitivity and stiffness modulus of WMA were studied [8]. The results of this research showed that reducing the mixing temperature, mixtures with additives required less compaction energy and their water susceptibility improved compared to the Reference mix at the three temperatures studied. Moreover, the stiffness modulus is affected by the manufacture and compaction temperatures affected the stiffness modulus, although this variation was smaller in the mixes manufactured with additives.

2. Objectives and scope

The goal of this paper is to check the rutting performance and fatigue life of warm-mix type Asphalt Concrete (AC) with different warm additives (tensoactives, waxes and zeolites) at different manufacturing and compaction temperatures.

3. Experimental research

3.1. Materials used and mixtures design

In this research an AC16Surf aggregate gradation adjusted to the centre of grading envelope was chosen (Table 1), using coarse ophite aggregates and limestone sand (Table 2). The asphalt mixtures were manufactured with a B-50/70 penetration bitumen (Table 3), with a percentage of bitumen of 4.85% w/m obtained using the Marshall method (UNE 12697-30: 2007).

Seven different asphalt mixtures were manufactured: R mix (pure bitumen) and 6 mixtures with additives (A1–A6). The additives used in this study, as well as their compositions and amounts are listed in Table 4.

All asphalt mixtures were mixed at three different temperatures, at 160 °C, typical temperature of HMA, at 140 °C and at 120 °C, temperatures of WMA. The compaction temperatures selected were the same than the manufacture (160 °C, 140 °C and 120 °C), placing the pre-compacted specimens in an oven at the specified compaction temperatures for a 30-min equilibrium period.

All mixtures were compacted using a roller compaction. The compaction can be performed either by load control or by height control. The height control was used to compact the HMA (reference mixture at 160 °C), applying a number of cycles with an increasing compaction energy until achieve the required height of the sample (60 mm for the wheel trucking test and 70 mm for fatigue test). The sequence obtained was applied to different combinations of temperature and additive (load control). For the fatigue test, the samples were cut to get the dimensions according to the European standard.

3.2. Test methods

3.2.1. Wheel-tracking test

The rutting performance of asphalt mixtures was measured by the wheel-tracking test. This test measures the rut depth produced by the repeated rolling of a loaded wheel (700 ± 10 N) for 10,000 loading cycles (EN 12697-22: 2008) at a test temperature of 60 °C [9].

Two samples were manufactured for each combination of additive-working temperature, and compacted using a roller compactor (EN 12697-33: 2007). The dimensions of the specimens were 260 mm × 410 mm × 60 mm in accordance with EN 12697-22: 2008, the density of the samples being 100% of the Marshall density [9].

The rutting resistance is measured through mean wheel-tracking slope calculated using the following equation:

$$WTS_{air} = \frac{(d_{10,000} - d_{5,000})}{5} \quad (1)$$

where WTS_{air} is the wheel-tracking slope for 1000 loading cycles (mm), d_{5000} is rut depth after 5000 loading cycles (mm), $d_{10,000}$ is the rut depth after 10,000 loading cycles (mm)

The Spanish standard states that the mean wheel-tracking slope must be between 0.07 mm and 0.10 mm, depending on the type of traffic and thermal zone in which the asphalt mixture will be used [9].

3.2.2. Resistance to fatigue

The fatigue test measures the distress on the asphalt mixtures produced by the accumulation of a high number of loads [10].

In this research, the four-point bending test was used, using prismatic specimens with the dimensions 63 mm × 410 mm × 50 mm (EN 12697-24: 2007). The test conditions were: a sinusoidal waveform at a frequency of 10 Hz in strain-control mode and a temperature of 20 °C. The failure criteria selected was defined as the loading cycle when a reduction of 50% of the initial stiffness modulus, obtained in cycle 100, is produced.

The reference mixture was manufactured at 160 °C and the mixtures with additives at 140 °C, that is, the temperature at which the additives showed the best rutting performance.

The fatigue model for samples tested in the four-point bending test has the following expression:

$$N = k_1 \varepsilon^{k_2} \quad (2)$$

where N is the number of strain applications to failure. ε is initial tensile strain in cycle 100, in μm/m. k_1, k_2 is the fatigue growth rate coefficients.

4. Results and discussion

4.1. Wheel-tracking test

The evolution of permanent deformation with the number of load cycles for the asphalt mixtures manufactured at different manufacture and compaction temperatures are presented in Fig. 1.

In all the cases studied, the rut depth (RD) increased as the mixing temperatures decreased (Fig. 2), and hence the main wheel-tracking slope (WTS) as well (Fig. 3). This effect can be explained by the increase of air voids as the working temperatures reduced. It was found that for the same mixture, an increasing of air void content resulted in an increase of the RD and WTS values. However, comparing all mixed together, the air void content was not directly related to a certain value of WTS, i.e., mixtures with the