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The use of additives for the improvement of the mechanical behavior of high modulus asphalt mixes

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HIGHLIGHTS

- HMAM with optimal fatigue resistance behavior avoiding cracking propagation were obtained.
- HMAM with fibers and crumb rubber increase the resistance to plastic deformation.
- The use of crumb rubber increases the stiffness, bearing and stress distribution capacity.
- HMAM with crumb rubber or fiber is more economical than HMAM with polymer modified binders.

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ABSTRACT

The high stiffness provided by high modulus asphalt mixes significantly decreases the loads transmitted by the traffic to the road foundation whilst at the same time increases their resistance against plastic deformations. Thus, the use of these types of mixtures can be an effective solution in road construction, due to the fact that they can reduce the thickness of the pavement, saving economic and material resources. Nevertheless, in some cases this high stiffness constitutes a drawback because it could reduce the fatigue resistance offered by these materials, leading to a premature appearance of cracks in the pavement, which decreases its service life. Due to this fact, the use of high modulus asphalt mixes is limited, especially in cold climates. In order to solve this problem, this research has been focused on the improvement of the mechanical performance of high modulus asphalt mixtures through the use of additives (crumb rubber and acrylic fibers), which could increase their fatigue resistance by maintaining the stiffness required. Different tests have been carried out under different temperatures for the mixtures assessment. The results obtained have shown that the incorporation of these additives could lead to a better mechanical behavior of high modulus asphalt mixes, and thus it could improve their performance.

1. Introduction

Since their appearance in the 80s, high modulus asphalt mixes (HMAM) have been regarded as one of the most effective solutions for the construction of road and airport pavements [1,2]. This type of asphalt mixtures are composed of a strong continuous mineral skeleton, which is combined with a hard binder, in order to achieve a high capacity to absorb the loads transmitted by the traffic [3]. These characteristics provide them with a high stiffness modulus, which reduces the appearance of structural distresses by minimizing the tensile strain at the bottom of the asphalt layer, and the compressive strain on top of the subgrade [4].

Because of this fact, the use of HMAM allows the construction of roads with major structural strengthening, which can lead to a reduction of 20–23% in the thickness of the pavement [5,6], resulting in a significant saving of asphalt binder and aggregates. Furthermore, the high stiffness provided by HMAM also increases the rutting resistance of the pavement (even higher than polymer modified bitumens [7]), which contributes to enlarge its service life.

During the last decades, HMAM have been used successfully in the construction of roads and airports in many European countries, EE.UU, China, South Africa, etc. [8–10], diminishing the cumulative damage produced by the traffic in the asphalt layers. Some studies have demonstrated that their use is also effective in pavement rehabilitation, even when different rates of RAP (reclaimed asphalt pavement) are used in their manufacture [11]. Nevertheless, the high stiffness provided by HMAM can also be a problem under

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certain circumstances, such as high load amplitudes and frequencies, as well as cold climates. As HMAM are very stiff, fatigue and thermal cracking resistance can be considerably reduced, which constitutes an obstacle for their application, especially in cold regions. In this sense, the appearance of cracks in HMAM can lead to a premature failure of the base course of the pavement, and thus the end of its service life.

The stiffness provided by high modulus binders makes them very resistant to plastic deformations, although other properties such as elastic recovery are considerably reduced [7]. The use of polymers as modifiers of these binders can considerably improve their performance, increasing about 5–10 times better resistance to fatigue cracking than the conventional high modulus bitumens [12]. Thus, the use of modified bitumens in the manufacture of HMAM can be a good solution in order to solve this problem. However, these types of binders are more expensive than conventional high modulus bitumens, and as HMAM are used in the thickest layer of the pavement (base course), their use can increase substantially the cost of the pavement (which limits the use of this solution). Because of this fact, it could be very interesting to find other alternatives which can improve the fatigue and cracking resistance of HMAM, providing a cost-effective and sustainable solutions that could guarantee its successful use in cold climates, and roads with high volume of heavy traffic.

Based on these considerations, the aim of this work is focused on improving the mechanical behavior of HMAM by using additives that can be incorporated directly to the mixture during its manufacture. For this purpose, two cost-effective and sustainable additives (acrylic fibers, AF, and crumb rubber, CR) were used to modify the mechanical properties of a HMAM manufactured with a conventional high modulus bitumen B20/30. These two mixtures (HMAM-AF and HMAM-CR) were compared with a reference one manufactured without additives and the same bitumen (HMAM-R), and with a HMAM manufactured with a polymer modified high modulus bitumen BM1 (HMAM-BM1). In order to provide a complete characterization of the mechanical performance of these mixtures, various laboratory tests have been conducted during this study: marshall tests, water sensitivity tests (including freeze/thaw cycles), wheel tracking tests, creep triaxial tests (at different temperatures), stiffness tests (at different temperatures), and fatigue four point bending tests. The results obtained showed that the use of acrylic fibers or crumb rubber can improve the mechanical behavior of conventional HMAM, and the performance of these type of mixtures can be compared with those obtained by a HMAM manufactured with a high performance polymer modified bitumen.

Finally, it should be highlighted that the present study has been conducted in the framework of FATE research project (Firmes Asfálticos para Temperaturas Extremas), which is being developed in Spain and aims to design long life asphalt pavements for extreme continental climates.

2. Methodology

2.1. Materials

Four different types of HMAM were studied during this research. All of them were manufactured using the same continuous mineral skeleton (Fig. 1), composed by limestone aggregates in the coarse and fine fraction, and calcium carbonate in the filler. In this sense, in order to provide a representative study of the influence of the additives in the mechanical performance of the mixtures, the same amount of bitumen was used in the manufacture of the four mixtures (5.1% over the total weight of the mixture, selected from different previous Marshall tests). Thus, the only differences between the four types of HMAM studied were the type of binder used in their manufacture (B 20/25 or BM1) and the type of additive incorporated to them (acrylic fiber or crumb rubber, Fig. 2).

B 20/25 is a conventional high modulus bitumen commonly used in the manufacture of this type of mixture, while BM1 is a high performance polymer modified bitumen which also offers a high stiffness combined with a good flexibility. Acrylic fibers are additives which are incorporated into the mixture in order to reinforce it by providing a high cohesion through a tridimensional net that increase the elasticity, the fatigue and cracking resistance, and the structural stiffness at high temperatures. They are added during the mix of the aggregates in order to guarantee a correct dispersion. On the other hand, an increase in the binder content of the asphalt mixture is not needed because acrylic fibers do not absorb bitumen. Finally, crumb rubber particles are added to the mixture using the dry process [13] with the aim of improving the fatigue and elastic properties of the mixture. Table 1 shows the main characteristics of these materials.

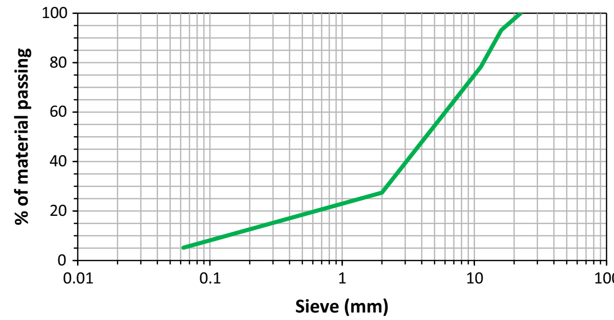

Fig. 1. Grain size curve.

Based on these considerations, Table 2 resumes the composition and the main characteristics of the four types of HMAM that have been evaluated during this work. The mixture HMAM-R has been established as a reference to provide a comparative analysis with the mixtures HMAM-AF and HMAM-CR, in order to evaluate the hypothetical improvement provided by the use of the additives. The percentages of acrylic fiber (0.3% over the total weight of the mixture) and crumb rubber (1.5% over the total weight of the mixture) have been chosen based on according providers recommendations, previous experiences [13,14], and results from previous preparatory tests carried out in the laboratory. The mixture HMAM-BM1 has been studied to compare if the mechanical performance offered by the mixtures modified with additives (HMAM-AF and HMAM-CR) is similar to that offered by a HMAM manufactured with a high performance modified bitumen.

Based on the dosage used for each additive, considering that the same aggregates are used in the manufacture of the mixtures, an average market prices of the binders used (480 €/t for the conventional bitumen B 20/25, and 700 €/t for the polymer modified bitumen BM1) and that no modifications should be done in the asphalt plant to incorporate these additives, it can be said that the use of acrylic fibers and crumb rubber suppose a much more cost effective solution than the use of polymer modified binders. Table 3 shows that in comparison with the mixture manufactured with the polymer modified bitumen, the raw materials costs can be reduced in a 10.5% when acrylic fibers are used and in a 27.3% when crumb rubber is used.

2.2. Testing plan

To analyze the influence of the additives in the mechanical behavior of the HMAM studied, different test methods and different test conditions have been considered. In this sense, the variety of the tests developed has covered the different aspects that can affect the long-performance of the HMAM during their service life. Thus, water sensitivity tests under extreme temperature conditions (including freeze/thaw cycles), resistance to plastic deformations tests (wheel tracking test and confined triaxial tests under different temperatures), bearing and stress absorption capacities (stiffness tests under different temperatures), and resistance to fatigue tests have been developed during this research.

Water sensitivity tests have been carried out based on EN 12697-12 [15], although during their performance, extreme test conditions such as low compaction energy (to simulate the most unfavorable conditions during the construction in cold climates) and freeze/thaw cycles (to verify the influence of the high stiffness in the resistance against water in cold climates) have been applied. Thus, these tests involve the manufacture of six test specimens with a diameter of 101.6 mm and a thickness of 60 mm that have been compacted with 35 blows on each side by a Marshall hammer. The specimens were subsequently divided into two sets of three specimens: a dry set and a wet set. The set of dry specimens was stored at room temperature in the laboratory (20 ± 5 °C), whereas vacuum was applied to the wet set for 30 ± 5 min until a pressure of 6.7 ± 0.3 kPa was obtained, then the specimens were immersed in water at a temperature of 40 °C for a period of 72 h. After that, they are stored at −18 °C for 16 h, and then immersed in water during 24 h at a temperature of 60 °C until thaw. Fig. 3 shows the conditioning to freeze of the wet set specimens. The next step was to perform an indirect traction resistance test on each of the cylinders (in both the dry set and the wet set). This was done at a temperature of 25 °C, and after a previous period of adjustment of 120 min to this temperature.

The evaluation of the resistance to plastic deformation was carried out thorough the wheel tracking test and the confined triaxial test. The wheel tracking test (EN 12697-22, [16]) involves the application of a load (700 N) on the test specimen