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Experimental evaluation of dense asphalt concrete properties for induction heating purposes

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HIGHLIGHTS

- We examine the electrical, thermal and induction properties of asphalt concrete.
- The electrical and thermal properties of asphalt are not related to the geometry of the fibers.
- We recommend the use of big diameters of fibers in dense asphalt concrete.

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ABSTRACT

Induction heating of asphalt concrete is a technique that has been recently developed to increase the self-healing rates of asphalt concrete. It consists in adding electrically conductive fibers to the asphalt mixture and heating them with an induction heating device. In this way, the temperature of asphalt concrete can be indirectly increased. But still, the factors that affect the increase of temperature are not well-known. With the purpose of finding them, 25 different mixtures, with the same aggregates distribution and amount of bitumen, but with two different lengths, four different quantities, and four different diameters of steel wool fibers have been considered. The influence of fibers on the air void content, electrical and thermal conductivity of dense asphalt concrete has been studied. Furthermore, the effect of these properties on the maximum temperature reached after a fixed time induction heating is analysed. It was found that steel wool fibers increase slightly the electrical and thermal conductivities of dense asphalt concrete. Additionally, in the case of the thermal conductivity, an increase on the volume of steel wool fibers serves to compensate the loss in the thermal conductivity that happens when the air void content is increased. Finally, it has been observed that the temperature reached due to the induction heating increases with the number of fibers in the mixture and with their diameter. As a recommendation, it is indicated that, for induction heating purposes, short fibers, with big diameters should be used.

1. Introduction

There have been various preliminary attempts to increase the self-healing rates of asphalt concrete [1]. This happens because asphalt concrete is a self-healing material, with the ability to repair its own damage. In Ref. [2] it was explained that healing of open cracks in asphalt mastic depends mostly on the capillary flow of binder through the cracks. For this process to happen, the temperature has to be high enough for the binder to start behaving as a Newtonian fluid. Different types of bitumen exhibit different non-Newtonian behaviour below different temperatures, ranging from 30 °C to 70 °C [3–6].

Temperature of asphalt concrete may be increased by means of induction heating [7,8]. This technique consists in adding electrically conductive fibers into the asphalt mixture (see Fig. 1). Then, with the help of an induction heating device, the fibers can be heated locally and so the asphalt concrete, with what cracks can heal. In Ref. [8] it was discovered that a very small volume of fibers, more than 0% serves to increase the temperature via induction heating, but that there is a maximum volume of fibers, 6–7%, above which the temperature does not increase any more. Additionally, in Ref. [9] can be seen that the increase of temperature in asphalt concrete due to induction heating depends mainly on the radius of the fibers, more than on their volume in the mixture. Moreover, more parameters which have great influence on the heating rates are the frequency and intensity of the alternating magnetic field used. Besides, in Ref. [10], which analyses the same mixtures as in the present article, it can be seen that the steel wool fibers

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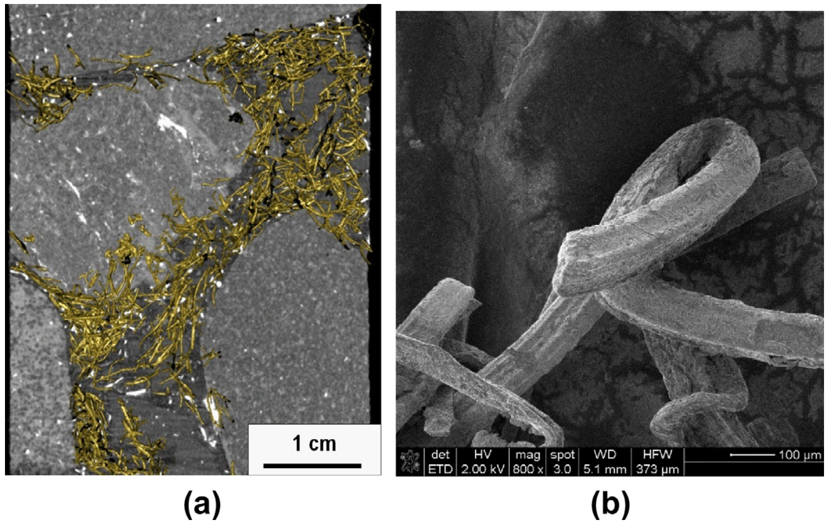

Fig. 1. (a) Image of steel wool fibers Type 00 (0.03642 diameter) in asphalt concrete. (b) SEM image of a steel wool fiber Type 0000 (0.02855 diameter).

may deteriorate the mechanical properties of the mixture in case fibers are not well dispersed (see Fig. 1).

Finally, the speed at which asphalt concrete cools down will have a great effect on the healing behaviour of this material. This happens because healing will take place while the temperature is higher than a certain threshold. In the case of adding conductive particles, the particle shape, the volume fraction and the thermal conductivity of the particles and the mixture will be key factors in the thermal modification of asphalt based mixtures [1].

But still it is not clear which diameter and which amount of fibers are more appropriate to heat dense asphalt concrete via induction heating. Additionally, it is not well known how electrically conductive fibers may affect the thermal and electrical properties of dense asphalt concrete and how are these characteristics related to the induction heating rates and to the air void content of the mixture. To find this out, this Paper investigates the effect of different percentages of steel wool fibers with different diameters and original lengths on the air void content, electrical resistivity and thermal conductivity of dense asphalt concrete. Furthermore, the effect of these properties on the maximum temperature reached after a fixed time induction heating is analysed.

2. Experimental method

2.1. Materials

A dense asphalt concrete mixture was used in this research. The dense aggregate gradation is shown in Table 1. The aggregates consisted of crushed basaltic material (size between 2 and 11 mm and density 2770 kg/m^3), crushed sand (size between 0.063 and 2 mm and density 2688 kg/m^3) and filler (size < 0.09 mm and density 2638 kg/m^3). The virgin bitumen used was 70/100 pen, obtained from Kuwait Petroleum, with density 1032 kg/m^3.

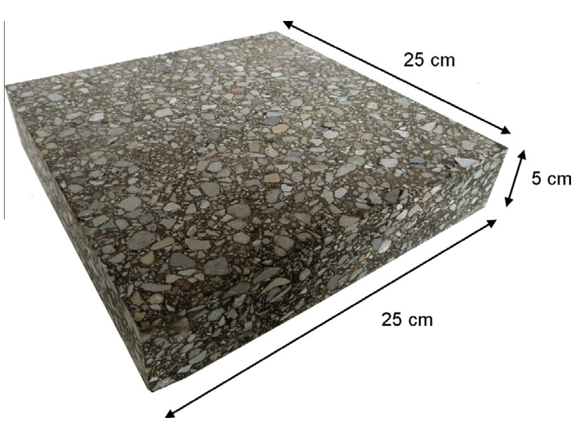

Fig. 2. Test sample used in the Paper.

Additionally, steel wool fibers were added to the mixture. The material used in the steel wool was low-carbon steel, with density 7180 kg/m^3. These fibers had four different diameters, 0.02855 mm (Type 0000), 0.03642 mm (Type 00), 0.08389 mm (Type 1) and 0.15498 mm (Type 3) and two different initial lengths: short fibers, with approximately 2.5 mm average length and long fibers, with around 7 mm average length. These are the same mixtures as the ones shown in [10]. Finally, four different amounts of fibers were used: 0%, 2%, 4% and 6%, by total volume of bitumen in the mixture (see Table 1).

In total 30 different types of mixtures were prepared. 24 with different original sizes, types and volumes of fibers, always maintaining the same mass of aggregates and bitumen, but changing the mass of fibers, 1 with the same amount of bitumen (5.6%), but without steel fibers (reference mixture) and 5 with different percentages of bitumen (5.25%, 5%, 4.75%, 4.5% and 4.25%).

2.2. Test specimens preparation

The materials were mixed in a laboratory planetary mixer at a mixing speed of 312 rpm. Two mixture batches were prepared for each of the 30 asphalt concrete mixtures studied. The amount of material in each mixture was something more than 16 kg. Materials were heated to 160 °C before mixing. The raw materials were added to the bowl in the following order: first the bitumen and the fibers, then the coarse aggregates, then the sand and finally, the filler. Materials were mixed during approximately 5 min.

The first 16 kg batch was used for preparing asphalt concrete slabs. These slabs were compacted by using a pneumatic laboratory wheel compactor [11]. Before the compaction started, the specimens were subjected to a pre-compaction with a low tire pressure (0.1 MPa) and a low maximum wheel load (1 kN). The effective compaction of the rolling-wheel specimen was performed at higher tire pressure (0.6 MPa) and a constant wheel load (5 kN). After the compaction, both faces of the samples were polished until they reached a height of 5 cm. From this, blocks of 25 × 25 cm^2 were sawn Fig. 2.

The second 16 kg batch was used to prepare cylindrical Marshall specimens with 10 cm diameter, approximately 6 cm height and exactly 1190 g of mass. Immediately after placing the mixture into the mould, they were heated to 140 °C and compacted with a Marshall hammer, applying 50 blows on each face of the specimens.

2.3. Air void content

The air void content was calculated in a geometrical way. For that, the exact volume and weight of each slab were measured in order to calculate the bulk density of each specimen. Additionally, as the exact percentage of materials and their density for each mixture were known, the theoretical density without voids for each mixture was found. From this, the air voids percentage was calculated as:

$$\text{Air void content} = \left(1 - \frac{\rho_b}{\rho_t}\right) \cdot 100 \quad (1)$$

where ρ_b is the bulk density of the mixture, measured in kg/m^3, and ρ_t is the theoretical density of the mixture, without voids, measured in kg/m^3.