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Effect of fibres addition on the physical and mechanical properties of asphalt mixtures with crack-healing purposes by microwave radiation

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HIGHLIGHTS

- Fibres distribution and mechanical behaviour of asphalt mixtures were analysed.
- Effect of environmental conditions on particle loss of mixtures was evaluated.
- Fibres presented a good spatial distribution into the asphalt mixture samples.
- Asphalt mixtures with higher fibre content may produce dense clusters.
- Fibres did not contribute to improve the mechanical properties of the mixtures.

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ABSTRACT

Microwave heating is regarded as a promising technique to promote crack-healing of asphalt mixtures reinforced with steel wool fibres. In addition to serving as a heat source when subject to microwave radiation, steel wool fibres are expected to affect the physical and mechanical properties of the asphalt pavements. However, it is not clear what this effect is, and what is the optimum fibre content that can provide effective crack-healing without having a negative impact on other relevant mixture properties. This paper reports a study of the steel wool fibres spatial distribution and their influence on the physical and mechanical properties of asphalt mixtures. For this purpose, five different dense asphalt mixtures, with the same aggregates gradation and bitumen content, but with five different percentages of steel wool fibres were manufactured. Then, their mechanical properties such as particle loss resistance in dry and wet conditions, and stiffness modulus and cracking resistance in Mode I of fracture at four different temperatures were evaluated. Samples of these mixtures were examined using Scanning Electron Microscopy and analysed using X-ray micro computed tomography to study the condition and distribution of fibres within the bitumen matrix. Microscopy results showed that fibres can be damaged during the mixing and compaction processes. A larger variability in the local distribution of fibres for mixtures incorporating a higher fibre content was observed in the tomography analysis, with presence of fibre clusters more than double of the average fibre content of the mixture. Although addition of fibres appears to reduce the bulk density of mixtures, according to tomography analysis differences in average porosity between samples were not statistically significant. Finally, it was confirmed that regardless of test temperature, steel wool fibres did not have a relevant influence on the improvement of particle loss resistance, stiffness modulus and cracking resistance of asphalt mixtures.

1. Introduction

An asphalt mixture is a material composed of aggregates and bitumen, and it is one of the most commonly used materials in pavement construction worldwide. As a reference,

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within the 18,000 km of paved roads in Chile, there are currently 16,000 km paved with asphalt mixtures [1]. However, environmental conditions combined with traffic loads contribute to premature deterioration of asphalt pavement materials, reducing their mechanical strength and durability over time. The main environmental factors affecting durability of asphalt mixtures are ageing [2], water damage [3] and thermal cracking [4]. These factors may have a negative influence on the stiffness of bitumen and on the particle loss resistance of asphalt mixtures. With the aim of improving the mechanical properties of asphalt mixtures against environmental damage, different types of fibres can be incorporated to the matrix of mixtures [5]. Many types of fibres are available for incorporation into asphalt mixtures [6]. For example, cellulose and mineral fibres [7]; polypropylene and polyester fibres [8]; and various polymers, steel wool, and other waste fibres [9] are sometimes added to asphalt mixtures. Metallic fibres in asphalt mixtures are known for enhancing their strength and fatigue characteristics while increasing their ductility [10]. In addition, they may contribute to prevent the formation and propagation of cracks [11], and, since the fibre material has high tensile strength relative to asphalt mixtures, they may improve the cohesive and tensile strength of mixtures [5]. Hence, fibre-reinforced asphalt mixtures may have a good resistance to ageing, moisture damage and resistance to cracking [6]. Metallic fibres (steel wool) can also be used to modify the electrical [12] and thermal conductivities [13] of mortar and asphalt mixtures, and to heal the open cracks via electromagnetic induction heating [12–19]. It is well known that asphalt pavements present self-healing properties when they register high temperatures during summer season, which means that cracks in the road can be closed by themselves. This happens because the viscosity of bitumen is temperature dependent. Thus, when bitumen reaches a temperature threshold (30–70 °C), which is different for each type of bitumen, it starts flowing through micro-cracks opened in the pavement, in a sort of capillary flow [16]. Consequently, metallic fibres can be used to increase heating rates of asphalt mixtures considering that these fibres can absorb and conduct more thermal energy than the other components of the mixture, aggregates and bitumen. Crack-healing of asphalt mixtures using electromagnetic heating consists on adding metallic fibres (steel wool) to the mixture, which are electrically conductive and magnetically susceptible to an electric field [17]. Therefore, with the help of an electromagnetic radiation device such as a microwave oven, it is possible to heat the asphalt mixtures with fibres, melting the bitumen and repairing opened cracks existing in the pavement. Microwave radiation is a heating technique where asphalt materials are exposed to alternating electromagnetic fields, in the order of Megahertz [20]. In previous researches, this microwave heating technique has shown potential for the crack-healing of asphalt mixtures [21] and polymeric composite materials [22] reinforced with steel wool fibres, although it has not been deeply explored.

This paper has been prepared in the frame of a research project focused on the development of a new fibre-reinforced asphalt mixture with self-healing properties via microwave heating [23]. For this reason, electrically conductive steel wool fibres have been mixed into the asphalt mixture. The addition of fibres may influence the physical and mechanical behaviour of the material. However, the mechanisms involved on these effects and the relationship between them and the fibre content needed for self-healing purposes requires further study. For these reasons, the steel wool fibres spatial distribution and their influence on the physical and mechanical properties of asphalt mixtures have been studied. To reach these objectives, five different dense asphalt mixtures, with the same aggregates gradation and bitumen content, but with five different percentages of steel wool fibres have been evaluated in the laboratory.

2. Materials and methods

2.1. Materials

A dense asphalt mixture has been used in this research. The mixture composition is shown in Table 1. The aggregates consisted of coarse aggregate or gravel (size between 5 and 12.5 mm, and density 2.779 g/cm^3), fine aggregate or sand (size between 0.08 and 5 mm and density 2.721 g/cm^3), and filler (size < 0.08 mm and density 2.813 g/cm^3). The bitumen used was type CA24 with a penetration of 5.6 mm at 25 °C and density 1.039 g/cm^3, according to Chilean Standard [24]. Properties of the bitumen used are shown in Table 2. In addition, steel wool fibres (see Fig. 1(a)) were added to the asphalt mixture. The material of the fibres was a low carbon steel with density 7.180 g/cm^3. The fibres had an average diameter of 0.157 mm with average aspect ratio of 30 and initial length ranged from 2 to 8 mm (see fibres length distribution in Fig. 1(b)), which means that both short and long fibres were added to the asphalt mixture matrix. Finally, different percentages of fibres were added to the mixture: 0%, 2%, 4%, 6% and 8%, by total volume of bitumen, to obtain five different types of asphalt mixtures: one asphalt mixture without fibres (reference mixture)

Table 1
Composition of the asphalt mixture.

Sieve size (mm)	Aggregate mass % retained	Cumulative aggregate mass % retained
12.5	16	16
10	13	29
5	24	53
2.5	16	69
0.63	17	86
0.315	4	90
0.16	3	93
0.08	2	95
<0.08	5	100
Bitumen CA24	(% of mass in the mixture)	5.3
Steel wool fibres (% volume of bitumen)	Length range (mm)	Average diameter (mm)
2% fibres 4% fibres 6% fibres 8% fibres	2–8	0.157

Table 2
Properties of the bitumen CA-24.

Experimental tests	Result	Standard Specifications
Absolute Viscosity at 60 °C, 300 mm Hg (P)	3077	Min 2400
Penetration at 25 °C, 100 g. 5 s. (0.1 mm)	56	Min 40
Ductility at 25 °C (cm)	>150	Min 100
Spot test hep./xil. (%xylene)	<25	Max 30
Cleveland Open Cup Flash Point (°C)	332	Min 232
Softening Point R&B (°C)	51	To be reported Min 99
Trichloroethylene solubility (%)	99.9	–
Penetration Index	−0.7	−1.5 a + 1.0
RTFOT		
Mass Loss (%).	0.00	Max 0.8
Absolute Viscosity at 60 °C, 300 mmHg (P)	7475	To be reported Min 100
Ductility at 25 °C, 5 cm/min (cm)	150	–
Durability Index	2.4	Max 3.5