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Self-healing of asphalt mixture by microwave and induction heating

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ABSTRACT

This paper aims to evaluate the effect of microwave and induction heating on the self-healing of asphalt mixture test samples. With this purpose, dense asphalt mixtures with four different percentages of steel wool fibres have been prepared to build semi-circular asphalt test samples. Asphalt self-healing has been characterised as the three-point bending strength of test samples before and after healing. This process was repeated ten times in every test sample. Moreover, self-healing was induced in the semi-circular test samples by heating them under microwave and induction. Besides, the chemical degradation of asphalt mixture under microwave and induction heating was monitored by measuring the mass of test samples before and after the heating process. It was found that microwave technology is more effective than induction heating to heal cracks in asphalt roads. Furthermore, the healing level of asphalt mixtures reduced with every healing cycle, until the test specimens could not resist more damage-healing cycles. It could be seen that microwave heating degrades bitumen, and increases the porosity of asphalt mixture. Finally, it was hypothesised that air voids in mixture play an important role in asphalt self-healing by increasing the internal pressure and mobility of bitumen during the heating process.

1. Introduction

Asphalt mixture is the main material used for building roads in the world. It is a composite material formed by aggregates and bitumen. Bitumen is a hydrocarbon product derived from petroleum and it is used to bind the aggregates [1]. Viscosity of bitumen is temperature dependant, and this causes that bitumen behaves as a Newtonian fluid when its temperature is above a certain threshold, between 30 °C and 70 °C [2], while its behaviour is non-Newtonian below this threshold. However, the reasons for this behaviour are still unclear.

Moreover, asphalt mixture is a self-healing material. When a cracked asphalt road is exposed to a temperature above the temperature threshold, bitumen can flow through the cracks, filling them [3]. Bitumen drains from the asphalt mixture into the cracks until the pressure and surface tension of bitumen filling the cracks equals that in the asphalt mixture [4]. Furthermore, cracks can self-heal if asphalt roads are not exposed to traffic loads that may open them even more [5]. However, this process may require several days for complete healing, which in practice is impossible due to continual traffic flow [6].

In addition, it has been previously reported that asphalt self-healing is influenced by (1) the viscosity of bitumen (bitumen with low viscosity accelerates the self-healing process [7]); (2) the chemical composition of bitumen (bitumen of different origins has different composition and healing properties [8]); (3) the age of the road (asphalt roads tend to become stiffer with time and environmental exposition [9]) (4) the type of aggregates used (mixtures where aggregates have a strong affinity for bitumen present better self-healing properties [10]) and; (5) the density of aggregate packing (mixtures with less dense and higher bitumen content show better healing properties [11]).

At the moment, there are different technologies in order to accelerate the healing process of asphalt mixtures. An example is asphalt induction heating [12], which consists in mixing ferrous materials in the asphalt mixture and exposing it to an alternating electromagnetic field with frequency in the order of Kilohertz [13]. This induces an electrical current in the ferrous particles that increase their temperature by the Joule principle, and the heat energy diffuses into the asphalt mixture, increasing the temperature of bitumen [11]. When this technique has been used in the laboratory, cracked asphalt beams have been able to recover up to 80% of their strength [14].

A second technique to increase the temperature of asphalt mixtures is microwave radiation heating, where asphalt materials are exposed to alternating electromagnetic fields, in the order of Megahertz [15]. Microwave heating affects to the water and bitumen in asphalt mixture. This causes that the polar molecules change their orientation as a result of the alternating magnetic field, which results in internal friction and in an increase of the temperature of the material. In addition, if ferrous particles are added to the mixture, these may reflect microwave radiation and accelerate the increase of temperature [16]. In previous researches ([17] [18],), this technique has shown potential for healing asphalt mixture and polymeric composite materials, although it has not been deeply explored. Additionally, authors have not found in the

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Table 1
Composition of the dense asphalt mixture.

Sieve size (mm)	Aggregate mass % retained	Cumulative aggregate mass % retained	Mass (g)
12.5	16	16	1056
10	13	29	858
5	24	53	1584
2.5	16	69	1056
0.63	17	86	1122
0.315	4	90	264
0.16	3	93	198
0.08	2	95	112
<0.08	5	100	350
Bitumen CA24	(% of massin the mixture)	5.3	350
Steel wool fibres (% volume of Bitumen)	Length range (mm)	Average diameter (mm)	
2% fibres	2–8	0.157	48
4% fibres			97
6% fibres			145
8% fibres			193

literature any document comparing asphalt healing via induction and microwave technology.

Finally, a third technique to accelerate asphalt self-healing is to replace fractions of aggregates in asphalt mixture with capsules containing oil [19]. When crack damage appears next to the capsules, they would open and release the oil, which would dissolve the bitumen and improve locally its flow capacity. Until now, it has been proven that capsules may resist asphalt mixing ([19] [20],), break in the presence of cracks [21], and release their content, softening bitumen around them.

The aims of this paper are to quantify the influence of asphalt induction and microwave heating on the self-healing properties of asphalt mixture along multiple breaking and healing cycles. With this purpose, (1) different amounts of steel wool fibres have been added into asphalt mixture; (2) their distribution in the mixture has been analysed; (3) physical and mechanical properties of test specimens have been studied; (4) asphalt test samples have been exposed to induction and microwave heating; (5) self-healing has been quantified through repeated breaking and healing cycles; and (6) the effect of induction and microwave heating have been analysed through Computed Tomography Scans of the test samples.

2. Materials and methods

2.1. Description of 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 [22].

In addition, steel wool fibres were added to the asphalt mixture (see Fig. 1(a)). The material used in the steel fibres was low carbon steel with density 7.180 g/cm^3. The fibres had an average diameter of 0.157 mm (see Fig. 1(b)) with average aspect ratio of 30 and initial length ranged from 2 to 8 mm (see fibres size distribution in Fig. 1(c)), which means that both short and long fibres were added to the asphalt mixture matrix (see entangled fibre in Fig. 1(d)).

Finally, 4 different percentages of fibres were added to the mixture: 2%, 4%, 6% and 8%, by total volume of bitumen. In total, 5 different types of asphalt mixtures were manufactured: 1 asphalt mixture without fibres (reference mixture) and 4 asphalt mixtures with different amounts of fibres, but using the same aggregates distribution and bitumen content.

2.2. Test specimens preparation

The materials were mixed in a laboratory planetary mixer at a mixing speed of 100 r.p.m. The amount of material in each mixture was approximately 6 kg (see Table 1). Materials were first heated

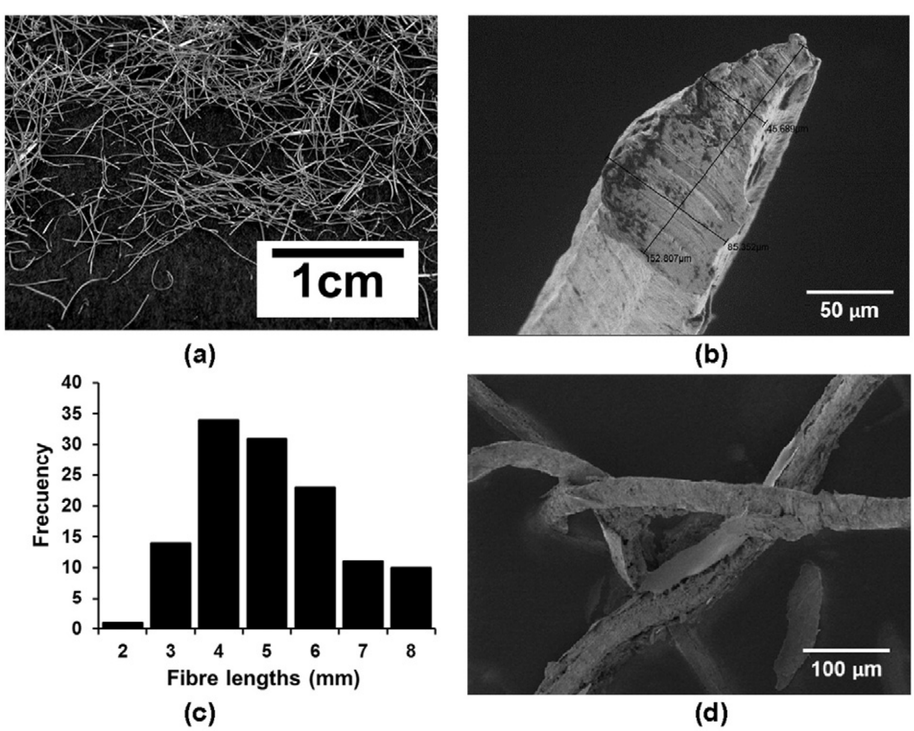

Fig. 1. (a) Steel wool fibres used. (b) Section of fibres. (c) Size distribution of steel wool fibres. (d) Fibres after mixing and compaction.