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Mechanical properties of asphalt mixture containing sunflower oil capsules

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ABSTRACT

Embedding encapsulated rejuvenators in asphalt mixture is a sustainable way to extend the lifetime of roads, and minimise the negative environmental impacts of current maintenance processes. The aim of this article is to investigate the use of encapsulated oil for use as rejuvenators in asphalt pavements. With this purpose, capsules of 5 different diameters have been built and their mechanical strength and composition characterised. Then, the capsules have been mixed in asphalt mixture, and their resistance to mixing and compacting has been observed. Finally, the effect of capsules in the indirect tensile strength, modulus, and fatigue life of asphalt mixture test samples has been quantified. It was observed that bigger capsules contained more oil and were less strong than smaller capsules. In addition, most of the capsules resisted the mixing and compaction processes. Asphalt mixture with capsules presented reduced indirect tensile strength and modulus, which happened because the capsules had lower strength than required. Finally, the fatigue life of asphalt mixture was not affected by the capsules.

1. Introduction

Asphalt mixture is a composite material of mineral aggregates and petroleum refined bitumen. When cracks (micro and macro) are generated in an asphalt road material, they can heal (close) when rest periods are experienced. Asphalt self-healing is a temperature-related phenomenon, which happens faster at higher temperatures. This healing process is the result of the temperature of the asphalt and therefore the bitumen, exceeding a certain threshold, generally between 20 °C and 40 °C based on previous research (Garcia et al., 2013). Asphalt self-healing almost stops below this threshold, while at higher temperatures the asphalt self-healing rate increases exponentially (Garcia et al., 2015a). At ambient temperature (20 °C), this process may require up to 1 month for complete healing (see reference Garcia, 2012), which in practice is impossible due to continual traffic flow.

Different authors have related that asphalt self-healing is influenced by (1) the viscosity of bitumen (bitumen with low viscosity accelerates the self-healing process (Pauli, 2014)); (2) the chemical composition of bitumen (bitumen of different origins has different composition and healing properties (Qiu, 2012)); (3) the type of aggregates used (mixtures where aggregates have a strong affinity for bitumen present better self-healing properties (Apeagyei et al., 2014)) and; (4) the density of aggregate packing (mixtures with less dense and higher bitumen content show better healing properties (Bhairampally et al., 2000)).

The self-healing process could be accelerated if capsules containing oil were added into asphalt mixture. Capsules would replace fractions of aggregates and stay in the mixture until crack damage appears. Then, the capsules would open and release the oil, which would dissolve the bitumen and improve its flow capacity (Garcia et al., 2010a). In addition, this process would decrease the stiffness of the mixture, rejuvenating and making it less prone to generate cracks.

In addition, current techniques to rejuvenate asphalt consist in spreading petroleum derived oils in the surface of the pavement (Boyer, 2000). As a result, oil does not normally impregnate the whole section of the pavement, only the first 10–20 mm from the surface, and may reduce the surface texture of asphalt roads (Asphalt maintenance and r, 2001). These problems can be minimised if capsules containing rejuvenators are introduced into asphalt mixture, and release their content when they detect an excessive ageing level in the pavement (Garcia et al., 2010a). Furthermore, replacing petroleum derived rejuvenators with encapsulated vegetable oils, such as waste cooking oil, would increase the lifetime, health and environmental standards of roads

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(Zaumanis et al., 2014), as vegetable oils have a strong chemical affinity with bitumen (Asli et al., 2012), are renewable materials (Yaakob et al., 2013) and if they are incorrectly disposed, they can pollute landfills and rivers (Vergara-Sanchez and Silva-Martinez).

In general, there are two types of capsules for releasing oil into asphalt mixture: those made by mechanical methods, see references (Garcia et al., 2010b) and (Garcia et al., 2011), and those made with chemical methods, see references (Chung et al., 2015; Su et al., 2013, 2014, 2015a, 2015c). In addition, different types of oil with rejuvenating properties, such as sunflower oil (Su et al., 2015b) and heavy aromatic oils (Garcia et al., 2010b) have been encapsulated and mixed into asphalt mixture in previous research. From these two materials, heavy aromatic oils may present human health risks in case the capsules are not perfectly sealed.

Capsules made by mechanical methods consist on a porous core, impregnated with oil and coated by a shell made of filler and a hard polymer. Their size may range from a few hundred microns to various millimetres. Capsules made by chemical methods are emulsion droplets surrounded by a thin polymeric layer, made of urea–formaldehyde or melamine–formaldehyde. Their size may range from under a micron to less than 100 μm. To date, authors have explained how to make the capsules (Garcia et al., 2010b, 2011; Chung et al., 2015), characterised them (Garcia et al., 2011; Su et al., 2014), proved that they resist asphalt mixing (Garcia et al., 2011; Su et al., 2013, 2015a), and show their rejuvenating and self-healing effects when they have been mixed with bitumen (Su et al., 2015b, 2015c; Zagar et al., 2012; Garcia et al., 2015b), although not with bitumen and aggregates, i.e. asphalt mixture, which is the real material used in roads. For both types of capsules, it is unclear if the mechanical properties of asphalt mixture will be affected by the presence of capsules, how many capsules will resist asphalt mixing and compaction, after how many loading cycles will capsules break, or if capsules are able to release the oil in asphalt mixture.

The aims of this article are (1) to quantify the effect of capsules containing sunflower oil on the strength and durability of asphalt mixture, and (2) to propose an optimum diameter of capsules has been proposed to minimise the number of capsules broken during mixing and compaction. With this purpose, capsules of 5 different diameters have been prepared using mechanical methods. The morphology, thermal stability, and mechanical properties of individual capsules have been examined. Then, capsules have been added into asphalt mixture and the percentage of surviving capsules has been calculated. Finally, the strength and durability of the mixture have been characterised and an optimum diameter of capsules has been proposed.

2. Experimental method

2.1. Capsule materials

Core materials used in the encapsulation included porous sand and sunflower oil. The porous sand was made of calcium silicate granules forming a microporous structure (Catsan hygienic litter, Effem Company, Verden), with 5 different particle sizes: 0.60–1.18 mm, 1.18–2.36 mm, 2.36–3.35 mm, 3.35–4.75 mm, and 4.75–5.6 mm. This material has thousands of micropores specially designed to absorb liquid. It has a density of 2.08 g/cm^3 and 87% of water absorption (Garcia et al., 2010b). See Fig. 1(a). These sizes of porous sand were originally chosen with the idea of substituting part of this fraction of aggregates in asphalt concrete with the capsules, to maintain the original specific surface of the aggregates.

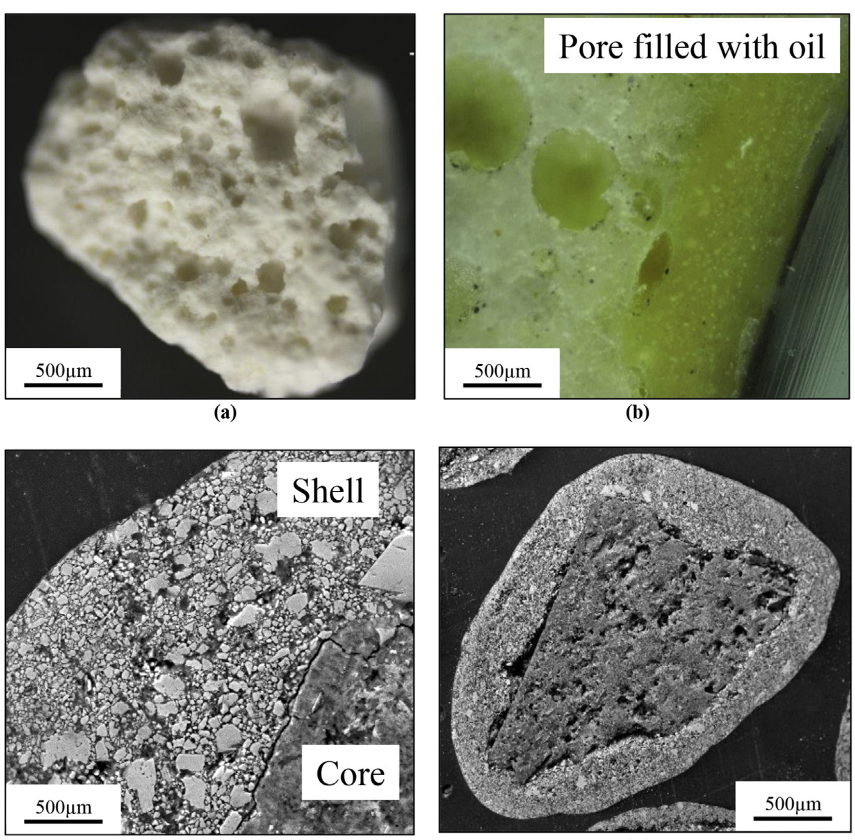

Fig. 1. (a) Porous sand. (b) Oil contained in the porous sand. (c) Detail of the shell. (d) Capsule.