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Internal asphalt mixture rejuvenation using capsules

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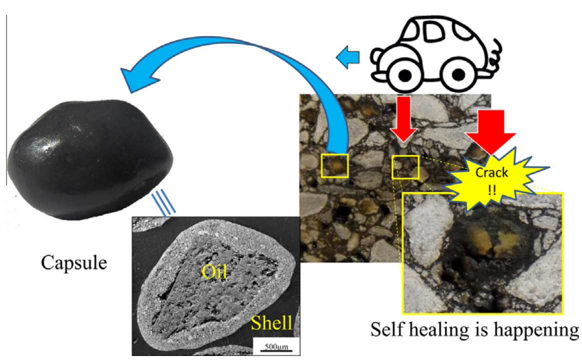
HIGHLIGHTS

- We have built capsules containing rejuvenators.
- We have mixed the capsules into asphalt mixture.
- The capsules reduced the viscosity of the mixture after a number of loading cycles.

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this article is to present the effect of capsules containing low-viscosity oil in asphalt mixture when they break under simulated traffic loading. With this purpose, sunflower oil capsules have been built and their mechanical composition and strength characterised. Then, the capsules have been added to asphalt mixture, as another aggregate, and slabs have been built. To quantify the effect of capsules in asphalt mixture, slabs have been subjected to cyclic loading for different numbers of cycles, let to rest and tested again. The differences in amplitude between cycles before and after the rest period have served to quantify the effect of capsules in asphalt mixture. In addition, the opening and healing processes of cracks have been observed by inspecting asphalt mixture before testing, after the cyclic loading, and after the rest periods, using computerised tomography scans. It was observed that (i) capsules broke gradually during cyclic compression; and (ii) oil from broken capsules softened (rejuvenated) the asphalt mixture during the rest periods.

1. Introduction

Asphalt roads are composed of bitumen and aggregates. Bitumen is a derivative of petroleum, of heterogeneous composition and is thermoplastic in nature. Aggregate particles are made from crushed stone with sizes varying from a few microns to several centimetres. The aggregates form the solid skeleton that maintains the material structure, while bitumen acts as the adhesive.

Asphalt mixture is a natural self-healing material. This means that when a crack is generated in the pavement structure, it can close (heal) when enough temperature and time without traffic are provided. This healing process is the result of the temperature of the bitumen exceeding a certain threshold (generally between 20 °C and 70 °C, [1]), which allows the bitumen to flow through the cracks, in a type of capillary flow [2]. However, this process may require several days for complete healing [3], which in practice is impossible due to continual traffic flow.

Although the phenomenon of asphalt self-healing is far from completely understood recent works have hypothesised that when two faces of a crack come together, the contact points in the crack melt, because bitumen is fluid. Then, 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].

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On the other hand, 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 [5]); (2) the chemical composition of bitumen (bitumen of different origins has different composition and healing properties [6]); (3) the age of the road (asphalt roads tend to become stiffer with time and environmental exposition [7]) (4) the type of aggregates used (mixtures where aggregates have a strong affinity for bitumen present better self-healing properties [8]) and; (5) the density of aggregate packing (mixtures with less dense and higher bitumen content show better healing properties [9]).

A way of improving the self-healing properties of asphalt mixture is to impregnate its surface with rejuvenators. These are liquids and consist on very aromatic distillates of petroleum (oil). Once on the surface of the road has been impregnated with rejuvenators, these diffuse in the mixture, reducing the viscosity of bitumen and reducing the viscosity of asphalt binder in the top portion of the pavement [10]. The problem is that the application of rejuvenators may reduce the skid resistance of asphalt roads, which can be significant for instance in runways or other areas where high speeds are likely to occur [11].

Previous researches have proposed to solve the problem of actual rejuvenators and improve asphalt self-healing by replacing fractions of aggregates in asphalt mixture with capsules containing oil [11]. When crack damage appears next to the capsules, they would open and release the oil, which would dissolve the bitumen and improve its flow capacity [12]. At the moment, there are two types of capsules containing rejuvenators. (1) Capsules with size under 100 μm consist of an oil droplet surrounded by a hard polymeric shell [14–19]. (2) Capsules with size above 100 μm consist of a porous sand core impregnated with oil and coated with a hard shell made of filler and epoxy [13]. Both types of capsules have been described in previous research (e.g. in references [8,11,12]); in addition, it has been proven that they resist asphalt mixing [13], break in the presence of cracks [17], and release their content, accelerating healing in bitumen, without aggregates [18]. The improvement of asphalt mixture self-healing, which is the actual material used for roads, or the effect after he capsules open, has never been shown before.

The aims of this article are to (1) observe the breaking process of capsules in asphalt mixture under simulated traffic, (2) quantify the softening/rejuvenating and healing effects of capsules after they break and release the oil in the mixture. With this purpose, capsules of 3.58 mm average diameter have been prepared. Their morphology, thermal stability and compressive resistance have been examined. Then, asphalt mixture slabs containing capsules have been prepared and subjected to cyclic compressive loading. Finally, the effect of capsules on the response of cyclic loading and self-healing of asphalt mixture has been quantified.

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 diameter between 2.36 mm and 3.35 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 [11]. The material used to fill the porous sand was sunflower oil. It was chosen because sunflower oil is a material that has been previously used as a rejuvenator for asphalt mixture [20] and because it is an easy material to find and has low health and environmental hazards.

The capsule wall-forming materials were particles of cement Type I 52.5R bonded by liquid epoxy resin (SP 106 Multi-Purpose Epoxy System). The medium particle diameter of cement Type I is typically about 10–20 μm. Cement was chosen because of its fineness, but any other type of filler could have been used.

The density of sunflower oil is 0.918 g/cm^3, of the porous sand, 2.315 g/cm^3, of the cement, 3.141 g/cm^3, and of the hardened epoxy 1.164 g/cm^3.

2.2. Encapsulation procedure

The capsules containing oil were fabricated following the method explained in reference [11]. First, the porous sand was sieved to the size mentioned above. The sand was dried in a stove at 70 °C during 24 h, to remove as much moisture as possible. To make the core of the capsules, 150 g of the porous sand were put in a tall container. Then, the oil was added until the sand was completely covered and everything was placed in a vacuum oven during 45 min, at 105 °C to reduce the viscosity of the oil, remove the air, and force the oil to penetrate into the porous sand voids. Finally, the excess oil was removed and the porous sand, now with oil inside the grains, was shaken by hand to homogenise it.

To produce the shell, the epoxy and the porous sand with oil were mixed by hand in a weight ratio 1:5 until all grains were uniformly covered by epoxy. In another container (20 cm diameter × 20 cm height), 12 steel balls with a diameter of 2 cm, 1 kg of cement, and the porous sand with oil and the epoxy were added. Then, the container was energetically agitated during 15 s, to separate the particles and allow the cement to form the shell.

Later, the capsules were sieved from the cement and let to cure for 8 h at 20 °C under a continuous horizontal movement at 400 rpm. After this, extra epoxy in a weight ratio 1:20 (1 g of epoxy for each 20 g of capsules) was added to cover the capsules surface and the capsules cured again for 8 h at 20 °C under a continuous horizontal movement at 400 rpm. For an example of the capsules, see Fig. 1.

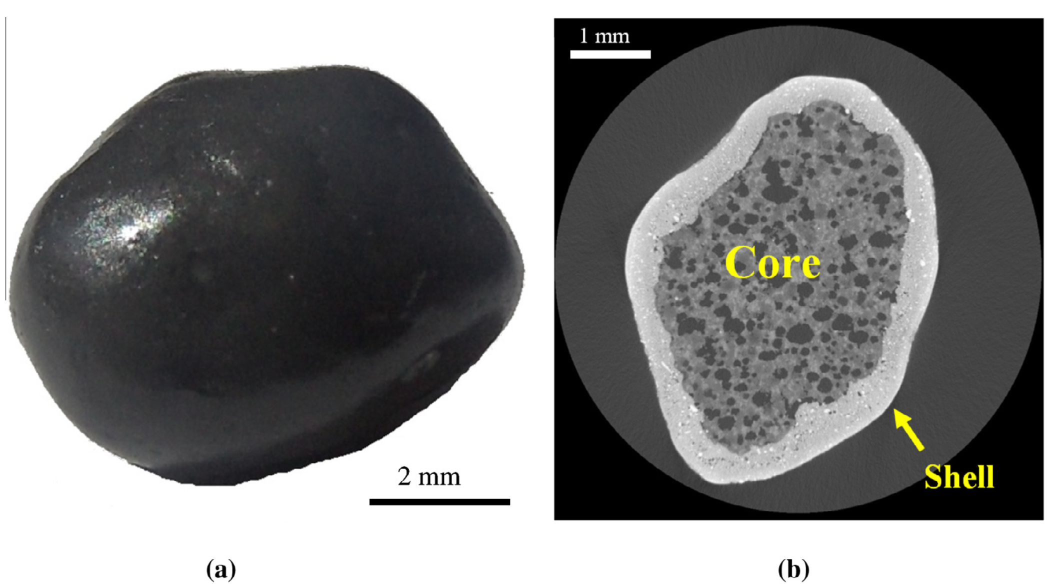

Fig. 1. (a) External aspect of a capsule. (b) Internal configuration of the capsules.