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Effect of bitumen properties in the induction healing capacity of asphalt mixes

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HIGHLIGHTS

- Effect of bitumen properties on induction healing capacity of asphalt mix was studied.
- Asphalt mixes with five types of bitumen were studied.
- Bitumen properties and healing capacity are not linearly correlated.
- Possible non-linear correlation between healing and coefficient of thermal expansion.
- Possible non-linear correlation between healing and stiffness and viscosity.

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ABSTRACT

The visco-elasto-plastic nature of asphalt mixtures gives the material the capacity to self-heal cracks. One of the most promising methods to accelerate the healing phenomenon is the addition of conductive particles to the mix that can be externally heated by applying electromagnetic induction. The present paper studies the influence of bitumen properties on the induction healing capacity of asphalt mixtures. The main conclusion that can be extracted is that, for the range of bitumens commonly used in Europe, the fact of changing the type of bitumen does not significantly affect the healing capacity of the resulting asphalt mix.

1. Introduction

Asphalt mixtures, most commonly composed by aggregates and asphalt bitumen, have been mostly used in road construction since, compared to other competitors like concrete pavements, they generally present advantages, such as lower paving costs [1], higher pavement-tyre adhesion even in wet conditions [2] and lower traffic noise [3]. Due to factors such as traffic loads and weather conditions, they progressively develop micro-cracks over the service life. If these are not properly treated in time, they can grow further and affect the structural integrity of the pavement, reducing safety and the comfort of traffic. As bitumen is a fluid, it tends to flow throughout the internal pore network of asphalt layers under the effect of gravity, capillarity, and hydrostatic forces until these forces reach equilibrium [4,5]. This flow can also occur through open cracks, which provides to asphalt materials the property of being self-healing [6]. However, as the viscosity of bitumen at environmental temperatures is significantly high [7], natural self-healing processes can last several weeks [8] and require that no traffic loads are acting in the given road section [9].

Two of the most promising methods to artificially accelerate the healing process are induction heating [6,10,11] and microwaves heating [12]. These methods involve the addition of electrically conductive particles to the mixture and their heating by applying an alternating electromagnetic field produced by an external coil [13]. The heat is transferred from the fibres to the embedding bitumen, reducing its viscosity. The temperature reached by the fibres depends on their diameters, material composition and lengths [14], it being possible to fully close cracks in seconds, as long as the global temperature of the mix is increased above a minimum threshold normally placed between 30 °C and 50 °C, depending on the type of bitumen used [8].

It is known that the main factors affecting this technology are the heating time and temperature [6,15,16], as well as the air voids content in the asphalt mix [17]. In addition, previous research

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described the effect of bitumen chemical composition and associated structure on asphalt pavement performance [18]. However, it is not clear yet how the intrinsic properties of bitumen affect the healing performance of the mix when subjected to electromagnetic induction. The present research aims at finding how far the fact of choosing a specific type of bitumen can improve the capability of asphalt mixtures to self-heal.

With this purpose, asphalt samples were manufactured with five different types of bitumen, from different sources and with different penetration grades, covering a wide range of binders that are normally used in Europe. For each binder, mechanical, rheological, compositional and thermal properties were obtained and correlated through statistical analysis to the healing performance of asphalt beams made with them.

2. Materials and methods

2.1. Description of materials

In this study, 5 different bitumens were used from different sources and pen grades, as shown in Table 1. The hot-mix asphalt samples for the induction self-healing were manufactured using limestone natural aggregate (density 2.67 g/cm^3), with continuous and dense gradation shown in Fig. 1. The target air voids content was set to 4.5%. The contents of the binders were fixed to 4.7%. Finally, the conductive particles used for induction heating were steel grit of uniform diameter between 1 and 2 mm. Metal grit was introduced in the mix by replacing the same volume of the natural aggregate in this fraction. The volumetric content of metal grit in the mix was fixed at 4%, corresponding to 11.2% by weight.

2.2. Manufacture of test specimens

Asphalt mixture was mixed in the laboratory at 160 °C for 2 min and then compacted in prismatic moulds by means of a roller compactor until the mixture reached the target air voids content. The dimensions of the obtained slabs were 310 × 310 × 50 mm^3. Then, eight 150 × 70 × 50 mm^3 prismatic samples (beams) were cut from each slab by a radial saw suitable for concrete and stone materials. Finally, a notch was cut at the midpoint of the bottom side in the direction of the loading from the central axis of the beams, with a thickness of 2 mm and a depth of 10 mm. This forced cracks to happen at the same point for all samples.

Table 1
Bitumen types used for the present investigation.

Ref.	Country	Supplier	Pen. grade	Needle pen. (10^{-1} mm)
1	Israel	Pazkar	40/60	49
2	Netherlands	Shell	70/100	70
3	Netherlands	Shell	50/70	46
4	Netherlands	Total	40/60	44
5	Netherlands	Total	70/100	73

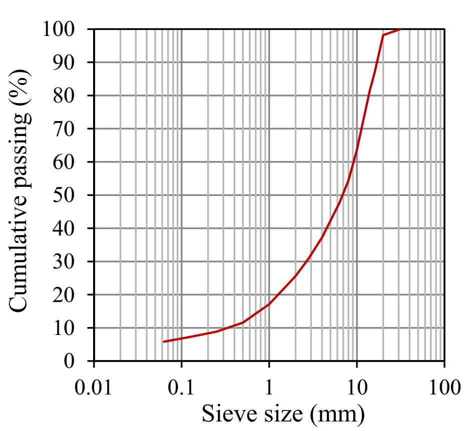

Fig. 1. Gradation curves of natural aggregate used for samples production.

2.3. Testing of asphalt self-healing properties

Asphalt self-healing was assessed through a 3-step test as follows:

First, the samples were split under 3-point bending configuration at −20 °C to produce brittle and clean cracks, without permanent deformation. The load was applied as an increasing ramp, under strain control conditions at a deformation rate of 50 mm/min. The ultimate force applied at the moment of break was registered as F_i. Then both separated halves were stored at 20 ± 2 °C for 4 h.

The second step consisted of gently putting both halves together and heating the set by means of electromagnetic induction (Fig. 2). An induction generator of 6 kW was used to supply electric current at 80 A and 348 kHz to a flat and square induction coil with dimensions 150 × 150 mm^2. With this configuration, the obtained heating power was 2800 W. The specimens were placed under the coil at a distance of 2 cm and exposed to induction heating for times that ranged between 15 s and 240 s. During the process, the surface temperature of the test samples was constantly monitored by using a 320 × 240 pixels, full colour infrared camera.

After that, the test samples were left at room temperature (20 ± 2 °C) for 4 h and then stored at −20 °C. Then, the 3-point bending test was repeated obtaining another ultimate force, F_f. The healing ratio (HR), or percentage of initial strength that was recovered due to a given healing process, was calculated as the ratio between F_f and F_i.

$$HR(\%) = \frac{F_f}{F_i} \tag{1}$$

It was explained above that batches of 8 samples were produced from the same slab. Thus, they have practically identical properties. When each of them is heated for a different time and consequently also reaching a different temperature, a different healing ratio is produced. Hence, curves of healing vs heating energy can be obtained.

2.4. Testing binder properties

2.4.1. Bitumen rheology

The rheology for the 5 types of bitumen has been studied according to Standard BS EN 14770-2012 [19] by using a dynamic shear rheometer (Bohlin Gemini HRnano), DSR Frequency Sweep, configured with a gap of 1 mm between the 25 mm spindle and the base, a range of oscillatory frequencies from 0.1 Hz to 10 Hz,

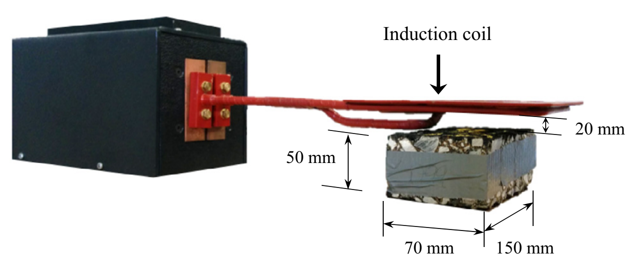

Fig. 2. Illustration of test sample subjected to induction heating.