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# Design and preparation of alginate capsules for in-situ rejuvenation in asphalt pavement joint mix

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**ABSTRACT:** An asphalt joint is formed when a fresh mix is laid and compacted next to an existing layer, brings about temperature difference during compaction, and therefore requires extra care in quality control and expose to higher cracking risks. Self-healing asphalt aims to stimulate the healing capacity of asphalt mixture and prolong its service life. The main objective of this study is to develop and optimize a calcium alginate capsules healing system for an asphalt joint mix. Capsules following two different self-healing concepts were prepared, namely conventional alginate capsules and conductive alginate capsules. Microscopy, Computed Tomography (CT) and Thermogravimetry analysis (TGA) were used to investigate the performance of alginate capsules. The results show that both types of capsules have a porous structure and a stable performance under high temperature, and therefore potentially survive from the asphalt mixing and production process. These capsules will be implemented and evaluated in full asphalt mix in future research.

## 1 GENERAL INSTRUCTIONS

### 1.1 Asphalt pavement joint

Asphalt mixture is widely used as a paving materials throughout the world. Generally, an asphalt joint is formed when a fresh mix is laid and compacted next to an existing layer, this usually causes a difference of temperature between two lanes during compaction, and therefore

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requires additional quality control to prevent pre-mature failure [1]. This joint concept can also be referred to asphalt plug joint which is used as the joint of a bridge to accommodate movements while ensuring a seamless transition between the bridge and the adjoining road surface [2].

However, the asphalt joint is vulnerable to significant cracking risks, mainly because of stress concentration and the challenges in ensuring quality during the construction process, and therefore requires frequent maintenance and has a relatively shorter lifetime (around 5~7 years) compared to conventional asphalt mix [3]. Hence, the primary objective of this research is to develop a more sustainable asphalt joint mix with enhanced performance and longer service life.

## 1.2 *Self-healing asphalt*

Asphalt is a self-healing material, and cracks generated in winter will somehow be healed during the rest period in summer. However, this intrinsic healing capacity is very limited. To improve this, various self-healing technologies were developed for asphalt, which included thermally induced methods and in-situ rejuvenation methods.

The thermally induced method aims to heat up the asphalt mixture with an external heating method, such as infrared heating, microwave heating and induction heating. All these thermally induced healing methods were proved to be effective in laboratory and gradually validated in field applications. However, these methods cannot solve the asphalt ageing problem and have a significant gradient or inhomogeneous heating-healing behavior. Moreover, the use of infrared and microwave heating is dangerous to humans and the lives nearby [4].

The in-situ rejuvenation method is to mix capsules/fibres that contained an asphalt rejuvenator into the asphalt mixture and allow the rejuvenator to release triggered by crack propagation, helping to close the cracks. The in-situ rejuvenation method is usually considered a slow process since it takes 24 to 48 hours for the rejuvenator to fully diffuse into the aged bitumen, but the aged bitumen rejuvenation makes the asphalt more durable after healing [4].

Recently, hybrid asphalt self-healing systems were developed to combine the advantages of different self-healing technology, and in-situ rejuvenation is usually an important part of the design [4]. To prolong the service life of asphalt joint mix, this study developed two different types of alginate capsules, namely conventional alginate capsules and conductive alginate capsules which can potentially achieve both in-situ rejuvenation and induction healing. Additionally, the morphology, microstructure and high-temperature stability of both types of alginate capsules were investigated using Microscopy, Computed Tomography (CT) and Thermogravimetry analysis (TGA), respectively.

## 2 MATERIALS AND METHODS

### 2.1 *Preparation of calcium alginate capsules*

The Calcium alginate capsules were prepared to achieve in-situ rejuvenation process. The information for materials used in the capsule preparation process is presented in Table 1. The sodium alginate salt, calcium chloride hexahydrate and magnetite powder are commercial products purchased from Sigma-Aldrich. As an environmentally friendly and economically viable alternative, soybean oil is used as the bio-rejuvenator in this study [5]. The alginate capsules were prepared with the following procedure: Firstly, all composites including alginate solution, rejuvenator and Magnetite powder (for conductive capsules only) were mixed; Then, the mixed solution are dropped into calcium chloride solution. Because of the reaction between alginate and calcium chloride, the dropped beads quickly form ball-shaped capsules and the calcium alginate capsules can be acquired after drying.

Table 1. The information of materials used in the capsule preparation.

| Materials                    | Producer and specification  |
|------------------------------|---|
| Alginate acid sodium salt    | Sigma-Aldrich, Product No. 180947   |
| Calcium chloride hexahydrate | Sigma-Aldrich, Product No. 442909   |
| Soybean oil                  | Bleumarine Bretania, Soy Bean Oil   |
| Magnetite powder             | Inoxia Ltd., EC 215-169-8 Purity $\text{Fe}_3\text{O}_4 >98.1\%$ and $\text{SiO}_2 <0.3\%$ , Density $4.6 \text{ g/cm}^3$ |

## 2.2 Microscopy and Nano-CT

A light Micro-scope was employed to investigate the diameter and morphology of both types of alginate capsules. A Phoenix Nanotom CT scanner was employed to investigate the microstructure and component distribution of both types of alginate capsules.

## 2.3 TGA

Thermogravimetry Analysis (TGA) was used to test the temperature stability of both types of alginate capsules. The analysis was conducted under argon gas (Ar) at a flow of 50 ml/min. The scanning began at 40 °C, increased at a rate of 5 °C/min until 160 °C, and then hold on 160 °C for 20 min. The mass changes within this period were recorded.

# 3 RESULTS AND DISCUSSION

## 3.1 Capsule morphology

Figure 1 shows the images of two types of alginate capsules. Most of the capsules have a stable, circular shape with uniform dimensions. The oil capsule is presented in light brown colour and has an average diameter of 2.74 mm (Figure 1a). The conductive is presented in black colour and has an average diameter of 2.82 mm (Figure 1b). Shiny particles can be found on the surface of the conductive capsules which can be magnetite powders attached within the outer layer of the calcium-alginate network.

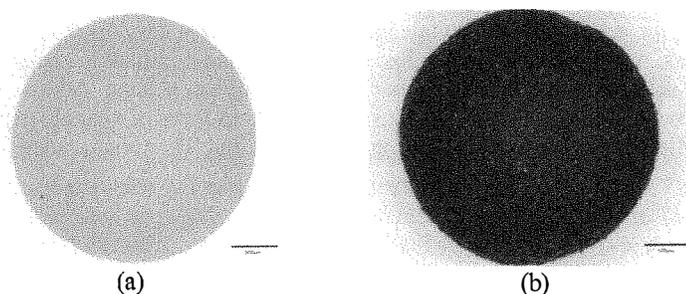


Figure 1. The microscopy of two different types of alginate capsules: (a) conventional alginate capsule encapsulating oil, (b) conductive alginate capsule encapsulating oil and conductive particles.

## 3.2 Capsule microstructure

Figure 2 shows the cross-sectional CT-scan images of both types of alginate capsules in which individual phases containing different brightness intensities can be segmented by grey-level thresholding. Figure 2a shows that the microstructure of oil capsules is composed of a complex cross-linking network and the soybean oil is contained in a large number of honeycomb-like rooms. While for the conductive capsules, Figure 2b shows that the grey value difference between phases is more significant, and the magnetite powders are presented in bright particles on the cross-sectional image. The Nano-CT scan results also demonstrate that all components are homogeneously distributed in all these capsules.

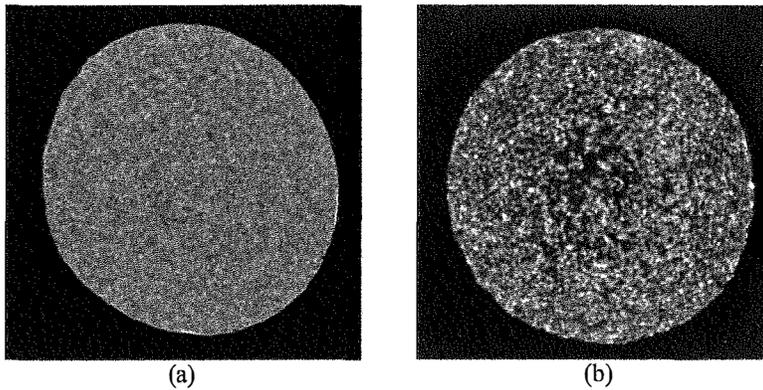


Figure 2. The microstructure of two different types of alginate capsules: (a) conventional alginate capsule encapsulating oil (oil capsule), (b) conductive alginate capsule encapsulating oil and conductive particles (conductive capsule).

### 3.3 High-temperature resistance

Figure 3 shows the TGA results of both types of alginate capsules in which the blue curve is referred to the calcium alginate capsules encapsulating industrial rejuvenator from previous study [4]. The results show that both types of capsules are relatively stable under 200°C, and the high-temperature stability is even better than the capsules prepared in the previous study [4], demonstrating a promising prospect to survive the high-temperature environment from the asphalt mixing and production process. However, the oil capsules are slightly more stable than conductive capsules, which might be because the conductive capsules have larger diameters therefore larger surface area for dehydration during the heating process.

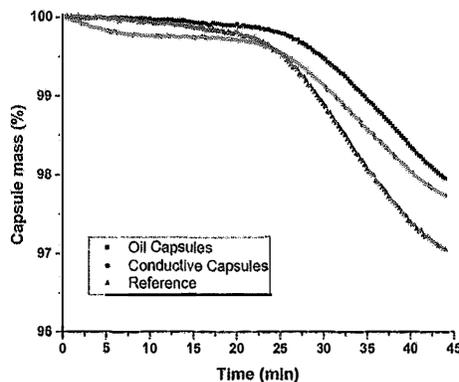


Figure 3. The TGA results of oil capsules and conductive capsules.

## 4 CONCLUSIONS AND RECOMMENDATIONS

This study developed and investigated two types of alginate capsules encapsulating bio-oil rejuvenator. The following conclusions can be drawn:

- The oil capsules are presented in light brown colour and have an average diameter of 2.74 mm, while the conductive capsules are presented in black colour and have an average diameter of 2.82 mm.
- Both types of capsules have sufficient high-temperature resistance to survive the asphalt mixing and production process.

This paper presents an initial exploration of the in-situ rejuvenation system for the on-going project 'Self-healing Asphalt Pavement Joint' (SHAPJ), and the thermally induced healing systems will be included. Further research findings will be presented in subsequent publications.

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