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# Physico-mechanical properties of asphalt concrete incorporated with encapsulated cigarette butts

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## HIGHLIGHTS

- Encapsulation of cigarette butts (CBs) with bitumen or paraffin wax has been studied.
- Inclusion of encapsulated CBs (ECB) in asphalt concrete (AC) has been investigated.
- Physico-mechanical properties of AC with different % of ECB have been discussed.
- AC with 10 and 15 kg/m$^3$ of ECBs with bitumen satisfied all the traffic requirements.
- AC with 10 kg/m$^3$ of ECBs with paraffin satisfied the light traffic requirements.

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## ABSTRACT

Discarded cigarette butts (CBs) are among the most common types of litter found around the world. As a possible solution to this problem, this study investigated the possibility of encapsulating CBs with different classes of bitumen and paraffin wax, and incorporating them into asphalt concrete (AC) for pavement construction. The idea behind encapsulation involves restricting the interaction of CBs with fluids and thus preventing chemical translocation. This paper presents and discusses the results of two investigations. The first involved assessing the effects of incorporating different amounts of CBs (10 kg/m$^3$, 15 kg/m$^3$ and 25 kg/m$^3$) encapsulated with different classes of bitumen (C170, C320, C600) into an AC mix manufactured with Class 170 bitumen. The second involved assessing the effects of incorporating 10 kg/m$^3$ of CBs encapsulated with paraffin wax into AC mixes that were manufactured with different classes of bitumen (C170, and C320). All samples, including the control AC samples (no CBs), were tested for mechanical and volumetric properties, including stability, flow, resilient modulus, bulk density, maximum density, air voids, and voids in mineral aggregates. For the first investigation, involving encapsulation of CBs with bitumen, using 10 kg/m$^3$ and 15 kg/m$^3$ of CBs in an asphalt mix gave results that satisfied the requirements for light, medium and heavy traffic conditions. For the second investigation, involving encapsulation of CBs with paraffin wax, the changes in mechanical and volumetric properties for 10 kg/m$^3$ CBs only satisfied the light traffic conditions for road pavements. The reduction in bulk density of AC caused by incorporating encapsulated CBs, increases the porosity, particularly when encapsulating in higher grade bitumen, which, in turn, lowers its thermal conductivity. This helps reduce the Urban Heat Island effect in urban environments.



## 1. Introduction

### 1.1. Recycling waste in asphalt concrete

Asphalt concrete (AC), which is also known as asphalt or dense graded asphalt [4,56], is commonly used in the construction of roads and pavements. It consists of up to 96% coarse and fine aggregates with the rest being filler and a bitumen binder [5]. Asphalt is usually mixed, spread and compacted whilst hot, and is therefore classified as a Hot Mix Asphalt [56]. It has a continuous distribution of aggregate particle size and filler, and low design air void content, ranging from 3 to 7% [46]. Rutting due to excessive permanent deformation, cracking due to fatigue, ravelling due to oxidation and hardening of the binder are common modes of failure for AC [5]. Therefore, attempts to improve the performance of

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AC are constantly being investigated [1]. The reuse and recycling of waste materials in asphalt mixes are gaining traction in the industry, and, despite complying with the required standards, are yet to achieve widespread adoption [42,43].

Crumb rubber from car tyres has been used internationally in asphalt mixes for many years [36], and has been successfully recycled into high strength concrete slabs. Experiments have confirmed that it improves the fire resistance in structural high strength concrete slabs by reducing the spalling damage caused by fire [26]. Recycled glass has also been investigated for use in AC. Pioneer Road Services [40] confirmed that using recycled glass in asphalt helped reduce the time for an asphalt surface to dry after it rains because the glass particles provide an impervious barrier. Another practice; namely, the incorporation of pulverised computer circuit boards, has been shown to increase the strength of AC [24]. A more interesting waste recycling practice involves the containment of nuclear and hazardous wastes. For example, bitumen has been used as an encapsulation medium for radioactive waste products in France, a technique that has been successfully practised for many decades [10].

Despite the potential benefits, several concerns arise when attempting to incorporate waste materials into Hot Mix Asphalt (HMA). Studies have shown that the inclusion of waste materials into HMA can affect the volumetric and mechanical properties of the mix [39,55,57]. However, according to a study by Kriech [29], traditional AC comprising aggregate, bitumen binder and filler has been shown to be a very benign material with little or no leachate properties of concern. Whilst little research has been undertaken to examine the leachate properties of asphalt mixes containing waste products, the findings suggest that the presence of bitumen in the mix restricts their interaction with water and reduces the translocation of the chemical disposition [7,13,45]. This indicates that bitumen is an excellent material to encapsulate waste materials, such as used CBs.

Bitumen is a highly viscous fluid derived from the distillation of crude oil with pre-existing natural wax [21,30]. The factors that influence the effect of wax on bitumen are the bitumen's chemical composition and rheological behaviour, the exposed temperature, and content, and the composition and crystallinity of the wax [15,58]. A study by Fazaeli et al. [21] involved analysing the influence of Fischer-Tropsch paraffin (FT-paraffin) wax on bitumen. The results indicated that the performance of bitumen at high temperatures improved under the influence of FT-paraffin, resulting in the asphalt mixture having increased resistance to permanent deformation. As FT-paraffin is a flow improver, the viscosity of bitumen at high temperatures is reduced. Consequently, the mixing and compaction temperature of the asphalt mixture decreases, resulting in lower energy consumption and emissions [14,15]. According to Fazaeli et al. [21], FT-paraffin has minimal influence on bitumen at intermediate and low temperatures.

To avoid the possible detrimental effects from paraffin wax, it is best that the wax content in bitumen is limited and should not exceed 3% [14]. In contrast, according to Wong and Li [58], in Mainland China, three different grades (A, B and C) are used to classify bitumen, with C comprising up to 4.5% paraffin wax but with the restriction that it can only be used for roads with lower traffic than A and B. The effects of wax on the bitumen quality and mixture performance have been reported differently. The debate on waxy bitumen is further complicated by the lack of a precise definition for wax, the different types of wax, and the poor precision of the test methods [31,58].

### 1.2. Cigarette butts

Cigarette butts (CBs) are one of the most common types of litter found around the world [2,9]. According to estimations from Euromonitor International [19], over 5.7 trillion cigarettes were consumed worldwide in 2013; and, each year, an estimated 4.5 trillion butts from the annual cigarette consumption are deposited somewhere in the environment [17]. This is equivalent to an estimated mass of approximately 1.2 million tonnes of CBs each year [32].

Although Euromonitor International [18] expects the global cigarette market to fall by 8% between 2015 and 2050, the consumption of cigarettes is expected to increase by more than 50% by 2025, mainly due to an increase in the world population [32,34,35]. This would suggest that billions of cigarettes will still be on the market in the future, and will lead to a continuation of a large number of CBs being deposited in the environment. In Australia alone, excluding illegal cigarettes on the black market, 16.2 billion cigarettes were consumed in 2015 [18,20], of which, approximately, 7 billion resulted in littered CBs [9,28].

The impact on the environment is exacerbated by the ubiquitous nature of CBs and long decomposition times. Plastic filaments, which are manufactured from synthetic fibres (cellulose acetate) derived from wood pulp, comprise 95% of CBs, and it is estimated that the decomposition of CBs varies from a couple of months to many years depending on the environmental factors [8,23,41,44].

Research indicates that the breakdown is at a reduced rate when the CBs are exposed to marine or freshwater conditions [9]. According to EPA Victoria [16]; it takes up to 12 months for CBs to break down in freshwater and 5 years in seawater. This is a major environmental concern, especially considering that 85% of the litter found in waterfront precincts is cigarette litter [54]. Cigarette filters are designed to absorb and trap particular smoke components, including tar and toxic chemicals [27].

The difficulty of dealing with cigarette butt waste is a global issue that is faced by municipal authorities and community groups throughout the world. Unfortunately, the research into applications for its reuse remains in their infancy [25], and commercially viable reuse is urgently required to ameliorate the ongoing effect arising from CB waste.

Given the low chemical reactivity of asphalt [29], and the large volume used in road and pavement construction, the addition of small quantities of waste materials, such as CBs, may result in viable applications in construction of flexible pavements while ridding the environment of this waste material. This paper presents and discusses the results of two investigations. The first involved assessing the effects of incorporating different amounts of CBs (10 $kg/m^3$, 15 $kg/m^3$ and 25 $kg/m^3$) into an AC mix manufactured with Class 170 bitumen after encapsulating them with different classes of bitumen (C170, C320, C600). The second part of the investigation involved assessing the effects of incorporating 10 $kg/m^3$ of CBs encapsulated with paraffin wax into AC mixes manufactured with different classes of bitumen (C170, and C320).

## 2. Materials and methods

### 2.1. Asphalt concrete incorporated with bitumen encapsulated CBs

#### 2.1.1. Encapsulation of CBs

Prior to mixing the CBs with AC, the CBs were exposed to heat in an oven at 105 °C for a period of 24 h (Fig. 1). This process dried the CBs and eliminated the moisture trapped inside them.

After drying, the second stage involved encapsulating the CBs by saturating them in hot bitumen (heated to 150 °C). As the characteristics of the bitumen constitute an important factor in the encapsulation of CBs, different classes of bitumen were used to compare and contrast their impact on AC. The classes of bitumen used were C170, C320 and C600 (Table 1). The C170 bitumen was provided by the Alex Fraser Group, and the C320 and C600 classes were provided by the Shell Company Pty Ltd of Australia.

Fig. 2 below displays the CBs that were encapsulated and left to cool on baking paper. It was found that soaking the CBs over a 5-min period allowed the hot bitumen to fully penetrate and be absorbed into the CBs.