Sustainability & Environment

Possible recycling of cigarette butts in stone mastic asphalt

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Abstract

Trillions of cigarettes are produced every year around the globe, resulting in a large amount of mephitic waste cigarette butts (CBs) being dumped into the environment. Waste CBs take years to decompose with most containing a cellulose-acetate based filter, tar, nicotine, tobacco, and many highly toxic chemicals that leach into the soil and waterbodies thereby resulting in contamination and toxicity. In the area of asset management, the road and highway sector is the largest in the world. This research work has investigated the possible recycling of CBs in stone mastic asphalt. Waste CBs were processed and encapsulated with bitumen before the preparation of the mix. Modified stone mastic asphalt samples were prepared by replacing up to 2% of coarse aggregate with bitumen encapsulated CBs in accordance with the existing AASHTOO and Austroads guidelines. Laboratory tests were conducted on the CB modified asphalt samples and the results were compared with those of the standard control samples prepared without CBs. The preliminary results found are promising and show that recycling encapsulated CBs in asphalt concrete could contribute a solution to CB pollution around the world. This paper presents the experimental procedures and discusses some of the significant outcomes of the study.

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1. BACKGROUND

1.1. Cigarette butt pollution

Around the world, approximately one billion people are cigarette smokers [1]. As reported by Euromonitor, during the year 2013, the total production of cigarettes was 5.7 trillion, 99% of which have a cellulose acetate (plastic based) filter. This production is expected to increase to 9 trillion by the year 2025 [2-4]. Hence, the ongoing concern about the recycling of waste cigarette butts. The 'Cigarette Butt Pollution Project' in the USA estimated that approximately one-third of the total production is littered in the environment [2, 5]. Cigarette butts contain toxic materials that spread into the environment slowly as cellulose acetate is photodegradable but not biodegradable [6]. In order to save the environment from the pollution caused by waste cigarette butts, efficient recycling methods are needed.

Cigarette butt waste clean-up is very costly, with a San Francisco litter audit study finding the cost to be more than $7 million annually [5]. Furthermore, the incineration of waste cigarette butts creates hazardous fumes that are severely detrimental to public health and the environment [7]. However, waste cigarette butts can be collected and processed for recycling in construction materials. Recent research at RMIT University has proved that waste cigarette butts can be used in the preparation of clay bricks [2, 8]. Mohajerani et al. (2017) developed a CB encapsulation method to incorporate CBs in dense asphalt for the first time [9]. Dense asphalt was prepared with bitumen C170 and C320 encapsulated with bitumen and paraffin wax, consecutively [9]. The results revealed the possibility of using encapsulated CBs in asphalt for light, medium, and heavy traffic conditions. The development of advanced materials incorporating waste cigarette butts will bring a new dimension to the construction materials.

Cigarette butt pollution exists all over the world. However, a sustainable technique to recycle waste CBs in asphalt concrete and bitumen can solve this problem. Previous studies have proved the prospect of recycling different waste materials in asphalt [10-12]. This study can contribute to the solution of CB pollution problem around the world and bring sustainability to the environment by introducing a new procedure to recycle CBs in asphalt concrete for flexible pavements. This research adds knowledge to the sector of waste management and the roads and highway industry.

1.2. Asphalt

Hot mix asphalt (HMA) can be dense or open graded. As the name suggests, dense-graded HMA has a lower void ratio compared to open grade HMA. Dense-graded HMA contains a large variety of particle sizes to spread through the asphalt concrete mix effectively. Furthermore, dense grade HMA suits all traffic condition types and is considered the most commonly used type of asphalt concrete around the world [13]. Open-graded HMA is typically used as a drainage layer due to the higher void ratio, which allows the mix to be more permeable [13, 14].

Stone mastic asphalt (SMA) is a gap graded asphalt that is commonly used throughout Europe [14]. The aggregates used in SMA mixes are often of higher quality compared to the aggregates used for standard HMA mixes due to the superior physical and mechanical properties that are required for the stone-to-stone contact structure. The high content of coarse aggregates in SMA creates high rutting resistance and improves the longevity of the structure [15].

The comparative differences between HMA and SMA are illustrated in Table 1. Although the gradation may vary among the different types of asphalt, the basic ingredients are mostly the same. In the case of HMA, open-graded aggregates and bitumen are used, while gap-graded aggregate, fibers, and bitumen are used in SMA.

Table 1: Advantages and disadvantages of HMA and SMA [14-16].

Type of Asphalt	Advantages	Disadvantages
Hot Mix Asphalt (HMA)	Low cost Effective in all traffic conditions	Lower rutting resistance Shorter service life Poorer quality aggregates used
Stone Mastic Asphalt (SMA)	Long service life High resistance to deformation Increased fatigue testing life Noise-reductive properties Decreased water spray when raining	Low skid resistance High cost Increased risk of flat spots occurring due to SMA design procedure

1.3. Use of waste materials in asphalt

According to the statistics, around 95% of the world's highways are flexible pavements that are constructed using asphalt concrete [11, 17]. The use of additives and modifiers can improve the properties and performance of asphalt concrete. Several research works have been carried out to investigate the use of waste materials in asphalt concrete, such as rice husk, fly ash, palm oil fruit ash, coffee grounds, waste cooking oil, waste rubber ground, steel slag, copper mine tailing, waste plastic, and crushed glass, etc. [18-23]. Waste cigarette butts can be a potential modifier in asphalt concrete and can introduce advanced asphalt concrete that will exhibit better engineering properties in terms of the stability, resilient modulus, and flow of asphalt concrete.

2. RESEARCH DESIGN

This research was designed by following the industry standards. The materials were selected according to the Austroads and VicRoads guidelines. Stone mastic asphalt was selected for this part of the investigation. The research design diagram is shown in Figure 1. In this research, asphalt samples were prepared with CBs by replacing coarse aggregates up to 2% by weight. Volumetric analysis and preliminary performance assessment were carried out for all samples, and the results were reviewed and compared with the control samples.

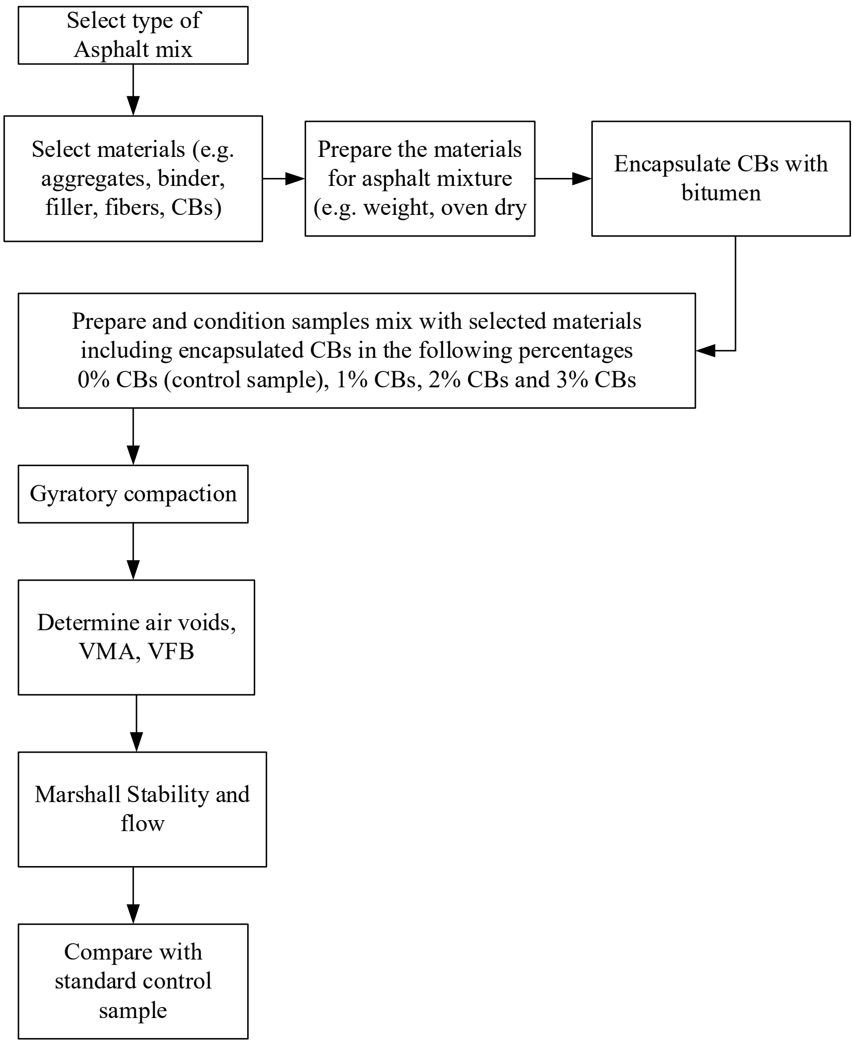

Figure 1: Research design

3. SAMPLE PREPARATION AND LABORATORY INVESTIGATION

3.1. Pre-processing and encapsulation of CBs

3.1.1 Background of CB encapsulation

Bitumen encapsulated CBs were first developed and incorporated in dense asphalt by Mohajerani et al. (2017) [9]. Encapsulation was done by curing oven dried CBs with hot bitumen. Figure 2 exhibits the bitumen encapsulated CBs and some of the dense asphalt samples prepared in this breakthrough research. The physical and mechanical performance of the samples were propitious and this work has widened the scope of research for recycling cigarette butts (CBs) in asphalt concrete [9]. Asphalt samples were prepared incorporating CBs 10 kg/m^3, 15 kg/m^3, and 25 kg/m^3, and without CBs (control samples). The impacts of different quantities of CBs encapsulated with different classes of bitumen in terms of the Marshall Stability and Flow of dense asphalt samples are shown in Figure 3.

Figure 2: Encapsulated CBs and a few dense asphalt samples used in the research conducted by Mohajerani et al. in 2017 [9]

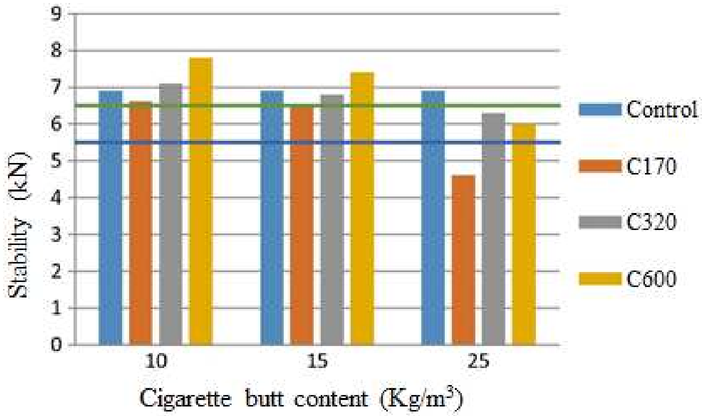

Figure 3: Marshall Stability and Flow of asphalt prepared with different amounts of CBs, encapsulated with C170, C320, and C600 [9]

Mohajerani et al. (2017) assessed the resilient modulus of asphalt concrete prepared with CBs and found that all the samples met the standard range 2500-4000 MPa for bitumen class C170 [9]. The results are shown in Figure 4.

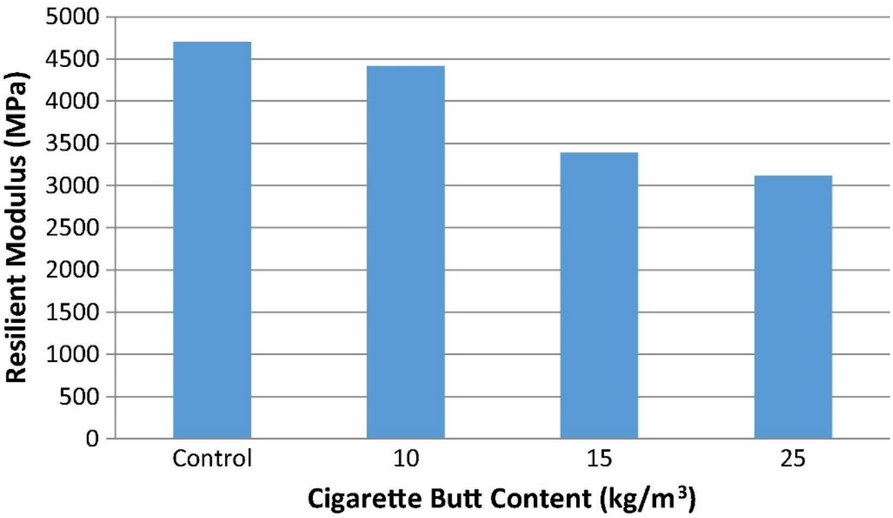

Figure 4: Resilient Modulus of Asphalt Concrete prepared with different amounts of bitumen class C170 encapsulated CBs [9]

3.1.2 Preparation of bitumen encapsulated CBs for stone mastic asphalt

Cigarette butts were pre-processed by encapsulation with bitumen. Encapsulation was achieved by curing CBs in hot liquid bitumen. Figure 5 and Figure 6 show the condition of the CBs before and after encapsulation, consecutively.

Figure 5: CBs before encapsulation. Waste CBs (left) and oven dried and cleaned CBs (right)

Figure 6: Encapsulated CBs

A few arbitrary encapsulated CBs were picked and cut into pieces to observe the sections. It was found that the CBs were encapsulated properly, and that all the pores of the CBs were filled with bitumen. The sections of the encapsulated CBs are shown in Figure 7.

Figure 7: Sections of Bitumen encapsulated CBs

3.2. Asphalt sample preparation

The samples were prepared in the laboratory following the Austroads and VicRoads standards. The type of aggregate was granite, the gradation of which was adapted from VicRoads section 404; illustrated in Table 2 [24]. The amount of materials used in the preparation of the sample is given in Table 3.

Table 2: Adapted gradation for the preparation of stone mastic asphalt

Sieve retained (mm)	% Passing (Adapted for this research)	% Passing range according to VicRoads Standard
9.5	95.0	90-100
6.7	35.0	25-45
4.7	32.0	18-32
2.36	22.0	15-30
<2.36	0.0	13-24

The stone mastic asphalt mix was prepared using selected aggregates as per the gradation, 6% of mineral fillers, 0.3% of cellulose fibers, and 6.5% of bitumen PMB class A10E. The asphalt mix was prepared at 170°C. Compaction was done with a Gyratory Compactor. Pictures of some of the prepared stone mastic asphalt samples are shown in Figure 8.

Table 3: Amount of materials in stone mastic asphalt sample

Aggregate Size (Retained)	% Measured for asphalt mix (by weight)
9.5 mm	4.36
6.7 mm	52.32
4.7 mm	2.62
2.36 mm	8.72
Fines	19.18
Filler (limestone)	6
Fiber	0.3
Bitumen	6.5

Figure 8: Preparation of stone mastic asphalt sample. Mix without addition of bitumen (top left), Mixing process with bitumen (top right), compaction done with gyratory compactor (bottom left), and compacted stone mastic asphalt samples (bottom right)

3.3. Laboratory testing

Preliminary laboratory investigation involved volumetric assessment and the Marshall Stability and Flow Test following AS/NZS 2891.5:2015 guideline. The stone mastic asphalt (SMA) samples were prepared following 4.8% - 5.2% air void according to VicRoads [24].

4. RESULTS AND DISCUSSION

After preparation of the control sample, the CB modified samples were prepared with bitumen encapsulated CBs by 1% and 2%. The aggregates retained in the 9.5 mm sieve were replaced with encapsulated CBs by weight. Volumetric analysis on the control sample and the Marshall stability and flow test were conducted for all the samples as a preliminary investigation. The results are shown in Table 4.

Table 4: Preliminary test results

Type of Sample	Type of test	Test Results	Standard check with the range
Control Sample	Air void	5%	VicRoads and Austroads (4.8%-5.2%)
	VMA	19.1%	VicRoads and Austroads (13%-20%)
	VFA	73.8%	VicRoads and Austroads (65%-80%)
	Marshall Stability	13.6 KN	VicRoads and Austroads (minimum 5.5KN)
	Flow	10.8 mm	Asphalt Institute (8 mm-16 mm)
Sample with 1% CBs	Marshall Stability	13.9 KN	VicRoads and Austroads (minimum 5.5KN)
	Flow	9.2 mm	Asphalt Institute (8 mm-16 mm)
Samples with 2% CBs	Marshall Stability	15.1 KN	VicRoads and Austroads (minimum 5.5KN)
	Flow	10 mm	Asphalt Institute (8 mm-16 mm)

The results show an increase in the stability with the increase of CBs in the mix. Figure 9 shows the change in stability of the samples before and after modification with encapsulated CBs. This shows that CB modified stone mastic asphalt can sustain under higher loading conditions. It has been observed that encapsulated CBs in stone mastic asphalt improves the strength. The flow value is within the range of 8-16 mm. Comparative analysis shows a better perspective of the results in Figure 10.

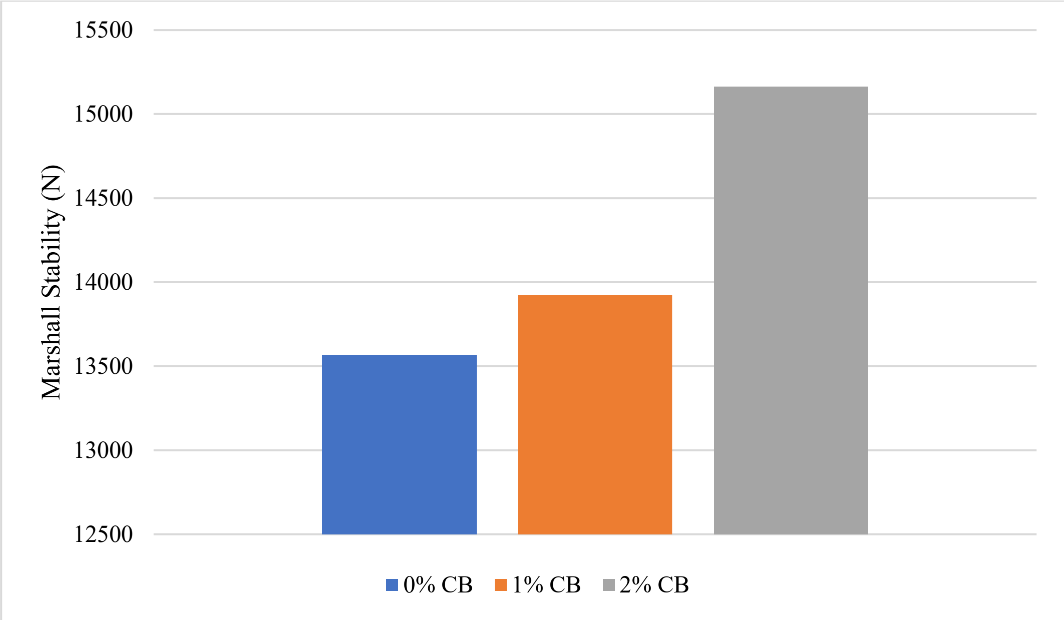

Figure 9: Stability of the samples

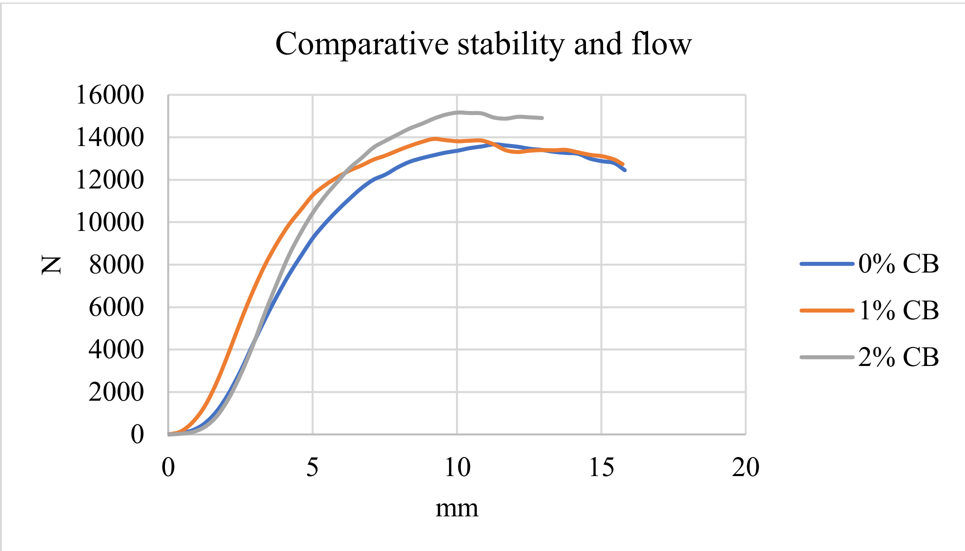

Figure 10: Comparative analysis of Marshall stability and flow results

The sustaining period of the samples was analyzed based on the Marshall stability and flow results in figure 11. It was found that the control sample with 0% CBs had a higher sustaining period, which is 13 seconds, however, this sample failed at a lower loading condition. Although the samples with 1% CBs and 2 % CBs failed quickly compared to the control sample, they can sustain higher loading conditions. The addition of 2% CB stone mastic asphalt presented a better sustaining period than the sample with 1% CBs under higher loading conditions.

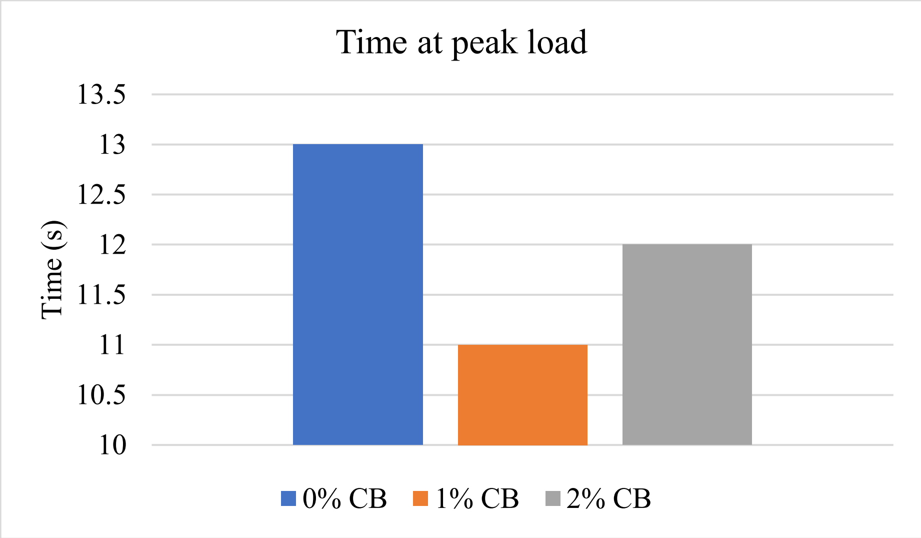

Figure 11: Sustaining period of samples

5. CONCLUSION

The aim of this study was to recycle waste CBs in asphalt. Stone mastic asphalt samples were prepared with bitumen encapsulated CBs in this research and the Marshall stability and flow test were performed to assess performance. The results from the laboratory investigation herald a new area to explore in the sector of advanced materials for flexible pavements. This paper has presented and discussed some of the results from a comprehensive study on recycling cigarette butts in asphalt. The results are promising, as incorporation of CBs enhanced the performance of asphalt. The outcomes were analyzed and compared with the control sample. This investigation reveals a possible sustainable method to recycle CBs in stone mastic asphalt. The results of this research provide evidence of the mechanical properties of this advanced material. This confirms the prospect of bitumen encapsulated CBs in asphalt concrete. This method can recycle up to 15kg CBs in each m^3 of stone mastic asphalt. The improved method of encapsulation and mixing process was found suitable for heavy traffic conditions. This work contributes to the roads and highways sector in terms of adopting a sustainable approach in construction.

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