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Mechanical, durability and microstructure properties of Cold Asphalt Emulsion Mixtures with different types of filler

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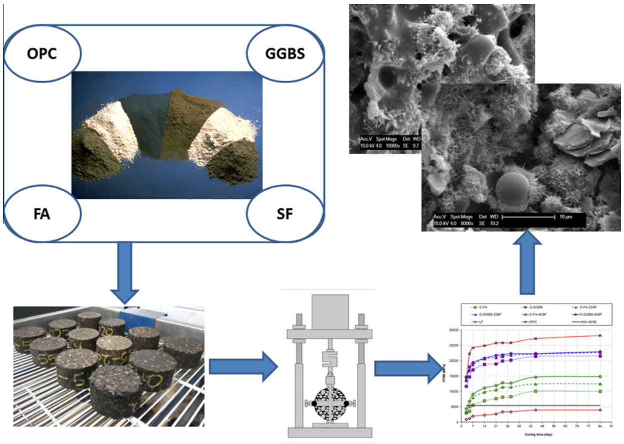
HIGHLIGHTS

- Study of engineering properties and microstructure of CAEMs.
- New approach to evaluate the engineering features via internal structure assessment.
- BBF in CAEMs produces a good performance compared to HMA and LF-CAEM.
- TBF in CAEMs produces a superior performance (especially SF and GGBS).
- SF in TBF-CAEMs alters the hydration mechanism and eliminates any hydration delay.

GRAPHICAL ABSTRACT



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ABSTRACT

The primary aim of this study is to investigate the enhancement of Cold Asphalt Emulsion Mixtures (CAEMs) using binary and ternary blended fillers (BBF and TBF), including an in-depth assessment of the microstructure. Ordinary Portland cement (OPC), fly ash (FA) and ground granulated blast furnace slag (GGBS) were used for the BBF while silica fume (SF) was added to the BBF to obtain TBF. The mechanical and durability results indicated that the TBF was more suitable than the BBF for the production of CAEMs. The microstructural assessment indicated that the effect of BBF on the internal microstructure of CAEMs was slightly negative and more noticeable in CAEMs containing FA. It is proposed that the addition of SF to BBF mixtures can eliminate the delay in formation of hydration products caused by the bitumen emulsion. Overall, the research suggests that the use of BBF-CAEMs might be appropriate for pavements in cold climate whereas TBF-CAEMs would be effective in road pavements exposed to severe conditions both in hot and cold climates.

1. Introduction

Nowadays, environmental issues about reducing energy consumption, reducing CO_2 emissions and managing wastes are being increasingly articulated and have been gaining attention

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worldwide. One of the most significant trends towards more eco-friendly asphalt mixes is the use of material such as recycled asphalt pavement, municipal solid waste incineration ash, construction and demolition waste material, cement kiln dust and coal ash [1–8].

Due to the many significant environmental and economic benefits that can be derived from using cold asphalt mixtures (CAMs), several research projects have been performed to study and develop the properties of these mixtures. The development of CAMs has commonly been by utilizing waste material/ by-products while achieving satisfactory hot mix asphalt (HMA) properties [6,7,9,10]. However, CAMs for sustainable and resilient pavements still has to meet the requirements of carrying heavy traffic loads from a mechanical perspective. Additionally, the properties of CAMs need to resist the impact of the environment from a durability perspective. In the current research, these two features will be termed as engineering properties. The enhancement of the engineering properties of CAMs mainly depends on the type, quantity and quality of the raw materials used. This might be considered as one of the most important factors to extend the use of CAMs for the use as a surface course.

Fillers can play a major role controlling the engineering properties of asphalt mixtures. It has been demonstrated that filler can significantly influence permanent deformation resistance, stiffness, fracture resistance, and moisture susceptibility of asphalt concrete [11,12]. A recent development aimed at achieving excellent engineering properties of CAMs is the use of manufactured fillers. This kind of filler is produced as a blend of reactive, semi-reactive and non-reactive natural fillers [6,7,13,14]. In this study, binary blended fillers (BBFs) contain a combination of fly ash (FA) or granulated blast furnace slag (GGBS) with ordinary Portland cement (OPC), while the ternary blended fillers (TBFs) are a combination of BBFs with silica fume (SF). These fillers are used for many reasons. FA, GGBS, SF are considered to be some of the most used supplementary cementitious material alternatives. Furthermore, their availability worldwide in substantial quantities can provide social, economic, and environment benefits.

An experimental study by Oruc et al. [13] assessed the mechanical properties of emulsified asphalt mixtures including 0–6% OPC, which was substituted for mineral filler. Their findings showed a remarkable improvement with a high percentage of OPC treatment, recommending these mixtures to be used as a structural layer. Al-Busaltan et al. [6] confirmed the enhancement of close graded CAEM to a stage where its mechanical properties were comparable to those of traditional asphalt concrete mixtures. The improvement was due to the replacement of the conventional mineral filler with a domestic fly ash. Al-Hdabi et al. [15] showed a significant improvement in mechanical properties and water damage resistance of cold rolled asphalt by incorporating a biomass fly ash with cement. Recently, the influence of chemical additives including OPC, hydrated lime (HL), and a combination of HL and GGBS on recycled mixture performance was investigated by Du [16]. The results showed that hydration products can increase the stiffness and cohesion of the asphalt mastic of the recycled mixture [16].

A comparison study between using coal ash and OPC in cold recycled asphalt mixtures was carried out by Modarres and Ayar [1]. The results revealed that the application of coal waste powder improved the mechanical properties of cold recycled asphalt material, but it could not achieve a positive impact on moisture damage resistance. Based on these comparisons, coal ash was found to have comparable effects to OPC. While previous studies have highlighted the importance of using OPC, HL and some specific kinds of fly ash in developing CAMs, there is a need to develop more sustainable CAMs using artificial by-products such as FA, GGBS and SF in combination with OPC. The purpose is to reduce the potential increase in production costs and environmental issues particularly in the manufacturing process of both cement and lime. However, the availability of alternative cement materials should be considered when choosing the type of fillers in CAMs.

Pouliot et al. [17] showed that the presence of a small quantity of bitumen emulsion in cement mortar had a delaying effect on the cement hydration. Furthermore, Du [18] agreed with this study and proposed a mechanism for the hydration process delay. He suggested that some of the bitumen droplets and cement particles come into contact due to intensive chemical adsorption, and as a result, some of the cement particles are encapsulated by an asphalt film, causing a delay or interruption in the hydration reaction. A study carried out by Wang et al. [19] showed that the total hydration heat decreased with an increase in bitumen to cement ratio in CAEM. Also, the study revealed that the addition of bitumen emulsion significantly influenced cement hydration behaviour in CEAM. In contrast, a recent experimental study carried out by Fang et al. [20] revealed that the behaviour of bitumen emulsion in the presence of cement and filler is still unclear and may slightly retard or accelerate cement hydration, but has no significant effect on the degree of cement hydration. These research studies have demonstrated developments in the properties of CAEMs by using different types of filler. However, this raises an important question as to how these fillers (cement/artificial by-products) interact with bitumen emulsion and affect the hydration and microstructural characteristics of CAEMs.

2. Research significance

This study aims to develop special types of CAEM by using artificial by-products such as FA, GGBS and SF in combination with OPC. Accordingly, it is hoped that wider utilization of CAEMs in the construction of highway and pavement materials (with both environmental and economic impacts) can be derived from the current research. Meanwhile, this work is designed to contribute to a deeper understanding of the microstructure and internal composition of the mixes concerned.

3. Material and testing program

3.1. Material characteristics

The aggregate used in this study was crushed limestone. The physical properties of the aggregate were: apparent density 2.70 Mg/m^3; absorption 0.4%; Los Angeles Coefficient 28. The gradation of the aggregate was within the limits of 0/14 mm size close graded surface course, according to BS EN 13108-1. This selection was made in order to ensure an appropriate interlock between the aggregate particles in the

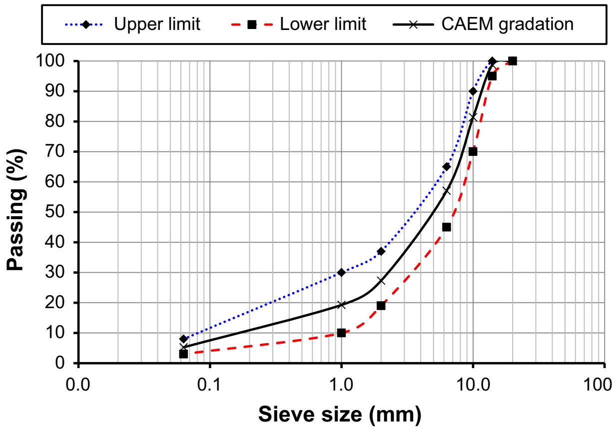

Fig. 1. Limestone aggregate gradation of 0/14 mm size close graded surface course according to BS EN 13108-1.