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High performance cold asphalt concrete mixture for binder course using alkali-activated binary blended cementitious filler

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HIGHLIGHTS

- An eco-friendly cold asphalt concrete for binder course mixtures has been developed.
- A novel alkali activated binary blended cement filler system has been uncovered.
- Mechanical and durability properties, and microstructure have been evaluated.
- Alkali activators have improved the levels of pozzolanic reactivity in the BBCF.
- A substantial improvement in mechanical properties for the novel ABBCF is demonstrated.

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ABSTRACT

A slow rate of curing and the long time necessary to achieve full strength has led cold asphalt mixes (CAM) to be considered poorer in comparison to hot mix asphalt over the last decades. This piece of research aimed to develop a new fast-curing and environmentally friendly cold asphalt concrete for binder courses mixture (CACB). It has the same gradation as that of traditional hot asphalt concrete mixtures but incorporates a binary blended cementitious filler (BBCF) containing waste, high calcium fly ash (HCFA) and fluid catalytic cracking catalyst residue (FC3R) activated by a waste alkaline NaOH solution. The research concludes that incorporating an alkali activated binary blended cementitious filler (ABBCF) with CACB significantly improves the mechanical properties and water susceptibility. In addition, the high performance ABBCF mixture has a substantial lower thermal sensitivity than traditional hot asphalt concrete binder course mixtures. SEM analysis revealed that the main crystallisation had taken place at an early stage of the new ABBCF. More significantly, the new CACB mixture has a comparable stiffness modulus with the traditional asphalt concrete binder course after a very short curing time (less than one day).

1. Introduction

Eco-friendliness, energy efficiency and cost effectiveness associated with safety are significant drivers accountable for the development of cold bituminous emulsion mixtures (CBEM) as a substitute for hot mix asphalts (HMA). CBEMs are popular types of cold asphalt mixtures (CAMs) that are produced with no application of heat in comparison to traditional HMA. Consequently, this technology contributes to the protection of environmental and occupational health and safety Needham [1,2]. In contrast to HMAs, CBEMs do not achieve their ultimate strength and other associated properties as quickly after application. CBEMs are identified to have low early strength, long curing times, the resultant mixtures having quite high porosites [3]. When comparing emulsion mixtures to HMA in general, they are of a relatively low quality as demonstrated by Ibrahim and Thom [4].

CBEM technology for road pavements has been employed in several countries. The USA and France have been using CBEMs since the 1970's and seem to have a substantial bank of knowledge about the performance of these mixtures [5]. The annual levels of manufacture has reached 1.5 million tonnes in France [6]. How-

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ever, using cold emulsified asphalt as structural layers which require a longer curing time for such materials to reach their full strength after construction is restrictive, mainly in the UK, because of high sensitivity to rainfall by these mixes in the early stages of installation [7]. Characteristics exhibited by emulsion bound mixtures continuously change (stiffness modulus, rutting resistance, water sensitivity, fatigue resistance, etc.) until they reach a steady state at a fully cured condition, although they may still contain a low amount of residual water. However, evolutional characteristics have been exhibited by CAMs, especially during their early life, where early cohesion is low, increasing gradually [8].

The mechanical properties of CBEMs have been examined by many researchers such as Terrel and Wang [9] who found that the addition of cement to emulsion-treated mixes resulted in an acceleration in the rate of the development of resilient modulus. Another study was implemented by Head [10] in order to improve the Marshall stability of modified cold asphalt mix. He found that with the addition of 1% Ordinary Portland Cement (OPC), the Marshall stability of modified cold asphalt mixes improved approximately 3-fold compared with un-treated mixes. An examination of the role of cement in emulsion-treated mixes to enhance the slow improvement of strength of these mixtures was carried out by Schmidt et al. [11]. They concluded that when cement was added to the aggregate at the time the asphalt emulsion was combined, mixes cured faster, additional resilient modulus (Mr) developed more quickly and there was a higher water damage resistance. Previous studies on the mechanical properties of three-phase cement–asphalt emulsion composites (CAEC) reported that most of the properties of both cement and asphalt were present in CAEC; longer fatigue life and low sensitivity to temperature in cement concrete and higher toughness and flexibility in asphalt concrete [12]. Brown and Needham [13] carried out a study on cement modified emulsion mixtures where the prime aim was the evaluation of the influence of adding OPC in emulsified mixes. They used a granite aggregate grading in the middle of 20 mm dense bituminous macadam with a single slow-setting emulsion. They concluded that the OPC addition enhanced the mechanical properties namely: stiffness modulus, resistance to permanent deformation and the fatigue strength of the emulsified mixes. Oruc et al. [7] performed an investigation to evaluate the mechanical properties of emulsified asphalt mixtures including 0–6% OPC which was substituted for mineral filler. A significant improvement was revealed with the addition of a high percentage OPC, leading them to speculate that cement modified asphalt emulsion mixtures might be utilized as structural layers. Al-Hdabi et al. [14] carried out experiments on the mechanical properties and water damage resistance of cold-rolled asphalt (CRA) incorporating OPC as a substitute to conventional filler and waste bottom ash (WBA). The results showed a considerable enhancement in stiffness modulus and uniaxial creep tests in addition to water sensitivity.

Other research implemented by Fang et al. [15] investigated the effect of cement on the rheology and stability of rosin-emulsified anionic bitumen emulsions. They used optical microscopy to examine how bitumen emulsion breaks and bitumen droplets morphology' in cement and filler. They concluded that cement, unlike limestone filler, reacts with rosin emulsifiers leading to flocculation and the partial coalescence of bitumen emulsions. Further to this, Gómez-Meijide and Pérez [16] proposed a new methodology for the global study of the mechanical properties of CAMs. They found that bitumen materials stabilized with emulsion and recycled aggregates from construction and demolition (C&D) are more flexible, showing improved resistance to permanent deformation and similar stress failures in comparison to mixtures with natural aggregates. That said, a higher water and bitumen content is needed [17].

Cement has been used widely in CBEMs, but cement production is accountable for 5% of global greenhouse gases (GHG) [18]. However, CBEMs can be further developed when manufactured with waste materials thus addressing environmental and economic concerns. That said, it is necessary to replace cement with waste materials that has the same or better performance. Research by Ellis et al. [19] considered a range of storage grade macadams consisting of recycled aggregates from different sources bound by bitumen emulsion and Ground Granulated Blastfurnace Slag (GGBS). They concluded that stiffness and strength can develop when GGBS is incorporated in high humidity conditions. Thanaya et al. [20] conducted experiments to use pulverized fly ash (PFA) as a filler in cold mix at full curing conditions, finding the cold mix stiffness equivalent to HMA. Al Nageim et al. [21] studied the addition of OPC and fly ash to CBEMs as a filler replacement. They conducting an experiment to show the development of mechanical properties in CBEM's and to identify the possibility of replacing OPC with fly ash. Recently, Nassar et al. [22] conducted investigations to improve the performance of Cold Asphalt Emulsion Mixtures (CAEMs) using binary and ternary blended fillers (BBF and TBF). They used OPC, fly ash and GGBS for the BBF while TBF was obtained by incorporating silica fumes with BBF. They concluded that the mechanical and durability properties indicated that TBF was more appropriate than BBF for the manufacture of CAEMs. In addition, they stated that a TBF mixture would be effective in road pavements which were subjected to harsh conditions both in hot and cold weathers.

Sadique et al. [23] aimed to develop a new cementitious material through the activation of a high calcium fly ash by a different alkali sulphate rich fly ash. They found that the cement free activation of fly ash was very effective. They revealed that the presence of a structure comprising Ca, Al, K and Si with high pH in two types of fly ashes, has the ability to break the glassy phase in the cement free system. In addition, Sadique et al. [24] performed a study to explore the pozzolanic reactivity of calcium rich fly ash by blending and grinding it in a cement-free system. They reported that the hydration effects and strength enhancement in the new blend were comparable to cement.

Fluid catalytic cracking catalyst residue (FC3R) is an industrial by-product generated from the fluid catalytic cracking process in petrol refineries. Pacewska et al. [25] investigated the hydration of cement paste as a function of adding spent catalyst residue to address catalytic cracking, reporting on the pozzolanic nature of the spent catalyst. They found both spent catalyst and microsilica to be similar when combined with $Ca(OH)_2$, and that the process of hydration was highly exothermic promoting fast setting of the cement paste. Mas et al. [26] studied the mechanical properties of mortars and roof tiles using a fluid catalytic cracking catalyst residue with various mixtures, varying the proportions of Na OH and waterglass. They concluded that the use of geopolymers in the design of a new product with reduced CO_2 emissions was feasibly and sustainable in the construction sector.

Chemical activation suggests that some chemicals can be used to activate the reactivity of cementitious components [27]. Alkaline activated materials have been shown to have enhanced higher level mechanical characteristics in comparison to cement. Consequently, the alkali activation of fly ash offers potential financial and environmental cost savings when used as a cement replacement [28]. Al-Hdabi et al. [29] stated that the incorporation of high alkali waste material as a filler replacement in CBEMs provides an ambient environment to activate the hydration process of the incorporated cementitious constituents.

There is demand for the development of sustainable novel CBEMs which use waste filler materials activated by alkali waste solutions and as such the main aim of this study has been to develop a fast-curing Cold Asphalt Concrete for Binder course