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Recycled hybrid fiber-reinforced & cement-stabilized pavement mixtures: Tensile properties and cracking characterization

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HIGHLIGHTS

- Waste fiber inclusion significantly improves the tensile properties of composite.
- Better behaviour comes from bonding action and interlocking with other components.
- Enhanced toughness indicates better ductility and longer decay time of pavement.
- Suggested fractal-based methodology accurately estimates cracking dispersion.
- Presence of fibres causes disordered cracking and increases dispersion of cracks.

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ABSTRACT

Cement-stabilized aggregate mixtures (CSAMs) have been used effectively within semi-rigid pavement structures. However, the sensitivity to cracking under tensile loading is the main problem that may cause a deterioration due to reflection to the overlaying layers. The primary objective of this research is to show the extent to which the steel fibers extracted from old tires might enhance the pre and post-cracking behavior of CSAMs and to understand how they affect the cracking characteristics. Mechanical performance was evaluated in terms of indirect tensile strength, modulus of elasticity, and post-peak load carrying capacity. Cracking properties were studied quantitatively, at the mesoscale level, using a combination of x-raying of the internal structure and fractal analyses through an image processing technique. A new methodology was suggested and implemented for this evaluation. Despite the low cement content, results indicated a decrease in the material stiffness with fiber addition and an improvement in both pre- and post-cracking behavior. There is a clear enhancement in the toughness and deformability of the mixtures indicating a ductile material. Better cracking behavior was observed after fiber incorporation. Finer cracks and more dispersion of these cracks suggest a reduced potential for reflection cracking. A fracture mechanism was proposed and confirmed by examining various cracking patterns.

1. Introduction

A cement-stabilized aggregate mixture (CSAM) is a cementitious material that consists of a mix of aggregate, cement and a small quantity of water for hydrating the cement and helping the compaction process [21]. It is normally used within semi-rigid pavements as a base and/or subbase layers to increase their structural capacity. Due to its low sensitivity to water and its high strength and uniformity, stabilized layers made of such material provide an excellent foundation to overlying layers. At the same time, stabilized layers protect the underlying layers by distributing the load over a wide area owing to their high rigidity.

Inherent features of CSAMs, however, are shrinkage and tensile cracking, low tensile strength and high rigidity which make them sensitive to overloading and fatigue. These cracks, unfortunately, cause a decrease in load-carrying capacity and transfer efficiency as well as problems for both overlying and underlying pavement courses. In addition to the additional stresses being applied on subgrades and wearing courses, reflection cracking represents a significant further challenge to the use of cement-stabilized layers [1].

The use of fibers may provide a good solution to control the above-mentioned problems, especially in the light of findings of previous studies conducted on concrete mixtures. Furthermore, and more importantly, using these fibers might control crack

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initiation, propagation rate, and width. Apart from the idea that the cracks developed in a cement stabilized aggregate layer reduce its load carrying capacity, these cracks also cause problems, especially in the case of wide cracks, to other layers.

The use of fibers to reinforce CSAMs of low cement content is a relatively new technique as compared with normal concretes and few investigations have been performed to study the effect of fibers on the performance of cemented mixtures. Shahid [27], Thompson [33], Sobhan and Krizek [28] and Coni and Pani [10] all conducted studies to reveal how industrial steel fiber reinforcement affects the mechanical performance of cement-stabilized materials. Others [18,37,38,14] have used industrial polypropylene fibers. In all these studies, the host materials were either natural or secondary aggregates. Overall, their findings showed an improvement in the performance of cement-stabilized mixtures from the mechanical properties point of view.

Despite several advantages gained from fibers in cemented mixtures, their high initial cost represents a challenge that limits their use [10]. This was probably the main motivation for some researchers to attempt using waste fibers in cement-stabilized mixtures. For instance, Sobhan and Mashnad [30] and Sobhan and Mashnad [31] used a waste plastic strip as reinforcement in a cemented aggregate. Such usage helps to reduce the cost of construction and might also enhance the performance in addition to increasing sustainability in highway construction. Even in the case of concrete mixtures, only a few researchers [3,9,26,20] have tried to utilize steel fibers extracted from post-consumer tires as reinforcement.

No study has been reported in the literature investigating the effect of waste steel fibers sourced from old tires on the performance of cement-stabilized aggregate. Even though Angelakopoulos et al. [4] and Neocleous et al. [23] used these waste fibers in roller-compacted concrete, their mixtures had quite different aggregate gradation and much higher cement content as prescribed by the Portland Concrete Association [25]. Furthermore, none of the previous studies have examined the internal structure and cracking properties of such composites. Therefore, a study was undertaken, and is here reported, to investigate how the inclusion of waste steel fibers in cement-stabilized aggregate of low cement content (as compared with other cementitious materials) may affect its behavior.

Cement-stabilized aggregate layers (either base or subbase or both) within the pavement structure are subjected to tensile stresses at the bottom of the layer. This, in turn, suggests that a tensile test would best simulate actual, in-situ, distress. It would also be instructive to investigate the cracking properties and the internal structure at a mesoscale level so as to better understand the fracturing mechanism and to identify the relationship with macroscale properties. Therefore, the aim of the study is to quantify and understand the behavior of these composites in order to optimize them with the eventual goal of overcoming the disadvantages of cement-stabilized base pavements in a cost-effective manner.

2. Experimental program

2.1. Constitutes materials

2.1.1. Aggregate

A crushed limestone aggregate was used during this investigation. This aggregate was sourced from Tunstead Quarry in Nottingham, UK at different fraction sizes which are 20 mm, 14 mm, 10 mm, 6 mm and dust. Grain size distributions for various stated fraction sizes was determined in accordance with BS EN 933-1:2012. Fig. 1 illustrates the gradation of different aggregates.

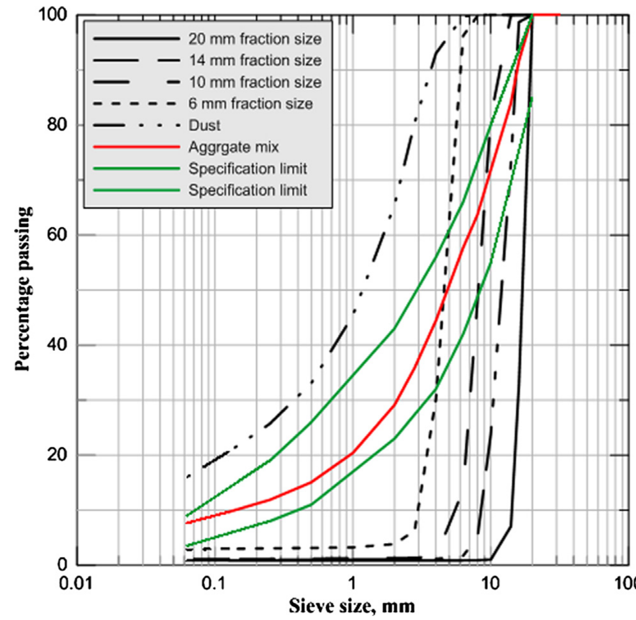

Fig. 1. Gradation of individual aggregate fraction sizes, aggregate mix and specification.

2.1.2. Recycled fibers

Recycled steel fibers, extracted from post-consumer tires, were utilized as reinforcement in cement-stabilized aggregate mixtures. Due to the nature of the fibers used in the tire manufacturing and recycling process, the fibers produced after the tire shredding process have different diameters and lengths. To evaluate the behavior of fiber reinforced cement-stabilized aggregate mixtures (FRCSAMs), it is necessary to quantify the fibers' geometrical properties. This is because the interlocking of the fibers with the aggregate and the bond strength of the fibers with the matrix is expected to be highly related to the fiber length in addition to the cement content. Therefore, both fiber diameter and length were characterized to help understand the effect of different geometrical properties of the fibers on the performance of modified mixtures, as different fiber properties may result in different performance.

To achieve this fiber quantification, a random fiber sample was taken from different locations of the fiber container. To measure the fiber diameters, a digital micrometer with a total range between 0 and 2.5 mm and a precision of 0.001 mm was used (Fig. 2). Regarding fiber lengths characterization, an image processing technique was adopted through the following procedure:

Fig. 2. Recycled steel fiber appearance and diameter measurement process.