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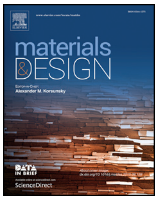

Effect of cementation level on performance of rubberized cement-stabilized aggregate mixtures

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ABSTRACT

An investigation and comparison is made of the effect of cement content on the performance of rubberized cement-stabilized aggregate mixtures and on cement-stabilized aggregate mixtures containing no rubber (RCSAMs and CSAMs). These materials are intended to be used as a base course for pavement structures. Three cement contents (3%, 5%, and 7% by dry weight of aggregate) were investigated. Rubberized mixtures were manufactured by replacing 30% of one aggregate fraction that has a similar gradation of crumb rubber. Performance was evaluated under static and dynamic testing. The investigated properties are unconfined compressive strength, indirect tensile strength, indirect tensile static modulus, toughness, dynamic modulus of elasticity, dynamic modulus of rigidity and dynamic Poisson's ratio. Increasing cement content increases strength of both types of mixtures, especially in the CSAMs. It is found that using crumb rubber at low cement content is more feasible than with high cement contents. Stiffnesses increased for both types of mixture as cement content increased but decreased on incorporation of crumb rubber. Energy absorption capacity was inversely related to stiffness. Mesostructural investigation revealed that the cracks were propagated through the rubber particles for all cement contents.

1. Introduction

Due to the expansion of the modern world, the number of waste tires stockpiled every year is increasing alarmingly. This has negative impact on both humans and the environment since these stockpiles can harbour vermin and represent possible combustion sites [41]. Over thirty years ago, different investigations have been conducted to evaluate the possibility of using rubber from waste tires as an aggregate in concrete mixtures. This would help protect the environment by reducing disposal impacts and save costs since using these tires as a replacement of aggregate will save natural resources. Researchers [3,10,12,17,18,24,26,28,30,35,37,40,41] have studied the use of waste tire materials in different types of concrete mixtures as an aggregate replacement in the form of fine, coarse or fine and coarse fractions simultaneously. The results of their assessment indicated, in general, a reduction in mechanical properties, improvement in the energy absorption capacity, reduction in stiffness and enhancement in impact toughness. The degree of decline or improvement of the mentioned properties was different depending on the size of rubber and whether coarse or fine fractions or both were replaced. Based on their findings and justifications, others [12,25,30] attempted treating the rubber particles with sodium hydroxide or using silica fume to enhance their interaction with the other constituents of the mixtures. Their investigations claimed better performance because these treatments improved the bond between rubber and the surrounding cement matrix.

However, very little has been documented about the effect of cement content on the performance of the mixtures in which rubber particles were used. In addition, limited research was found in the literature regarding use of crumb rubber in cement stabilized mixtures typically used as a base course or subbase course in the pavement structure in spite of a long history of investigation for these waste materials in civil engineering applications. These layers' potential to consume large quantities of natural resources as compared with other civil engineering applications [4,6]. To fill these gaps in the literature, the authors investigated the effect of cement content on the performance of cement-bound aggregate mixtures (CSAMs) and rubberized cement-bound aggregate mixtures (RCSAMs).

This paper reports this investigation and develops an understanding of the interaction between cement and rubber i.e., investigating of the effect of the relative stiffness of the rubber and the surrounding matrix on the overall performance of the mixture. This, in turn, can be

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considered as an exploratory step for studying the effect of other sizes and proportions of rubber so as to validate its use in a more sustainable "green" pavement structure.

2. Cement-stabilized materials

Cement-stabilized mixtures are normally used as base or subbases course within pavement structures so as to improve the structural capacity of pavement structure in terms of strength and stiffness. [20] described cement-stabilized mixtures as a mixture of aggregate and Portland cement moisturized with small quantities of water for compaction and cement hydration purposes. Additionally, the Portland Concrete Association [29] has classified cementitious materials into four types depending on their water and cement contents. Roller-compacted concrete and normal concrete are the mixtures in which high cement levels are normally used. However, the method of construction is different due to low water content in the first type as compared with the latter. Flowable fill and cement stabilized materials, on the other hand, have low cement contents but different water content.

3. Objectives and motivations

The motivation of this research is to understand the behaviour of cement-stabilized aggregate modified with crumb rubber extracted from post-consumer tires under different degrees of stabilization. This will help to make beneficial reuse of the tire rubber which, in turn, may ensure conservation of natural resources as well as reducing the environmental problems of disposal. Another motivation is to achieve cement-stabilization of granular materials that have less sensitivity to cracking than the stiff mixtures conventionally obtained, thereby reducing fatigue failure [39]. Furthermore, reflection cracks in overlying pavement layers may be reduced. So, studying how the cement may affect the performance of rubberized mixtures might lead to improve stabilized aggregates from economic and practice points of view. Thus, the purpose of this paper is to study the effect of cement content on the properties of rubberized cement stabilized mixtures, mainly in terms of tensile performance, and to compare this with conventional stabilized mixtures. It also seeks to develop an understanding of the mechanisms of their failure. Tensile performance was selected because the stabilized pavement layers are normally designed based on critical tensile stress at their bottom. Limited information, even for rubberized concrete, could be found regarding the investigation of the mesostructure, of the failed samples to reveal how the cracks propagated.

4. Experimental methodology

4.1. Materials

In this study, a crushed limestone aggregate with maximum size of 20 mm was used. This was collected, dried and stored at different fraction sizes (i.e., 20 mm, 14 mm, 10 mm, 6 mm and less than 6 mm (dust)). The gradations of both natural aggregate and crumb rubber were performed based on BS EN 933-1:2012.The gradation of the different fraction sizes is presented in Fig. 1. The physical properties of the crumb rubber are shown in Table 1.There were insignificant quantities of tire-derived steel or textile in the rubber, these having been removed by the processing. Portland cement CEM I 52.5 N confirming to BS EN 197-1:200 was used to stabilize the aggregate mixtures. Tap water was used to hydrate the mixtures.

4.2. Mixture design

Different aggregate fractions were combined together in different proportions in order to secure the [CBGM2-0/20] gradation as stated in BS EN 14227-1:2013 and hence to eliminate any variability in aggregate gradation. This was necessary so as to produce comparable mixtures due to the high dependency of strength on mixture density [38] which is governed, to large extent, by the aggregate gradation. The proportions used were 11%, 20%, 11%, 13% and 45% for 20 mm, 14 mm, 10 mm, 6 mm and dust, respectively. The final gradation after blending the above five sizes is illustrated in Fig. 2 with appropriate specification limits.

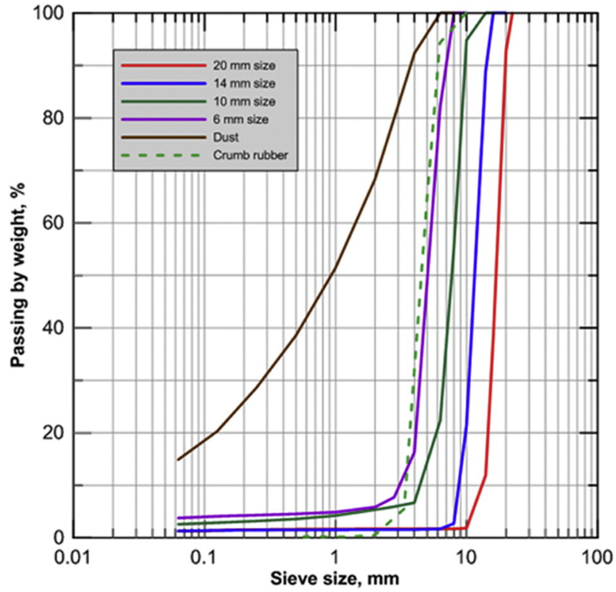

Fig. 1. Gradation of different fraction sizes including crumb rubber.

Three cement contents were used in this investigation. These are 3%, 5% and 7% of the dry weight of aggregate. These were selected based on previous studies [36]. Drnevich et al. [8] and Chilukwa [7] recommend vibratory compaction for granular material as the method most simulative of field compaction. Consequently, the optimum water content for each aggregate-cement mixture was estimated in accordance with BS EN 13286-4:2003 utilizing the vibratory compaction procedure. The optimum water content for each cement content is shown in Table 2. Given the small volume of rubber in overall mixture and the low water absorption of both rubber and natural aggregate, difference in water absorbability after natural aggregate replacement make no significant difference to water demand for compaction or cement hydration.

Cement-bound aggregate mixtures have a similarity with normal concrete where both of them are cementitious materials and also a similarity with asphaltic mixtures since both of them are compacted mixtures. Consequently, it was decided to try a small amount of rubber replacement as used in asphaltic mixtures [13] to avoid affecting compaction characteristics. To constitute the rubberized mixtures, 30% of the 6 mm fraction size was replaced by the same volumetric percentage. This size was selected due to the similarity between the gradations of crumb rubber and the 6 mm fraction size which, in turn, should secure the same packing skeleton. Owing to the considerable differences between specific gravities of natural aggregate and crumb rubber, proportioning on a weight basis was ruled out. To do so would add a significantly extra volume of 6 mm size particles, meaning that the packing in the CSAMs and RCSAMs were no longer comparable. Cement

Table 1
Physical properties of crumb rubber [24].

Property	Value
Specific gravity	1.12
Apparent density	489 kg/m3
Thermal conductivity	0.11 W/k m
Tensile resistance	4.2–15 MPa
Speed of combustion	Very low
Water absorption	0.65 (negligible)