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Flexural shear behaviour of reinforced Crumbed Rubber Concrete beam

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HIGHLIGHTS

- Shear capacities of reinforced CRC beams were experimentally measured.
- Results were compared with the available design guidelines for conventional concrete.
- FEA with available material models for conventional concrete was used to simulate the results.

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ABSTRACT

This paper investigates the flexural shear behaviour of reinforced beams made from different Crumbed Rubber Concrete (CRC) mixes having similar compressive strength and different proportions of crumbed rubber. As part of the study concrete beam specimens, made from six different CRC mixes, were prepared and tested to failure under flexural load. For each mix, one beam with a large amount of shear reinforcement and another one without any shear reinforcements were used to distinguish between their bending and shear failure behaviour clearly. The experimental results allowed the comparison between the shear failure behaviour of beams with different CRC mixes. The measured shear capacities were used to examine the applicability and accuracy of available design guidelines for conventional concrete on predicting the shear capacity of reinforced CRC beams. The experimental results were also used to determine the adequacy of existing conventional concrete material models to numerically simulate the shear behaviour of CRC beams using finite element analysis.

1. Introduction

Concrete is one of the most widely used materials in the world and as a result require significant natural resource every year. The sources of the natural resources needed for concrete are depleting gradually. The availability of natural aggregates at a reasonable rate is a big concern of the concrete industry [1]. Usually in concrete around 20–30% of its volume is comprised of fine aggregates, depending on the mix proportion. As the yearly consumption of concrete is more than 30 billion tons, even if a small percentage of natural aggregate is replaced with recycled material, it will result in considerable savings of natural resource [2]. Consequently, over the years, researchers have tried to introduce various recycled materials in concrete with varying degrees of success. On the other hand, scrap tyre rubber is generated from used tyres in the automobile industry which, even after almost 100 years, is rapidly growing in various part of the world. For example, it has been reported that Australia has discarded around 51 millions Equivalent Passenger Unit (EPU) tyre waste in 2013–2014 [3]. As a result, used tyre mountains are accumulating everywhere. The utilisation of this waste has become an environmental concern worldwide. Therefore, the use of scrap tyre particle in concrete provides twofold benefit to the environment as it helps to reduce both natural resource demand of concrete production and waste management problem of scrap tyre. As a result, considerable research has been conducted over the last two decades, to determine the various material properties of concrete containing tyre particles. Crumbed Rubber Concrete (CRC) is such concrete, in which the fine aggregate is partially or fully replaced with crumbled scrap tyre rubber.

Over the years a large number of studies have been carried out investigating the material properties of CRC. All these studies took a conventional concrete mix and developed a number of CRC mixes by partially replacing fine aggregate with the same amount of crumb rubber while keeping the other mix proportions same. Then the behaviours of the CRCs mixes were compared with the original conventional concrete. These studies have found that introduction of rubber reduces the compressive strength [4–8], tensile strength

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[9,10] and modulus of elasticity [11–14] of the concrete compared to the original normal concrete. They have also reported that an increase in rubber content and proportional decrease in fine aggregate content will further reduce these material properties. This reduction in mechanical properties is caused by the low adherence capacity between rubber particle and cement matrix [15]. As rubber has lower unit weight compared to fine aggregates, CRC is lighter in weight than conventional concrete [16,17]. CRC has higher energy absorption capacity compared to conventional concrete [18–21]. It should be noted that in all these comparisons, lower strength CRCs were compared with higher strength conventional concrete. As a result, these studies created an impression that CRC is inferior to conventional concrete and not suitable for the structural application. However, recent research has shown that CRC can achieve adequate compressive strength (30–45 MPa) to be used for structural applications [22–24]. To use these higher strength CRC in structural members such as beam or columns, their behaviour under structural load must be properly evaluated. Very few studies are available in the literature regarding the reinforced CRC beams. One study found that CRC increases the cracking resistance of the beam compared to normal concrete [25]. Same authors have studied about the applicability of effectively using finite element software on CRC beams and showed that the material models for conventional concrete available in the commercial finite element software ANSYS can be utilised for simulating the load-deflection behaviour of the beam until peak load [26]. Replacement of rubber is not limited to conventional concrete. Some research studies have been extended to investigate properties of reinforced self-consolidating rubberized concrete beams [27]. The authors have observed the reduction of crack width, compared to conventional concrete. Again in these studies, comparisons have been made between CRC and conventional concrete of different compressive strength. Another study has been carried out to evaluate the shear capacity of reinforced CRC beams with a different dimension of beam width, effective depth and shear span [28]. Authors have stated that the available design guidelines and shear models can be used to predict the shear capacity of beams. However, this study is limited to one CRC mix that unable to check the effect of rubber on shear capacity. Therefore, there is a lack of study investigating the behaviour of various CRC mixes that have the similar compressive strength and different proportions of crumb rubber. At the same time, the difference in behaviour of CRC compared to that of conventional concrete of same compressive strength is not well understood.

In this context, the authors undertook research program aiming to understand the behaviour of various CRC mixes having the similar compressive strength and different proportions of rubber content. The research program also aimed to compare the behaviours of CRC and conventional concrete of same compressive strength and eventually develop design guidelines and constitutive material models for reinforced CRC beams. As part of it, few CRC mixes were developed that have the similar compressive strength and different proportions of rubber content. It is found that despite having different rubber content, the developed CRCs have similar mechanical properties and were compatible with the conventional concrete of same compressive strength [29]. It is also found that identical reinforced beams made from the developed CRCs behave similarly under flexural loads [30]. This paper particularly presents a study investigating the flexural shear behaviour of the reinforced beams made from CRCs developed in the research program. In this study, experiments were conducted to measure the responses of the beams under flexural load and shear capacities of the beams. This study also aims to evaluate the compatibility of using available design guidelines for conventional concrete to calculate the ultimate shear capacity of the reinforced CRC beams. Finally, the accuracy of the existing constitutive material models for normal concrete on simulating the shear behaviour of the CRC beams was evaluated using finite element analysis. Thus, this study comprises three sections, namely, comparison of shear performances of similar strength reinforced CRC beams, comparison of experimental results with available design guidelines and available consecutive material models for numerical analysis.

2. Experimental procedure

2.1. Overview

As part of the experimental program, the flexural shear capacities of various reinforced beams, made from different CRC mixes of similar compressive strength were measured and compared. CRC mixes of two different strength groups, group 40 (strengths ranging from 40 to 46 MPa) and group 30 (strengths ranging from 30 to 35 MPa) as reported in [29] were used. Again, for each strength group three different CRC mixes were used, resulting in total six different mixes. For each CRC mix two beams were tested, one with full shear reinforcement for flexural failure and another without any shear reinforcement. The beams were tested till failure under flexural load. Additionally, standard material tests of concrete mixes used in each of the twelve beams were conducted on the day of testing of the respective beams to determine the material behaviour of the mixes used in these beams. All specimens were moist cured for 28 days before testing.

2.2. Materials and concrete mixes

Scrap truck tyre rubber was used for making the crumb rubber used in this study. Three different particle sizes were used as 2–4 mm, 1–3 mm and particles passing #30 (600 μm) mesh. These three sizes were mixed to obtain similar particle size distribution in both crumb rubber, and fine aggregates as recommended in [24]. The crumb rubber mixture contained 40% from particles passing #30 mesh, 35% from 1 mm to 3 mm and 25% 2–4 mm. Natural sand was used as the fine aggregate with 2.6 specific gravity. Two nominal sizes of coarse aggregates accompanied namely 10 mm and 14 mm with 2.67 and 2.7 specific gravity respectively. All other properties of aggregates were confirmed with AS 1012.2 [31].

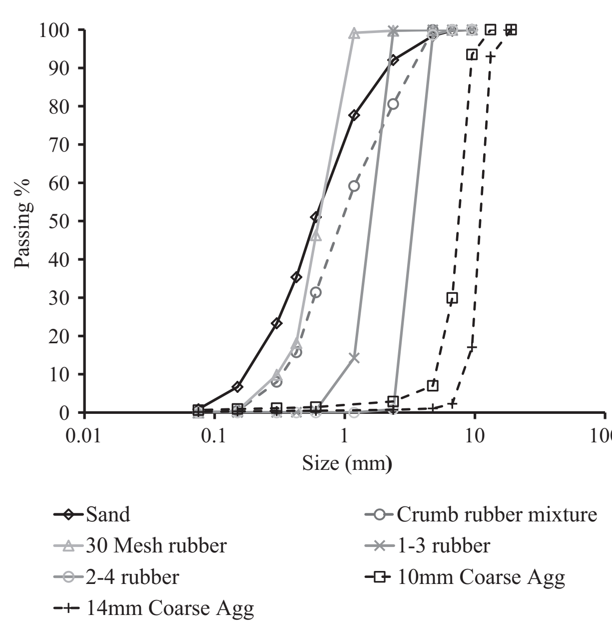

Fig. 1. Particle size distribution of aggregates.