Construction and Building Materials 154 (2017) 644–657

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of rubber particles on the flexural behaviour of reinforced crumbed rubber concrete beams

Agampodi S.M. Mendis, Safat Al-Deen *, Mahmud Ashraf

School of Engineering and Information Technology, The University of New South Wales, Canberra, Australia

HIGHLIGHTS

- Twelve reinforced Crumbed Rubber Concrete (CRC) beams were prepared and tested.
- Experimental results were compared with the available design guidelines for normal concrete.
- The behaviours of these beams were simulated using finite element analysis.

ARTICLE INFO

Article history:
Received 23 April 2017
Received in revised form 13 July 2017
Accepted 29 July 2017
Available online 8 August 2017

Keywords:
Crumbed rubber concrete
Waste tyre rubber
Flexural behaviour

ABSTRACT

This paper investigates the flexural behaviour of reinforced beams made of Crumbed Rubber Concrete (CRC) mixes of similar compressive strengths. For this purpose, twelve beams of identical reinforcement arrangements and support conditions were prepared using six different CRC mixes. These beams were tested to failure under a two-point bending load, and their flexural responses were measured during the experiments. Relevant material property tests of the constituent materials were also carried out. These experimental results were used to compare beam response between beams made of similar strength CRC mixes. The applicability of available design guidelines for conventional concrete, on predicting the flexural capacities of CRC beams were also investigated. Additionally, finite element analysis were conducted using constitutive material model for normal concrete to simulate the flexural behaviours of these beams. Simulation results were then used to determine the accuracy of the constitutive model for predicting the behaviour of CRC.

1. Introduction

In Crumbed Rubber Concrete (CRC), the fine aggregate is partially of fully replaced with crumbed scrap tyre rubber. Every year, all over the world, significant numbers of used tyres are discarded by its user. Recent research [1] has reported that Australia alone has produced around 51 millions Equivalent Passenger Unit (EPU) tyre waste in 2013–2014. As a result, management of waste generated from scrap tyres has become a significant environmental problem. This issue is similar for most of the countries of the world, and a more environmentally sustainable solution for scrap tyre waste management is needed. On the other hand, as the most popular building material, concrete requires a significant amount of natural resources for its manufacturing process. Acquiring these natural raw materials (fine and coarse aggregates) at large quantities causes significant environmental problems [2]. Therefore, use of CRC has twofold environmental benefits, they are, reduction of scrap tyre waste management problem and natural resource demand of concrete production. As a result, in the last three decades, a large number of researchers investigated the behaviour of CRC.

Most of the studies related to CRC investigated the effect of rubber in concrete at the material level. Generally, in these studies, a normal concrete mix is chosen, and different CRC mixes are created by introducing a different amount of crumbed rubber and proportionately decreasing the fine aggregate in the original mix. Then the mechanical properties of the CRCs are compared to the original normal concrete. As stronger and heavier fine aggregate is replaced by weaker and lighter rubber particles, CRCs have lower compressive strength [3–6], and unit weight [7,8], compared to the original normal concrete. Similarly, CRCs exhibit lower elastic modulus [9–11], tensile strength [3,12], workability [13,14], higher ductility [15–17] and higher energy absorption capacity [18–21]. It is important to note that in the case of normal concrete, compared

* Corresponding author at: School of Engineering and Information Technology, UNSW, Canberra, ACT 2610, Australia.

E-mail address: s.al-deen@unsw.edu.au (S. Al-Deen).

http://dx.doi.org/10.1016/j.conbuildmat.2017.07.220
0950-0618/

to higher strength ones, lower strength concrete also exhibit lower elastic modulus and tensile strength [22]. However, the comparison between higher strength normal concrete to lower strength CRCs in these studies created a notion that CRC is weaker than conventional concrete. As a result, CRC is not adopted by the industry for making structural members such as beams, columns, etc. A number of recent studies have reported that CRC can achieve compressive strength around 45 MPa [23–25] which can be used for structural purpose. The lack of appropriate design guidelines, however, does not allow practising engineers to incorporate CRCs in their design. Appropriate design rules for CRC structures are very much required to promote its use in the construction industry.

Extensive research studies conducted over the last century has demonstrated that similar strength concretes behave similarly under structural loads irrespective of the mix proportion used. Recently the authors have shown that the mechanical properties of CRC are very similar to the normal concrete of same strength [26]. However, there are very few studies investigating the behaviour of CRC structural members. A study regarding the cracking resistance of the reinforced CRC beams has reported that the rubber content increases the cracking resistance compared to normal concrete [27]. In another study [28], same authors simulated the load-deflection behaviour of a reinforced CRC beam using finite element software ANSYS and the software can be effectively used in simulating loading process of the reinforced CRC beam. Interestingly [29] reported a reduction of cracking moment in reinforced self-consolidating rubberized concrete beams. These conflicting findings highlight the need for more research on the behaviour of reinforced CRC beams. There is a lack of systematic study investigating the behaviour of reinforced beams, made from different CRC mixes of same compressive strength, under structural loads. This paper aims to address this knowledge gap. Numerical simulations are now extensively used to understand the response of a structure when subjected to various types of loading. Currently, there are no constitutive material models available to simulate the behaviour of CRC structures numerically. In addition, there is a lack of study investigating the suitability of using existing material models, typically used for normal concrete, to simulate the behaviour of CRC structure.

In this context, the aim of this paper is to investigate the flexural behaviour of reinforced CRC beam experimentally and evaluate the compatibility of using available design guidelines for conventional concrete on CRC. Additionally, adequacy of an existing constitutive material model of normal concrete for predicting the behaviour of CRC beams using finite element analysis is evaluated. For this purpose, identical reinforced CRC beams made from different CRC mixes of similar compressive strength were tested to failure under flexural load. The experimental results were used to compare the predicted behaviour using available design guidelines for normal concrete. The test measurements were also used as a benchmark to compare the finite element analysis result.

2. Experimental programme

2.1. Overview

As part of the experimental program, identical reinforced CRC beams made from different CRC mixes of similar compressive strength were prepared and tested. Total six different CRC mixes were used, of which three had target strength of 40–45 MPa (referred as Group 40) while the other three had 30–35 MPa (referred as Group 30). Different CRC mixes had different proportion of crumbed rubber despite having similar target strength. For each mix, two reinforced beams were cast in different batches and were tested under flexural load, totalling twelve beams. In addition, standard tests were carried out to determine the material properties of the constituent materials used in the beams, which were later used for finite element model benchmarking. All concrete material property tests were carried out on the same day of beam testing.

2.2. Raw materials

Three different sizes of crumb rubber were used in the CRC mixes. To achieve a similar particle size distribution of fine aggregates it is replacing; the final crumbed rubber mix contained 40% from size passing #30 mesh, 35% from size 1 mm to 3 mm and 25% from size 2 mm to 4 mm. For fine and coarse aggregate, natural sand and two sizes (10 mm and 14 mm) of crushed stone chips were used respectively. Particle size distribution of all aggregates and crumb rubber particles are presented in Fig. 1. General purpose Ordinary Portland Cement was used as the cementitious material for all mixes. To increase workability, high water reducing admixture was used. Mix proportions of six mixes are tabulated in Table 1.

Steel bars complying with AS 4671 [30] were used for both tensile and shear reinforcement. D500N10 deformed rebar was used for tensile reinforcement while straightened wire of 6 mm diameter was used for stirrups. The average yield strength of tensile reinforcement and stirrups, obtained from direct tensile strength tests, was 550 MPa and 500 MPa respectively.

2.3. CRC material properties

Standard cylinders of 100 mm diameter and 200 mm height were used to determine uniaxial compressive strength, stress-strain relationship and splitting tensile strength while standard prisms of 100 mm × 100 mm × 350 mm were used to determine the modulus of rupture (flexural tensile strength) of the CRC mixes. All specimens (reinforced beams, cylinders and prisms) were cured for 28 days at constant 23 °C and 100% humidity. Measured Mechanical properties of CRCs on the day of beam testing are shown in Table 2. The stress-strain relationships for all batches are presented in Fig. 2. Measurements from only one specimen from each batch are shown in this figure to reduce the number

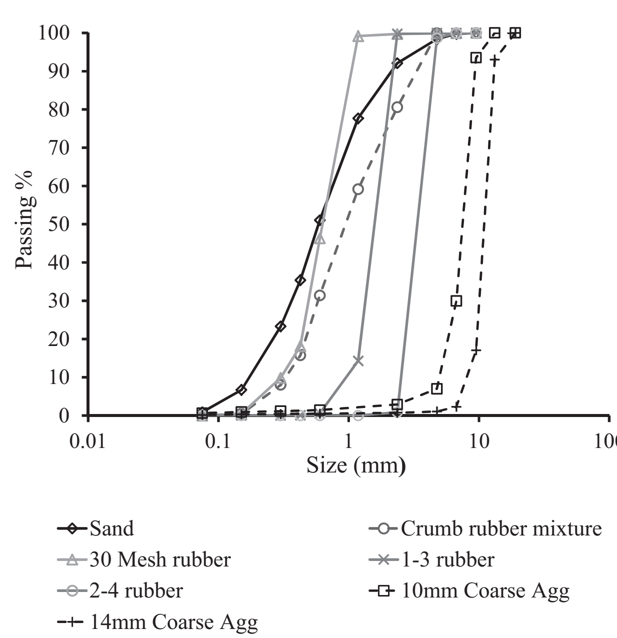

Fig. 1. Particle size distribution of aggregates.