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Material properties of basalt fibre reinforced concrete made with recycled earthquake waste

J.F. Dong [a,b], Q.Y. Wang [b,*], Z.W. Guan [c,d]

[a] School of Architecture and Environment, Sichuan University, Chengdu 610065, China
[b] Key Laboratory of Energy Engineering Safety and Disaster Mechanics, Ministry of Education, Sichuan University, Chengdu 610065, China
[c] School of Mechanical Engineering, Chengdu University, Chengdu 610106, China
[d] School of Engineering, University of Liverpool, Liverpool L69 3GQ, UK

HIGHLIGHTS

- Mechanical properties and microstructures of basalt fibre reinforced RAC were studied.
- Effects of the RCA replacement ratio on compressive behaviour of the RAC and BFRC columns.
- The influence of the basalt fibre content on the mechanical properties and cyclic axial compression.
- The basalt fibre could be used in RAC to enhance its structural behaviour.

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ABSTRACT

Concrete waste constitutes the major proportion of construction waste which counts on about 50% of the total wastes generated. The use of recycled aggregates serves to promote the recycling of concrete in the construction industry as well as to suit the reconstruction need in earthquake areas. This paper presents an investigation on mechanical properties and microstructures of basalt fibre (BF) reinforced recycled aggregate concrete (RAC). The main parameters considered in the study are the replacement ratio of recycled coarse aggregates (RCA) and the content of the basalt fibre. The research work is focused on the influences of the above parameters on the failure mode, compressive strength, tensile strength, elastic modulus, Poisson's ratio and the ultimate strain of the BF reinforced RAC. The results show that the mechanical properties of RAC can be enhanced by using BF. The SEM observations of the concrete reveal that the BF accumulated in pores and on the surface of the attached mortar can not only strengthen the RAC, but also improve the microstructure of the interfacial transition zone (ITZ), which further enhances the strength and ductility of the RAC. Therefore, the basalt fibre reinforced RAC can be used in construction to reduce the environmental hazards from a large amount of earthquake waste from collapsed buildings.

1. Introduction

In recent years, due to the increasing demand for infrastructure development, the consumption of concrete keeps growing. It is estimated that the emission of carbon dioxide from the concrete production is about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere [1]. The earthquake on 12 May 2008 in Sichuan was one of the most destructive earthquakes in modern Chinese history, which generated approximately 382 million tons of construction wastes just from the collapsed buildings alone [2]. Recycling construction wastage is a promising way towards sustainable construction as it is beneficial to the environmental preservation and saving of natural resources. Therefore, utilizing the recycled coarse aggregates (RCA) obtained from crushing of demolition concrete or earthquake waste concrete for a new concrete production is one of the significant efforts in achieving a sustainable construction. There has been some work already carried out to explore the important properties of the recycled aggregate concrete (RAC), such as workability, compressive, flexural and tensile strengths, elastic modulus and sources of the concrete waste [3–5]. It is shown that the failure mode of RAC is similar to that of the natural aggregate concrete

* Corresponding author.
E-mail addresses: dongjf@scu.edu.cn (J.F. Dong), wangqy@scu.edu.cn (Q.Y. Wang), zhongwei.guan@liv.ac.uk (Z.W. Guan).

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(NAC) [6,7]; however, there are some properties of RAC that are inferior to those of concrete made with natural aggregates [8–11].

The mechanical properties of RAC are influenced greatly by RCA, which gives a higher porosity and water absorption, lower density and strength, and weaker interfacial transition zones (ITZs) than those of natural aggregate concrete. Casuccio et al. [12] and Liu et al. [13] found that the failure of RAC is characterised as a lower strength and elastic modulus, a higher peak strain and a significant reduction in fracture energy. Kwan et al. [14] indicated that the RCA content has an inverse effect on the compressive strength, tensile strength and elastic modulus, as RCA increase the porosity and the presence of weak interfacial bonding between aggregate and matrix. The negative effects of RCA on RAC properties limit the structural uses of this material in civil engineering. However, some researchers pointed out that the shortcomings of RCA could be mitigated by appropriate mixing approaches [15–17], such as surface treatment or pre-soaking recycled aggregates [18–20]. Based on the microstructures through scanning electron microscopy (SEM), Katz [21] found that RCA are covered with loose particles which prevent the good bonding between the cement matrix and RCA. The author also found that the treatments by impregnation of silica fume solution and by ultrasonic cleaning could increase the compressive strength by 15% and 7%, respectively [21]. These treatments can fill up some pores and cracks in RCA, resulting in a denser concrete, and further improve the interfacial zone and give a higher strength when compared to the RAC without those treatments. Nevertheless, there still exists a weak ITZ, as water can be easily absorbed by small pores and thus form $Ca(OH)_2$ crystals. A possible approach forward is to utilize fibres as reinforcements for concrete to improve its ITZ, strength and ductility by preventing and reducing the occurrence of macro or micro cracks.

It has been shown that the presence of fibres could increase the concrete strength due to the sewing effect on the crack initiation and propagation, and also offer the concrete with enhanced ductility. There are various types of fibres that can be added to concrete mixing, including steel fibre [22,23], glass fibre [24,25] and polyethylene terephthalate (PET) fibre [26,27]. However, those fibres appear to reduce the workability of concrete. Basalt fibre (BF), made from volcanic rock through melting process with environmental friendly and non-hazardous nature [28–30], possesses excellent physical and mechanical properties, such as high chemical stability [31], non-combustible and non-explosive nature [32], resistance to high temperature [29], better mechanical properties as well as cheaper than E-glass fibres [33]. As the result, BF has been used as a reinforcing material for concrete recently. In regarding to the BF reinforced concrete under impact loading, the researches carried out by Li and Xu [34,35] showed that the addition of basalt fibres could improve deformation and energy absorption capacities of the concrete significantly, whereas there is no notable enhancement on the dynamic compressive strength.

There has been extensive experimental research on either the physical properties of RAC and fibre reinforced concrete, as indicated above. Also, some attempts were made to study the mechanical properties of fibre reinforced RAC with the effects of fibre content and replacement ratios of fine and coarse aggregates [25,28,36]. However, regarding to the influence of the basalt fibre content on the physical and mechanical properties of recycled aggregate concrete, there is limited research output that has been published in this aspect. Therefore, mechanical properties of RCA, RAC and BF reinforced RAC (BFRC) were investigated in this study. In addition, SEM microstructures of such materials were obtained to have insight into understanding of the microstructures of the concrete materials in reflection to their mechanical properties.

2. Experimental details

2.1. Materials

Ordinary Portland Cement (namely 32.5 grade), complying with the Chinese Standard GB175-1999 [37] was used in the study. The chemical compositions, together with the physical and mechanical properties, are shown in Tables 1 and 2, respectively. For the natural coarse and fine aggregates, crushed aggregates and river sand with a maximum size of 2.36 mm were prepared, respectively.

The recycled coarse aggregates used in this study were obtained by crushing the earthquake waste concrete from the collapsed buildings in Dujiangyan after the Sichuan earthquake on 12 May, 2008. The physical properties of the natural coarse aggregates (NCA) and the recycled coarse aggregates are shown in Table 3. The nominal size of NCA and RCA is 20 mm and their grading curves are shown in Figs. 1 and 2, respectively. It can be seen that the size grading of the coarse aggregates is similar, which comply with the requirements of Chinese Standard GB/T 14685-2001 [38].

The chopped basalt fibres were provided by Chengdu Dianshi Basalt Fibre Technology Engineering Co. Ltd. (China). The fibres are in bundles so that they do not have uniform diameter, as shown in Fig. 3. The length of the individual fibre is between 15 and 19 mm, with 13 μm in diameter. The other properties supplied by the manufactory, together with the specific weight, tensile strength, elasticity modulus and elongation at failure, are shown in Table 4.

2.2. Concrete mixtures

Experiments were conducted on the use of basalt fibres and recycled coarse aggregates in concrete composites. When making recycled aggregate concrete, cement, river sand, water and three RCA replacement ratios, i.e. 0, 50 and 100%, were used. In addition, three portions of basalt fibre (0, 2 and 4 kg/m^3) were applied in the recycled aggregate concrete to make the corresponding BF reinforced RAC. Mix design was in accordance with the Chinese Standard JGJ55-2011 [39], and concrete specimens were prepared using different proportions of RCA, NCA and BF, as listed in Table 5. In terms of B0R0, the letter B represents the basalt fibre, the first number '0' represents the content of basalt fibres, the letter R represents the RAC, and the number followed represents the percentage of RCA. Before mixing, the RCA were pre-soaked to minimize their effects on the workability and water/cement ratio of the concrete, due to their high water absorption [5]. The amount of water used to pre-soak the RCA was calculated according to the effective absorption of RCA to maintain a constant water/cement ratio of 0.53. The different dosages (in kg/m^3) of the normal and recycled aggregate concrete between the NCA and the RCA, as shown in Table 5, were due to their different specific gravity values (Table 3). The sand, cement, coarse aggregates and basalt fibres were placed and dry-mixed for about 2 min before water was added, then slump tests were carried out to determine the corresponding workability.

2.3. Specimen preparation and test method

The tests conducted in this study include the evolution of compressive strength with different proportions of recycled coarse aggregates at the ages of 3, 7, 14, 21, 28 and 90 days, along with the splitting tensile strength, the four-point flexural strength, the elastic modulus and the Poisson's ratio of the recycled aggregate concrete with or without basalt fibres added at the age of 28 days. Here, a universal testing machine with a 3000 kN capacity was used, with a loading rate set to 0.5 kN/s. All the specimens