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Compressive behaviors of cubes and cylinders made of normal-strength demolished concrete blocks and high-strength fresh concrete

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HIGHLIGHTS

- The mix of normal-strength DCBs and high-strength FC is feasible to applications.
- The weaker DCBs affect the specimens' compressive behaviors more significantly.
- The effect of DCBs on cylindrical strength is greater than that on cubic strength.
- Formulas are proposed to describe the compressive behaviors of the specimens.

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ABSTRACT

To reduce the cost of reuse of waste concrete, demolished concrete blocks (DCBs) having distinctly larger size than conventional recycled aggregates were adopted in researches and practical applications in the past several years for structural members, which were made of normal-strength DCBs and normal-strength fresh concrete (FC). To extend the use of DCBs to high-strength concrete structures, the mechanical behaviors of concrete mix made of normal-strength DCBs and high-strength FC should be investigated carefully. In this paper, thirty 300 mm cubic specimens and twenty-four cylindrical specimens (diameter 300 mm, height 600 mm) with different replacement ratios of DCBs (0%, 20%, and 33%) were fabricated using two kinds of high-strength FC (74.9 MPa, and 112.2 MPa) and two types of normal-strength DCBs (23.2 MPa, and 33.1 MPa), and the compressive behaviors of the cubes and cylinders under uniaxial loadings were experimentally studied. Based on the test results, formulas have been presented to determine the combined compressive strength, modulus of elasticity, and peak strain of the concrete mix made of normal-strength DCBs and high-strength FC. It is found that: (a) the specimens made of normal-strength DCBs and high-strength FC generally displayed a gradual failure, while the specimens made of high-strength FC alone exhibited a sudden failure, and the DCBs and FC bonded well, implying the mix of normal-strength DCBs and high-strength FC being feasible to practical applications; (b) the larger the difference between the demolished concrete's strength and the fresh concrete's strength is, the more significant the influence of the DCBs on the combined compressive strength, modulus of elasticity, and peak strain of the specimens is; (c) the influence of the DCBs on the combined compressive strength of the cylinders is more significant than that on the combined compressive strength of the cubes, leading the ratio of the combined cylindrical strength to the combined cubic strength being only about 0.65; and (d) the proposed formulas agree well with the test results on the whole.

1. Introduction

The amount of construction and demolition waste has increased enormously over the last decade in the world, especially in the developing countries like China and India [1]. More than 200 million tons of waste concrete are currently produced annually in the mainland of China [2]. Recycling of the waste concrete is beneficial and necessary for both environmental preservation and effective utilization of nonrenewable natural resources.

On-going researches on recycling of the waste concrete mainly relate to recycled aggregate concrete (RAC). A series of investigations on the processing and physical and mechanical properties of recycled aggregates [3–6], the mechanical properties and

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durability of RAC [7–15], and the performances of RAC structural members [16–20] have been carried out worldwide. The positive results further support and encourage the application of RAC in building structures, while the guidelines and specifications related to recycled aggregates and RAC have been documented by some organizations [21].

Although the RAC provides an attractive choice of recycling waste concrete, manufacturing high-quality RAC is not easy, and it frequently consists of time- and cost-consuming process of waste concrete fine crushing, screening and purification, thus making it less economical and energy-saving in actual practice. At present, a large amount of waste concrete still ends up at disposal sites. In order to explore a more efficient approach to reuse the waste concrete directly as an acceptable structural material, some new kinds of structural members containing both fresh concrete (FC) and broken demolished concrete with distinctly larger size than conventional recycled aggregates (usually with a size of ⩽40 mm) were proposed and investigated by the authors [22–27]. Here the term of "broken demolished concrete" refers to the demolished concrete blocks (DCBs, usually with a size of 100–300 mm) or demolished concrete segments (DCSs, usually with a size of >500 mm in length). Adopting DCBs or DCSs rather than recycled aggregates directly in new structural members may avoid the complicated and time- and energy-consuming production of recycled aggregates (e.g., the unit energy consumption of DCBs or DCSs in the production process is only about 40–60% of the unit energy consumption of recycled aggregates), and then reduce the cost of reuse of waste concrete. On the other hand, in comparison with common concrete with natural aggregates alone, the DCBs (or DCSs) and FC combined concrete is obviously cheaper in large-scale actual practices, but is more expensive in tests due to the labor cost for a small amount of DCBs (or DCSs) being very high in laboratory. It is found from the test results that the mechanical properties, seismic performances, and fire resistance of the structural members containing FC and DCBs or DCSs are similar to or slightly lower than those of the conventional members containing FC alone. But it should be noted that this conclusion is obtained for the case that the strength of FC and the strength of demolished concrete are close to each other. Considering that at present the available demolished concrete is often normal-strength concrete, while high-strength concrete has been widely used in newly-built structures (e.g., high-rise buildings, bridges, offshore structures, etc.), the mechanical properties of concrete specimens made of normal-strength DCBs and high-strength FC need to be investigated carefully.

In this paper, the compressive behaviors of cubic and cylindrical specimens made of normal-strength DCBs and high-strength FC under uniaxial loadings have been experimentally studied, and the influences of the strength of DCBs, strength of FC, and replacement ratio of DCBs on the compressive behaviors of the specimens have been discussed.

2. Experimental procedures

2.1. Specimen design

Thirty 300 mm cubic specimens and twenty-four cylindrical specimens (diameter 300 mm, height 600 mm) were fabricated using two kinds of FC (i.e., FC I and FC II) and two types of demolished concrete (i.e., DC I and DC II). Each kind of FC was from a same batch of ready-mix concrete which was mainly made of Portland cement, natural crushed granite (coarse aggregate), river sand (fine aggregate), slag, fly ash, and silica fume. The mix proportions of the two kinds of FC are shown in Table 1. For each kind of FC, three 150 mm cubes were cast to obtain the concrete's compressive strength on the testing day. The measured test-day cubic compressive strengths of FC I and FC II are, respectively, 74.9 MPa and 112.2 MPa. It can be seen from Table 1 that: (a) the less the water-to-binder ratio is, the higher the strength of the FC is; (b) the higher the cement grade is (the compressive strength of Cement P.II 52.5R is larger than that of Cement P.II 42.5), the larger the strength of the FC is; and (c) the more the silica fume (with much less fineness than cement, fly ash and slag) is used, the higher the strength of the FC is. The three phenomena are in accordance with the conventional mix design guidelines.

DC I was obtained from a waste bridge pier reserved in the construction site for more than 2 years, and DC II was obtained from the beams in a waste industrial factory building built more than 10 years ago (Fig. 1). For each type of demolished concrete, three cylindrical samples (diameter 100 mm, height 100 mm) were drilled from the waste components (i.e., waste pier or waste beams) and the cylindrical compressive strength of the demolished concrete was measured, then the equivalent 150 mm cubic compressive strength of the demolished concrete on the testing day was ascertained according to the Chinese standard CECS 03-2007 [28]. The test-day cubic compressive strengths of DC I and DC II are, respectively, 33.1 MPa and 23.2 MPa. Before concreting, concrete cover of the waste components were removed first by using pneumatic picks, and then longitudinal reinforcements and steel stirrups in the waste components were removed by using crowbars and cutting pliers. After that, core concrete of the waste components was broken into blocks by using simple tools such as pneumatic picks and hammers. Based on the experimental studies and actual practices conducted by the authors in the past six years [22–27], it is suggested that the best ratio of the characteristic size of DCBs to the short side of the specimen's (or structural member's) cross section ranges from 1/3 to 1/2, to ensure the casting quality of DCBs and FC combined concrete. In this way, the characteristic size of the broken DCBs was mainly ranging from 100 mm to 150 mm in this study (Fig. 2).

All the cubic and cylindrical specimens were made at the same day in the laboratory of South China University of Technology. Table 2 gives the details of the specimens. In this table, the specimens are identified by the notations CU*ef-g* and

Fig. 1. Beams from waste industrial factory building.

Fig. 2. Demolished concrete blocks (DCBs).

Table 1
Mix proportions of two kinds of fresh concrete.

Fresh concrete	Water (kg/m^3)	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Slag (kg/m^3)	Silica fume (kg/m^3)	Fly ash (kg/m^3)	Water reducer (kg/m^3)	Water-to-binder ratio
FC I	143	273 (P.II 42.5)	1099	733	84	0	63	4.6	0.34
FC II	133	345 (P.II 52.5R)	1080	720	46	25	46	6.0	0.28