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Compressive behaviors of cylindrical concrete specimens made of demolished concrete blocks and fresh concrete

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HIGHLIGHTS

- The combined compressive strength of concrete cylinders decreases with the increasing of the characteristic ratio.
- A formula is proposed to describe the relationship between the combined compressive strength and the characteristic ratio.
- A model is given to determine the combined compressive strength of cylinders with various sizes and characteristic ratios.
- The interface zones between DCBs and FC are not obviously weaker regions in structural members.

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ABSTRACT

Adopting demolished concrete blocks (DCBs) rather than recycled aggregates in structural members may reduce the cost of reuse of waste concrete. Here DCBs have distinctly larger size than the conventional recycled aggregates. To investigate the effect of DCBs' size on axial behaviors of the specimens made of DCBs and fresh concrete (FC), and to check whether the interface zones between DCBs and FC are weaker regions in the specimens, two series of tests were conducted in this paper. In the first series of tests, twenty-four cylindrical specimens made of DCBs and FC with a replacement ratio of 30% and twelve cylindrical specimens made of FC alone were fabricated and tested under uniaxial compressive loadings. The height-to-diameter ratio of all the specimens was the same as 2.0, and the diameters of the specimens ranged from 150 mm to 400 mm. The influences of both the cylinder dimensions and the characteristic size of DCBs on the specimens' compressive strength, the modulus of elasticity, and the strain at peak stress have been experimentally investigated. Based on the test results, a formula is presented to describe the relationship between the characteristic ratio (i.e., a ratio of the characteristic size of DCBs to the cylinder diameter) and the compressive strength, and a model is established to determine the compressive strength of concrete cylinders with various diameters and different characteristic ratios. In the second series of tests, three 200 mm × 200 mm × 50 mm specimens cut from two 400 mm × 400 mm × 200 mm samples made of DCBs and FC were axially loaded, and the initiation and propagation of the specimens' surface cracks were recorded using the two-dimensional digital image correlation technique. It is found that: (a) the effect of cylinder size on the strength of the specimens made of DCBs and FC is similar to the effect of cylinder size on the strength of the specimens made of FC alone, but the size effect on the relative strength for the former specimens is a little more distinct than the size effect on the relative strength for the latter specimens; (b) in the case that the cylinder dimensions keep constant, the strength of the specimens made of DCBs and FC decreases gradually with the increasing of the characteristic ratio; (c) for both the cylindrical specimens made of FC alone and those made of DCBs and FC, the cylinder dimensions and the characteristic size of DCBs have no clear effects on the modulus of elasticity and strain at peak stress; (d) both the presented formula and the established model mentioned above are in good agreement with the test results; and (e) microcracks do not concentrate in the interface zones between DCBs and FC, and these zones are not obviously weaker regions in structural members.

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1. Introduction

The environmental protection, energy-saving and emission reduction are very important topics, which are directly connected with the survival of the human race. The subject of concrete recycling is regarded as an important issue in the general attempt for sustainable development [1]. The difficulties of disposing of the concrete rubble and demolition waste together with a developing scarcity of the virgin aggregate have prompted an urge to recycle the enormous waste concrete [2]. On-going research and practice of recycling of demolished concrete mainly related to the technology of crushing and sieving concrete debris to produce recycled aggregates for new concrete. In recent years, intensive researches on recycled aggregate concrete (RAC) have been carried out, including the mixture design, mechanical properties, durability, and structural behaviors, meanwhile some application guidelines for RAC have been documented by many researchers and organizations, and the potential benefits and drawbacks of using recycled aggregates in concrete are well understood and extensively indicated [1–14].

Indeed 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. In order to explore a more efficient approach to reuse the demolished concrete directly as an acceptable structural material, some new kinds of structural elements containing both fresh concrete (FC) and broken demolished concrete with distinctly larger size than the conventional recycled aggregates were proposed by Wu et al. [15–17]. The term of "broken demolished concrete" herein refers not to the recycled aggregates (usually with a size of $\leqslant$40 mm) used in RAC, but to the demolished concrete blocks (DCBs, usually with a size of 200–300 mm) or demolished concrete segments (DCSs, usually with a size of >500 mm in length) instead. 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, and then reduce the cost of reuse of demolished concrete.

Many experimental and theoretical investigations have been carried out to examine the size effect in concrete structures [18]. Some sound and representative theoretical bases [19–22] on the size effect have been established by former investigators, and extensive researches have been conducted to verify the fracture mechanics type size effect for various types of failure of concrete structures [23–28]. Previous studies show that the compressive strength of concrete tends to decrease with the increasing of the specimen size [29,30]. However, the known researches only focused on the specimens made of FC alone, and no information is now available for those made of DCBs and FC.

The first purpose of this study is to experimentally investigate the effects of both the characteristic size of DCBs and the specimen dimensions on the compressive strength, modulus of elasticity, and strain at peak stress of cylindrical specimens made of DCBs and FC, and to suggest a model for determination of the mechanical behaviors of concrete cylinders subjected to axially compressive loadings with various diameters and different characteristic size of DCBs.

To measure the deformation and crack development for concrete and other quasi-brittle materials, researchers have proposed the use of the digital image correlation (DIC) technique as a nondestructive method. Corr et al. [31] utilized the DIC technique to examine the interface transition zone (ITZ) of plain concrete and the softening and fracture behaviors of the ITZ region. The DIC technique was also used to define the process of fracture in concrete at different deformation levels with the full-field measuring method by Choi and Shah [32]. A set of modifications to the Newton–Raphson-based DIC technique were presented by Helm [33] to analyze the concrete specimens with multiple growing cracks. In order to investigate the relationship between surface cracking and fracture of concrete, Lawler et al. [34] used DIC and X-ray micro-tomography to track the cracking. Xiao et al. [35] utilized the DIC technique to check the crack propagation in recycled aggregate concrete under uniaxial compressive loading.

Based on the DIC technique, the second purpose of this study is to examine the initiation and propagation of cracks in axially loaded specimens made of DCBs and FC, and to check whether the interface zones between DCBs and FC are weaker regions in the specimens.

2. Experimental procedures

2.1. Specimen design

In the first series of tests, all the cylindrical specimens were made of DCBs and FC. The FC being prepared for all the specimens was from a same batch of ready-mix concrete. The demolished concrete was obtained from a waste RC bridge pier reserved in the construction site for more than 2 years. Both the FC and the demolished concrete were mainly made of ordinary Portland cement, natural crushed limestone (coarse aggregates), and rive sand (fine aggregate). The mixture proportions of the FC and demolished concrete are listed in Table 1. The massive waste concrete was broken into blocks by simple tools. The prepared DCBs were divided into five piles with different characteristic sizes (i.e., about 50 mm, 67 mm, 100 mm, 133 mm, and 167 mm, respectively), as shown in Fig. 1. To measure the compressive strengths of the DCBs and FC on the testing day, six 150 mm cubes made of FC alone were cast, and six core samples with a diameter of 100 mm and a height of 100 mm were drilled from the waste pier. According to CECS 03-2007 [36], the compressive strength of the core samples with a height-diameter ratio of 1.0 is equivalent to the 150 mm cubic compressive strength. In this way, based on the measured cylindrical compressive strength of the core samples, the 150 mm cubic compressive strength of the demolished concrete was ascertained.

All the cylindrical specimens with the same height-to-diameter ratio of 2.0 were made in the laboratory of South China University of Technology, and were classified into three groups (Group-4, Group-5, and Group-6). Table 2 gives a summary of the details of the specimens. In this table, the specimens are identified by the notation CYM-N, where "CY" denotes a cylinder, "M" is the diameter of the cylindrical specimen, and "N" indicates the characteristic size of DCBs. For instance, "CY300-50" means that the specimen is a cylinder with a diameter of 300 mm and a characteristic size of DCBs of about 50 mm. Although the diameters of the specimens in Group-4 vary from 150 mm to 400 mm, the ratio of the characteristic size of DCBs to the cylinder diameter (named as characteristic ratio hereafter) is almost unchanged as about 1/3, in this way the influence of specimen dimensions on the mechanical behaviors (i.e., cylindrical compressive strength, strain at peak stress, and modulus of elasticity) can be examined. For the specimens in Group-5, the diameters of the cylinders are invariable, but the characteristic size of DCBs increases gradually, so the effect of the characteristic ratio on the specimens' mechanical behaviors can be studied. The specimens in Group-6 with different diameters were made of FC alone, and their measured mechanical behaviors are compared with those of the cylinders in Group-4 made of DCBs and FC. In Table 2, the replacement ratio of DCBs, η, denotes a ratio of the weight of DCBs filled in the cylindrical specimen to the total weight of the specimen.

During the casting of the cylindrical specimens made of DCBs and FC, a layer of fresh concrete with a thickness of about 20 mm was poured into the mould first, and then DCBs and FC were put into the mould alternatively, meanwhile vibrating the concrete mix continuously to ensure proper filling and compactness. The casting of the cylindrical specimens is shown in Fig. 2. All the specimens were covered with wetted cloths for 14 days after casting.

In the second series of tests, three 200 mm $\times$ 200 mm $\times$ 50 mm specimens (named as S1, S2, and S3) cut from two 400 mm $\times$ 400 mm $\times$ 200 mm samples made of DCBs and FC were prepared. The demolished concrete and FC used in the two samples were, respectively, the same as those adopted in the aforementioned cylindrical specimens. The characteristic size of DCBs was about 67 mm, and the replacement ratio of DCBs was also 30%. To obtain high-precision measurements, artificial speckles were made on the front surfaces of the specimens by spraying paint to the front surfaces. One 400 mm $\times$ 400 mm $\times$ 200 mm sample is shown in Fig. 3, the photos of Specimen S3 before and after being speckled are shown in Fig. 4, and the pictures of Specimens S1 and S2 before being speckled are shown in Fig. 5.

2.2. Testing procedures

The cylindrical specimens were end-capped with high-strength gypsum and tested under axially compressive loadings. The loading process was displacement controlled at a strain rate of 10×10^{-6}/s according to ASTM C39 [37]. To perform