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Influence of demolished concrete blocks on mechanical properties of recycled blend concrete

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HIGHLIGHTS

- The effect of DCBs on mechanical properties of RBC is notable.
- Formulas are proposed to describe the mechanical properties of the RBC specimens.
- The mechanical properties of RBC are affected by the weak interface.

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ABSTRACT

Recycled blend concrete (RBC) is a concrete mix made of fresh concrete (FC) and coarsely-crushed demolished concrete blocks (DCBs) larger than the conventional recycled aggregates. Structural members made of RBC have been used in engineering structures for several years, indicating that RBC is a practicable method for recycling demolished concrete (DC). To use RBC for structural applications, the mechanical properties of RBC are essential for the analysis and design of structural members. However, there are no design codes or specifications for the mechanical property requirements of RBC. Mechanical property data of RBC are scarce in the literature. Hence, this paper reports the results of an experimental investigation on the mechanical properties of RBC and establishes the relationship of the mechanical properties of RBC with the strength and replacement ratio of DCBs. Compressive, tensile and flexural tests on the specimens made of RBC with various strengths and replacement ratios of DCBs were carried out. The formulas for the compressive, tensile and flexural strengths, modulus of elasticity, and non-dimensional stress-strain relation of RBC have been formulated to account for the effects of the strength and the replacement ratio of DCBs. The microstructure of the interface zones between DCBs and FC and failure mechanisms were also investigated.

1. Introduction

The production of concrete consumes substantial natural resources (such as cement, coarse and fine aggregates) which impact the natural environment significantly. In addition, a large quantity of demolished concrete (DC) has been generated from demolition, not only causing pollution to the environment but also creating waste disposal issues. The DC can be reused by the building industry to reduce environmental impact. The use of recycled aggregate concrete (RAC) is an effective measure to develop environmentally-friendly concrete and achieve sustainable development in the construction industry [1]. In recent years, many studies on RAC have been carried out [2], relating to the mixture design [3], compressive behaviors [4], tensile behaviors [5], modulus of elasticity [6], fatigue limit [7], fracture properties [8], durability [2,9], creep and shrinkage [10]. Some guidelines on application of RAC have also been documented by many researchers and organizations, such as RILEM TC 121-DRG [11], BS6543 in Britain [12], DAfStb in Germany [13], ACI 555-01 in US [14], and JCJ/T 240-2011 in China [15].

Producing high-quality recycled aggregates is a complicated process, including crushing, screening and purification, etc. The recycled blend concrete (RBC) is proposed as a more economical approach to recycling DC. RBC is a concrete mixture composed of fresh concrete (FC) and coarsely-crushed demolished concrete blocks (DCBs) with distinctly larger size than conventional recycled aggregates. Large size DCBs (e.g., 40–300 mm) along with FC are

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placed into hollow steel sections, thereupon leading to new composite structural elements filled with RBC.

Preliminary studies of the use of structural members filled with RBC have been reported, including columns [16,17], walls [18], beams [19], and beam-to-column joints [20]. These work mainly focused on the mechanical properties and the seismic behaviors of RBC-filled structural elements. The effect of specimen dimensions and characteristic ratio (i.e., a ratio of the characteristic size of DCBs to the specimen size) on compressive behaviors of specimens made of RBC also has been studied [21–23]. Practical applications of RBC-filled steel columns have been reported (see Fig. 1) [16]. To promote the use of RBC, the Building Department of the Guangdong province in China has developed a guide specification titled "Technical specification for composite structures containing demolished concrete blocks" [24].

The effects of various factors on the tensile, flexural and compressive strengths for conventional concrete [25], self-compacting concrete [26], lightweight concrete [27] and high-strength concrete [28,29] have been studied. The conversion factors between cubic compressive strength and cylindrical compressive strength for conventional concrete have been provided in the design codes and standards [30–32].

However, information regarding the mechanical properties for RBC is very scarce in the literature. It is uncertain if the formulas for the compressive, flexural and tensile strengths of the conventional concrete can also be applied for RBC. How much difference between the stress-strain relationship of RBC and that of the conventional concrete is also unknown. For RBC-filled structural elements, the lacking of equations to determine mechanical properties has resulted in significant discrepancy between experimental results and calculated results based on finite element method. This may be because that the difference between RBC and conventional concrete has apparently been ignored. To predict and simulate the structural behaviors of RBC-filled composite members accurately, the effect of DCBs on the mechanical properties of RBC should be quantified first, and then the formulas of the mechanical properties of RBC should be established for the design of RBC structural members and RBC-filled composite members.

A number of studies have found that the interface zone in conventional concrete and RAC [33–35] is very weak. However, little research on the microstructure in interface zone between FC and DCBs in RBC has been reported and it was not known how the interface zone influences the mechanical properties of RBC until now.

This paper reports the experimental results of the compressive, tensile and flexural tests on RBC specimens. The effects of the replacement ratio of DCBs and the strength of DC on mechanical behaviors of the RBC are investigated. Formulas for the compressive, tensile and flexural strengths, the elastic modulus, stress-strain relation of RBC are formulated. In addition, the microstructure of the interface zones between DCBs and FC and the mechanism how DCBs influence the mechanical properties of RBC are investigated.

2. Experimental procedures

2.1. Materials

The concrete used in the investigation consisted of one type of FC and four types of DC of different compressive strengths. The FC was from the same batch of ready-mixed concrete made of ordinary Portland cement, natural coarse and fine aggregates and water. Local crushed limestone and silica sand were used for the coarse and fine aggregates of the FC, respectively. The mineral compositions of the crushed limestone and silica sand were obtained by X-ray spectrometry. The crushed limestone typically consists of calcite and very little clay containing potassium and iron. The silica sand consists of quartz and tiny amount of clay containing potassium, iron and calcium. The mix proportions of FC are listed in Table 1 and the cubic compressive strength of the FC was 34.5 MPa.

Four types of DC (denoted as DCI, DCII, DCIII and DCIV) were collected from demolished buildings and civil works built several years ago. For each type of DC, the cylindrical samples of diameter 100 mm and height 100 mm were cored for compressive strength. According to the Chinese specification CECS 03-2007 [36], the compressive strength of a cylindrical sample with diameter 100 mm and height 100 mm is equivalent to the compressive strength of a 150 mm cube. The test results for the cylindrical samples of DCI, DCII, DCIII and DCIV, i.e. their cubic compressive strength, were 21.8 MPa, 30.6 MPa, 44.4 MPa and 57.1 MPa, respectively. The strength of the DC is in the range of 20 MPa to 60 MPa, covering the strength of most DC from buildings and civil works. The characteristic size of the selected DCBs varied from 35 to 60 mm, with a majority (nearly 80%) between 45 and 55 mm, as shown in Fig. 2.

Casting RBC specimens is different from casting FC specimens. The DCBs were put into the mold while pouring the FC and vibrators were used to ensure proper filling and consolidation. Typical casting of RBC specimen is shown in Fig. 3. All the specimens were covered with wet burlaps for at least 14 days, and were then cured in the laboratory at room temperature for about 60 days until testing.

2.2. Specimen design and tests

Compressive, tensile and flexural tests were carried out to assess the effects of the compressive strength and the replacement

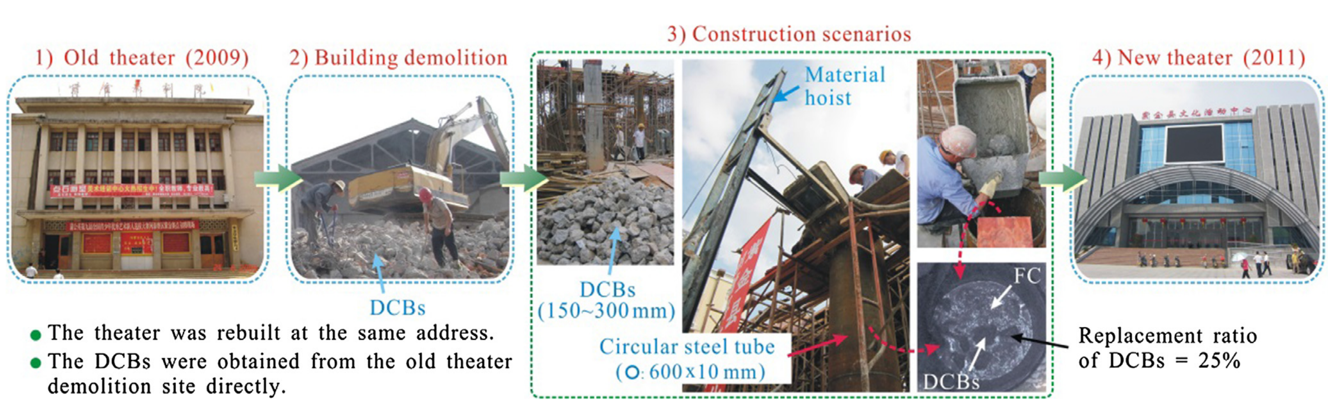

Fig. 1. Application of columns filled with RBC in a theater building in Guangdong, China.