Construction and Building Materials 187 (2018) 50–64

Contents lists available at ScienceDirect

Construction and Building Materials

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

Shape effect on compressive mechanical properties of compound concrete containing demolished concrete lumps

Bo Wu [a,*], Yong Yu [a], Zongping Chen [b], Xiaolong Zhao [c]

[a] State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510640, PR China
[b] College of Civil Engineering and Architecture, Guangxi University, Nanning 530004, PR China
[c] China Academy of Building Research, China Academy of Building Research, Beijing 100013, PR China

HIGHLIGHTS

- Shape effect on compressive behavior of compound concrete is revealed.
- Lateral deformation characteristics of compound concrete are studied.
- Existing strength prediction formula for cubes is extended to cylinders and prisms.

ARTICLE INFO

Article history:
Received 8 November 2017
Received in revised form 1 July 2018
Accepted 11 July 2018

Keywords:
Compound concrete
Demolished concrete lumps
Fresh concrete
Compressive strength
Elastic modulus
Peak strain
Volume dilatancy

ABSTRACT

The viability of directly using coarsely crushed demolished concrete lumps (DCLs) to replace a portion of the new pouring concrete in structural members has been demonstrated in previous research and in practice. However, there is no information focused on the shape effect on the compressive mechanical properties of the compound concrete now. Meanwhile, the lateral deformation characteristic (e.g., volume dilatancy) of the compound concrete made of DCLs and fresh concrete still remains not very clear. To deepen the knowledge related with this concrete type, a total of 93 specimens containing DCLs including cubes, cylinders, and prisms were fabricated and axially loaded up to failure. The replacement ratio of DCLs considered in this study covered a relatively wide range (i.e., 0%, 20%, 30% and 40%). The test results indicate that the compressive strength of cubic compound concrete samples is about 1.30 that of similar cylindrical samples, and is 8.3% larger than that for conventional concrete. The compressive strength of the compound concrete measured with prismatic samples is about 1.08 times that measured using cylindrical samples, while this ratio is about 1.0 for conventional concrete. A formula has been established to predict the compressive strength of the cubic, cylindrical, and prismatic compound concrete specimens with a lateral dimension of 150–300 mm, and the predicted strength is usually within ±10% of the measured value. The ratio of the critical load (i.e., the load at which the volume of the concrete starts to increase) to the ultimate load decreases slightly with increasing DCL replacement percentages.

1. Introduction

Over the past 50 years the construction industry worldwide has generated a huge amount of waste. Typical construction and demolition waste (CDW) from construction, renovation and demolition activities includes concrete, clay brick, glass, asphalt and wood. The most common method of disposal is to send CDW to a landfill. This is obviously deleterious for the environment [8]. At the same time, with economic development, shortage of natural resources have progressively become a cause of great concern to the construction industry [41]. Consumption of concrete now approaches 17.5 billion tonnes per year worldwide, which indicates that at least 13 billion tonnes of aggregate, 2.6 billion tonnes of cement and 1.75 billion tonnes of water are necessary to cast it [20]. In some countries with scarce natural resources the supply of aggregate or the raw materials for producing cement is not sufficient and searching for alternative resources seems imperative. In such situations, re-utilization of waste concrete is meaningful not only for environmental protection but also to sustain the development of the economy.

Nowadays, using crushed concrete debris as recycled aggregate (RA) is widely regarded as one of the most economical and environmentally-friendly ways of recycling demolished concrete

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* Corresponding author.
E-mail address: bowu@scut.edu.cn (B. Wu).

https://doi.org/10.1016/j.conbuildmat.2018.07.086
0950-0618/

[45]. It efficiently reduces the use of natural aggregate and the problems of mining it. Research on this subject has been conducted for a long time. It started with basic observations of the effects of using RA on the compressive strength of concrete, as well as its economic feasibility [26]. Since then, research on recycled aggregate concrete (RAC) has become a hot topic and an area of considerable interest worldwide. Many investigations have now tested the fatigue properties, durability and micro-structure of concrete made with RA [5,23,26,32,38,42]. The results have prompted RAC's being considered promising and environmentally beneficial.

However, the actual application of RAC in real structures has lagged significantly [14]. In China, for instance, the annual production of waste concrete has reached approximately 200 million tonnes [16], but RAC is still applied primarily in non-structural applications such as road construction and backfilling [44]. The reasons hampering wider use of RAC are multifold [14], but one may be that technologies such as smart dismantling and demolition, crushing, and autogenous milling are needed to manufacture high-quality recycled aggregate [25,18,22]. That makes large-scale production of RA time-consuming and less attractive economically.

In order to lessen that difficulty, the authors proposed a more eco-friendly method for recycling waste concrete [33]. That method requires only that waste concrete be coarsely crushed into large lumps (referred as demolished concrete lumps or DCLs) for direct mixing with new concrete (referred as fresh concrete, FC) during casting. Recycled aggregate are usually smaller than about 31.5 mm in diameter, but DCLs commonly range in size from 60 to 300 mm. This gives the proposed recycling approach several advantages [31]. (1) Producing concrete lumps is much simpler than crushing to small pieces and sieving; (2) an increased recycling ratio can be achieved since the mortar of waste concrete is reused simultaneously in the new mixing; and (3) less heat of hydration is generated because less fresh cement is employed.

A series of experiments with specimens made of DCLs and FC have been conducted since 2008 documenting the mechanical and durability-related properties of compound concrete, the short- and long-term bearing behavior of structural members (beams, columns, walls and joints) containing DCLs, and the seismic and fire performance of components filled with DCLs [33–42,44]. Those tests have shown that the mechanical properties and structural performance of members containing DCLs are similar to or only slightly inferior to those of such members cast using FC alone. So it is feasible to use compound concrete in civil construction. In addition, several structural members containing DCLs have been included in real constructions, as shown in Fig. 1.

But more research is still needed before this new technique can be widely accepted. Bearing this in mind, the present study was designed to document the compressive behavior of compound concrete specimens in uniaxial compression. A considerable number of investigations have already been conducted on the compressive behavior of compound concrete [43,34,36,37,17]. In 2011, for example, Zhang and Wu documented the compressive strength of 300 mm concrete cubes filled with DCLs, and they found that the strength can be estimated by a linear combination of the compressive strengths of the demolished concrete and fresh concrete weighted by their mass fractions. Wu's group subsequently investigated the effects of the specimen size and the characteristic size of the concrete lumps on the compressive responses of cubes and cylinders containing DCLs and showed that the larger the lumps' average size, the lower the combined compressive strength of the compound concrete, though the range of the degradation is generally within 10% [34,36]. Meanwhile the combined elastic modulus and combined peak strain of the compound concrete were not affected by the characteristic size of the lumps on the whole. Further experiments with cubes and cylinders made of normal-strength demolished concrete and high-strength fresh concrete revealed that the compressive strengths of the cubes and cylinders was more influenced by the demolished concrete [37]. Most recently, a group led by Liu systematically studied the uniaxial compressive, direct tensile and flexural mechanical properties of compound concrete specimens with various DCL replacement ratios [17].

(a) Reinforced concrete slab (b) Composite slab

(c) Reinforced concrete beam (d) Steel tubular column

Fig. 1. Example applications of structural members incorporating DCLs.