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Review

Mechanical properties of recycled concrete made with different types of coarse aggregate

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HIGHLIGHTS

- Mechanical properties test for two types of recycled coarse aggregate concrete were performed and the the results were discussed.
- Equations of relationships between the compressive strength and flexural strength of recycled aggregate concrete were presented.
- Expressions of stress-strain curves for recycled coarse aggregate concrete were proposed.

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ABSTRACT

One of the most important issues that determine many properties are the types of coarse aggregate in recycled concrete. This paper is arming to experimental study the influence of two different types of coarse aggregate (recycled crushed rock aggregate and recycled pebbles aggregate) on the mechanical properties of recycled concrete. The properties of these two types of recycled coarse aggregate (RCA) derived from waste concrete were investigated. Using these RCA and corresponding types of natural coarse aggregates, recycled concrete specimens according to different replacement percentage were produced and tested. Finally, Analysis and comparisons of the mechanical properties of RAC, including compressive strength, flexural strength, elastic modulus and Poisson's ratios etc., were made between these recycled concretes. The results show that different types of RCA have significant variance in mechanical properties. The recycled concrete containing crushed rock aggregate presents a lower relative strength and elastic modulus than that containing pebble aggregate while the toughness of them is contrary. The theoretical expression for stress-strain relationship and equations for the relationships between various strength of recycled concrete with each type of coarse aggregate are also presented.

Contents

1. Introduction . . . 498
2. Experimental program . . . 498
   2.1. Materials . . . 498
   2.2. Mix proportions . . . 499
   2.3. Specimens preparation . . . 499
   2.4. Tests . . . 500
3. Test results and discussion . . . 500
   3.1. Failure pattern . . . 500
      3.1.1. Cube compressive failure mode . . . 500
      3.1.2. Prism compressive failure mode . . . 501
   3.2. Stress-strain curves . . . 501
   3.3. Compressive strength . . . 501
   3.4. Flexural strength . . . 502

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3.5. Static modulus of elasticity and Poisson's ratio . . . 502
3.6. Energy absorption capacity . . . 503
4. Relationships between strengths . . . 504
5. Approximation of the stress-strain relations . . . 504
6. Conclusions . . . 505
Acknowledgment . . . 505
References . . . 505

1. Introduction

With economy development, rapid growth in urbanization has led to huge scale new construction, especially in some emerging economies countries. These construction works require large quantities of consumption and production of natural aggregate, which result in the intensification of natural aggregate resources shortage and the difficulty of sustainable development. Furthermore, a large number of old structures, which are nearing the end of their life span, need to dismantle and replace in many countries, result in the production of large amounts of construction and demolition waste. In China, the amount of construction and demolition waste has amounted to 30%–40% of the total city solid wastes [1], which will significantly increase the load of landfill. Therefore, recycling of concrete demolition waste as recycled aggregate to partially or fully substitute natural aggregate for recycled aggregate concrete (RAC) has been recognized as an effective way to offset the shortage of natural aggregate, disposal of waste concrete and related environment problem [1,2].

In recent years, even though reuse of RCA to make RAC has received increasing research interest in academic and has been extensively studied, the practical engineering application of RAC is still low [3] or mainly in non-structural concrete [4] explained by the disadvantage and discreteness of their properties, including strength, elastic modulus, toughness, stress-strain relationship, and so on, compare with natural aggregate concrete (NAC) [5–12]. There are many factors related to the deterioration of properties for RAC, which limits its widespread used in structural concrete. Firstly, the replacement percentage (RP), which is defined as the ratio between the weight of recycled coarse aggregate to the total weight of coarse aggregate in a concrete mix [8], is deemed as a vital influence on the properties of RAC [13]. Xiao et al. [6] and Topçu et al. [14] found that the strength of RAC decreases as RP increases while Ho et al. [7] and Etxeberria et al. [9] observed the opposite results. The contradiction of the results was found due to the quality loss of RCA which to be mainly depended on the specific gravity of RCA [18], the moisture state of RCA [5,19], the amount of old adhered mortars [20]. Furthermore, the strength [15,16] and the age of original concrete [17] have a significant impact on the properties of RAC. Researches show that the concrete made with RCA from original concrete with weak strength resulted in lower strength. But the quality of RCA had little influence on the strength of RAC when comparing it to those of high performance conventional concrete. The properties of RAC made with RCA crushed at age 3 days were worse than those made with aggregate crushed at age 1 or 28 days.

Most studies have indicated that, no matter what factors, the fluctuation and adverseness of the mechanical and physical properties of RAC is ultimately due to bad quality and weak link of aggregate-cement matrix interfacial transition zone, which the failure of RAC is often occurring [11,21–24]. However, previous research has shown that different coarse aggregate types strongly influence the mechanical properties of the interfacial transition zone (ITZ) [25] due to the significant difference of their surface and shape. Wu et al. [26] and Rocco et al. [27] considered the impact of coarse aggregate type on mechanical properties of concrete, and they found that different types of coarse aggregate has significant effect on the fracture energy further result in the variation of concrete strength. Concrete made with crushed aggregates provides higher values of the fracture energy than for concrete made with spherical ones. Ribeiro et al. [28] also found that, due to their smoother surface and therefore weaker anchorage, pebble aggregates present areas dislodged from the matrix, leading to concretes with them have lower fracture energy than those with crushed rock.

Summarizing the existing research found that the influence of different types of coarse aggregate on mechanical performance of RAC is not a well-known area while that has been extensively studied on conventional concrete. Nevertheless, due to the adhered old mortar, the RCA originated from crushed concrete with different types of natural coarse aggregate have further variation compared with accordingly natural coarse aggregate (NCA). The mechanical performance of recycled concrete made with them is a meaningful area requiring further research. Consequently, this paper presents an experimental study on the mechanical properties, including compressive strength, flexural strength, stress-strain curves, elastic modulus, Poisson's ratios and energy absorption capacity, of recycled concrete made with different types of coarse aggregate.

2. Experimental program

2.1. Materials

The constituent materials describe as follows:

- Ordinary Portland cement with a 28-day compressive strength of 42.5 MPa.
- Fine natural aggregate (medium-coarse river sand).
- Two types of NCA: crushed rock aggregate (CRA) and pebbles aggregate (PA). They all had a maximum size of 20 mm and a minimum size of 5 mm.
- Two types of RCA originated from crushed waste concrete with crushed rock and natural pebbles as coarse aggregate respectively, which are denominated RCRA and RPA. They are in the same maximum and minimum size of NCA. The crushed waste concrete collected from concrete block produced in laboratory with target strength of 30 MPa .

All RCA were produced by a jaw crusher, and were then sieved to obtain aggregates with required size. After that, they were washed with water to remove surface fine particles such as dust and clay.

The RCRA is composed of crushed natural rock and mortar. And likewise, the RPA is composed of natural pebbles and mortar. However, the content of mortar for RCRA and RP is different due to the various shapes and surfaces of CRA and PA. CRA is irregular and has a rough surface while PA is approximately rounded and has a smooth surface. In Fig. 1, two types of natural coarse aggregate and two types of recycled coarse aggregate are presented.

The physical properties determined on NCA and RCA were tested according to Chinese code GB/T 14685-2011 [29]. The amount of adhered mortar in RCA was measured using the