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Uni-axial compressive stress-strain relation of recycled coarse aggregate concrete after freezing and thawing cycles

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HIGHLIGHTS

- The complete compressive stress-strain curves of RAC after freezing and thawing cycles were measured in this study.
- Theoretic stress-strain curve of RAC after freezing and thawing cycles was presented.
- Parameters of descending branch in stress-strain curve of RAC were given after freezing and thawing cycles.

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ABSTRACT

The mass loss, compressive strength, dynamic elastic modulus and stress-strain relationship of recycled coarse aggregate concrete under different cycles of freezing and thawing were investigated by comparison with normal concrete in the research reported in this paper. Forty-eight prism specimens with the size of 100 mm × 100 mm × 300 mm and ninety-six cubic specimens with the size of 100 mm × 100 mm × 100 mm were fabricated and tested. Test results show that, the mass loss of recycled coarse aggregate concrete decreased first then increased with the increase of freezing and thawing cycles; the relative cubic compressive strength and the relative dynamic elastic modulus of recycled aggregate coarse concrete decreased linearly with the increase of freezing and thawing cycles. The stress-strain curve of recycled aggregate concrete first ascended rapidly and then descended rapidly after exceeding the peak stress till to 1.5 times of the peak strain, finally turned into a slow decrease process. The ductility of recycled coarse aggregate concrete became worse with the increase of freezing and thawing cycles. Theoretic stress-strain curve of recycled coarse aggregate concrete after different cycles of freezing and thawing was presented and it was in good agreement with the experimental results from the other researcher.

1. Introduction

With the development of construction industry, a lot of waste demolished concrete is generated every year. In 2010, the amount of construction and demolition (CD) waste in China is about 1.55 billion tons, accounting for 30–40% of the total waste [1]. If this trend will continue, landfills will be saturated and environment will be polluted. Therefore, how to dispose of the huge amount of waste has become interests of many researchers. It has been reported that this huge amount of CD waste can be potentially used as recycled aggregates (RAs) for the production of recycled aggregate concrete (RAC). And the use of such CD waste as RAs will not only reduce landfills use but also help to minimize the use of natural aggregates (NAs) [2].

The behavior of RAC is significantly affected by its durability, and the freezing-thawing durability is one of the major concerns associated with the application of RAC. Some studies on the freezing-thawing durability of RAC have been investigated. Zaharieva et al. [3] pointed out that the freezing-thawing resistance of RAC is lower than that of natural concrete (NC). The main reason seems to be higher porosity and lower the freezing-thawing resistance of RAs themselves. Kasai et al. [4] found that a high replacement ratio of RAs declines the freezing-thawing resistance of RAC. Gokce et al. [5] investigated the freezing-thawing resistance of RAC. Test results showed that RAC made with an air-entrained admixture had better performance than RAC made with non-air-entrained admixture. Salem et al. [6] reported that RAs originated from concrete made with an air-entrained admixture produced high-quality freezing-thawing resistance of RAC. Haitao et al. [7] conducted a research on the freezing-thawing resistance of high strength (50 MPa) RAC made with 100% replacement of RAs. Test

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results showed that, compressive strength, splitting tensile strength and bending strength of RAC decreased with the increase of freezing and thawing cycles. After 50 cycles of freezing and thawing, the bending strength decreased by 40%. Richardson et al. [8] conducted an experiment on the freezing-thawing resistance of RAC based on the ASTM 666 standards. The test results showed that RAs with the addition of additives can be used for applications where freezing and thawing of concrete occur whilst still providing the durability that NAs offer.

The stress-strain relationship of RAC is important in theoretical and numerical analysis as well as engineering design of RAC structures. In recent years, several investigations have been performed for the stress-strain relation of RAC. Xiao et al. [9] investigated the compressive strength and stress-strain relation of RAC with different replacement ratio of RAs, and obtained the approximate stress-strain curves of RAC according to the analytical expression in Chinese Code GB50010 [10] for uniaxial compression of NC. Du et al. [11] investigated the complete stress-strain curve of RAC with 100% replacement ratio of RAs, and constituted the model of stress-strain of RAC under uniaxial compression loading. Huda et al. [12] conducted a research on the stress-strain curves at the age of 120 days of RAC with different RAs replacement ratio, and found that the pattern of the stress-strain curves was similar for all RAC mixes but the value of the strain corresponding to the peak stress was higher for RAC compared to that of NC. Belén et al. [13] also developed an analytical expression of the stress–strain curve of RAC using the experimental results, and verified the proposed model equation by comparing it to the experimental data. The results showed that the proposed model equation satisfactorily describes the effect of RAs on the stress–strain curve.

However, very limited information is available on the stress-strain relations of RAC after freezing and thawing. A previous research study by Shang [14] investigated the compressive stress-strain relations of RAC after freezing and thawing, and presented a calculation model based on NC stress-strain relation, but freezing and thawing cycles were not considered in the model, and a larger deviation between the theoretical values and experimental values can be seen in the descending branch of stress-strain curves.

The objective of this study is to investigate the influence of freezing and thawing cycles on the mass loss, the compressive strength, dynamic elastic modulus and stress-strain curve of RAC with 100% replacement ratio of RAs, and to present an analytical expression for stress-strain relationship of RAC after different freezing and thawing cycles. The results presented in the study are significant for using the RAC in cold areas.

2. Experimental program

2.1. Materials

2.1.1. Recycled coarse aggregate (RCA)

There is great randomness and variability for RCA made of different sources of original concrete. To ensure the unification of source of RCA, the waste concrete in this test was totally from waste concrete blocks demolished from a cement road in Nanjing university Aeronautics and Astronautics. After crushing, washing and grading into 5–31.5 mm continuous gradation, RCA conforming the standard was prepared. Table 1 shows the grading profile of RCA. Water absorption and crushing index of RCA are 5.7% and 10.4%, respectively, being measured according to a method in JGJ 52-2006 [15]. The RCA used in the study conformed to the requirements of Grade Ⅱ [16].

Table 1
Grading profile of RCA.

Sieve Size (mm)	Grader Retained (%)	Accumulated Retained (%)	Continuous Gradation (%)
31.5	2.25	2.25	5–0
25.0	18.21	20.46	
20.0	15.76	36.22	45–15
16.0	14.38	50.60	
10.0	32.52	83.12	90–70
5.0	10.41	93.53	100–90

2.1.2. Natural coarse aggregate (NCA)

The NCA used in this experiment was made of natural stone, the size of particles was 5 mm to 40 mm.

2.1.3. Fine aggregate

The natural river sand used in this test was medium sand. The performance indicators conform the requirements in JGJ 52-2006 [15], grading profiles and performance of sand are shown in Tables 2 and 3, respectively.

2.1.4. Cement

The cement used in this test was ASTM Type Ⅱ Portland cement produced by the China Jiangnan Cement Co., LTD. Its specific surface area was 385 m^2/kg.

2.1.5. Admixtures

The admixtures used in this test were GYQ®-III concrete air-entraining agent and PCA® (I) carboxylic acid high range water reducer provided by Jiangsu Bote New Materials Co., LTD. The quality of admixtures conformed to GB 50119-2013 [17]. Before casting specimens, twelve groups of proportion tests were conducted in order to obtain the optimum dosage of air-entraining agent and water reducer.

2.1.6. Release agent

GBT 50082-2009 [18] specifies that it is forbidden to use hydrophilic release agent molding specimens for freezing and thawing tests. The DL-J04 hydrophilic release agent used in this test came from Shenzhen Xindeli chemical Co., LTD. The main components of the release agent are polymer organic matters and can be diluted with water in any proportion conforming to the requirements of the test.

Table 2
Grading profile of sand.

Sieve Size (mm)	Grader Retained (%)	Accumulated Retained (%)	Continuous Gradation (%)
5.00	3.20	3.33	10–0
2.50	9.16	12.49	25–0
1.25	8.13	20.62	50–10
0.630	25.75	46.37	70–41
0.315	45.70	92.07	92–70
0.160	29.70	93.30	100–90

Table 3
Performance of sand.

Fineness Module	Mud Content (%)	Particle Diameter (mm)
2.6	2.1	<5