Construction and Building Materials 175 (2018) 55–63

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical properties of sea sand recycled aggregate concrete under axial compression

Yijie Huang *, Xujia He, Qing Wang, Yuedong Sun

Shandong Provincial Key Laboratory of Civil Engineering Disaster Prevention and Mitigation, Shandong University of Science and Technology, Qingdao 266590, PR China

HIGHLIGHTS

- The failure process of SSRAC was influenced by the RCA and SS.
- The compressive strength of SSRAC was higher than that of ordinary concrete.
- The effect of SS Cl^- on the elastic modulus decreased with increasing RCA content.
- Expressions for the stress-strain relation of SSRAC were obtained.

ARTICLE INFO

Article history:
Received 6 October 2017
Received in revised form 22 March 2018
Accepted 16 April 2018
Available online 26 April 2018

Keywords:
Sea sand recycled aggregate concrete
Recycled coarse aggregate (RCA)
Sea sand
Mechanical behavior
Stress-strain curve

ABSTRACT

The properties of axially loaded sea sand recycled aggregate concrete (SSRAC) were experimentally and theoretically investigated in this paper. The main parameters in the test are the sea sand chloride ions (Cl^-) content and the recycled coarse aggregate (RCA) replacement percentage. The influences of sea sand Cl^- and RCA content on the compressive strength, stress-strain relation and failure pattern of SSRAC were studied. Test results showed that both the strength and deformation of specimen changed with the variation of sea sand Cl^- content and RCA replacement percentage. The compressive strength of SSRAC was higher than that of ordinary concrete. The elastic modulus increased, while the peak strain decreased due to the effect of sea sand. It was also indicated that the influence of recycled coarse aggregate replacement percentage on the properties of SSRAC decreased with increasing sea sand Cl^- content. The Poisson's ratio and stress-strain curve of SSRAC were similar to those of ordinary concrete. Finally, a numerical expression for the stress-strain curves of SSRAC under axial loading was presented, which could be used in the theoretical and practical studies.

1. Introduction

The rapid development of concrete engineering has caused serious environmental and social problems (pollution and excessive resource consumption, etc.) in recent years. The output of construction waste increases rapidly, and the consumptions of river sand and natural coarse aggregates are huge every year [1,2]. For the sustainable development of concrete engineering, it is necessary to develop an environmental-friendly material.

Sea sand recycled aggregate concrete can use demolished concrete and sea sand as coarse aggregate and fine aggregate, respectively. It is a new kind of environmental-friendly material which can be directly applied to practical engineering. The density, strength and particle shape of recycled coarse aggregate are similar to those of natural gravels [3]. The sea sand has low clay dosage and cost, desired size fractions and abundant storage advantages compared to the manufactured sand and recycled sand [4,5]. So, the SSRAC has good prospects for application. However, the RCA contains older mortar and some impurities, and there are much Cl^- and shell particle in the sea sand; the properties of SSRAC are complicated. In order to analyze the influences of RCA and sea sand, many studies have been performed in this field.

Bravo et al. [6] and Etxeberria et al. [7] investigated the influence of RCA on the properties of concrete. It was found that the strength development of concrete with RCA was similar to that of ordinary concrete. Xiao et al. [8] and Poon et al. [9] studied the compressive strength of recycled aggregate concrete (RAC). It was indicated that the prismatic and cubic compressive strengths of RAC with 100% RCA replacement percentage were lower than those of ordinary concrete. The strength decreased 10% on average. The elastic modulus and Poisson's ratio of concrete with RCA

* Corresponding author.
E-mail address: 302huangyijie@163.com (Y. Huang).

https://doi.org/10.1016/j.conbuildmat.2018.04.136
0950-0618/

Nomenclature

a, b	parameters in numerical formula	r	RCA replacement percentage
E_c	elastic modulus of concrete	ψ	sea sand Cl^- content
f_c	prismatic compressive strength of SSRAC	υ	Poission's ratio
f_{cu}	cubic compressive strength of SSRAC	υ_o	initial Poisson's ratio
$N_{\max}$	peak load	ε_c	peak strain

varied with the variation of RCA content [10–12]. Test results showed that the elastic modulus of RAC decreased with increasing recycled aggregates, while the change of Poisson's ratio was not obvious. Rao et al. [13] analyzed the tensile properties of RAC by test. It was found that the tensile strength of recycled concrete was lower than that of ordinary concrete, while the peak tensile strain increased with increasing RCA content. Li et al. [14], Wu et al. [15] and Xiao et al. [8] found that the curvature of stress-strain relation of concrete varied with the variation of RCA replacement percentage. Li et al. [16,17] studied the crack propagation and micro-structural properties of RAC. It indicated that the micro-cracks initiated in the ITZs of recycled concrete with different nano-particle contents. The number and width of cracks of RAC under freeze-thaw cycles increased with increasing of alternating times of repetitive load. Folino et al. [18] also investigated the mechanical properties of concrete with RCA under triaxial confining pressure. The strength and deformation of concrete were obviously improved due to the confinement. Additionally, the properties of concrete with sea sand have been studied by experimental and theoretical analyses. The results indicated that the workability, durability and mechanical properties of sea sand concrete were influenced by chloride ions (Cl^-) and shell particle. Limeira et al. [19] and Kumar et al. [20] found that the workability of sea sand concrete was different from that of ordinary concrete. The fluidity and density of concrete with sea sand decreased, while the change of absorption was not obvious. The compressive and tensile strength of sea sand concrete varied the variation of sea sand Cl^- content [21,22], and the peak strain of concrete decreased with the increase of sea sand Cl^- content. It was also found that the elastic modulus of concrete with sea sand was more than that of ordinary concrete [23], while the change of Poisson's ratio was not obvious. Dias et al. [24] and Dolage et al. [25] obtained the durability of concrete with sea sand. Test results showed that the corrosion of steel bars in concrete with allowable Cl^- content was similar to that of ordinary concrete, while the steel corrosion was obvious when the sea sand Cl^- content exceed the limit.

However, there were few studies on the mechanical properties of SSRAC under axial loading. The coupling effect of sea sand and RCA was not investigated. In this study, experiments were carried out to provide a comprehensive evaluation of the mechanical properties of SSRAC. The coupling influence of RCA and sea sand on the elastic modulus, Poisson's ratio, compressive strength, peak strain and stress-strain relation (SSR) was analyzed. A numerical expression was presented to describe the SSR of SSRAC. The results obtained in this paper are significant to the application of SSRAC in the real project.

2. Experimental designs

2.1. Materials

Ordinary Portland cement was adopted in this test. The coarse aggregate consisted of RCA and natural gravel (Fig. 1). The RCA was obtained after crushing and sieving of waste concrete from a demolished pavement. The properties of RCA and natural gravel are listed in Table 1. The fine aggregate used in this test were river sand (RS) and sea sand (SS) (Fig. 2). The sea sand was obtained from Qingdao harbor, China. Basic properties of RS and SS are presented in Table 2. The mix proportion is as follow. Cement: Sand: Coarse aggregate: Water = 410: 571.2: 1213.8: 205. Due to the higher water absorption of RCA, the used RCAs were maintained at saturated surface dry conditions before mixing. The water amount used to presoak the RCA was calculated based on the effective absorption of RCA.

2.2. Specimen preparation and design

All specimens were fabricated under standard conditions. The cement, sand and 1/3 of water were mixed for about 1 min, and then coarse aggregates and another 1/3 of water were added and mixed for about 2 min. Finally, the rest of water were added and mixed uniformly. The specimens cured for 28 days under laboratory conditions (20 °C ± 2 °C, relative humidity of 90 ± 5%).

The details of SSRAC specimens are listed in Table 3. There are 12 groups of specimens with different RCA replacement percentages (0, 50% and 100%) and SS Cl^- content (0, 0.05%, 0.081% and 0.184%). Each group has 18 prismatic specimens ($100 \times 100 \times 300$ mm^3) and 18 cubic specimens ($100 \times 100 \times 100$ mm^3). The prismatic specimens were used to obtain elastic modulus, Poisson's ratio and stress-strain relation. The cubic specimens were utilized to obtain cubic compressive strength.

Specimen is named according to test parameters. Taking SSRAC23 as an example, SSRAC is sea sand recycled aggregate concrete, the first number "2" denotes 100% RCA replacement percentage, and the second number "3" represents 0.184% SS Cl^- content.

2.3. Test instruments and loading program

The loading system as shown in Fig. 3 consisted of two parts: a 2000kN electro-hydraulic servo tester, and a computer system. The load and deformations were automatically collected by computer system. The measured axial deformation was deformation of mid-span of prismatic concrete (100 mm).

The specimen was preloaded with 10% of predicted peak load before actual loading, which could ensure the normal work of the test set-up and lessen the effect of stress concentration. The loading program adopted the displacement pattern. The loading rate was 0.03 mm/min during the test.

3. Experimental results

3.1. Experimental phenomena

3.1.1. Ordinary concrete

In the initial stage of loading, the deformation of prismatic concrete was small. The relation between axial load and deformation was nearly linear. When the axial load reached 0.4–0.5 the peak load (N_{max}), the load-deformation curve became nonlinear, while