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Experimental investigation of whole stress-strain curves of coral concrete

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HIGHLIGHTS

- Constitutive relationship of coral concrete in different strength grades was studied.
- Stress-strain curves of coral concrete in different strength grades were analysed.
- Failure of coral concrete under uniaxial compression test was studied.
- Possible applications of coral concrete in engineering structures were suggested.

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ABSTRACT

The constitutive relationship of coral concrete (CPC) was researched using prismatic specimens under uniaxial compression. The equal stress cycle loading and unloading and equal strain monotonic loading methods were adopted. The elastic modulus (E_c) and Poisson's ratio (μ) were determined. The results showed that when the specimen strain was close to the maximum, CPC was rapidly damaged in the form of splitting. The whole stress-strain curve ascent stage was composed of concave and convex curves, while the descent stage was relatively short. The ratio of residual stress (σ_{ri}) and peak stress (σ_{0i}) was 0.30–0.50, and with increase in the strength grade, σ_{ri}/σ_{0i} decreased. The two-part constitutive equations of CPC were presented, which could reflect all the characteristics of the compression tests. With increase in the strength grade, the μ of coral concrete first increased and then decreased. The E_c of CPC tended to increase. To expand the application of CPC in island engineering construction, superfine cement paste, silicon mortar, or polymer could be used to strengthen the coral surface. Adding steel bar, steel fibre, or organic fibre into CPC could also increase the CPC strength and tenacity.

1. Introduction

A coral reef is a special rock-soil that mainly includes aragonite and high-Mg calcite, with more than 96% $CaCO_3$, and it is abundant in the South China Sea islands. These reefs provide a kind of new engineering material, i.e., coral aggregate, for developing islands [1,2]. Coral concrete (CPC) is composed of coral debris as a coarse aggregate, coral sand as a fine aggregate, seawater, and cement. This material can be useful in improving the marine power in China, developing the South China Sea islands, and building basic infrastructure. Engineering activities such as the construction and repair of concrete structures may sometimes require ships to transport sand and water from the mainland, which may located be far away from the coral island. This would be expensive as well as subject to natural conditions such as stormy waves. It is therefore difficult to ensure that the engineering activities will be completed on time. Under the condition that the local ecological environment is not affected, it may be feasible to obtain raw materials locally from the reef island. It is of theoretical significance and practical value to use seawater and coral reef sand dug up from construction of docks and dredging waterways, as well as to collect coral and coral sand washed by the waves, instead of using fresh water and normal aggregates.

Studies on CPC in China and other areas have mainly concentrated on investigating the durability, mix proportion design, and the basic physical and mechanical properties of CPC. In 1951, American scholar Dempsey [3] reported that the corrosion to dense, high-quality CPC was negligible, but CPC exposed to a humid environment for a long time might be corroded. In 1982, Australian scholar Vines [4] discovered that CPC from Samoa in the South Pacific had poor strength structure and durability. In

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1985, Japanese scholars Ootani [5] also reported on the performance of CPC from Miyakojima. In 1990, Australian scholar Bullen [6] used "FA + water-reducer" in the CPC mix proportion design. In 1991, American scholar Rick [7] investigated the durability of three coral concrete buildings in Bikini in the Pacific. The results showed that a practical CPC structure with 24.7 MPa of 28 day compressive strength could endure 38.6 MPa of compressive strength after 11–16 years, representing an increase of 56%. This confirmed that high-quality CPC exhibits long-term stability and compressive strength. In 1996, Indian scholars Arumugam et al. [8] conducted extensive research on the regulations of the development of CPC cube compressive strength. Japanese scholars Tehada et al. [9] in 2005 and Wattanachai et al. [10] in 2009 reported that steel rebar erosion developed faster in CPC than in ordinary concrete (OPC) with the same mix proportion because of the amount of chloride salt in coral aggregates. In 2012, Malaysian scholars Kakooei et al. and Iranian scholars Akil et al. [11,12] studied the oxygen permeability and rebar corrosion of CPC. They found that polarization resistance of a steel rebar in CPC (W/C = 0.48, 28 days f_{cu} = 16 MPa) was less than that in OPC (W/C = 0.48, 28 days f_{cu} = 25 MPa) with the same mix proportion, and the erosion speed of a rebar in CPC was twice or more that in OPC. In 1989, Chinese scholars Zhaolin et al. [13,14] prepared different CPC specimens and systematically studied their mechanical properties, such as the cube compressive strength, splitting tensile strength, flexural strength, prism axial compressive strength, and elastic modulus. In 2012, Chinese scholars Lei et al. [15] systematically studied the basic mechanics and the flexural fatigue properties of CPC. They found that CPC had properties similar to that of light aggregate concrete (LPC) in terms of the strength development, failure mechanism, and failure performance. In 2013, Chinese scholars Yingtao et al. [16] systematically researched on the reinforcement behaviour of CPC in terms of the elastic modulus, frost resistance, and corrosion resistance, and compared it with that of OPC having the same mix proportion. They found that appropriate FA or SG into the CPC could enhance its elastic modulus and promote its anti-freezing and anti-corrosion ability. In 2016, Chinese scholars Qiao et al. [17] compared and analysed the cost effectiveness of CPC and OPC and found that the life cycle cost of CPC was lower than that of OPC. These studies have provided references for the applications of CPC.

The whole stress-strain curve of uniaxial compression is a comprehensive macroscopic reaction to the mechanical properties and forms the main basis for studies on the bearing capacity and deformation of concrete structures [18]. Several researchers have investigated the whole stress-strain curves of OPC and LPC [19–21]. Compared with that of OPC, the ascent stage of the whole stress-strain curve of LPC is closer to a straight line. This indicates that the strain value in the maximum stress spot is greater and the decline stage is steeper. However, there has been no detailed study on the whole stress-strain curves for CPC, in which coral is used instead of an ordinary aggregate and sea water is used instead of fresh water. From the perspective of structure design, it is of great importance to carry out a systematic study on the whole stress-strain curve of CPC, and compare it with that of OPC and LPC with the same strength grade, in order to provide the basic constitutive relationship for the application of the CPC.

2. Materials and methods

2.1. Raw materials

The coral sand from South China Sea island (Fig. 1a) was unwashed (containing chlorine salt), and the mud concentration was 0.5%. The apparent density was 2500 kg/m^3, bulk density was 1115 kg/m^3, and fineness modulus was 3.5 (Fig. 2). The coral from South China Sea island (containing chlorine salt) (Fig. 1b and c) was broken into irregular particles with a maximum diameter of 20 mm. A continuous gradation of 5–20 mm was obtained through sieving (Fig. 2) with apparent density of 2300 kg/m^3, bulk density of 1000 kg/m^3, and cylinder compressive strength of 3.8 MPa. The CPC was made using 52.5 Ordinary Portland Cement, which was produced by China Jiangnan Cement Co., Ltd, and Class I FA was produced by Zhenjiang. Class S95 milled SG was made by Jiangsu Jiangnan Grinding Company. JM-B Naphthalene series superplasticizer was made by Jiangsu Building

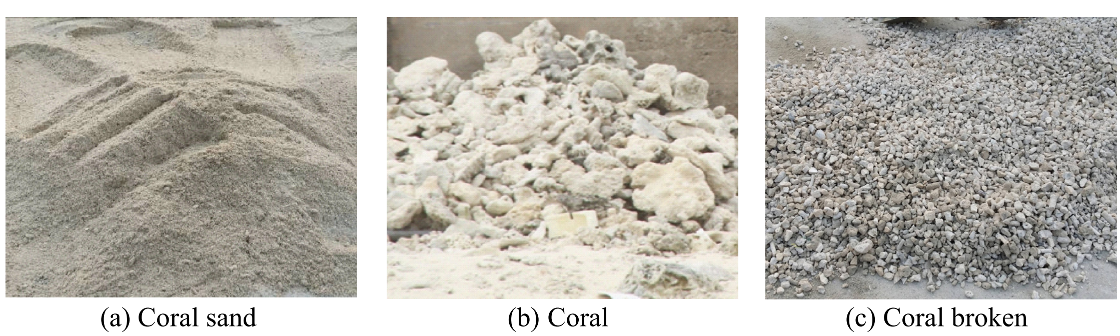

Fig. 1. Coral sand and coral in the South China Sea island.

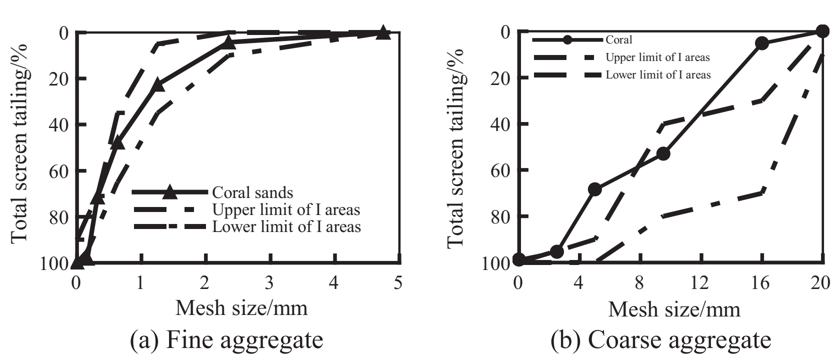

Fig. 2. Coral sand and coral aggregate grading curve.