

Study on bond performance between FRP bars and seawater coral aggregate concrete

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HIGHLIGHTS

- FRP bars are applied in seawater coral aggregate concrete.
- Hoop effect is weaker for coral concrete in compression compared to normal concrete.
- Bond performance between FRP bars and seawater coral aggregate concrete is clarified.
- A four-linear bond stress-slip model is proposed to describe the local bond behavior.
- Local bond parameters are determined analytically based on fracture mechanics.

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ABSTRACT

Application of FRP (fiber reinforced polymer) and SCAC (seawater coral aggregate concrete) in island construction can overcome the shortcomings in conventional steel and concrete. This paper is concerned with the bond performance between FRP bars and SCAC by pullout tests. The effect of fiber type, diameter and bond length of FRP bar and curing condition on the bond behavior is analyzed. It is found that the maximum average bond stress decreases with the increasing of the bond length and the bar diameter. The bond strength is slightly reduced for the specimens immersed in seawater compared to those cured in standard condition for FRP bars bonded to SCAC. Moreover, a four-linear model for local bond stress-slip relationship is proposed with four characteristic parameters, and an analytical approach is then presented to predict the maximum pullout load based on the model. The analytical results show good agreement with the experimental ones, and the proposed four-linear model with four characteristic parameters proves to be reasonable in the present study.

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1. Introduction

With the development of marine resources all over the world, construction of islands far away from the mainland becomes an important task. However, high cost induced by long distance ship transport of raw materials brings a big challenge to practical island engineering. In South China Sea, hundreds of islands have abundant coral reef [1] which often becomes coral broken blocks and coral sand under the washing action of typhoon and ocean wave [2,3]. The main mineral composition of coral reefs and sand is aragonite and high-magnesian calcite and the percentage of calcium carbonate is more than 96% [3]. If coral sand and reefs are used as aggregates instead of river sand and crushed stones,

respectively, and seawater is adopted to mix concrete in island construction, long distance ship transport of aggregates and fresh water from mainland will be avoided. Thus, the construction cost can be highly reduced and the period is shortened correspondingly. According to the literature [4], coral aggregates can be used to produce concrete in the regions where the natural river sand and stones are rare. Effort is then made to study the properties of coral aggregate concrete (CAC) by researchers.

Coral aggregates give no damage on concrete performance based on the results of alkali-aggregate reaction tests [5,6] and can be used as concrete aggregates in some buildings in the Asia-Pacific region [7]. The fineness of coral sand is lower than that of river sand [6]. Moreover, sulphate-resistant cement [8,9] and calcium sulfoaluminate cement [10] can be used for CAC. And water-to-cement ratio should be controlled by using presoaked coral aggregates due to their high water absorption [6]. The early age strength of seawater coral aggregate concrete (SCAC) is

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relatively high but the subsequent strength increases slowly due to the presence of chloride ions in seawater [1,2,11,12]. The interfacial transition zone (ITZ) between cement paste and coral aggregate is denser [13] and the micro-hardness of ITZ is higher than that of normal concrete with the same grade of strength [2] due to the porous properties of coral aggregate. Thus, the splitting tensile strength and elastic modulus are larger than those of normal concrete with the same strength [11]. But brittleness is significant in the failure mode of CAC under compression [14]. The spalling failure can be prevented by confining SCAC with FRP (fiber-reinforced polymer) tubes [15].

The porous nature of coral aggregate increases the permeable channels in concrete which improves the ability of chloride and sulphate penetration. In the tropical marine environment, CAC structures suffer premature failure from chloride erosion more easily due to the effect of typhoon [16]. Therefore, it is crucial to improve the durable performance of CAC. Da et al. [17] found that CAC prepared with magnesium sulphate cement has better resistance to chloride penetration compared to that made by ordinary Portland cement. Moreover, the addition of fly ash, blast furnace slag and metakaolin can reduce the chloride diffusion coefficient of CAC [18]. It is well known that the reinforcement is necessary in CAC structures. However, steel should not be adopted in SCAC due to the steel corrosion under the environment of high chloride content [19–21].



(a)



(b)

Fig. 1. Coral aggregates used in the experiment: (a) Coral coarse aggregate; (b) Coral sand.

FRP bars are non-metallic materials composed of fibers and resin and have high resistance to chloride corrosion, and can be used as reinforcement in CAC. In fact, FRP bars have been successfully applied in normal concrete structures during the past two decades [22]. ACI Committee 440 [22] proposed a guidance for the design and construction of structural concrete reinforced with FRP bars. Bond performance dominates in the serviceability, durability and capacity of reinforced concrete structures [23]. It mainly depends on the types, diameters and surface conditions of FRP bars. The types of FRP bars include GFRP (glass FRP) bars, CFRP (carbon FRP) bars, AFRP (aramid FRP) bars and BFRP (basalt FRP) bars. The surface of FRP bars is often classified as sandblasted, sand grain-covered, ribbed, braided, spiral glued and indented types [24]. Bond properties between FRP bars and concrete have been extensively studied by researchers [23–33]. The interfacial failure of sandblasted and sand grain-covered FRP bars bonded to concrete is induced by abrupt detachment between sand grains and internal smooth bars [24]. For deformed FRP bars, however, a certain damage often occurs on the outer surface of FRP bars, such as delamination of glued spirals, shearing-off of ribs, etc. [23,25–33]. No significant damage was observed in the surrounding concrete [23,25–28]. But for FRP bars with indented and ribbed surface, cracks may be found in the concrete [29]. The bond strength mainly depends on the properties of fibers [31,32] and resin matrix [26,33]. The interfacial behavior can be quantitatively described by bond stress-slip relationship. Typical bond stress-slip models include Malvar model by Malvar [29], modified BPE model by Cosenza et al. [24] based on BPE model by Eligehausen et al. [34] and CMR model by Cosenza et al. [24].

It is worth noting that FRP bars should be especially used in SCAC which may have high chloride content since they show good resistance to chloride erosion. Thus, FRP bar reinforced seawater coral aggregate concrete structures will be widely applied in island construction. Bond performance between FRP bars and SCAC is then crucial to the structural behavior as discussed above. But very limited studies are concerned with the bond properties of FRP bars to SCAC so far. The intention of this paper is to analyze the bond performance between FRP bars and SCAC aimed at the effects of

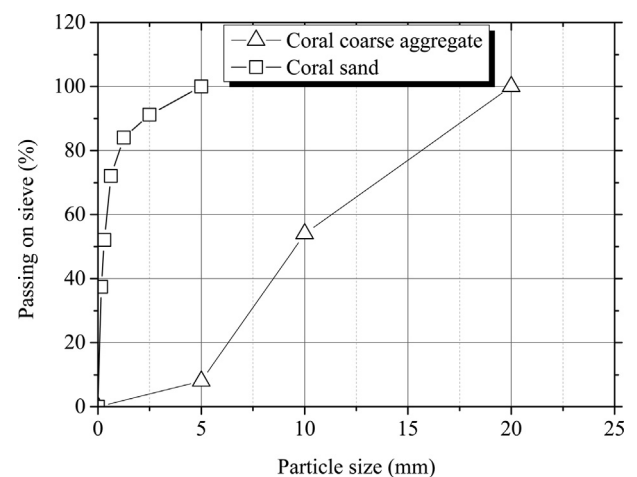


Fig. 2. Size distribution of coral aggregates.

Table 1

Chemical composition of artificial seawater (g/L).

NaCl	MgCl ₂	Na ₂ SO ₄	CaCl ₂	KCl	NaHCO ₃
22.16	5.265	3.861	1.082	0.745	0.207

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