Experimental Study on Bond Properties between FRP Bars and Coral Concrete

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Abstract: The bonding behavior between Fiber Reinforced Plastic (FRP) bars and concrete is the most basic mechanical behavior of FRP-reinforced concrete structural, which affects the structural calculation and performance analysis. However, few studies involved coral concrete. The experimental study on the bond behavior between FRP bars and coral concrete was carried out. The results showed that the bond strength of FRP and coral concrete can meet the general engineering needs.

1. Introduction
Coral concrete is a new type of concrete which is made of natural coral fragments instead of traditional gravel, and mixed with sand and seawater. Because there is no need to transport materials other than cement from the mainland, the use of coral concrete can save cost, accelerate the construction period, and has high application value in Sea Island construction projects. At present, a lot of studies have been done on coral concrete, R.A.Arumugam’s study (Arumugam and Ramamurthy, 1996) on the mix ratio and mechanical properties of coral concrete showed that the early strength of coral concrete increased rapidly and the latter strength increased slowly. Wang's (Wang, 2012) research showed that the strength, formation mechanism and failure modes of coral concrete are different from those of ordinary concrete and common lightweight aggregate concrete. However, the corrosion of steel bars caused by the salt contained in coral concrete and seawater could not be effectively overcome, which has been the major barrier to the application of coral concrete (Li, et al, 2013)

In recent years, because of its excellent mechanical properties, corrosion resistance and other advantages, the fiber reinforced plastic (FRP) rebars have been widely used in engineering field, (Chen, et al, 2007) which also provide a new way for the reinforcements of coral concrete structures (CSA S806 02, 2002; Ye and Feng, 2006). However, neither the traditional reinforced concrete theories nor the related researches (Achillides and Plakoutas, 2004; Chaallal and Benmokrane, 1993; Italmas, et al, 2015; Robert, 2010) of FRP-reinforced concrete structure can accurately describe the bond mechanical behavior of FRP-coral concrete structure.

2. Experimental Program

2.1. Materials

2.1.1. FRP bars
The FRP ribbed reinforcing bars used in this text were manufactured by Haining Anjie Composite
Material CO. The surface condition and mechanical properties of the FRP bars are shown in Fig. 1.

![Fig.1 Surface condition of the FRP bars](image1)

### 2.1.2 Coral concrete
The intended strength grade of coral concrete for testing is C20. The mix proportion and measured mechanical properties of the coral concrete are shown in Table 1.

| Concrete strength | Mix proportion of coral concrete/(Kg·m$^{-3}$) | Water-cement ratio | Cube compressive strength (MPa) | Splitting tensile strength (MPa) |
|-------------------|-----------------------------------------------|--------------------|--------------------------------|-------------------------------|
| C20               | Coral 716, Sand 830, Cement 380, Seawater 180 | 0.47               | 22.5                           | 2.01                          |

### 2.2 Test specimens fabrication and maintenance
Ten groups of CFRP-Coral concrete specimens and five groups of GFRP-Coral concrete specimens were made, according to the design requirements of the Canadian Standards Association (CSA). Each group contained 3 standard bonded specimens. For example, C6-8d-25 indicate specimens group of CFRP bar with diameter of 6mm, embedment length of 48mm (8×6mm) and concrete cover of 25mm thick. As shown in Fig. 2

![Fig.2 Pull-out specimen](image2)

### 2.3 Test setup
The pullout test setup consisted of a universal hydraulic testing machine, 4 high-strength screws, a square steel plate with a hole in the center where the FRP bar could pass through and 2 electronic dial indicators, as shown in Fig. 3.

![Fig.3 Pull-out test arrangement](image3)

### 3 Test results and discussion

#### 3.1 The failure mode and Bond stress–slip curves
a. Splitting failure  
b. Pull-out failure  
c. Fracture failure  
d. Sectional view of the specimen

Fig.4 pictures of different bond failure
The test results show that the stress processes and test phenomena of the pullout tests for FRP bars-coral concrete are similar to those of FRP-common concrete. The typical pictures of different bond failures are shown in Fig. 4. The typical τ~s curve of FRP bars-coral concrete can be divided into 4 stages, as shown in Fig. 5.

![Typical bond-slip curves of pull-out failure](image)

Fig.5 Typical bond-slip curves of pull-out failure

![Comparison of bond-slip curves for different bonded specimens](image)

Fig.6 Comparison of bond-slip curves for different bonded specimens

There are great differences between the mechanical properties of FRP bars and steel bars, and between the coral concrete and common concrete (Guo, 2006; Wu, 2009; Zheng, 2006), which led to significant differences in the τ~s curves of different kinds of bonded specimens, as shown in Fig. 6. In general, the bond strength between FRP bars and concrete is lower than that of steel bars.

First, the residual section of the τ~s curves of FRP bar have a process of rise and fall, and the distances between the adjacent peaks and troughs are approximately equal to one rib spacing of the FRP bar, while the remaining curve of steel bar tend to be smooth. Furthermore, the residual bond stress of FRP bars-coral concrete is about 60%~80% of the ultimate bond stress, while the residual stress of FRP bars-common concrete is about 50%~60%, and that of reinforced concrete is about 20%~40%. The reason is that the concrete between the ribs of steel bar is badly damaged during the pullout progress and can not continue to provide mechanical bite force.

Second, the slope of the rising section of the curves for steel bars are obviously larger than that of FRP bars, mainly because that the elastic modulus of the FRP bars are about 25%~75% of the steel bars.

Third, at the initial stage of the ascent, the slope of the curves of the FRP - coral concrete is slightly smaller than that of the common concrete. It is because that the elastic modulus of coral concrete is lower than common concrete, i.e., the strain of coral concrete should be greater than common concrete under the same stress.

3.2. Affect factors

3.2.1. The thickness of concrete cover layer
With the increase of the cover layer, the peripheral concrete has a confinement effect on the interface
of the inner concrete. As a result, the coral concrete around the FRP bar is less likely to split, the average bond stress is enhanced correspondingly. As seen from Table 3, as other conditions were the same, the average bond stresses increased obviously when the embedment lengths were relatively short (8d-12d).

3.2.2. The embedment length
An increase in embedment length decreases the peak stress and average bond stress value for both CFRP and GFRP bars. As shown in Fig. 7, when the embedment length increases from 8d to 12d, the peak stress and the average stress are decreased by 15.30% and 13.18%; from 12d to 20d, the peak stress and the average stress are decreased by 4.72% and 2.68%. The same effect is also reported for steel bars and FRP bars-common concrete specimens. This is considered to be caused by the nonlinear distribution of bond stresses on the bar: The longer the embedment length was, the shorter the high stress zone and the lower the average bond stress was.

3.2.3. Differences between coral concrete and common concrete
The coral aggregates are quite different from the tradition stone aggregates in material quality: the coral aggregates are light, porous, brittle, low in strength and elastic modulus, so they are more easier to be broken and deformed than stone aggregates when they are squeezed. Therefore, the mechanical bite force and cohesive force are lower than those of common concrete using stone aggregate, and the FRP bars are more inclined to be pulled out instead of concrete splitting in coral concrete.

4. Conclusions
(1) The mechanical properties and experimental phenomenons of FRP bars-coral concrete are similar to those of FRP bars-common concrete, the τ-s curves can be roughly divided into 4 stages: micro slip section, slip section, descent section and residual section. And the bond properties of FRP bars-coral concrete can meet the needs of general engineering.

(2) The average bond stress of FRP bars-coral concrete increased with the raise of relative concrete cover layer and decreased significantly with the increase of embedment length. Splitting failure occurred when the relative concrete cover layer was small; otherwise, when the relative concrete cover layer became larger, the specimens failed with the pullout or fracture of the FRP bars.

(3) During the pullout failure, the ribs of the FRP bar were sheared and abraded smoothly, and there were obvious friction marks and visible friction residue on bond interface of concrete. Apparently, the surface characteristics of the bar, such as surface hardness of rein and interface height, had significant influences on the bond stress.

(4) There are certain differences between coral concrete and common concrete. Coral aggregate are light in weight, loose, porous, friable, lower in strength and elastic modulus compared with ordinary gravel aggregate. So that the bonding strength of FRP bars-coral concrete is lower than common concrete, and the slippage is larger.

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