# Strengthening mechanism and microstructures of fiber reinforced coral concrete

Lei WANG [1,2]Ni SHEN [1]， Dapeng YU [1] ,Feng Fu [3*], Kai Qian[1]

1.College of Civil Engineering and Architecture, Guilin University of Technology, Guilin Guangxi 541004, China;

2. Guangxi Key Laboratory of Geomechanics and Geotechnical Engineering, Guilin, Guangxi 541004, China;

3. School of Mathematics, Computer Science & Engineering, University of London, London, EC1V0HB, UK

## ABSTRACT

In this paper, the strengthening mechanism of different dosage and length of carbon fiber, sisal fiber and polypropylene fiber on the microstructures and mechanical properties of Coral Concrete was studied through mechanical tests and microstructure analysis using Scanning Electron Microscope (SEM). Based on the mechanical tests and analysis of the microstructure, the strengthening effect and strengthening mechanism of fiber in coral concrete, as well as the mechanical properties of cementitious coral concrete were investigated. The results show that compared to normal mortar, the workability of the coral concrete is poor due to its light weight, high porous and rough surface, making the evenly dispersion of fibers in the concrete difficult, therefore, reduces the strengthening effect the fibers. However, the addition of fibers can significantly enhance the flexural strength and toughness of the coral concrete, improve the mechanical properties of coral concrete, but excessive high fiber dosage and extra-long fiber will significantly reduce the working performance of coral concrete, due to the fiber curling and clustering, especially for carbon fiber. In addition, the optimal length and content of different types of fiber are investigated. It is also found that, the strengthening effect of sisal fiber is better than polypropylene fiber and carbon fiber.

**Keywords: Concrete structures, Composite structures,** Failure ,Coral concrete; Mechanical properties; Microstructure; Scanning Electron Microscope; strengthening effect; fiber,

## 1. Introduction

In the construction of offshore reef islands, using coral sand as fine aggregate to prepare structural concrete can effectively solve the problem of traditional building material shortage with good economic benefits [Yodsudjai et al. 2003; Lee 2003; Yi G. 2017; Wang et al. 2018]. Coral sand is a kind of natural calcium lightweight aggregate with low compressive strength,

[*]Corresponding author email: cenffu@yahoo.co.uk

high porosity and high water absorption [Da et al. 2016; Lyu et al. 2019]. There are significant differences in microstructure between the concrete with coral sand and the concrete with natural river sand. Liu [2018] shows that coral aggregate has the characteristics of rough and porous surface, which can be "nested" into cement paste and can be more effective compared to river sand. Guo [2017] and Ma [2019] found that coral mortar and coral concrete have the same basic characteristics, both contain more capillary water and larger porosity. Wang [2017] and Da [2016] show that the elastic modulus of coral aggregate concrete is lower than that of natural aggregate concrete due to the defects of coral aggregate material itself, which leads to large shrinkage deformation; Huang [2018] studies the mechanical properties of the specimen by uniaxial compression test, and finds that the failure mode of coral aggregate concrete is relatively malleable compared to that of natural aggregate concrete, and the failure mode of coral aggregate concrete is less ductile. The mode is brittle failure, and the compressive strength of coral aggregate concrete is lower than that of natural aggregate concrete. Guo [2017] measured the flexural strength of standard sand concrete and coral sand concrete by 3-point bending tests, the test results show that the flexural strength of coral sand concrete is lower than that of standard sand concrete. Therefore, compared with natural aggregate concrete, coral concrete has many disadvantages, such as large shrinkage deformation, high brittleness and low flexural strength, which seriously restrict its application in large-scale projects.

An effective way to solve aforementioned problem such as low flexural strength of coral concrete is the addition of proper amount of fibers. Shu [2015] discovered that macro carbon fiber has a positive impact on the stiffness and toughness of cement concrete, which can effectively improve the mechanical properties of concrete under the tensile action; khushnood [2018] showed that adding well dispersed carbon fiber into the concrete matrix greatly improves the toughness and anti-crack performance of cement concrete, with the ultimate toughness of 15% carbon fiber concrete will be increased about 3 times. Wang [2018] soaked the carbon fiber bars in seawater at different temperatures, and found that there was no obvious debonding and void between the carbon fiber bars and the resin interface, which indicated that the carbon fiber had better corrosion resistance; Filho [1999] measured the plastic shrinkage of sisal fiber concrete by the test method proposed by Sanjuan and Moragues [1994], and the results showed that sisal fiber can delay the first crack and control the crack growth. Reis JML [2012] shows that sisal fiber can significantly improve the fracture performance of polymer concrete. Izaguirre [2011] found that polypropylene fiber can improve the tensile performance of limestone concrete, and control the development of cracks through fiber bridging, so as to reduce the amount of limestone. Plastic shrinkage and early drying shrinkage of concrete; Nam [2016] and Ostertag [2007] showed that adding polypropylene fiber into cementitious materials can effectively reduce drying shrinkage and significantly improve the crack resistance and frost resistance of cementitious materials; Jiang [2016] used polypropylene fiber to strengthen and repair concrete, and studied its mechanical properties and working properties, the results showed that there is no obvious increase its compressive strength but the bond strength and bending strength. The shrinkage, wear resistance, impermeability and frost resistance of polypropylene fiber cement concrete are reduced.

Due to the unique feature of coral concrete, the research on fiber-reinforced coral concrete is still rare. Therefore, in this paper, the strengthening mechanism of different dosage and length of carbon fiber, sisal fiber and polypropylene fiber and their influence on the microstructures and mechanical properties of Coral Concrete was studied through mechanical tests and microstructure analysis using Scanning Electron Microscope (SEM). Based on the mechanical tests and analysis of the microstructure, the strengthening effect and mechanism of fiber, as well as the mechanical properties of cementitious coral concrete were investigated.

## 2. Test Program

### *2.1 Test Material*

The cement is P.O 42.5 grade ordinary Portland cement, mixing with domestic water, natural coral sand. Three different types of fiber, carbon fiber (CF), sisal fiber (SF) and polypropylene fiber (PPF) are used, as it shown in Fig.1. The concrete mix design is in accordance to the ordinary concrete with same gradation method. The tests are performed according to the standard test method for basic performance of building concrete (JGJ / T 70-2009). It can be seen from table 1 that, apparently, the density of coral sand is slightly higher than that of standard river sand, but because coral sand contains more internal pores, its bulk density is significantly lower than that of standard river sand. Under the same 0.5 water cement ratio, its content is less than one quarter of that of standard river sand concrete, and its workability is poor. Please refer to Table 2.

**Table 1 The properties of sand**

| Sand type | Fineness modulus | Apparent density/ ($kg \cdot m^{-3}$) | Packing density/ ($kg \cdot m^{-3}$) | Standard consistency/ mm |
|---|---|---|---|---|
| Standard sand | 2.93 | 2650 | 1630 | 86 |
| Coral sand | 2.93 | 2700 | 1480 | 18 |

**Table 2 The mechanical properties of the fiber**

| Fiber type | Length/ mm | Diameter/ μm | Density/ ($g \cdot cm^3$) | Elastic modulus/ GPa | Tensile strength/ MPa | Elongation at break/ % |
|---|---|---|---|---|---|---|
| CF | 6,12,18 | 7 | 1.76 | 230 | 3530 | 1.5 |
| SF | 6,12,18 | 75 | 1.45 | 26 | 780 | 6 |
| PPF | 6,12,18 | 31 | 0.91 | 3.5 | 400 | 30 |


（a）Coral sand


（b）CF


（c）SF


（b）PPF

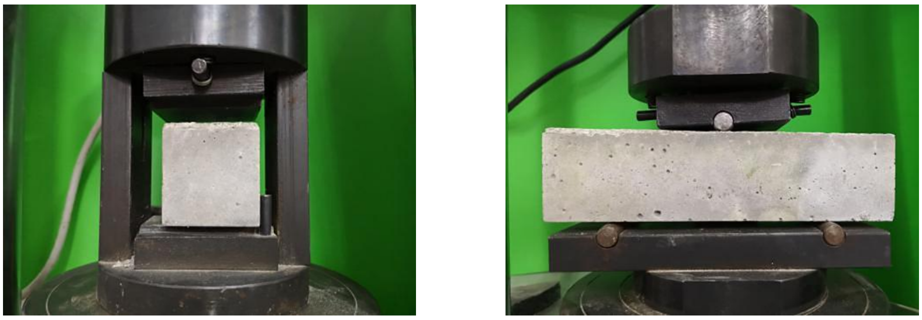
**Fig.1 Test material**

## *2.2 Test setup*

In accordance to the test method of cement concrete strength in Chinese design code GBT17671-1999, 46 groups of coral concrete specimens with carbon fiber, sisal fiber and polypropylene fiber in 4 different dosages and 3 different lengths were casted. The water cement ratio was 0.5, and the cement sand ratio was 1:3. The coral concrete with the same water cement ratio and without fiber (NF) was used as the control group, and the mix proportion was shown in Table 3. 40mm × 40mm × 160mm standard size specimens were casted with the curing period is 28 days. After the test specimens are casted, they are placed at a lab environment of (20 ± 2) ℃ and 95%humidity for curing. The bending and compressive test pieces are performed with the specific loading device shown in Fig.2

**Table 3 Mix proportion of concrete**

| Concrete type | Coral sand/ kg | Cement/ kg | Water/ kg | Fiber type | Fiber length/ mm | Fiber content/ (kg·m$^{-3}$) |
|---|---|---|---|---|---|---|
| Unmixed Coral concrete | 1620 | 556 | 278 | - | - | - |
| Fiber Coral concrete | 1620 | 556 | 278 | CF、SF、PPF | 6、12、18 | 0.5、1.0、1.5、2.0 |



（a）compressive test （b) Flexural test

**Fig.2 Test set up**

### *2.3 Microstructure analysis*

To gain further insight of the effective mix proportion for UHPC, the UHPC samples were inspected by the Scanning Electron Microscopy (SEM) method at Guilin university of technology. SEM observed the high-resolution morphology of the samples to obtain the microstructure information of the samples as follows: porosity characteristics of coral mortar on the fracture surface of the mortar specimen, adhesion of hydrated products on the fiber surface, and interface state of coral mortar and fiber. During the SEM observation, the original sample was cut into a specified size and coated with gold (when the sample contained conductive substances). The microstructure of the sample was observed and photographed by means of SEM -S-4800 available in Guilin university of technology, the device is shown in Fig.3. All samples were inspected as taken from the specimen without any further processing. Below is the discussion of the effect of different parameters on the SEM observations.

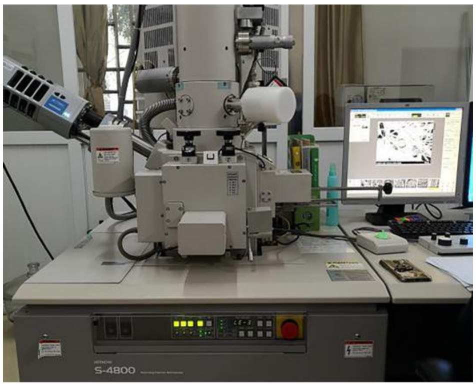


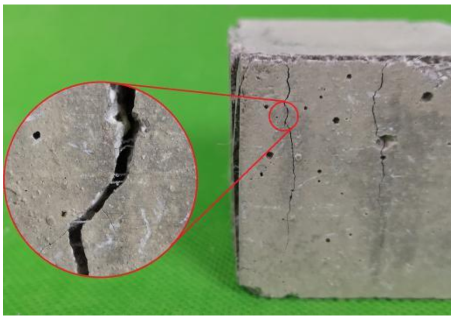

**Fig.3 The scanning electron microscope**

## 3. Test Results and discussion

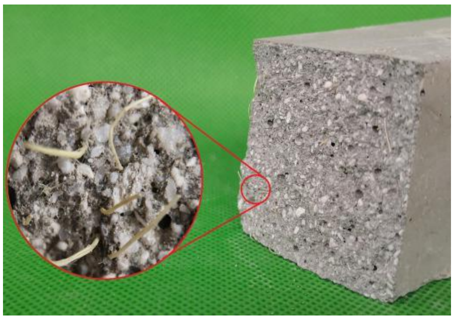
### *3.1 Failure mode of coral concrete*

When the coral concrete without fiber is damaged under compression tests, there is no obvious sign of cracking before it is broken into several pieces, showing obvious brittle failure characteristics. The addition of fiber has greatly changed the failure modes. The connection of the fiber at the crack and fracture surface has made the specimen maintain a certain integrity during the failure. However, the brittle failure has been reduced to a certain extent, as shown in Fig. 4 (a). The compressive strength of fiber reinforced coral concrete has not been improved, only a few specimens have been slightly improved due to the addition of fiber in the test, and the strength of most of the fiber specimens has been reduced, especially for the carbon fiber specimens with larger fiber dosage of2.0kg/ $M^{-3}$and fiber length of 18m, the compressive strength has been reduced by about 11.4%. The main reason is that the long and excessive carbon fiber is very difficult to evenly disperse into the coral cement paste. The weak interface and initial defects caused by the carbon fiber reduce the compressive strength of the mortar, as shown in Fig.5.

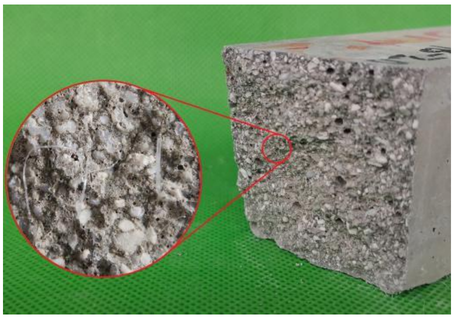
In the bending tests, the coral concrete specimen without fiber breaks into two sections with a loud noise, and the failure is sudden, showing obvious brittleness. However, for the test specimen with fiber, at failure, the integrity of the specimen is still maintained, as the fiber across the cracks plays a "bridging role" which significantly improve the toughness of coral mortar. The flexural strength of the fiber coral mortar specimens is improved to different extent, but the reinforcement effect of the specimens with different fiber and content is different. Compared with plain coral mortar, the flexural strength of carbon fiber mortar with fiber length of 6 m and content of 1.0 kg/$M^{-3}$ increased about 27.7%. Different from ordinary river sand, because the strength of coral fine aggregate itself is significantly lower than quartz sand, coral sands fracture on the surface, and the larger the particle size, the more fractures. As it shown in Fig. 4 (b), sisal fiber breaks on the fracture location. As it shown in Fig. 4 (c), polypropylene fiber breaks and pulls out together. As it shown in Fig. 4 (d), carbon fiber has high tensile strength and is very difficult to disperse, only a few of fiber break, the remaining are pulled out in bundles.

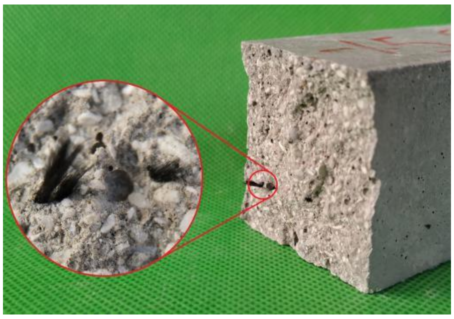


（a）The compression failure modes of fiber coral concrete



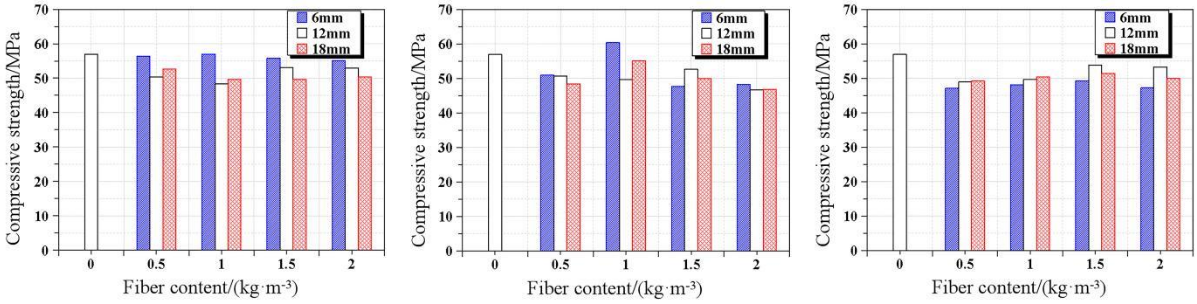
（b）Flexural failure section of SF coral concrete specimen





（c）Flexural failure section of PPF coral concrete specimen （d）Flexural failure section of CF coral concrete specimen

**Fig.4 Failure state of different fiber coral concrete**




（a）CF （b）SF （c）PPF

**Fig.5 Compressive strength of fiber coral concrete specimens**

### *3.2 The theoretical stress-strain relationship of fiber reinforced coral concrete*

In the current research, stress-strain curve is usually used to investigate the brittleness of cement mortar materials. Because this test did not focus on the stress-strain behavior of fiber reinforced coral mortar under different loading conditions, it is difficult to get a complete and systematic curve. Based on the comprehensive analysis of references [Wang et al. 2017] and the test results, the theoretical curves of fiber reinforced coral mortar can be obtained, as shown in Fig. 6.

(1) **stress and compaction stage (OA)**: at the low stress level, the deformation of the specimen is larger, and the slope of the stress-strain curve is smaller.At this time, the internal structure of coral mortar specimen is compressed and the number of pores decreases.

(2) **crack propagation stage (AB)**: with the increase of load, the microfracture in the specimen gradually increased and expanded to the macroscopic level. The increase of the slope of the stress-strain curve is accelerating, and the specimen is in the stage of linear elasticity. Due to the random distribution of fiber can prevent the expansion of the original crack and the generation of new crack, so adding an appropriate amount of fiber can significantly improve the brittleness of coral mortar specimens. As the load continues to increase, the compressive strength gradually approaches the ultimate compressive strength, and the curve tends to the ultimate compressive strength. It's gentle.

(3) **structural failure stage (BC)**: the stress decreases slowly in a short period of time, but with the microfracture in the specimen continue with transfixion and connect into sections, the curve enters a rapid descending stage, and the deformation increases sharply.

(4) **residual stage (after point C)**: the fiber material being stretched to failure or relative slippage at the fiber-mortar interface. The stress-strain curve of the specimen decreases slowly, the stress level is low, and there is a certain residual strength.

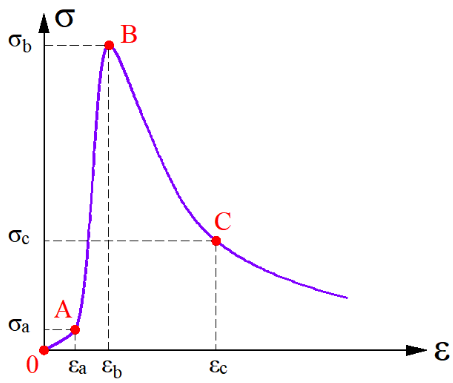



**Fig.6 Theoretical $\sigma \sim \varepsilon$ relationship**

### *3.3 Effect of coral sand on the mechanical properties and microstructure of the coral concrete*

The workability of fresh coral sand is significantly lower than that of standard river sand mortar due to its light, porous and rough surface. Under the same gradation and water cement ratio, coral paste with low mobility reduce the even dispersion of fibers, which affects the role of fibers in improving the performance of coral sand concrete. The SEM results also indicate another significant influence. As shown in the SEM image in Fig.7, in addition to the atmospheric pores formed inside the mortar in the process of mixing, there are still a lot of fine voids in the section of the coral mortar. This may be because coral sand with the porous structure contains more air inside, and its porosity is close to 50% [Liu et al. 2019; Yang et al. 2019]. In the process of mixing and water absorption, part of the air is discharged from the inside of the particles, and part of the air can be discharged from the fresh concrete through mixing. The air that cannot be discharged formed the space between the cement paste and coral particles after mortar hardening. In addition, during the compacting process of fresh coral concrete, the rising and discharging of bubbles in coral concrete, the porosity in the upper part of the specimen is more than that in the lower part.

The addition of fiber into the slurry of cement forms a complex fiber matrix, which can reduce the segregation tendency of coral concrete due to the settlement of aggregate in the slurry, reduce early cracking of due to water evaporation or temperature change, and further reduce the number and scale of internal cracks of coral mortar [Aly et al. 2008; Ardanuy et al. 2015; MA et al. 2018]. However, the fibers will also hinder the discharge of air bubbles inside the coral concrete, resulting in the increase of porosity and the decrease of compactness of the coral concrete, which is quite different from the ordinary concrete. The increase of porosity reduces the compressive strength of the specimen, and at the same time affects the bond performance between the fiber and the mortar matrix.

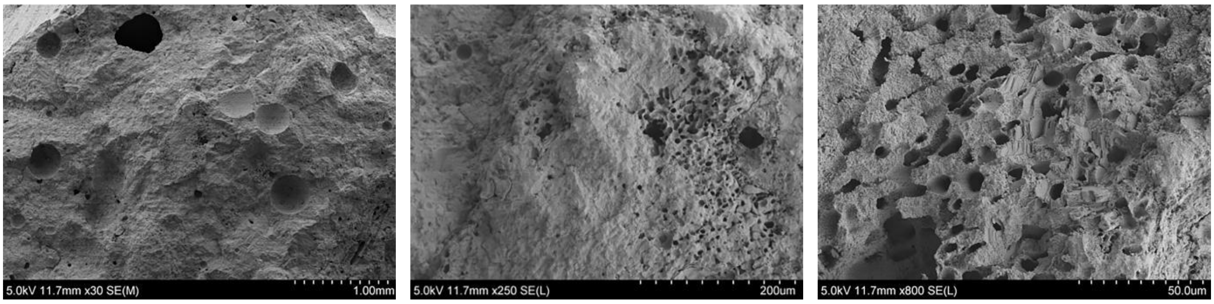



**Fig.7 Porosity of coral concrete specimen (Microstructure observed at 30,250 and 500 magnification)**

### *3.4 Effect of type of fiber on the mechanical properties and microstructure of the coral concrete*

According to the mechanism of fiber strengthening and toughening, the mechanism of fine fiber and coarse fiber reinforced concrete is quite different under almost the same composition. Assuming that the fiber can be evenly distributed, the larger number of fine fibers tends to control the development of micro cracks, they are also forming a larger bonding zone with sand slurry, to improve the strength of cement paste. For coarse fiber, it is only before they are pulled out, it also helps to restrain the development of macro cracks and improve the toughness of the composite.

As shown in Fig.8, the fiber can effectively improve the flexural strength of coral concrete, but the reinforcement effect is quite different. Among them, the flexural compression ratio of sisal fiber coral mortar is the highest, which is 38.0% higher than that of plain coral mortar on average.

It should be noted that the behavior of specimens largely depends on the properties of fiber itself and the interface between fiber and cement matrix. Therefore, the strength, toughness, surface condition and dispersion ability of fiber have significant influence on the performance of fiber mortar. As shown in the SEM image in Fig.9, carbon fiber [Lin et al. 2011; Lestari et al. 2013; Ryan et al. 2013] has poor dispersion performance due to its hydrophobicity and agglomeratability under the same test conditions and test steps, and there are forming many blusters in mortar. Coral slurry cannot fully wrap carbon fiber, as the surface of carbon fiber is smooth, the bond between carbon fiber and slurry is relatively weak, and the high tensile strength of carbon fiber is not fully utilized, which leads to the strengthening effect of carbon fiber coral mortar lower than expected. Compared with carbon fiber, sisal fiber [Fernandes et al. 2013; Klerk et al. 2015; Haque et al. 2015] and polypropylene fiber [Ausias et al. 2013; Ruan et al. 2013; Coppola et al. 2015] have good dispersion and no obvious agglomeration phenomenon. Because sisal fiber has rough surface and has obvious hydrophilic characteristics, cement hydration products are easy to be embedded in the fiber surface, which increases the adhesion between fiber and coral mortar, and its reinforcement effect is better than polypropylene fiber. The failure modes for sisal fiber coral mortar specimens is mainly fiber fracture, while for polypropylene fiber, most of them are pulled-out.

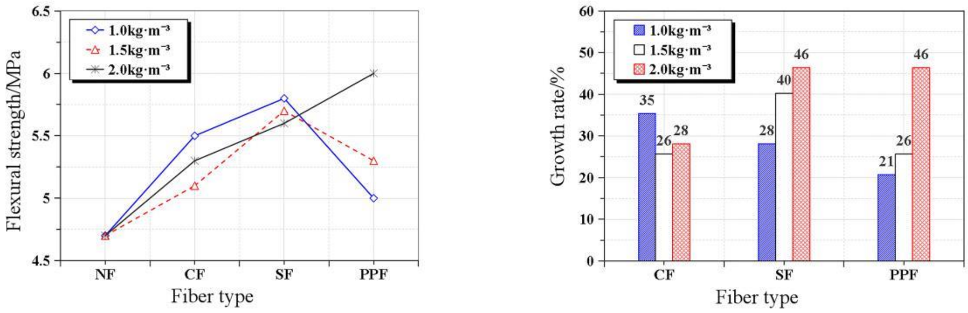
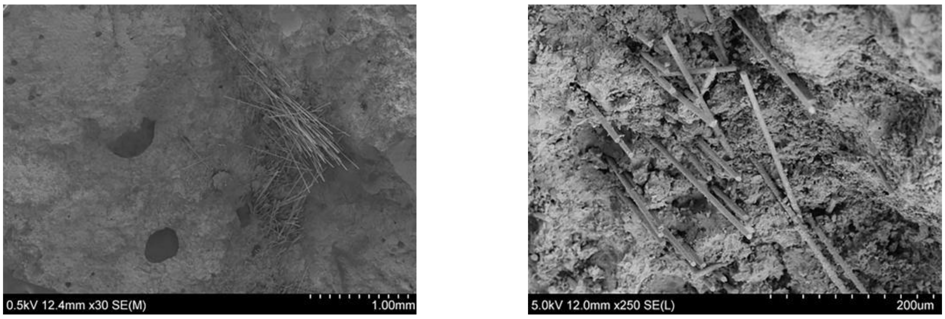
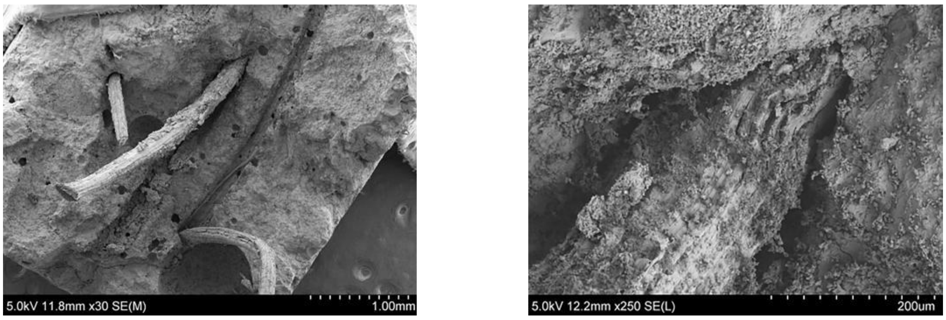


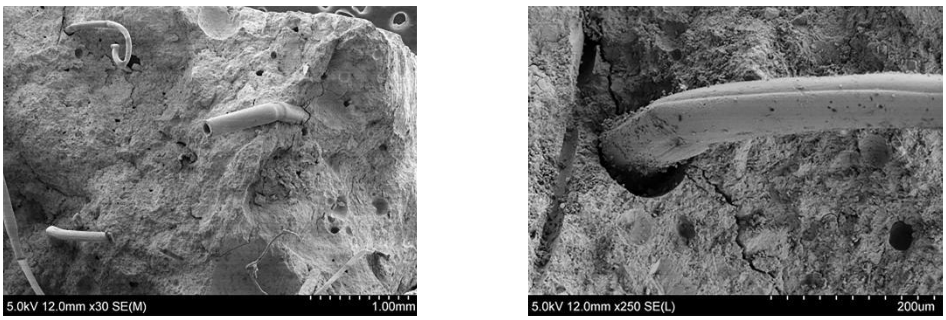

**Fig.8 The flexural strength and growth rate of flexural and compressive strength ratio of different fiber coral concrete**




(a) CF




(b) SF



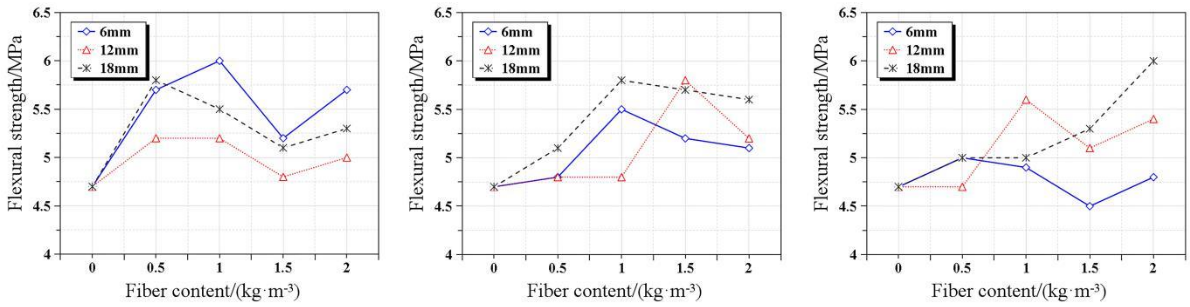

(c) PPF

**Fig.9 SEM images of fracture of different fiber in coral concrete (Microstructure observed at 30,250 magnification)**

## *3.5 Effect of dosage and length of fiber on the mechanical properties of the coral concrete*

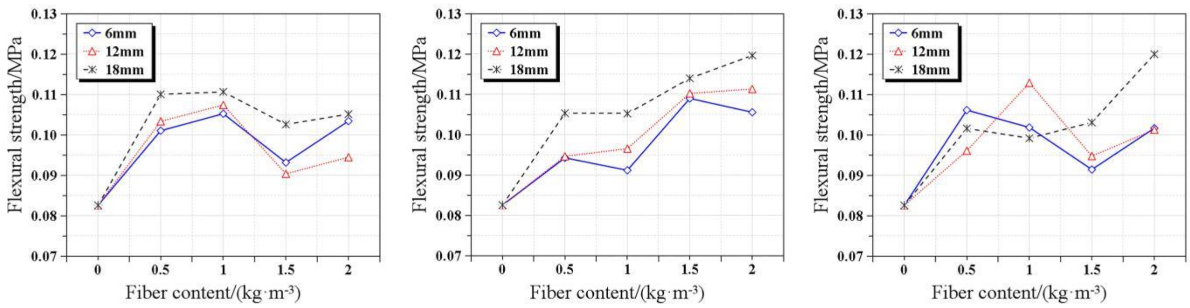
Similar to other kinds of mortar, the fiber content and length have significant influence on the mechanical properties of coral mortar. With the increase of sisal fiber content, the flexural strength of coral mortar gradually increases and then decreases, and the flexural and compression strength gradually increases. When the fiber dosage is between 1.0kg/M$^{-3}$ - 1.5kg/M$^{-3}$, the flexural strength reaches the maximum value. With the increase of the content, the flexural strength increases gradually, and the flexural compression ratio also increases gradually; carbon fiber belongs to fine fiber. When the dosage is between 0.5kg/M$^{-3}$ and 1.0kg/M$^{-3}$, the flexural strength enhancement is more obvious. With the increase of the content, the enhancement is gradually weakened, as shown in Fig.10 and Fig.11.

The ratio of fiber length to diameter determines the tensile peak stress of the fiber. Therefore, under the condition of evenly dispersion, the longer the sisal fiber is, the more obvious the reinforcement effect is. As shown in Fig.10, when the fiber content is the same, the flexural strength of 18mm sisal fiber coral mortar is 11.9% and 7.9% higher than that of 6mm and 12mm respectively, which is obviously better than that of 6mm and 12mm. At failure, most of carbon fiber is pulled out rather than broken. The high fiber content and length diameter ratio significantly reduce the working performance of mortar, causing fiber curling and clustering, reduce the overall performance of fiber mortar. It can be seen from Fig.12 that in a certain range, with the increase of the aspect ratio, the flexural properties of sisal fiber and polypropylene fiber coral mortar are enhanced, while the properties of carbon fiber coral mortar are reduced. In this paper, 6mm long carbon fiber is the best reinforcement for coral mortar, and its flexural strength is 21.3% higher than that of plain coral mortar, which is obviously different from sisal fiber and polypropylene fiber.




（a）CF （b）SF （c）PPF

**Fig.10 The flexural strength of coral concrete with different content of fiber**




（a）CF （b）SF （c）PPF

**Fig.11 The flexural strength of coral concrete with different dosage of fiber**

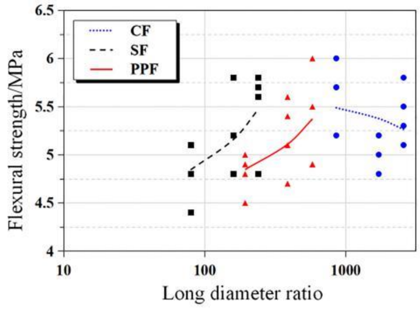



**Fig.12 Effect of fiber length on flexural strength of coral concrete**

In general, the mechanical properties of coral concrete are obviously lower than that of ordinary concrete. Although the addition of fiber can improve the flexural strength and toughness to a certain extent, the effect is not ideal. However, coral sand contains a lot of salt, due to the erosion, the conventional steel fiber cannot be used. The future research on new type of fibers and mixing proportion is in need.

## 4. Conclusion

In this study, the experimental tests and microstructural analysis of fiber reinforced coral concrete are performed, below findings can be made:

1) Due to the large porosity and rough surface of coral sand, the workability of fresh coral mortar is poor, and the evenly dispersion of fibers is difficult, therefore, the enhancement of the fibers in improving the performance of coral concrete is limited.

2) The addition of fiber cannot effectively improve the compressive strength of coral mortar but can significantly enhance the flexural strength of coral concrete.

3) The fiber coral concrete specimen can still maintain a certain integrity at failure stage, and the brittle failure characteristics can be improved to a certain extent. The reinforced effect of sisal fiber is better than that of polypropylene fiber and carbon fiber.

4) Under the condition of uniform dispersion, increasing fiber content and length can improve the performance of coral concrete, but relative high fiber content and length diameter ratio will greatly reduce the working performance of concrete and cause fiber curling and clustering, therefore, reduce the overall performance of the coral concrete.

**List of tables**

Table 3 Mix proportion of concrete

**List of Figure**



## Acknowledgments

This paper is supported by the National Natural Science Foundation of China (51568013), the High-Level Innovation Team in Colleges and Universities and Excellence Scholar Program "Island and Coastal Environment Concrete Structure "in Guangxi (201738-2) and Innovation-driven Development Project "Development and Demonstration of High-Erosion Construction Materials in Complex Marine Environment" in Guangxi (AA18242007-5). The views expressed are the authors' alone.

## Funding

Funder: National Natural Science Foundation of China. Award Number 51868014.
Funder: Colleges and Universities and Excellence Scholar Program, Guangxi. Award Number: 201738-2.
Funder: Innovation-driven Development Project, Guangxi, Award Number AA18242007-5.

## Availability of data and materials

The data used to support the findings of this study are available from the authors upon request.

## Competing interests

The authors declare that they have no competing interests.

## Reference

Aly T, Sanjayan J G, Collins F. (2008). Effect of polypropylene fibers on shrinkage and cracking of concretes. Materials and Structures, 41(10):1741.

Ardanuy M, Claramunt J, Toledo Filho R D. (2015). Cellulosic fiber reinforced cement-based composites: A review of recent research. Construction and building materials, 79: 115-128.

Ausias G , Bourmaud A , Coroller G , et al. (2013). Study of the fibre morphology stability in polypropylene-flax composites. Polymer Degradation and Stability, 98(6):1216-1224.

Chaohua Jiang, Shanshan Huang, et al. (2016). Effect of Polypropylene and Basalt Fiber on the Behavior of Concretes for Repair Applications. Advances in Materials Science and Engineering. Advances in Materials Science and Engineering, 2016:1-11.

Coppola B , Maio L D , Scarfato P , et al. (2015). Use of polypropylene fibers coated with nano-silica particles into a cementitious mortar. Polymer processing with resulting morphology and properties: feet in the present and eyes at the future. AIP Publishing LLC.

Da B , Yu H , Ma H , et al. (2016). Experimental investigation of whole stress-strain curves of coral concrete. Construction and Building Materials, 122, 81-89.

Fernandes E M, João F. Mano, Reis R L. (2013). Hybrid cork-polymer composites containing sisal fibre: Morphology, effect of the fiber treatment on the mechanical properties and tensile failure prediction. Composite Structures, 105:153-162.

GUO Chao. (2017). Study on engineering properties of coral aggregate concrete in south China sea. Southeast University. (in Chinese)

Haque R , Saxena M , Shit S C , et al. (2015). Fibre-matrix adhesion and properties evaluation of sisal polymer composite. Fibers and Polymers, 16(1):146-152.

Izaguirre A , Lanas J , Alvarez J I (2011). Effect of a polypropylene fiber on the behavior of aerial lime-based concretes[J]. Construction and Building Material, 25(2):992-1000.

Khushnood R A , Muhammad S , Ahmad S , et al. (2018). Theoretical and experimental analysis of multifunctional high-performance cement concrete matrices reinforced with varying lengths of carbon fibers. Materiales de Construcción, 68.

Klerk D, David M. (2015). The durability of natural sisal fibre reinforced cement-based composites[J]. Natural Fibre in Concrete.

Lee S C. (2003). Prediction of concrete strength using artificial neural networks. Engineering Structures, 25(7), 849-857.

Lestari Y, Bahri S, Sugiarti E, et al. (2013). Effect of different dispersants in compressive strength of carbon fiber cementitious composites.

Lin D, Wang C J , Dong F B , et al. (2011). Surface Modification of Carbon Fiber by Polymer Emulsions and Mechanical Property of Modified Carbon Reinforced Concrete. Advanced Materials Research: 233-235.

Liu Jinming, Ou,Zhongwen et al. (2018). Literature Review of Coral Concrete. Review Article-Civil Engineering, 43, 1529-1541.

Liu,L Liu H, et al.(2019). Strength, Stiffness, and Microstructure Characteristics of Biocemented Calcareous Sand. Canadian Geotechnical Journal, 56(10): 1502-1513.

Lyu B, Wang A , Zhang Z , et al. (2019). Coral aggregate concrete. Part I. numerical description of physical, chemical and morphological properties of coral aggregate. Cement and Concrete Composites, 100, 25-34.

Ma L , Li Z , Liu J , et al. (2019). Mechanical properties of coral concrete subjected to uniaxial dynamic compression. Construction and Building Materials, 199, 244-255.

Ma Y, Yu S, You L, et al.(2018). Effect of Fiber Parameters on Crack Reduction of Cement Based Materials. Journal of Building Materials, 21(05): 797-802.(in Chinese)

Nam J, Kim G, et al.(2016). Frost resistance of polyvinyl alcohol fiber and polypropylene fiber reinforced cementitious composites under freeze thaw cycling. Composites Part B: Engineering, 90: 241-250.

Ostertag•C.P. CK. Yi.(2007). Crack/fiber interaction and crack growth resistance behavior in microfiber reinforced concrete specimens. Materials and Structures, 40:679-691.

R.D.Tolêdo Filho, M.A. Sanjuán. (1999). Effect of low modulus sisal and polypropylene fiber on the free and restrained shrinkage of concretes at early age. Cement and Concrete Research, 29(10), 1597-1604.

Reis J M L. (2012). Sisal fiber polymer concrete composites: Introductory fracture mechanics approach. Construction and Building Materials, 37, 177-180.

Ruan S Q , Lin C Y , Jiang S X .(2013). Study on the Influence of Polypropylene Fiber and SBR Latex on the Static Strength of Rubber Mortar. Applied Mechanics and Materials, 318:297-302.

Ryan G , Huang B , Shu X , et al.(2013). Laboratory evaluation of tensile strength and energy absorbing properties of cement mortar reinforced with micro- and meso-sized carbon fibers.

Construction & Building Materials, 44(7):751-756.

Sanjuán M.A., Moragues A. (1994). A testing method for measuring plastic shrinkage in polypropylene fibre reinforced concretes. Materials Letters, 21(3-4), 239-246.

Shu X , Graham R K , Huang B , et al. (2015). Hybrid effects of carbon fibers on mechanical properties of Portland cement concrete. Materials & Design, 65, 1222-1228.

Shuai Yang and Wenbai Liu.(2019). Research on Unconstrained Compressive Strength and Microstructure of Calcareous Sand with Curing Agent. Journal of Marine Science and Engineering, 7, 294.

Wang A. , LYU B. , Liu K. et al. (2018). A Review of Properties and Microstructure of Coral Aggregate Concrete. Materials Review, 32 (9), 1528-1533.

Wang J , Feng P , Hao T , et al. (2017). Axial compressive behavior of seawater coral aggregate concrete-filled FRP tubes. Construction and Building Materials, 147, 272-285.

Wang L , Mao Y , Lv H , et al. (2018). Bond properties between FRP bars and coral concrete under seawater conditions at 30, 60, and 80℃. Construction and Building Materials, 162, 442-449.

Yi G , Zhuo-Bin W , Xiao S , et al. (2017). Experimental research on basic mechanical properties of coral aggregate concrete. Journal of Naval University of Engineering, 19(1), 64-68.

Yijie Huang, Xujia He, et al. (2018). Effects of coral recycled and natural coarse aggregates on the mechanical properties of concrete. Construction and Building Materials, 192, 330-347.

Yodsudjai W., Otsuki N., Nishida T., Yamane H. (2003). Study on strength and durability of concrete using low quality coarse aggregate from circum-pacific region. Fourth Regional Symposium on Infrastructure Development in Civil Engineering (RSID4), April, Bangkok, Thailand.

Wang Laigui , Chen Qiang, et al. (2017). Experimental Study on Mechanical Properties of Cement Mortar Ｒeinforced by Polypropylene Fiber. Bulletin of the Chinese Ceramic Society. (in Chinese)