Study on the Effect of Polypropylene Fibres on the Mechanical and Structural Properties of Early-Age Coral Concrete

Xiaofei Zhang* , Zhengliang Dong

Xi 'an University of Technology,State Key Laboratory of Ecological Water Conservancy in Northwest Arid region,Xi 'an,China

* Corresponding author: zhangxiaofei_lgd@163.com

Abstract. In the construction of island and reef projects, the use of coral dredged channel to prepare concrete aggregate can effectively solve the problem of raw material shortage, shorten the construction period, reduce the construction cost, and blend a certain amount of fiber into coral concrete, can improve the mechanical structure of coral concrete. The design strength of C30 polypropylene fibre (PF) coral concrete as the object of study, respectively, curing 7d, 14d, 21d, 28d, a total of 20 groups of different specimens, and its mechanical properties of the experimental investigation, and finally the use of FE-SEM scanning electron microscopy to study the microstructure of coral aggregate concrete, analysis of PF enhancement and modification mechanism of coral concrete. The experimental results show that PF can increase the compressive and tensile strength of coral concrete to different degrees, and there is an optimal mixing ratio of PF, and when the mixing ratio of PF deviates from the optimal ratio, the improvement effect on the mechanical properties of coral concrete will gradually decrease. The age of curing has no effect on the damage morphology of coral concrete specimens, and the damage morphology of the fibre-doped specimens is significantly improved compared with that of the ordinary specimens.

Keywords: Coral aggregate concrete;Polypropylene fiber; Structural performance;Scanning electron microscope

1 INTRODUCTION

With the continuous development of island construction, coral aggregate concrete, as the main building material, presents a good prospect for development.The use of coral reefs and coral sand from nearby islands can save transportation costs and greatly shorten construction time. Compared with ordinary concrete, the high porosity of coral aggregate is favorable for the full combination of aggregate and mortar. However, the high porosity of coral aggregate leads to lower strength and higher brittleness of coral concrete, which can affect the safety of the structure[1,2], Therefore, it is nec-

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essary to study the structural modification of CAC for further application in engineering.

Studies have shown that the addition of fibres can improve the strength and toughness of concrete and can effectively solve the defect of low strength of CAC. Polypropylene fibre (PF) has the advantages of being green, corrosion-resistant, high temperature-resistant, good compatibility with concrete, low cost, simple preparation process, light weight and good elasticity [3]. Numerous scholars at home and abroad have already studied PF. Qin et al [4] investigated the effects of admixtures such as fly ash, polypropylene fibres and basalt fibres on the abrasion resistance and microhardness of coral reef sand concrete, revealing the damage of coral reef sand concrete. They found that the crack resistance of the fibres and the improvement of the bond between the cement mortar and the fibres could reduce the wear of CASC. The results of Wang Qianxi [5] showed that a certain amount of PF mixed into concrete can increase its compressive strength by 3.0% to 5.3%. The study of Ede et al [6] found that the best effect was achieved when polypropylene fibres were mixed at a volume level of 0.25%, when the increase in the compressive strength of the concrete was about 9%.

Up to now, domestic and foreign scholars have conducted relatively abundant research on fibre-modified plain concrete, while relatively few experimental studies have been conducted on fibre improvement of CAC mechanical properties. In addition, there is a relative lack of research on the synergistic mechanism between fibres and coral aggregates. Therefore, in order to investigate the effect of fibre reinforcement on the mechanical properties of CAC, 20 cubic coral concrete specimens were tested. The difference in reinforcement effect between bond properties was analysed using fibre admixture and curing age as parameters, and the microscopic and damage characteristics of CAC were observed using scanning electron microscopy (SEM). The results of the study can provide a relevant basis for the engineering application of PF-reinforced CAC structures.

2 TEST MATERIALS AND PROGRAMS

2.1 Test Material

Cement is an indispensable material in the preparation of CAC, which has the functions of increasing bonding, strength enhancement and durability improvement. For this test, ordinary silicate cement of P.O.42.5 was used. The measured performance index of cement is shown in Table 1, the coarse aggregate comes from the medium-grained coral stone in the western sea of Hainan, with the size of 0.95-4.5cm, see Fig. 1, the basic parameters of coral aggregate are shown in Table 2.The coral aggregate grading table is shown in Table 3. The fine aggregate used in this test is medium sand, which has a fineness modulus of 2.5. Too short fibres do not enhance the tensile and flexural effects significantly, and have a weak inhibiting capacity for cracks, while too long fibres are prone to agglomerate and intertwine with each other, which affects the test results. Therefore, the length of 12mm fibre was selected for this test, and the PF used was from Changsha Lime Xiang Building Material Co., Ltd, and the fibre type was bundled monofilament, and the diameter of its monofilament was 18 μm, and the colour was white, see Fig. 2. Fly ash is usually collected and captured through the flue gas dedusting system and utilized as a mixing material in the concrete as a resource, and the fly ash selected in the test was the Class I fly ash produced by Hejin Longjiang Fly Ash Development and Utilization Co. Ltd. The naphthalene-based water reducing agent added in the test was HS-DEFOAMER567, which was in the form of a colourless viscous liquid, and the efficient water reducing agent played a key role in the fluidity performance, solving the problem that the CAC's hydrogel ratio was low and the fluidity would be affected. The water is ordinary tap water in Xi'an city.

Table 1. Measured performance parameters of ordinary silicate cement

Form	Heat Loss	Specific Surface Area	Solidification Time/min		Flexural Strength/MPa		Compressive Strength/MPa	
National Standard	%	m^2/kg	Condensation	Congeal	3d	28d	3d	28d
Measured Value	3.02	357	203	250	5.9	7.7	27.4	45

Table 2. Basic performance parameters of coral aggregate

Grain Size Gradation mm	Packing Density kg/m^3	Apparent Density kg/m^3	Mud Content %	Indicators of Crushing %
9.5~45	1820	2700	1.5	12.5

Table 3. Coral aggregate grading scale

Sieve(mm)	>44.5	39.5	34.5	29.5	24.5	19.5	14.5	<9.5
Split Hole Sieve Balance(%)	0	1.7	18.9	15	14.1	30.5	15.6	4.2
Cumulative Sieve Residue(%)	0	1.7	20.6	35.6	49.7	80.2	95.8	100

Fig. 1. Coral aggregate

Fig. 2. Polypropylene fiber

In this experiment, the curing age was set to be 7d, 14d, 21d and 28d for the test, and the gradient of the change of the volume admixture proportion of fiber was set to 0.05%, and five groups of PF admixture were configured: 0, 0.05%, 0.1%, 0.15%, 0.20%, respectively. This allows for a better observation of the changes in the properties of the fiber concrete to determine the optimum fiber admixture ratio. The specimen numbering was carried out using different letter and number combinations, where the control group was numbered as PC and the fiber concrete was numbered as PF, followed by the age of curing and fiber admixture, e.g., PF-7-0.05% refers to a specimen with a fiber admixture of 0.05% and a curing age of 7d.

2.2 Specifications

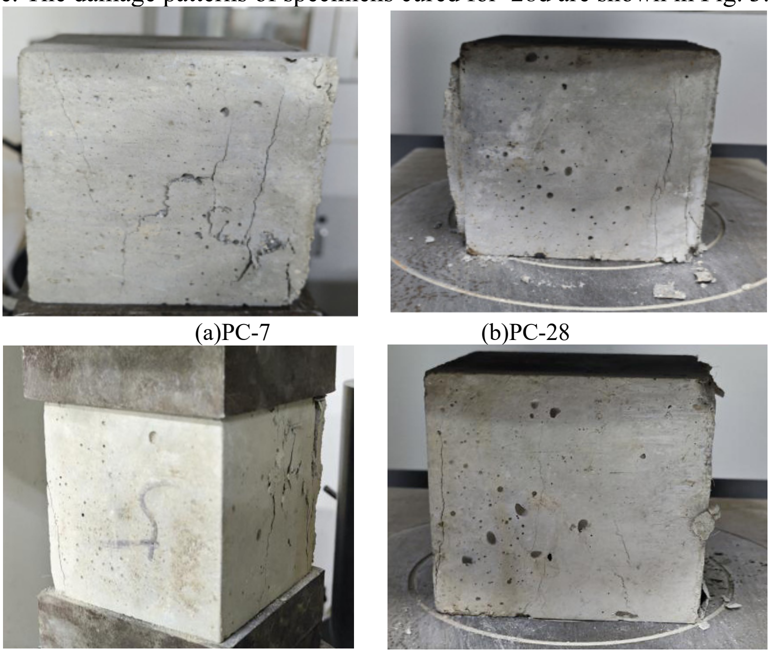
The basic principle of concrete proportion design is to meet the concrete strength performance and durability and other parameters under the conditions of the index, according to the choice of materials and the availability of construction conditions to design an economically reasonable proportion of each mix material dosage relationship. Polypropylene fibre concrete proportion design methods include: fibre volume rate method, fibre instead of aggregate method, fibre instead of fine aggregate method and secondary synthesis method. This test selected the fibre volume rate method as the basis for the design of polypropylene fibre coral concrete proportion. The concrete ratios used in this test are quoted from reference, and the concrete ratios of the baseline reference group are shown in Table 4. The concrete ratios are kept unchanged when fibers are added, and the amount of water reducing agent is corrected in real time according to the actual condition of mixing. Group 1 is the reference group, numbered PC.

Table 4. Base concrete mix ratio

Water-Cement Ratio	Sand Rate	Water kg/m^3	Cement kg/m^3	Sand kg/m^3	Coral Coarse Aggregate kg/m^3	Water Reducing Agent %
0.4	0.6	240	600	686	457	0.05

2.3 Pilot Program

Concrete specimens with dimensions of 100 × 100 × 100 mm were selected for testing. The specimens were divided into 20 groups according to the age of curing and the different fiber dosage, including 4 groups of specimens in the control group and 16 groups of specimens in the fiber dosage group, with 3 specimens in each group, making a total of 60 specimens. The equipment used in this test is universal testing machine. The damage patterns of specimens cured for 28d are shown in Fig. 3.



(a)PC-7 (b)PC-28

(c)PF-7-0.2% (d)PF-28-0.2%

Fig. 3. Damage pattern of PF compressive group specimen

3 RESULTS AND ANALYSIS

3.1 Effect of PF on the Compressive Strength of Cubes

The test data are shown in Table 5, and the analysis of the data in Table 5 shows that the admixture of PF in coral concrete can improve the compressive strength of concrete, and it can be observed from Figures 4 and 5 that, when the curing age is 7d and 14d, and the volume admixture of PF is increased from 0% to 0.1%, the compressive strength shows an upward trend, and the peaks are 31.30Mpa and 35.74Mpa, which are equivalent to the base group strength of 1.324 times and 1.105 times; when the PF dosage continues to increase, the increase is significantly reduced; when the maintenance age of 14d and 28d, the volume dosage of PF increased from 0% to 0.15%, the compressive strength showed a rising trend, the peak values were 37.70Mpa and 39.30Mpa, equivalent to the benchmark group strength of 1.123 times and 1.135

times. When the PF doping continued to increase, the increase decreased significantly. The strength of all specimen groups increased with the increase of the age of maintenance, in which the strength of specimen groups maintained for 28d reached more than 35 Mpa. When the fibre doping was 0.2%, the growth rate of compressive strength was the lowest for all test groups, and the percentage increase in the ring was 11.8%, 7.5%, 5.1% and 3.4% in that order. The optimum volumetric dosage range for this cubic compressive test is 0.1%-0.15%.

Table 5. PF Coral concrete cubic compressive strength and growth rate

Type of test block	serial number	PF volume rate %	compressive strength /MPa	relative strength	growth rate /%
Ordinary coral concrete	PC-7	0	23.64	1.000	/
PF Coral Concrete	PF-7-0.05	0.05	29.45	1.246	24.577
	PF-7-0.10	0.10	31.30	1.324	32.403
	PF-7-0.15	0.15	30.29	1.281	28.130
	PF-7-0.20	0.20	26.44	1.118	11.844
	PC-14	0	32.33	1.000	/
	PF-14-0.05	0.05	35.33	1.093	9.279
	PF-14-0.10	0.10	35.74	1.105	10.547
	PF-14-0.15	0.15	35.71	1.105	10.455
	PF-14-0.20	0.20	34.77	1.075	7.547
	PC-21	0	33.57	1.000	/
	PF-21-0.05	0.05	36.80	1.096	9.622
	PF-21-0.10	0.10	37.20	1.108	10.813
	PF-21-0.15	0.15	37.70	1.123	12.303
	PF-21-0.20	0.20	35.27	1.051	5.064
	PC-28	0	34.63	1.000	/
	PF-28-0.05	0.05	38.67	1.117	11.666
	PF-28-0.10	0.10	39.00	1.126	12.619
	PF-28-0.15	0.15	39.30	1.135	13.485
	PF-28-0.20	0.20	35.80	1.034	3.379

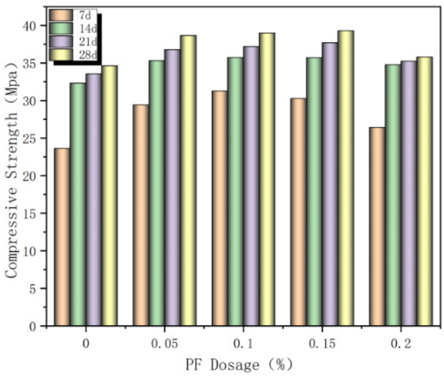


Fig. 4. CAC compressive strength chart

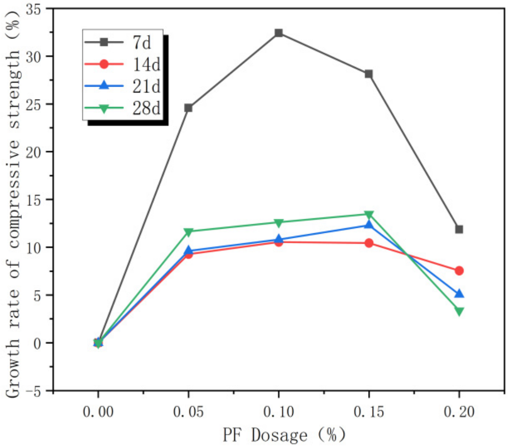


Fig. 5. CAC intensity growth rate graph

3.2 Effect of PF on the Splitting Tensile Strength of Cubes

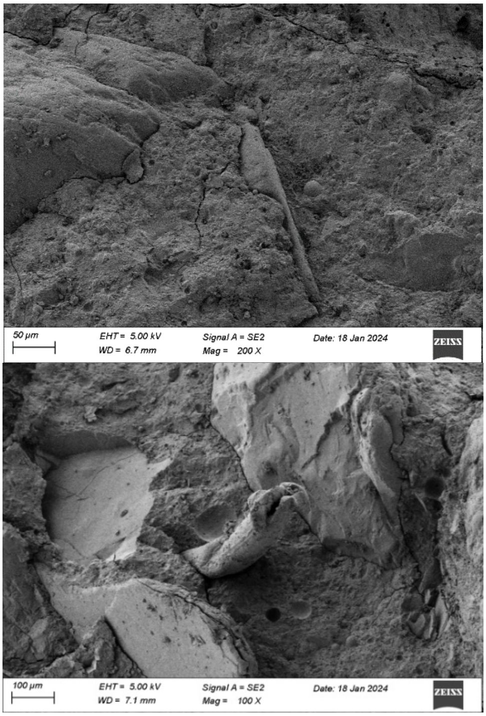


Fig. 6. SEM micrograph of coral concrete

PF itself has strong hydrophilicity, and its molecular chain contains a large number of strong polar cyano groups with strong chemical reaction activity, which will produce strong hydrogen bonding when encountering free water in the concrete, thus enhancing the bond between the fibres and the cement matrix. In addition, when the fibres in coral concrete are bonded to the cement matrix through hydrogen bonding, the negative charge on the surface of the fibres attracts the cations in the cement matrix, which can promote the hydration reaction of the cement matrix and cause the fibre surface to gather a larger number of hydration products, which can be sufficiently adhered to the surface of the matrix to enhance the bonding between the fibres and the coral concrete, thus enhancing the strength of the coral concrete material.

From Fig. 6, it can be found that a large number of hydration products are all attached to the surface of the fibres, and these hydration products can enhance the bonding between the fibres and the concrete matrix to achieve the overall synergistic force between the fibres and the concrete, which can make the fibres more uniformly dispersed in the concrete, thus further enhancing the toughness of the coral concrete.

4 CONCLUSIONS

Analysing the data, the following conclusions are now obtained:

(1) With the gradual increase of PF doping ratio, the compressive strength of the specimens showed a trend of increasing and then decreasing. Among them, the minimum peak of growth rate of compressive strength appeared in the 0.15% fibre doping at 28d of maintenance, which was 39.30%.

(2) When the curing age is 7 d, the growth rate of compressive strength of PF on CAC is 24.58%, 32.40%, 28.13% and 11.84%, which are greater than 11.67%, 12.62%, 13.49% and 3.38% when the curing age is 28 d.

(3) This study only focuses on the effect of PF on the compressive strength of CAC, and does not conduct a comprehensive study on the mechanical properties of CAC, which has certain limitations, and can be followed up by a systematic study on the split tensile strength, axial compressive strength, and four-point bending strength.

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Author 1: Zhang Xiaofei(1978-), Male, Zhouzhi, Shaanxi, PhD, Professor, Master Professor, Research direction is hydraulic structure stress analysis, E-mail: zhangxiaofei_lgd@163.com, Mobile phone: 18092214168

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