Experimental Study on Mechanical Properties of Seawater Sea-Sand Recycled Concrete Under Sulfate Attack

Xiangsheng Tian, Yijie Huang, Jingxue Zhang, and Li Dong

Abstract The preparation of seawater sea-sand recycled concrete (SSRAC) by combining seawater, sea-sand and recycled coarse aggregate is of great significance for the utilization of marine resources and environmental protection in China. The sulfate corrosion test in this paper uses dry wet cycle to simulate the alternating dry wet environment, and compares the ordinary concrete (OC) and freshwater river sand recycled concrete (RAC) to study the mechanical property deterioration characteristics of SSRAC in dry–wet cycle (30d, 60d, 90d, 120d). The results show that with the increase of the dry–wet cycle, the apparent damage of SSRAC gradually extends from the diagonal to the periphery, and finally the cracks spread all over the whole. The mass, strength and strength corrosion resistance coefficient of SSRAC show the same law as OC and RAC, which increase first and then decrease. The resistance of SSRAC to sulfate attack is lower than OC and slightly higher than RAC, and the strength corrosion resistance coefficient is lower than 75% at 120 times of dry–wet cycle.

Keywords Seawater sea-sand recycled concrete · Sulfate attack · Wet-dry cycles

1 Introduction

With the rapid development of the construction industry, a large amount of construction waste occupies land resources and causes environmental pollution. As a new type of green concrete, SSRAC has good working and mechanical properties [1–3]. In addition, seawater and sea-sand in Marine resources is used to replace traditional freshwater and river sand, which is conducive to alleviating the problem of increasingly exhausted sand resources. Recycled coarse aggregate obtained from broken waste concrete is used to replace gravel, which is a good solution to the subsequent treatment of waste concrete.

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On the other hand, the soil and groundwater in the eastern coastal areas of China contain high concentrations of sulfate, and the service life of the project is reduced due to the superposition of external environment such as long-term sulfate attack and dry–wet cycle. However, so far, the research on SSRAC by domestic and foreign scholars is not perfect, and the research on its durability is also rare. Therefore, it is of great engineering significance to study the deterioration mechanism and rule of seawater sand reclaimed concrete under sulfate attack environment to improve the durability of Marine reclaimed concrete structure and prolong its service life.

2 Experiment Materials and Methods

2.1 Materials and Mix Ratio

Three different types of concrete (OC, RAC, SSRAC) are used in the test. The cement is P·O 42.5 ordinary Portland cement. River sand and sea-sand are selected as the fine aggregate. The coarse aggregate includes gravel and recycled coarse aggregate (RCA). The physical properties of coarse aggregate and fine aggregate are shown in Tables 1 and 2 respectively. The purity of anhydrous sodium sulfate shall be Grade II analytical pure (AR). The reference water cement ratio of each concrete is 0.57, the strength grade is C30, and the mix of concrete materials is shown in Table 3. The water absorption of RCA is much higher than gravel, so an appropriate amount of additional water should be added when placing RAC and SSRAC.

Table 1 Physical properties of coarse aggregates

Material	Size (mm)	Bulk density ($kg{\cdot}m^{-3}$)	Apparent density ($kg{\cdot}m^{-3}$)	Water absorption (%)	Crushing index (%)
Gravel	5.0~25	1572	2585	0.8	8.52
RCA	5.0~25	1415	2495	6.8	11.73

Table 2 Physical properties of fine aggregates

Material	Size (mm)	Apparent density ($kg{\cdot}m^{-3}$)	Clay content (%)	Cl- content (%)	Shell content (%)
Sea-sand	0.15~4.75	2560	0.82	0.096	1.08
River sand	0.15~4.75	2610	2.91	–	–

Table 3 Concrete mixture ratio

Specimen	Material usage (kg·m^{-3})							
	Freshwater	Seawater	Cement	River sand	Sea-sand	Gravel	RCA	Additional water
OC	188	–	329.82	727	–	1137	–	0
RAC	188	–	329.82	727	–	–	1137	22.74
SSRAC	–	188	329.82	–	727	–	1137	22.74

2.2 Test Piece Production and Methods

Dry–wet cycle was used to simulate dry wet alternate environment in sulfate attack test. The performance of SSRAC in sulfate attack (30d, 60d, 90d, 120d) under dry–wet cycle conditions was studied by comparing OC and RAC. According to the Standard for Test Methods of Long term and Durability of Ordinary Concrete (GB/T 50082–2009) and considering the sulfate content in coastal areas of China. Determine to use 5% Na_2SO_4 solution, and the dry–wet cycle system is determined, as shown in Fig. 1.

The size of test piece is 100 mm × 100 mm × 100 mm test piece. Weigh the mass of the test piece every 10 dry–wet cycles, test the compressive strength (f_{cu}) and splitting tensile strength (f_{ts}) of the test piece every 30 dry–wet cycles, And the mechanical property test shall be carried out on the specimens with standard curing at the same age. Specific test data are shown in Tables 4 and 5.

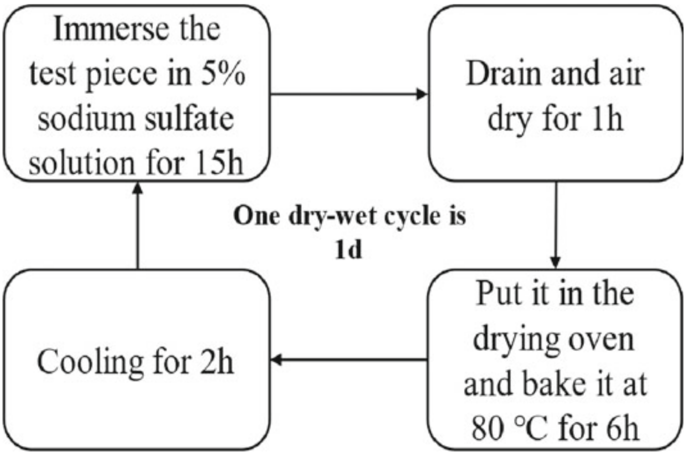


Fig. 1 The dry–wet cycle system

Table 4 Cube compressive strength (f_{cu}) at different erosion ages

Specimen	f_{cu} (MPa)								
	0d	30d		60d		90d		120d	
	W	W	SS	W	SS	W	SS	W	SS
OC	40.41	43.08	43.20	44.95	45.95	46.18	41.80	47.41	30.39
RAC	33.63	34.83	35.26	35.62	36.25	36.31	28.81	36.80	14.85
SSRAC	35.04	35.78	36.79	36.53	37.77	36.88	30.78	37.23	16.22

Table 5 Splitting tensile strength (f_{ts}) at different erosion ages

Specimen	f_{ts} (MPa)								
	0d	30d		60d		90d		120d	
	W	W	SS	W	SS	W	SS	W	SS
OC	3.48	3.67	3.81	3.75	4.11	3.96	3.01	4.14	2.46
RAC	2.82	3.10	2.97	3.24	3.10	3.33	2.07	3.34	1.29
SSRAC	2.97	3.12	3.19	3.27	3.40	3.38	2.46	3.41	1.45

Notes 0d means that the test blocks have been standard cured for 28 days but have not yet eroded. W stands for standard curing. SS stands for sulfate attack. *Definition* SSRAC-SS-60 represents 60 dry–wet cycles of seawater sea-sand recycled concrete under sulfate attack

3 Test Results and Analysis

3.1 Apparent Damage to Concrete

The apparent damage characteristics of concrete are shown in Fig. 2. The surface of the concrete specimen is complete and the edges and corners are clear when the dry–wet cycle is not carried out after 28 days of standard curing; After 30 dry–wet cycles, many small holes appear on the surface of the concrete specimen. When 60 dry–wet cycles are performed, some of the cement slurry on the surface of the specimen appeared spalling, and microcracks appeared at the edges and corners and gradually sanding. When the cycles were 90 times, the OC edges and corners were sanding and spalling, the surface cement slurry spalling, and the edges and corners of RAC and SSRAC were spalling. The cracks at the corners continue to extend along the corners and become more obvious. When 120 cycles are performed, OC corners are peeled off, Slender cracks appear along the corners, RAC and SSRAC cracks are all over the whole.

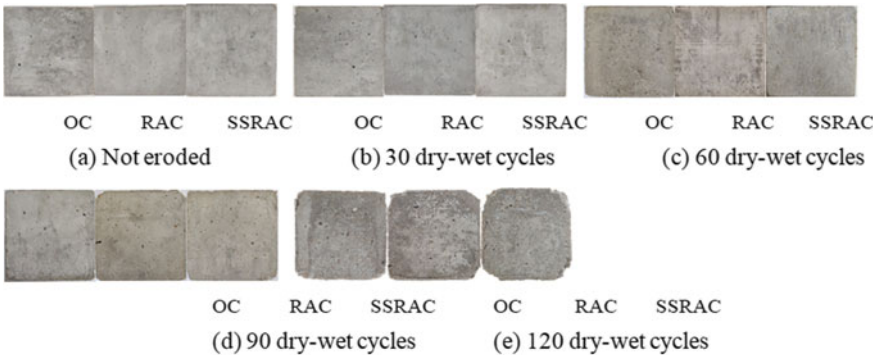
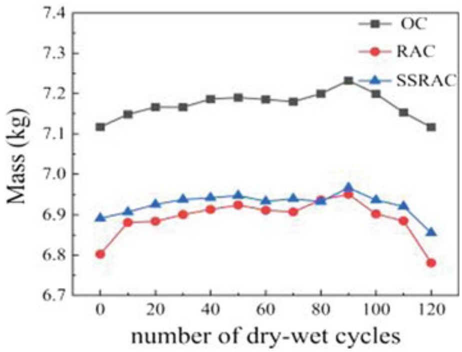


Fig. 2 Apparent changes

3.2 Mass

To a certain extent, the mass change can reflect the development law of performance deterioration of sulfate erosion concrete, and the change rule of specimen mass with the number of cycles is shown in Fig. 3. The mass change law of OC, RAC and SSRAC is similar, and it is mainly divided into two stages. In the first stage, the mass of concrete rises. Among them, the mass of OC, RAC and SSRAC reached a maximum value at 60 dry–wet cycles. This is due to the reaction of sulfate ions with cement hydration products to form expansive substances in the early stage of erosion, which improves the compactness of the concrete, and leads to the continuous growth of concrete mass. In the second stage, the mass of the concrete specimen deteriorates. This is due to the gradual decomposition and dissolution of hydration products such as calcium hydroxide and calcium silicate in concrete specimens, which causes surface ablation, and at the same time, as the ettringite expansion specimen appears cracks, with the increase of the number of dry–wet cycles, the cracks at the corners of the concrete continue to develop and appear peeling.

Fig. 3 The change rule of specimen mass with the number of cycles



3.3 Strength

The change rule of cube compressive strength (f_{cu}) of different types of concrete with the number of cycles are shown in Fig. 4. With the increase of the number of dry–wet cycles, the compressive strength of OC, RAC and SSRAC showed a change law of first increasing and then decreasing, and all reached the maximum at 60 dry–wet cycles. Among them, OC-SS-60 increased by 13.28% compared with OC-W-0, RAC-SS-60 increased by 7.65% compared with RAC-W-0, and SSRAC-SS-60 increased by 7.68% compared with SSRAC-W-0 for the cubic compressive strength. This is due to the fact that sulfate ions react with cement hydration products to form expansive substances in the early stage of erosion, which fills the pores inside the concrete, resulting in the continuous growth of concrete strength [4]. With the increase of the number of dry–wet cycles, the erosion products ettringite and gypsum continue to generate, the pores of the concrete are filled, and its interior continues to expand, accelerating the formation and development of microcracks, resulting in a decrease in the strength of concrete.

The change rule of splitting tensile strength (f_{ts}) of different types of concrete with the number of cycles is shown in Fig. 5. Similar to the change law of compressive strength, the f_{ts} of OC, RAC and SSRAC first increased and then decreased with the number of dry–wet cycles, and all reached a peak at 60 times, among which OC-SS-60 increased by 17.09% compared with OC-W-0, RAC-SS-60 increased by 9.66% compared with RAC-W-0, and SSRAC-SS-60 increased by 14.05% compared with SSRAC-W-0. In the early stage of erosion, the erosion products improve the compactness of the concrete, which in turn improves the tensile strength of the splitting. The expansion stress generated by the erosion products in the later stage of erosion makes the concrete lose its tensile capacity due to the compression of the invaded layer, so that the surface of the layer not subject to sulfate erosion will generate tension, which is superimposed with the tension generated under the splitting load, resulting in a significant decrease in the tensile strength of concrete splitting in the later stage of erosion [5].

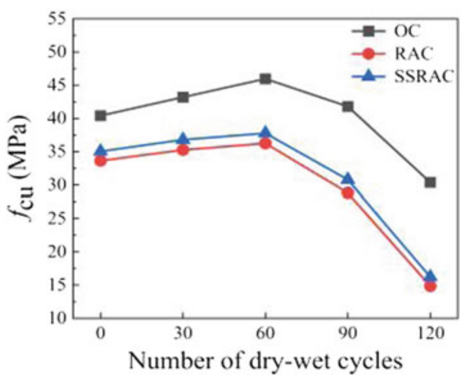
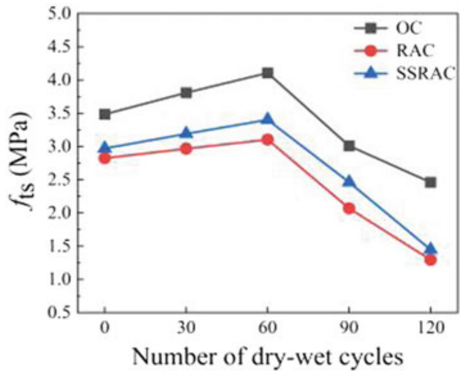


Fig. 4 The change rule of f_{cu}

Fig. 5 The change rule of f_{ts}



3.4 Strength Corrosion Resistance Coefficient

In order to analyze and evaluate the deterioration of concrete mechanical properties caused by sulfate attack, according to formula (1), defines the cube compressive strength corrosion resistance coefficient (K_c) and split tensile strength corrosion resistance coefficient (K_t).

$$K = \frac{f_0}{f_n} \tag{1}$$

where, K represents the strength corrosion resistance coefficient; f_0 represents the strength of concrete at the same age without sulfate attack (MPa); f_n is the concrete strength after n times of sulfate attack dry–wet cycles (MPa).

As can be seen from Fig. 6, the strength of OC, RAC and SSRAC is lower than that of not attacked concrete after 90 times of dry–wet cycles, and the corrosion resistance coefficient is lower than 75% at 120 cycles. It can be seen that after 120 dry–wet cycles of erosion, the K_c and K_t of OC are higher than those of SSRAC and RAC, and the K_c and K_t of SSRAC are slightly higher than RAC. This is because there are chloride ions in seawater sea-sand, and the transport rate of chloride ions is greater than that of sulfate ions, resulting in chloride ions entering the concrete first, which can react with the AFm to form Friedel salt [6–8], and due to the reduction of the AFm, the formation of ettringite is reduced, thereby alleviating the degree of damage of sulfate to SSRAC.

4 Conclusion

(1) With the increase of the number of dry–wet cycles, the apparent damage gradually expanded from the diagonal to the periphery. The apparent damage of OC

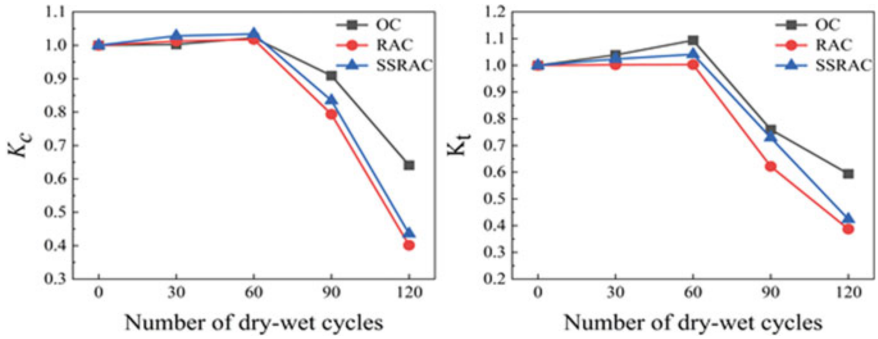


Fig. 6 The change rule of strength corrosion resistance coefficient with the number of cycles

was significantly lower than that of RAC and SSRAC, and the apparent damage of SSRAC was slightly lower than that of RAC.

(2) The mass, compressive and tensile strength of the three types of concrete increased first and then decreased rapidly with the number of dry–wet cycles. Among them, the compressive strength and splitting tensile strength of SSRAC increased by 7.8% and 14.5%, respectively, and then decreased by 57.1% and 57.4%, respectively.

(3) Under the same number of dry–wet cycles, the mass, compressive strength and splitting tensile strength of SSRAC were higher than those of RAC and lower than those of OC. Among them, the strength of OC, RAC and SSRAC at 90 dry–wet cycles is lower than that of uneroded concrete, and the corrosion resistance coefficient of each strength is lower than 75% at 120 times of dry–wet cycle.

(4) Under the action of dry–wet cycle and sulfate attack, OC has higher sulfate attack resistance than SSRAC and RAC. Due to the influence of chloride ions in seawater and sea-sand, the sulfate corrosion resistance of SSRAC is slightly better than that of RAC.

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