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Evaluation of the damage process of recycled aggregate concrete under sulfate attack and wetting-drying cycles

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HIGHLIGHTS

- The damage process of RAC exposed to sulfate attack under wetting-drying cycles was investigated.
- The incorporation of RCA showed an obvious impact on the resistance of RAC against sulfate attack.
- The water-soluble SO_4^{2-} contents of RAC were measured.
- XRD, ESEM and XCT were used to investigate the microstructure alteration of RAC.

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ABSTRACT

The evaluation of the damage process of recycled aggregate concrete made with different recycled coarse aggregate (RCA) replacements (30%, 50%, 70% and 100%) exposed to sodium sulfate solution (50 g/l) under wetting-drying cycles is investigated in this paper. Fly ash and granulated blast-furnace slag modified recycled aggregate concrete were examined by comparison with plain recycled aggregate concrete. Mass change, relative dynamic modulus of elasticity and water-soluble SO_4^{2-} contents of the specimens were measured. XRD, ESEM and XCT were used to investigate the changing of corrosion products and microstructure of interior concrete. The results indicate that the incorporation of RCA shows an obvious impact on the resistance of concrete against sulfate attack under wetting-drying cycles. Additionally, the FA and GBFS modified recycled aggregate concretes exhibit better resistance than plain recycled aggregate concrete. The analysis of corrosion products from XRD and microstructure from XCT and ESEM is in accordance with the results of water-soluble SO_4^{2-} contents, mass change and E_{rd}.

1. Introduction

Over the last ten years, the urbanization in China has led to a large amount of construction and demolition wastes (C&DW) which have reached to 40% of the total city solid wastes [1]. Waste concrete occupies a large percent among all the C&DW. The annual production of waste concrete in China has reached to 100 million tones and accounts for about 1/3 of the total C&DW. The most serious problem is the disposal of C&DW. Consequently, standards and directive frameworks [2–4] have been published to control and dispose C&DW and promote the conservation of natural resources since there is critical shortage of natural aggregates in China.

In general, when compared to natural aggregates, recycled coarse aggregates (RCA) sourced from C&DW have the following differences in properties, lower density, higher water absorption and porosity and higher crushing index. Since the microstructure of recycled aggregate concrete (RAC) is much more complicated than that of natural aggregate concrete. RAC possesses two ITZs, one is between aggregate and the old mortar (old ITZ), the other is between the RCA and the new mortar (new ITZ). Some lectures report that the old ITZ is weak link as it consists of porous hydration products and cracks [5,6]. However, some researchers conclude that the old ITZ is not always the weakest point which depends on the relative quality of the old ITZ and new ITZ [7]. The research on the properties of RCA makes it possible to be used in production of recycled aggregate concrete [8–10]. Some researches on mix approach for RAC report that optimal mix approach can improve the performance of recycled aggregate concrete [11,12]. And some lectures report that Carbon-conditioning is an effective means of enhancing performance of recycled aggregate concrete [13–15]. Moreover recent studies on the properties of high performance concrete employing RCA have been published

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Table 1
Chemical composition of binder materials.

	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Fe_2O_3 (%)	Loss
Cement	21.20	5.32	64.37	0.55	2.00	4.42	1.50
FA	52.85	29.25	6.11	0.78	1.45	5.63	2.97
GBFS	32.89	16.36	37.36	7.02	2.90	0.37	0.86

Table 2
Properties of coarse aggregates.

Aggregate	Apparent density (kg/m^3)	Water adsorption (%)	Crushing index value (%)
NCA	2690	0.4	8.9
RCA	2580	3.6	15.5

[16–18]. A series of investigations have been carried on the mechanical properties of recycled aggregate concrete over the past few years. It is generally agreed that the use of RCA will lead to degradation in the mechanical properties and other performance [19–25]. Although some studies on the durability of recycled aggregate concretes have been published [26–28], little information on the exposure of recycled aggregate concrete to sulfate attack can be found in the literatures [29,30]. Recycled aggregate concrete exposed to sulfates could result in expansion damage of concrete. And recycled aggregate concrete is not permanently saturated and wetting-drying cycles is possible. It is necessary to know the characteristics of recycled aggregate concrete under sulfate attack, so that it can help to understand the damage process of recycled aggregate concrete and optimize the design of recycled aggregate concrete.

The objective of this paper was to evaluate the damage process of recycled aggregate concrete under the combined actions of sulfate attack and wetting-drying cycles. Recycled aggregate concrete made with variable replacements of RCA (0%, 30%, 50%, 70% and 100%) were exposed to sodium sulfate solution (50 g/L) under wetting-drying cycles for about 9 months. During the corrosion period, specimens were periodically evaluated by means of mass change, E_{rd} and water-soluble SO_4^{2-} contents. After 9 months of exposure, samples were taken for microscope observations. Besides, the influence of fly ash (FA) and granulated blast-furnace slag (GBFS) were also studied.

2. Experimental program

2.1. Materials and mix proportions

Chinese standard 42.5R (II) Portland cement, FA and GBFS was used in this paper. The chemical compositions of binder materials are shown in Table 1. River sand with fineness modulus of 2.8 was used. Natural coarse aggregates (NCA) and recycled coarse aggregate (RCA) with maximum size of 20 mm were used. The properties of NCA and RCA are shown in Table 2. It can be observed that RCA have lower apparent density, higher water absorption and higher crushing index value. This is because of porosity of adhered mortar and micro cracks generated during the RCA production process. The mix proportions of concretes are given in Table 3. The compression strength and flexural strength of concretes after curing 56 days are given in Table 4.

Table 4
Mechanical properties of concretes.

No.	Compression strength	Flexural strength
B0	49.1	8.0
B30	50.4	8.0
B50	48.3	7.8
B70	47.3	7.2
B100	46.0	7.1
B100F30	47.5	7.3
B100S30	47.1	7.2

2.2. Experiment programs

Concrete specimens were cast in molds of 70 × 70 × 280 mm and cured in the condition of 20 ± 2 °C and 95% of relative humidity for 60d. Except for two opposite vertical surfaces (70 × 280 mm), other four surfaces of the specimen were covered with epoxy resin before experiments in order to obtain one-dimensional SO_4^{2-} content.

In the present study, sodium sulfate solution (50 g/L) was used. The specimens of concrete were immersed in the sodium sulfate solution for 21 h, then followed by air drying for 3 h. Then, drying for 45 h at a temperature of 60 °C, followed by air cooling for 3 h. This period of 72 h represents a wetting-drying cycle. The wetting-drying cycle was repeated until the mass loss exceeded 5 percent or relative dynamic modulus of elasticity decreased lower than 60 percent.

2.3. Testing parameters

2.3.1. Mass change

The mass change of the specimen during a certain testing age was monitored as a possible indicator of degradation. The mass of the specimen before and after immersion in aggressive environments was measured on an electronic scale (capacity of 5 kg and an accuracy of 0.01 g) . Consequently, the mass change was calculated as follows:

$$W = \frac{m_n - m_0}{m_0} \times 100\% \quad (1)$$

Table 3
Mix proportions of concretes.

No.	W/B	Replacement ratio (%)	Water	Cement	FA	GBFS	Fine aggregate	NCA	RCA	Super plasticizer
B0	0.5	0	195	390	0	0	740	1026	0	–
B30	0.5	30	195	390	0	0	740	717	307	0.15%
B50	0.5	50	195	390	0	0	740	512	512	0.18%
B70	0.5	70	195	390	0	0	740	307	717	0.20%
B100	0.5	100	195	390	0	0	740	0	1024	0.25%
B100F30	0.5	100	195	273	117	0	740	0	1024	0.25%
B100S30	0.5	100	195	273	0	117	740	0	1024	0.25%