Construction and Building Materials 174 (2018) 130–137

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Chloride penetration into recycled aggregate concrete subjected to wetting–drying cycles and flexural loading

Bing Qi [a,b], Jianming Gao [a,b,*], Fei Chen [a,b], Daman Shen [a,b]

[a] Southeast University, School of Materials Science and Engineering, Nanjing 211189, China
[b] Jiangsu Key Laboratory of Construction Materials, Nanjing 211189, China

HIGHLIGHTS

- Chloride penetration into RAC subjected to wetting–drying cycles and flexural loading was investigated.
- Chloride diffusion coefficient for RAC was determined by the error function solution to Fick's second law.
- Chloride binding capacity of RAC was analyzed.
- Chloride ions transport progress in RAC were monitored by in situ X-ray computed tomography.

ARTICLE INFO

Article history:
Received 12 December 2017
Received in revised form 3 April 2018
Accepted 13 April 2018

Keywords:
Recycled aggregate concrete
Wetting–drying cycles
Flexural loading
Chloride penetration

ABSTRACT

This paper presents the experimental results of chloride penetration into Recycled Aggregate Concrete (RAC) subjected to sodium chloride solution coupled with wetting–drying cycles and flexural loading. Detailed chloride profiles were tested by potentiometric titrimeter which show the variation of water-soluble (free) and acid-soluble (total) chloride contents in RAC. For purpose of studying the influence of coarse Recycled Concrete Aggregate (coarse RCA) on the chloride penetration, different replacement of coarse RCA were used by ranging from 0%, 30%, 50%,70% and 100% ratio by weight. Additionally, the effect of mineral admixtures and stress ratio on such penetration was studied. The chloride diffusion coefficient for RAC was calculated by the error function solution to Fick's second law. The chloride binding capacity of RAC was also analyzed. Finally, X-ray computed tomography (X- CT) was used to estimate chloride transport progress in RAC for the first time. The results show that the chloride profiles in RAC is dependent on the mixtures and the flexural loading applied to the concrete. Coarse RCA induces considerable influence on chloride penetration in concrete. The addition of mineral admixtures makes concrete more compactness hinder chloride ions ingress into interior concrete. The increased magnitude of flexural loading results in higher chloride contents in RAC probably due to micro-cracks generated and extended. The influence of coarse RCA replacement and mineral admixtures on the chloride binding capacity is obvious, but the influence of stress ration is no regularity. The results of X-CT indicate that the solution does not transport through the old attached mortar in coarse RCA.

1. Introduction

For the past few years, the disposal of construction and demolition wastes (C&DW) has become world-wide problems, leading to the potential threats of environment pollution. C&DW is one of the most voluminous waste generated in China due to the rapid urbanization [1]. It accounts for approximately 40% of the total city solid wastes. The recycling of C&DW is beneficial and necessary not only to consume C&DW but also to conserve natural resources.

Coarse RCA is obtained mainly by screening, crushing and sieving of waste concrete. The properties of coarse RCA is different from natural coarse aggregate (NCA) due to the old attached cement mortar, resulting in higher water absorption, lower strength, and higher crushing value [2–5]. The properties of coarse RCA can be significantly improved by modified production technology [6–7]. And the autogenous cleaning process can be considered to reduce water absorption [8]. Also some effective methods have been proposed from recently published papers to improve the quality of coarse RCA. The acid treatment is concluded to be an

* Corresponding author at: Southeast University, School of Materials Science and Engineering, Nanjing 211189, China.
E-mail address: jmgao@seu.edu.cn (J. Gao).

https://doi.org/10.1016/j.conbuildmat.2018.04.122
0950-0618/

Table 1
Chemical composition of cement, FA and GBFS.

	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
Coarse RCA	2580	3.6	15.5

effective and environmentally friendly method to improve the quality of coarse RCA by removing the old attached cement mortar. The low concentration acid was chosen such as hydrochloric acid [9], sulfuric acid and phosphoric acid [10], and acetic acid [11]. The quality of the old cement mortar attached on coarse RCA can be modified by a CO_2 curing method [12], and the mechanical and durability properties can be improved [13,14]. However, it is recognized that the incorporation of coarse RCA leads to obvious influence on the hydration processes [15], workability [16], mechanical properties [17,18], deformation behavior [19] and durability [20]. Several treatments have been studied to improve the properties of new concrete: pre-saturation of coarse RCA [21], use of water-reducing admixtures [22,23], two-stage mixing approach [24,25], and use of nano-particles [26,27]. Recently, coarse RCA used in high performance and self-compacting concrete has been presented [28,29].

As the research on Recycled Aggregate Concrete proceeds, some studies on the chloride penetration in RAC through experimental tests [30] and numerical simulations [31,32] have been published. It is concluded that the partial use of fly ash increased chloride resistance of RAC [33–35]. And the chloride diffusion coefficient in RAC depends on mix proportions of the concrete, and on the properties of new cement paste and old attached cement mortar. However, limited information about the chloride penetration in RAC under coupled factors can be available [36]. It can be inferred that the chloride penetration in RAC may be quite different under coupled factors from the single factor. And it is difficulty to consider the coupled factors associated with long-term experiment.

This paper aims at investigating the effect of coarse RCA on chloride penetration into concrete subjected to both wetting–drying cycles and flexural loading. RAC made with variable replacements of coarse RCA (0%, 30%, 50%, 70% and 100%) were subjected to sodium chloride solution coupled with wetting–drying cycles and flexural loading for about 9 months. The chloride profiles including water-soluble and acid-soluble chloride contents were tested. And the chloride diffusion coefficient was calculated and the chloride binding capacity was analyzed. Furthermore, the chloride transport progress in RAC was estimated by X-CT for the first time.

2. Materials and methods

2.1. Materials

The cement used was 42.5R (II) Portland cement according to Chinese standard. The replacement of fly ash (FA) and grounded blast furnace slag (GBFS) was 30%. Table 1 outlines their chemical compositions. The fine aggregate used was natural river sand and the fineness modulus was 2.8. The particle sizes of natural coarse aggregates (NCA) and coarse RCA were range from 5 to 20 mm. The properties of NCA and coarse RCA are presented in Table 2. The mix proportions of concretes are presented in Table 3. The properties of raw materials and concrete mix proportions were mentioned in previously published literature [37].

2.2. Specimens preparation

The size of concrete specimens was 70 mm × 70 mm × 280 mm for chloride profiles test and 10 mm × 10 mm × 20 mm for chloride transport progress test by X-CT. All the specimens were placed in the curing room with the temperature of 20 ± 2 °C and relative humidity of 95% for 56 d. The samples were coated by epoxy with the exception of two opposite vertical surfaces to obtain one-dimensional chloride penetration profiles.

2.3. Experimental programmer

The samples applied with flexural load or without for contrast were exposed to 3.5% sodium chloride solution under wetting–drying cycles. Each wetting–drying cycle was consist of four steps: immersion in sodium chloride solution for 21 h; drying in the air for 3 h; drying at 60 °C for 45 h; cooling in the air for 3 h. Fig. 1 depicts the equipment utilized for applying flexural loading.

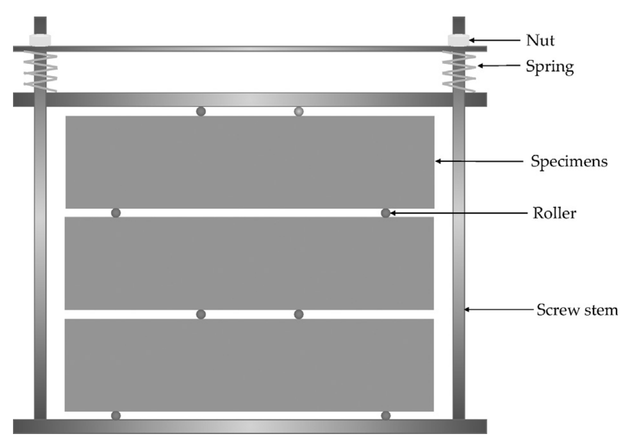

Fig. 1. The schematic diagram of loading equipment.

Table 3
Mix proportions of concretes.

NO.	Replacement ratio (%)	Water	Cement	FA	GBFS	Sand	NCA	Coarse RCA	Super plasticizer (%)
B0	0	195	390	–	–	740	1026	–	–
B30	30						717	307	0.15
B50	50						512	512	0.18
B70	70						307	717	0.20
B100	100						–	1024	0.25
B100F	100	195	273	117	–	740	–	1024	0.25
B100S	100	195	273	–	117	740	–	1024	0.25