Cement and Concrete Composites 86 (2018) 130–138

Contents lists available at ScienceDirect

Cement and Concrete Composites

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

Performance of mortar prepared with recycled concrete aggregate enhanced by CO_2 and pozzolan slurry

Caijun Shi [a,*], Zemei Wu [a,b,**], Zhijie Cao [a], Tung Chai Ling [a], Jianlan Zheng [c]

[a] Key Laboratory for Green & Advanced Civil Engineering Materials and Application Technology of Hunan Province, College of Civil Engineering, Hunan University, Changsha 410082, China
[b] Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, Rolla 65401, MO, USA
[c] Department of Civil Engineering, Fuzhou University, Fuzhou 350002, China

ARTICLE INFO

Article history:
Received 8 March 2017
Received in revised form
16 September 2017
Accepted 30 October 2017

Keywords:
Recycled concrete aggregate
Pozzolan slurry treatment
CO_2 enhancement
Fluidity
Mechanical properties
Durability

ABSTRACT

One of the most promising strategies to manage the large volume of construction and demolition (C&D) waste is recycling and utilizing it for the production of new concrete. However, recycled concrete aggregate (RCA) derived from C&D waste possesses relatively higher porosity and water absorption capability, which often limits its wild utilization. In this study, pozzolan slurry (includes silica fume, nano-SiO_2, and fly ash slurries) and CO_2 treatments as enhancement methods for RCA were investigated. Test results showed that CO_2 treatment was more effective in reducing water absorption and enhancing fluidity, whereas pozzolan slurry treatment could decrease fluidity. Mortars prepared with treated RCA exhibited better mechanical strength and higher resistance towards carbonation and chloride-ion diffusion than those with untreated RCA. Both pozzolan slurry and CO_2 treatments enhanced not only the properties of RCA, but also the old and new interfacial transition zones (ITZs) as demonstrated in the measured micro-hardness and SEM observation.

1. Introduction

The quantities of construction and demolition (C&D) wastes rapidly increase with the rapid development of economy and construction. The reuse of C&D wastes by recycling them as aggregates in concrete can not only conserve resources and enhance sustainability, but can also alleviate the demand for landfill [1,2]. Generally, recycled concrete aggregate (RCA) consists of 65%–70% original aggregates and 30%–35% original cement by the volume of concrete [22]. However, some detrimental properties associated with RCA can limit its uses in concrete applications [3]. These detrimental effects are mainly due to the adhered old mortar possesses relatively higher porosity and water absorption properties, resulting in poorer workability and lower mechanical strength when used in new concrete [4]. Micro-cracking that occurs during demolition and crushing processes could further weaken their performance. It is reported that the compressive and tensile strengths of concrete made with RCA were decreased by 40% when compared to those with natural aggregate [5]. High water absorption can lead to high water demand of concrete [6]. When concrete contains more than 50% RCA, cracks are more likely to appear because of more introduction of weak interface and reduction in tensile strength [7].

In the past few years, different treatment methods were adopted to enhance the inferior properties of RCA. In general, the enhancement techniques of RCA can be classified into two main methods, as summarized in Table 1: (1) Physical treatment method - through mechanical grinding, pre-soaking in water, polymer emulsion, filler lime powder or calcium carbonate biodeposition, etc. [8–9,11]; and (2) Chemical treatment method - through pre-soaking in acid, pozzolan slurry or sodium silicate, CO_2 enhancement, etc. [10]. Removing adhered mortar may damage aggregates due to intense collision and grinding and result in the second pollution as well. Strengthening adhered mortar is to improve the weak zones through chemical reaction and/or filling ability.

Tam et al. [11] pre-soaked RCA in hydrochloric acid (HCl), sulphuric acid (H_2SO_4), and phosphoric acid (H_3PO_4) solutions to remove the adhered old mortar on the RCA surface, and

* Corresponding author.
** Corresponding author. Key Laboratory for Green & Advanced Civil Engineering Materials and Application Technology of Hunan Province, College of Civil Engineering, Hunan University, Changsha 410082, China.
E-mail addresses: cshi@hnu.edu.cn (C. Shi), zemianmian@gmail.com (Z. Wu).

https://doi.org/10.1016/j.cemconcomp.2017.10.013
0958-9465/

Table 1
Treatment methods for recycled concrete aggregate [3].

Treatment method	Physical treatment	Chemical treatment
Removing adhered mortar	Mechanical grinding	Pre-soaking in acid
	Pre-soaking in water	–
Strengthening adhered mortar	Polymer emulsion	Pozzolan slurry (or mixed with a small amount of cement)
	Filler lime powder or calcium carbonate biodeposition	Sodium silicate
	–	Carbonation

investigated the basic properties of the resulting RCA and concrete mixes. Test results showed a significant reduction in water absorption of the RCA and an increase in mechanical properties of RCA concrete. In order to effectively remove the old mortar and obtain good-quality RCA, the concentration of acid solution used should be controlled within a satisfactory range. Cuneyisi et al. [12] assessed the influence of different acid concentrations (0.1, 0.5, and 0.8 mol of HCl) and durations of treatment on the properties of aggregate and concrete. They found that the use of low concentration of HCl at 0.1 molarity could potentially remove the loose adhered mortar on RCA surface, and the time of immersion in an acid bath did not show a significant influence on the amount of mortar lost.

Kou et al. [13] investigated the effect of the impregnation method with different concentrations (6%, 8%, 10%, and 12%) of polyvinyl alcohol (PVA) on the properties of RCA. The results indicated that a 10% concentration of PVA was generally optimum for reducing the water absorption. The use of impregnated PVA recycled aggregate improved the mechanical properties and resistance to chloride-ion penetration and shrinkage of RCA concrete. Spaeth et al. [14] studied the water resistance effect of RCA using siloxane, silane, and a combined solution of both polymers. Among all polymer solutions, siloxane resulted in the highest reduction in water absorption, followed by the combined solution and then silane. In terms of the influence of solution concentration, 5% siloxane resulted in a decrease of 45% water absorption, whereas 90% reduction was achieved by increasing the concentration up to 45%. In general, the polymer solutions can reduce the water absorption, but they may cause a negative impact on the concrete properties, such as a decrease in compressive strength. Zhu et al. [2] studied the durability of recycled aggregate concrete treated with different dosages of silane-based water repellent agents. The silane-based water repellent was used either for RCA surface coating or integrally added into the concrete mixture. It was found that both concrete surface and integral silane treatments can improve the durability of recycled aggregate concrete by increasing the resistance to capillary water absorption, carbonation, and chloride-ion penetration.

Du et al. [15] blended various pozzolan slurries, such as cement paste, cement with fly ash, and cement with waterproof powder additive, and observed that RCA-treated waterproof cement-based slurry gained better properties than the other two pastes. A study by Singh et al. [16] found that a small particle size of pozzolan slurry of nano-SiO_2 was efficient in enhancing the quality of RCA due to its high pozzolanic reactivity. Therefore, it can be concluded that the efficiency of the slurry treatment relies on the type, particle size, and the reactivity of pozzolan used as well as the content of calcium hydroxide remaining in the adhered mortar for pozzolanic reaction.

Carbonation treatment is based on the interaction between adhered paste (i.e. calcium hydroxide and hydrated calcium silicate) and CO_2 resulting in the formation of solid calcium carbonate in a relatively short time [17,18]. Zhan et al. [19] reported that 24-h CO_2 curing of RCA led to decrease in water absorption by 19%–25% and porosity by 18%–21% when compared to that before carbonation. Kou et al. [20] adopted CO_2 curing to improve the properties of concrete that prepared with recycled aggregates in a 100% CO_2 chamber under a positive 0.1 Pa pressure. The drying shrinkage of the mixture made with CO_2 cured aggregate was approximately 10%–15% lower than that of the reference sample, while the resistance to chloride ion penetration was 41%–46% greater. Shi et al. [21] used CO_2 to pre-cure and accelerate the carbonation reaction and strengthen the concrete properties. This technique increased the early strength of concrete associated with pore refinement by calcium carbonate. Carbonation can increase the solid content by 13% due to the chemical reaction between CO_2 and calcium hydroxide or calcium silicate hydrate [22,23]. According to the aforementioned studies, there was a lack of comparison information on the performance of recycled concrete/mortar that treated by different methods.

This paper aims at evaluating the efficiency of different enhancement methods, including pozzolan slurries and CO_2 treatments, for recycled concrete aggregate (RCA). RCA used in this study was crushed from parent concrete with a strength grade of 30 MPa. The properties of RCA before and after treatment were examined and its effect of being added in the production of cement mortar was identified. The fresh, mechanical, and durability properties of RCA mortar as well as the microstructure with particular focus on the interfacial transition zone (ITZ) were examined and compared.

2. Experimental program

2.1. Materials

2.1.1. Recycled concrete aggregate

Recycled concrete aggregate (RCA) used in this study was derived from concrete samples with a strength grade of C30 (28-d compressive strength of 30 MPa). RCA with a particle size less than 4.75 mm and a fineness modulus of 2.45, i.e. sand, was prepared in accordance with the Chinese standard of Type I fine aggregate [24]. The particle size distribution of the RCA is presented in Table 2.

2.1.2. Treatment of RCA with pozzolan slurries

Three different pozzolan slurries, namely silica fume slurry, fly ash slurry, and nano-SiO_2 slurry, were prepared. The specific surface areas of silica fume, fly ash, and nano-SiO_2 are 18,500, 427, and 160,000 m^2/kg, respectively. Nano-SiO_2 slurry was prepared with a water-to-solid ratio of 20:1, whereas, for the silica fume and fly ash slurries the water-to-solid ratio was fixed at 10:1. To ensure better dispersion of the fine particles, ultra-sonication was used for mixing the slurries. Following the mixing process, the dynamic viscosity of the slurries was determined by using a digital viscometer with a rotational speed of 30 rpm at a temperature of 15 °C [25]. The dynamic viscosity results are given in Table 3. The fly ash slurry treatment rendered the lowest dynamic viscosity of RCA while the nano-SiO_2 slurry treatment exhibited the highest value.

For the slurry treatment, RCA was first dried at 60 °C for 48 h. After that, it was mixed in the freshly slurry for 30 min and soaked