Journal of Cleaner Production 112 (2016) 466–472

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Review

Performance enhancement of recycled concrete aggregate – A review

Caijun Shi [a,*], Yake Li [b], Jiake Zhang [a], Wengui Li [a], Linlin Chong [a], Zhaobin Xie [a,c]

[a] College of Civil Engineering, Hunan University, Changsha, Hunan, 410082, China
[b] WOWA International Engineering & Consulting Co. Ltd, Shenzhen, Guangzhou, 518067, China
[c] College of Civil Engineering and Mechanics, Central South University of Forestry and Technology, China

ARTICLE INFO

Article history:
Received 18 March 2015
Received in revised form
5 August 2015
Accepted 13 August 2015
Available online 21 August 2015

Keywords:
Recycled concrete aggregate
Adhered cement mortar
Enhancement treatment
Strength

ABSTRACT

Recycled concrete aggregate differ from natural aggregate as the former contains hardened cement mortar. The adhered cement mortar on recycled concrete aggregate has higher porosity and water absorption and lower strength than natural aggregate do. It has negative effects on the mechanical properties and durability of fresh and hardened concrete made with recycled concrete aggregate. Therefore, it will facilitate the applications of recycled concrete aggregate if the adhered cement mortar can be enhanced. Removing and strengthening the adhered mortar are the two main methods for enhancing the properties of recycled concrete aggregate. This paper reviews the published enhancement methods for recycled concrete aggregate, and points out their advantages and disadvantages so as to facilitate the selection and further development of suitable enhancement methods for recycled concrete aggregate. It suggests that carbonation treatment is an efficient and feasible method for improving the mechanical properties and durability of recycled concrete aggregate. Carbonation treatment of recycled concrete aggregate is not only an efficient way for enhancing the properties of recycled concrete aggregate, but also an environmental friendly approach.

1. Introduction

Construction and demolition (C&D) wastes account for a large portion of solid wastes and the generation of which has been increasing rapidly in China. Recycling/reusing C&D wastes is an important issue to foster sustainable development and has become a focus of research efforts in recent years. Different types of solid waste materials have been considered as the aggregate/or in any other form in concrete, such as the discarded tire rubber (Thomas and Gupta, 2015; Thomas et al., 2015) and copper tailing (Thomas et al., 2013). Such application of those solid waste showing feasibility of reusing the waste as the construction materials.

Recently, effective uses of recycled concrete aggregate (RCA) in cement and concrete industry have attracted a lot of attention from both the environmental and resource preservations (Hu et al., 2013). Because the natural aggregate cannot be reproduced in short term, and aggregate typically accounts for 60 to 75 percent of concrete by volume (Taylor et al., 2007). Thus, to use the waste concrete as the recycled aggregate not only solve the resource issue, but also saved the land for disposal the waste concrete. However, use of RCA for the production of concrete may cause some mechanical problems (Gómez-Soberón, 2002; Katz, 2003; Etxeberria et al., 2007; Ajdukiewicz and Kliszczewicz, 2002; de Juan and Gutiérrez, 2009; Bravo and de Brito 2012) and durability concerns (Kou et al., 2011; Tam et al., 2007; Rao et al., 2007) due to the poor quality of RCA. Poon et al. (2002) reported that replacing 50% or more coarse and fine natural aggregate with RCA can significantly reduce the compressive strength of concrete, and Talamona and Tan (2012) also obtained similar findings. RCA differs from natural aggregate (NA) mainly because it contains two additional components: adhered mortar and an interfacial transition zone (ITZ) between the NA and the original cement mortar. Because the original cement mortar attached on NA is more porous than NA. RCA have higher porosity and water absorption, and lower strength compared with NA. The water absorption of RCA ranges 3–12% compared with 1–5% for NA (Gómez-Soberón, 2002; Katz, 2003). The density and absorption of RCA depend upon the W/C ratio of the original concrete (Etxeberria et al., 2007) and the amount of adhered mortar. Also, the crushing process and the dimension of RCA affect the amount of adhered mortar (Ajdukiewicz and Kliszczewicz, 2002; de Juan and Gutiérrez, 2009). High water absorption of RCA required the pozzolanic materials and

* Corresponding author.
E-mail address: cshi@hnu.edu.cn (C. Shi).

http://dx.doi.org/10.1016/j.jclepro.2015.08.057
0959-6526/

superplasticizer to make concrete of equivalent fresh and hardened properties to those of natural aggregate concrete (Gómez-Soberón, 2002; Kou et al., 2011; Tam et al., 2007; Rao et al., 2007).

Concrete consists of three components: hardened cement paste, aggregate and ITZ between the cement paste and the aggregate. ITZ is usually the weakest region in concrete due to its higher porosity and cracks than those in either hardened cement paste or aggregate (Zhang et al., 2015a). RCA in concrete resulted in more ITZs than NA, which includes original ITZs between the original aggregate and the adhesive mortar and the new ITZs between the adhesive mortar and the new mortar matrix. Etxeberria et al. (2006) found that the adhered original mortar was the weakest portion in recycled concrete. However, Otsuki et al. (2003) evaluated ITZs by Vickers microhardness test and found that the characteristics of original ITZs were depended on the qualities, rather than the quantity of adhered mortar. When a low W/C ratio was used to prepare the new concrete, the new ITZs were less porous than the original ITZs which was more critical in affecting the properties of the hardened concrete. When the W/C ratio of the original concrete was high, the strength of new concrete was controlled by the new ITZs (Ryu, 2002). The higher the strength of the original concrete was, the less porous the ITZs of recycled concrete was (Poon et al., 2004). Therefore, it is of interest to enhance the properties of RCA to make them comparable to those of NA. The challenges in RCA include how to effectively reduce the absorption and porosity of RCA, and that can improve the durability of the RCA.

2. Enhancement treatments

Removing and strengthening the adhered mortar are the two common methods for improving the properties of RCA. Table 1 summarized the methods for improving the properties of RCA and these are described more in details in the following sections.

3. Removal of adhered mortar

Mechanical grinding, pre-soaking in water/acid are the common methods to remove the adhered mortar. Mechanical grinding is a popular treatment because of the simple procedure to produce high quality RCA (Sun and Xiao, 2004). However, mechanical grinding could easily damage RCA due to collision and grinding by introducing micro-cracks.

3.1. Mechanical grinding

The adhered mortar can be separated as much as possible from the natural aggregate using crushing and ball-milling, which can also improve the shape of aggregates due to collision and peeling-off effects. The mechanical grindings include following types (Gjorv and Sakai, 1999):

1) Mechanical grinding

The principal function of traditional grinding is achieved by rolling vibration effects of a high speed rotating eccentric gear in a grinding mill. The adhered mortar would be ground pulversied by this action. It can be further modified by improving the eccentric gear to gain a higher speed, and thus to enhance the peeling-off efficiency of the mortars and the quality of RCA. Montgomery (Montgomery, 1998) removed the adhered mortar from the virgin aggregate by ball-milling and investigated the influences of adhered mortar contents on the properties of RCA.

2) Selective heat grinding (Bru et al., 2014)

Selective heat grinding uses microwave to heat up and weaken the original ITZs between the virgin aggregate and the adhered mortar. Then mechanical grinding can effectively remove the adhered mortar to obtain the high quality RCA.

3) Heat grinding

Crushed recycled concrete was heated at around 300 °C to dehydrate the adhered mortar and make it more embrittle, before grinding them in a mill. Generally, the higher the heating temperature, the easier the mortar can be removed. However, when the temperature is higher than 500 °C, the properties of RCA may be degraded. Using this method, Tateyashiki et al. (2001) obtained high quality RCA by heating then grinding the crushed concrete. However, Ma et al. (2009) heated concrete from C&D wastes at 750 °C to separate aggregates from the cement paste because limestone start to decompose at 750 °C.

3.2. Pre-soaking in water

Pre-soaking in water can separate impurities and obtain higher quality RCA. Katz (2004) adopted ultrasonic water cleaning repetitively to remove the weak adhered mortar until the water was clear. They found that it was effective in removing the adhered mortar, and increased the compressive strength of the recycled aggregate concrete; but the strength increase was about 7% at 28 days. Although this method could effectively wash away loose, weak adhered mortar, stronger mortar cannot be removed.

3.3. Pre-soaking in acid

The hydration products of cement in hardened paste can be dissolved in acid solution. Thus, acidic solution can be used to remove the adhered mortar effectively and enhance the quality of RCA. Tam et al. (2007) used three 0.1 mol acids, which were hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and phosphoric acid

Table 1
Enhancement treatments for RCA.

Enhancement methods	Physical treatment	Reference	Chemical treatment	Reference
Removing adhered mortar	Mechanical grinding	Gjorv and Sakai, 1999; Montgomery 1998; Tateyashiki et al., 2001; Ma et al., 2009	Pre-soaking in acid	Tam et al., 2007
	Pre-soaking in water	Katz, 2004	–	–
Strengthening adhered mortar	Polymer emulsion	Kou and Poon 2010; Zhu et al., 2013; Spaeth and Djerbi Tegguer, 2014; Tsujino et al., 2007; Wan et al., 2004; Qiu, 2003	Pozzolanic solution (or mixed with little cement)	Katz, 2004; Shayan and Xu 2003; Tam et al., 2005; Tam and Tam 2008; Kong et al., 2010; Li et al., 2010; Du et al., 2002;
	Filler lime power or calcium carbonate biodeposition	Shayan and Xu 2003; Grabiec et al., 2012	Sodium silicate	Spaeth and Djerbi Tegguer, 2014; Shayan and Xu 2003; Cheng and Wang, 2005; Pelisser et al., 2011
	–	–	Carbonation	Kou et al., 2014