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Interfacial properties of modeled recycled aggregate concrete modified by carbonation

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HIGHLIGHTS

- Modeled recycled coarse aggregate (MRCA) was designed and modified by carbonation.
- Interfacial properties of modeled recycled aggregate concrete (MRAC) were studied.
- Both test and simulation results confirmed the effect of carbonation modification.

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ABSTRACT

Modeled recycled coarse aggregates (MRCAs) were designed with different water to cement ratios (*w*/*c*) of old hardened mortar (OHM). Each type of MRCAs was modified by carbonation. All carbonated and uncarbonated MRCAs were used to cast modeled recycled aggregate concrete (MRAC) specimens. Push-out tests were conducted to investigate the influence of MRCA carbonation modification on interfacial properties of MRAC. Based on the load–displacement curves, the peak load and peak displacement were mainly analyzed to assess the effect of carbonation modification. The experimental results show that the peak load increased while peak displacement decreased as the MRCA was intensified by carbonation. The effect of carbonation modification was more obvious at a higher *w*/*c*. With the increase of *w*/*c* of new hardened mortar (NHM) or OHM, the corresponding peak load decreased, whereas the peak displacement tended to increase at first and then decrease. A simulation study was also conducted by software ABAQUS and verified by the experimental results. The parametric study confirms that interfacial properties of MRAC significantly depend on carbonation depth, distribution of OHM and shape of MRCA.

1. Introduction

Gravel and sand, which account for most composites in concrete, have been exploited and used in construction industry widely. However, with the economic development of China, production of concrete is consuming lots of natural resources every year. Besides, China is also faced with the problem of waste concrete. Most of these waste concrete results from demolition of old buildings or disasters like earthquakes. It is reported that approximately 200 million tons of waste concrete are currently produced annually in the mainland of China [1], which leads to encroachment of lands and potential soil damage. To resolve the issue of waste concrete and shortage of natural resources, recycled aggregate concrete (RAC) technique comes into being as an ecological method.

Compared with natural aggregate concrete (NAC), the mechanical properties of RAC are more difficult to predict. RAC is characterized as a multi-phase material with several different representative scales: at macroscopic scale, RAC could be regarded as a homogeneous material; whereas at mesoscopic scale, it is composed of coarse aggregates, old interfacial transition zones (ITZs), OHM, new ITZs and NHM [2], as shown in Fig. 1. Compared with natural coarse aggregates (NCAs), due to the existence of adhered OHM, recycled coarse aggregates (RCAs) have the characteristics of high porosity, low density, high water absorption and low strength, which are traditionally considered to lead to a reduction of the mechanical properties of RAC [3–5]. What's more, by existing investigations, ITZ is even more porous than OHM. It has been proved that old ITZs between aggregates and OHM, as well as new ITZs between OHM and NHM have a great influence on the mechanical properties of RAC [6,7]. Therefore, it is an effective way to improve the mechanical behaviors of RAC by improving the properties of ITZs. In recent years, many investigators have

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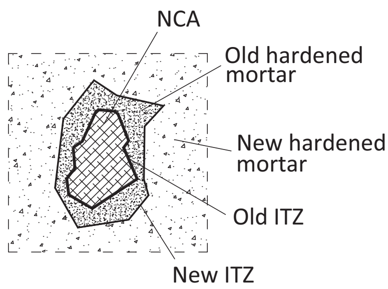


Fig. 1. Variant phases of RAC.

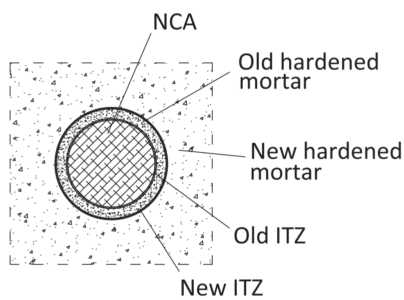


Fig. 2. Schematic of MRAC.

engaged in studies on the modification of RCA. Du et al. [8] reported that specific chemical grout intensified the RCA, proving that it is feasible to modify the RCA. Wan et al. [9] concluded that the compactness of ITZ can be improved by decreasing the w/c and adding appropriate amount of fly ash. Tam et al. [10] firstly proposed that the two-stage mixing approach (TSMA) could increase the compressive strength and decrease the strength variability. Kong et al. [11] reported that three-stage mixing approach, namely enveloping volcanic ash around the RCA, improved the microstructure at ITZ of RAC. Zhu et al. [12] found that the mechanical properties of particle shaped RCA were much higher than those of simply-crushed RCA. Noguchi et al. [13] confirmed that microheating technique effectively removed the adhered OHM to improve the quality of RCA. Shah and Hou et al. [14,15] revealed that nanoSiO_2 could speed up the hydration process of cement and therefore increase the early-age strength of cement paste. Shah and Konsta-Gdoutos et al. [16,17] reported that elastic modulus and fracture energy were significantly increased if carbon nano-tube was added to mortar.

Carbonation is a neutralizing procedure, in which carbon dioxide (CO_2) in the atmosphere react with calcium hydroxide

Table 1
Mix proportion of mortar.

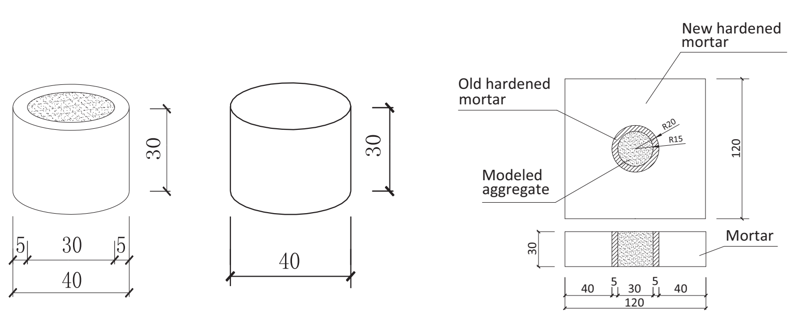
Strength grade	w/c	Unit mass (kg/m^3)		
		Cement	Water	Sand
M20	0.68	529	353	1224
M30	0.45	680	333	1098
M40	0.37	835	316	974

($Ca(OH)_2$) dissolved in the concrete pore water, producing calcium carbonate ($CaCO_3$) and water (H_2O). In addition, hydrated calcium silicate (CSH), un-hydrated tri-calcium-silicate (C_3S) and bi-calcium-silicate (C_2S) consume carbon dioxide (CO_2) as well. Carbonation can effectively improve the compactness of cement mortar, decrease the porosity and water absorption, and increase the density and strength of concrete containing RCA [18,19]. Furthermore, the carbonation approach has the advantage of lower cost and being more environmental friendly compared with other approaches [20]. Besides, although there are variations in different calculating models of carbonation depth for concrete proposed by many researchers [21–23], the basic fact is widely accepted that carbonation occurs only in the surface layer under atmospheric conditions during the life of structures. Carbonation depth can be predicted by equation proposed by Jiang et al. [23]:

$$x_c = 839(1 - \mathrm{RH})^{1.1}\sqrt{\frac{W/\gamma_c C - 0.34}{\gamma_{HD}\gamma_c C} n_0} \cdot \sqrt{t} \quad (1)$$

where x_c is the predicted carbonation depth, RH is the relative humidity, W and C are unit amount of water and cement, γ_c is an adjusting coefficient about type of cement, γ_{HD} is an adjusting coefficient about degree of cement hydration, n_o is the CO_2 concentration, and t is carbonation time. For concrete with 0.45 w/c, the average carbonation depth is about 7.2 mm in 50 years under atmospheric conditions. Considering the average dimension of concrete structure elements, the carbonation depth can be ignored. It means that most mortar, part of which becomes OHM of RAC, remains uncarbonated. Therefore it is predictable that carbonation might be an effective approach to improve the mechanical properties of RCA by improving the interfacial properties.

MRAC proposed in 2012 by Xiao et al. [24] is a simplified analysis model of RAC. The existing researches have demonstrated that MRAC can be used to investigate the relation between the mesostructure of each phase and mechanical behavior of RAC [2,24]. In this model, the NCA is simplified as a regular cylinder while the OHM is simplified as thin cylindrical vessel surrounding the NCA. The cylindrical NCA is called as modeled natural coarse aggregate (MNCA), and the cylinder with adhered OHM is named as modeled recycled coarse aggregate (MRCA). Specimens that are cast by MRCA and mortar are termed as MRAC [6], as shown in Fig. 2.



(a) MRCA (b) Mortar specimen (c) MRAC

Fig. 3. Geometric dimensions of specimens.