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Integrated interface parameters of recycled aggregate concrete

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HIGHLIGHTS

- Micro properties of diverse interfaces in recycled concrete (RC) are explored.
- Mechanical and durability properties of RC are weakened as RA replacements increase.
- An integrated interface parameter of RC is proposed.
- The rationality of the proposed interface parameter is discussed and proven.
- Mechanisms of the macro inferiority of RC are quantitatively analyzed.

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ABSTRACT

An integrated interface parameter of recycled aggregate concrete (RC), ξ, is proposed, based on experimental study of three RC groups with the recycled coarse aggregate (RA) replacements of 0%, 50% and 100%, respectively. Experimental study includes micro properties of diverse types of aggregate/mortar interfaces in RC, i.e., the length, width, and elastic modulus, and the macro properties of concrete materials, i.e., the compressive strength, density degree and chloride ion diffusion coefficient. The rationality of the proposed ξ is proven by the comprehensive relevant interface information and its good correlations with both RA replacement ratios and concrete macro properties, respectively. ξ-based model prediction of macro concrete properties was also found reliable. The mechanism of RC's inferiority to natural aggregate concrete can thereby be quantitatively revealed based on ξ.

1. Introduction

Recycled aggregate concrete (RC) using recycled aggregates (RA) has raised worldwide interest because of its great potential benefits in controlling the over-discharge of construction and demolition (C&D) wastes. The use of RC may also reduce the consumption of natural resources, including the landfills used for disposing of these wastes and the natural aggregate (NA) for producing natural aggregate concrete (NC) [1]. Previous research verified that RC is generally inferior to NC in its material properties on the macro scale, including workability [2–6], mechanical properties [7–11], and durability [3,12–14].

To reveal the inferiority mechanism of RC in the macro properties compared to NC, the interface transition zone (ITZ) is the key because ITZs are treated as the primary weak points in cement-based materials [15,16]. With the introduction of RA, more types of ITZs are produced in RC than in NC, as illustrated in Fig. 1. According to Fig. 1, only one type of ITZ exists in NC, lying between the virgin aggregate and the new cement mortar, which is labeled as ITZ_1 in this study. By contrast, in RC, e.g., RC with the 50% replacement of RA, there exist three types of ITZs as follows: the ITZ_1s between the NA and the new mortar, the ITZ_2s inside the RA between the old virgin aggregate and the surrounding old mortar, and the ITZ_3s between the old mortar and the new mortar. It should be noted that RA are usually obtained by crushing and grinding, through which the old cement mortar may be partially or even completely removed from some RA particles, and some old ITZs, i.e., ITZ_2s, may have also been damaged or even removed. Therefore, when these RAs with the embedded virgin aggregate partially exposed are cast into concrete mixtures, new ITZs will form between the exposed virgin aggregate and the new cement mortar. This new type of ITZs can be treated as the same with ITZ_1-s, because both of them are interfaces between virgin aggregate and new cement mortar. In a word, in RC, there do exist three types of ITZs: ITZ_1s and the ITZ_3s are newly formed interfaces after casting, while ITZ_2s are the old ITZs originally existing in RA. The diverse types of ITZs in RC and the porous old mortar adhering to RA are potential weak points in RC, which can weaken the properties of RC on the macro scale. Furthermore, in Fig. 1,

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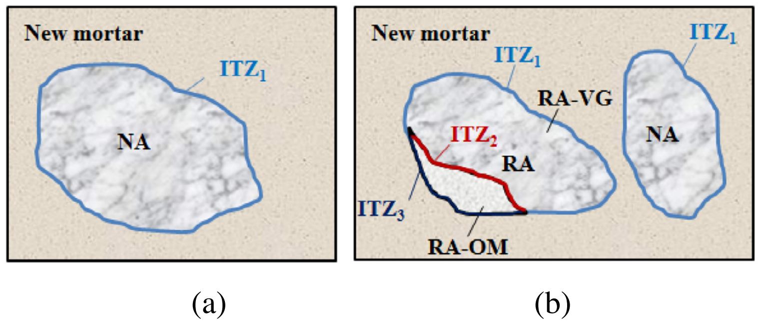

Fig. 1. Schematic diagram of the microstructure of (a) NC and (b) RC with the partial replacement of RA.

RA-VG represents the old virgin aggregate in RA, while RA-OM represents the old mortar adhering to the old virgin aggregate in RA.

Researchers have begun to explore the properties of ITZs in RC and their influence on macro properties. For example, C. S. Poon verified that the interface between RA and cement is relatively loose compared with the interface formed between NA and cement [17]. Ryu found that the compressive strength of RC depends on the relative quality of old and new ITZs in RC. When the water-cement ratio is low, the strength characteristic of the concrete is governed by the effect of old ITZs. When the water-cement ratio is high, the predominant governing factors are the new ITZs [18]. Xiao et al. found that the ratio of the old ITZ's mechanical properties (elastic modulus and strength) to those of the old mortar matrix affects the stress-strain curves and failure processes of modeled recycled aggregate concrete (MRAC). Increasing the ratio resulted in higher strength, but lower ductility. The ratio of new ITZ's mechanical properties to those of the new mortar matrix has a negligible effect on the compressive strength of MRAC, while the tensile strength of MRAC increases as this ratio increases [19]. However, these studies tend to be limited to just one or two single property parameters of ITZs, which means that they cannot comprehensively and reliably reflect both the geometric and mechanical features of all the diverse types of ITZs in RC, thereby the mechanism of RC inferiority to NC in macro properties could not be sufficiently revealed.

Therefore, the focus of this paper is to propose a reasonable and reliable interface parameter, to comprehensively reflect the geometric and mechanical properties of the diverse types of ITZs contained in RC, and furthermore, to quantitatively investigate the influence of multiple ITZ properties on the macro properties of concrete materials. The rationality of the proposed interface parameter of RC is discussed from multiple angles. The proposed interface parameters will reveal the essential differences between RC and NC in interface features. In addition, our findings connect the interface properties and the macro material properties, so that the mechanism of RC's inferiority to NC can be quantitatively investigated on the macro scale.

2. Materials

2.1. Concrete materials

2.1.1. Coarse aggregate

The RA employed in this study was purchased from a plant in Shanghai, China. It was observed that the old cement mortar had been partially removed from some RA particles through RA's producing procedure, rendering the old virgin aggregate in these RA particles partially exposed to the atmosphere. New ITZs would form between these exposed old virgin aggregate and the new cement mortar in concrete mixtures, as has been proposed as ITZ_1s in the Introduction Section. The NA used in this study was crushed limestone ranging from 5 to 25 mm in size. Since there was no ready-made RA with the same size range as NA produced by this RA manufacturer, the employed RA was obtained by mixing two groups of RAs with different size ranges (5–15 mm and 15–25 mm). The mixture was obtained according to certain proportions determined after several trials to ensure that the employed RA and NA were similar in both size ranges and size distributions. The size distributions of NA and RA are illustrated in Fig. 2.

According to Fig. 2 the two groups of coarse aggregates employed in this study demonstrated the similar size distribution. The percentage of particles below 16 mm for RA was slightly higher than that for NA, which indicated that smaller particles in RA accounted a larger proportion than in NA. This may be attributed to the crushing operation through the procedure for producing RA, as through crushing the old cement mortar was likely to fracture and be broken into smaller particles. Still the difference between the two curves in Fig. 2 is acceptable, therefore the similar size gradation of the two groups of coarse aggregates on micro properties of concrete could be negligible.

The crushing value and the mud content of the employed RA and NA were tested according to *The National Specification Pebble and Crushed Stone for Construction* (*GB/T* 14685-2011). It was found that the crushing value of RA was higher than that of NA; the crushing values of RA and NA were 11.3% and 8.0%, respectively. The presence of the weak, porous old mortar adhering to the old virgin aggregate of RA may have affected the surface strength of RA and as a result the anti-crushing property of RA was weakened. Besides, the mud contents were 3.5% and 0.6%, for RA and NA, respectively. Such differences were also mainly induced by crushing through RA's production, during which the old mortar was partly ground to become fine particles.

A natural water absorption of coarse aggregates was defined and measured in this study, which was employed in the mix design method to adjust the water amount for the RC mixture to ensure good RC workability. The natural water absorption in this study, w_n, was defined as the water absorption (by weight) of the naturally air-dried (AD) coarse aggregates, rather than the oven-dried (OD) aggregates. w_n was calculated as follows:

$$w_n = \frac{m_1 - m_0}{m_0} \times 100\% \quad (1)$$

where m_0 was the weight of each of the three air-dried (AD) samples for RA and NA. Each AD sample weighed approximately 5.0 kg. The three samples were soaked in water for 24 h and then removed from the water; excess water was absorbed by a wet cloth until the samples were surface saturated dried (SSD). m_1 was the weight of each SSD aggregate sample.

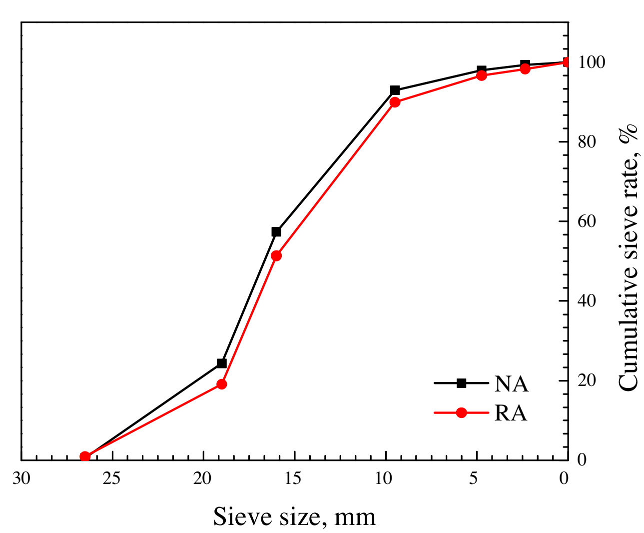

Fig. 2. The size distribution of NA and RA employed in this study.