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Experimental study of interfacial transition zones between geopolymer binder and recycled aggregate

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HIGHLIGHTS

- Systematically studied the ITZ between geopolymer (GP) and recycled aggregate (RA).
- Water to solid (W/S) ratio has a great effect on the bond strength of ITZ.
- GP-RA ITZ shows higher bond strength than GP-NA, OPC-NA and OPC-RA ITZs.
- There is a great potential to use RA to produce geopolymer concrete.

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ABSTRACT

This paper experimentally studies the interfacial transition zone (ITZ) between geopolymer binder (GP) and recycled aggregate (RA). Since RA consists of exposed stone surfaces and the attached paste/mortar from the original ordinary Portland cement (OPC) concrete, both the ITZ between GP and natural aggreate (NA) and that between GP and residual OPC paste/mortar (ROPM) were studied. For comparison, the ITZ between OPC paste and NA and that between OPC paste and ROPM were also studied. The GP was produced from waste concrete fines (WCF) and class F fly ash (FA) at a WCF/FA mass ratio of 1, using a mixture of 10 M NaOH solution and Na_2SiO_3 solution at a mass ratio of 2 as the alkaline activator. Four-point bending tests were conducted to measure the bond strength of the different types of ITZs at a water to solid (W/S) of 0.30, 0.35 and 0.40 for the GP and OPC paste after 7 and 14 days' curing, respectively. Scanning electron microscopy (SEM) imaging was also performed to investigate the microstructure of the ITZs. The results indicate that when NA is used, the bond strength of both the GP-NA and OPC-NA ITZs decreases with higher W/S ratio. This is mainly because higher W/S ratio leads to a more porous microstructure in the ITZ. When ROPM is used, higher W/S ratio leads to smaller bond strength for the GP-ROPM ITZ but greater bond strength for the OPC-ROPM ITZ. This phenomenon is mainly caused by the high water absorption capacity of ROPM. Based on the measured bond strength values for the NA- and ROPM-based ITZs, the bond strength of the RA-based ITZs was estimated by considering the average area coverage of ROPM on the RA surface. The GP-RA ITZ has high bond strength, implying the great potential for utilizing waste concrete (both WCF and RA) to produce geopolymer concrete.

1. Introduction

Ordinary Portland cement (OPC) is widely used as the binder material in concrete production. However, the process of manufacturing OPC consumes a huge amount of natural source materials and releases a tremendous quantity of greenhouse gases [1,2]. The tremendous energy consumption during OPC production and the negative effects related to global warming have attracted increasing attention to the OPC industry. Due to the growing awareness of environmental protection and global warming issues, advocates have been pushing the construction industry to look for alternative materials [3–5]. On the other hand, the substantial amount of waste concrete from the repairing and upgrading of deteriorating infrastructure systems is becoming a challenging issue [6]. It is increasingly difficult to find appropriate places for disposal of waste materials. To address this issue, researchers have been conducting extensive studies on recycling and utilizing waste concrete. However, so far, the utilization of waste concrete is still limited to low grade applications such as construction of roadbeds

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and backfills or partial replacement of natural aggregate in production of structural concrete [7–16].

Very few researchers have attempted to recycle waste concrete completely. Some of them have repeated the OPC kiln procedure on waste concrete to acquire clinker. However, intense energy is required for this approach and a large amount of CO_2 is emitted during the kiln procedure [17,18]. Recently, Ahmari et al. [19] proposed a less energy consuming method to produce a new type of cementitious material based on the geopolymerization technology. They used a mixture of waste concrete fines (WCF) and class F fly ash (FA) as the source material and a mixture of NaOH solution (N) and Na_2SiO_3 solution (SS) as the alkaline activator to produce geopolymer binder (GP). By adjusting the WCF/FA and SS/N mass ratios, the effect of the Si/Al, Ca/Si and Na/Al ratios on the strength of GP was studied. The highest uniaxial compaction strength (UCS) of GP paste, about 35 MPa, was obtained at 10 M NaOH, SS/N = 2 and WCF/FA = 1. The GP paste samples were cured at room temperature for seven days.

In OPC concrete, the ITZ is the weakest link between the aggregate and the cement paste/mortar [20]. The stress that causes the failure of ITZ is significantly lower than that of either the aggregate or the paste/mortar, and as a result the ITZ determines the strength of the entire concrete [21]. Researchers [22–26] have conducted extensive research to study the bond strength of ITZs between cementitious material and aggregate. Jiang [22] used class F fly ash to modify OPC and investigated the bond strength of ITZ between the modified OPC and limestone aggregate. After curing for three days at 20 ± 3 °C, the bond strength varied from 1.65 to 2.31 MPa. Similarly, Guo et al. [23] used class F fly ash and ground granulated blast–furnace slag to modify OPC. They conducted bending tests to measure the bond strength between the modified OPC and basalt aggregate. After curing for 91 days, the bond strength ranged from 2.2 to 4.0 MPa. Beside the active mineral additions, researchers also studied addition of dispersible polymers to the OPC to enhance the bond strength of ITZ. For example, Jenni [24] added cellulose ether and redispersible polymers which included VC (vinyl–acetate/ethylene/vinyl-chloride copolymer), SA (styrene/acrylic copolymer), EVA (ethylene/vinyl-acetate copolymer), and PVA (polyvinyl alcohol) into the OPC for modification. The bond strength between the modified OPC and ceramic tile varied from 0.62 to 1.19 MPa. Lee and Deventer [25,26] studied the bond strength of ITZs between natural stone aggregates and GP. They used class F fly ash/kaolin-based GP and basalt/siltstone aggregates and conducted 3-point bending tests to measure the bond strength. Their results show that the bond strength of the different ITZs varied from essentially 0–1.27 MPa.

Based on the experimental results from Ahmari et al. [19], a hypothesis is proposed that the aggregate from the waste concrete crushing process can be used together with the GP to produce geopolymer concrete with good mechanical properties. The recycled aggregate (RA) contains both exposed stone surfaces and the residual OPC paste/mortar (ROPM) from the original concrete (Fig. 1(a)). Beside the original interfacial transition zones (ITZ) between ROPM and NA, two new types of ITZs, the one between GP and NA and the other between GP and ROPM (Fig. 1(b)), will be formed in the new geopolymer concrete. The newly formed ITZs are important in determining the strength of the geopolymer concrete and thus will be studied in this paper. Specifically, this paper first measures the bond strength of the ITZ between GP and NA and the ITZ between GP and ROPM using 4-point bending *d* tests. Based on the measured bond strength values of the two types of ITZs, the bond strength of the ITZ between GP and RA was estimated by considering the average area coverage of ROPM on the surface of RA. For comparison, the bond strength of the OPC-NA and OPC-ROPM ITZs were also measured and the bond strength between OPC and RA estimated. Besides, scanning electron microscopy (SEM) imaging was performed to study the microstructure of the different ITZs.

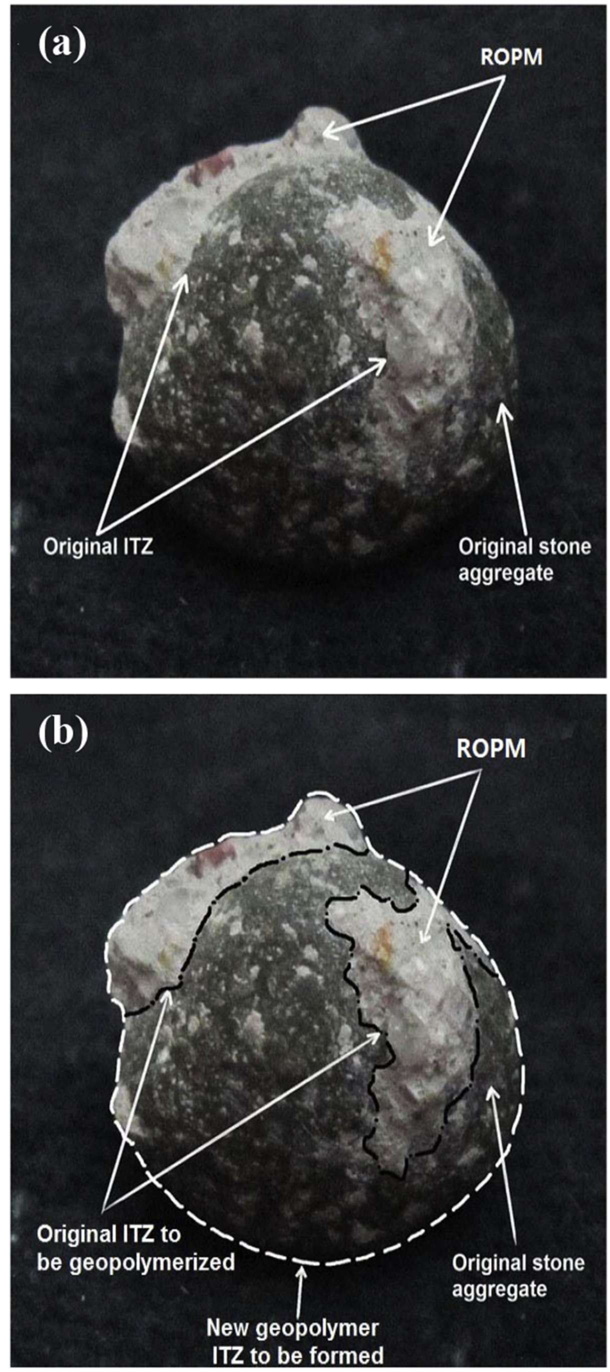

Fig. 1. (a) Recycled concrete aggregate (RA) with residual OPC paste/mortar (ROPM) and original interfacial transition zone (ITZ); (b) Geopolymerized recycled concrete aggregate (It is noted that actual RA may not be so round as shown here and can take different shapes).

2. Experiment study

2.1. Materials

The WCF was obtained from the fine portions by crushing the OPC concrete specimens already tested in the Structures Laboratory at the University of Arizona. These OPC concrete specimens