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Study on interfacial transition zone properties of recycled aggregate by micro-hardness test

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HIGHLIGHTS

- ▶ We analyzed the physical characteristics on the ITZs between RAs and mortar.
- ▶ The RAC is seriously affected by the existing cracks within the RAs.
- ▶ The ITZs properties determine the bond strength between RAs and mortar.
- ▶ The old ITZs were weak compared to the new ITZs by cracks and voids with RAs.

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ABSTRACT

This study was undertaken using two experimental approaches for analyzing the influence of recycled aggregate on recycled aggregate concrete: The failure shape of recycled aggregate after loading and the internal properties of recycled aggregate that influence on strength of recycled aggregate concrete; the change of mechanical properties in the interfacial transition zone between the aggregate and mortar by a micro-hardness test. The recycled aggregate concrete, contrary to fail mode of natural aggregate concrete, failed by both interfacial transition zone failure between the mortars and aggregate and cracks through the inner parts of the recycled aggregate. For the interfacial transition zone properties between the aggregate and mortar, a micro-hardness value in the old interfacial transition zone was lowest, while the micro-hardness value in the new interfacial transition zone was high next to the old interfacial transition zone. Regarding the interfacial transition zone properties of mortar, a micro-hardness value in the old mortar was similar to or somewhat lower than that of the new mortar. This study confirmed interfacial transition zone properties between old mortar and new mortar, between the aggregate and mortar, and the amount of the old mortar that influenced properties of the recycled aggregate.

1. Introduction

In concrete, the interfacial transition zones (ITZs) serve as a bridge between the mortar matrix and the coarse aggregate particles. Even when the individual components are of high stiffness, the stiffness of the concrete may be low because of breaks in these bridges (i.e., voids and micro-cracks in the interfacial transition zone), which do not permit stress transfer [5]. Hsu and Slate [10] also emphasized the importance of aggregate–mortar matrix interfacial bonds. Yuan and Guo [2] and Zimbelman [7] suggested that the bond between the aggregate and the mortar matrix depends on three different factors. These are: the mechanical keying of the hydration products of cement with the rough surface of the aggregate (often covered with fine cracks); the epitaxial growth of hydration products at some aggregate surfaces; and the physical–chemical bond between the hydrating cement paste and the aggregate. Therefore, the interfacial transition zone should be considered when the strength of concrete is evaluated. In recycled aggregate concrete in particular, there are more interfacial transition zone than normal aggregate concrete as can be seen in Fig. 1, which is a sectional view of recycled aggregate concrete (RAC). More recently, the effect of aggregate properties such as modulus of elasticity, surface texture and size on the weakness of an interfacial transition zone and the failure process of concrete were also discussed by Akçaoğlu et al. [11].

However, studies on the variation of mechanical properties that influence the failure of recycled aggregate concrete by formation of interfacial transition zone between recycled aggregate and mortar, unlike that in normal concrete, are still poor. In addition, researchers are taking a different view about the interfacial transition zone

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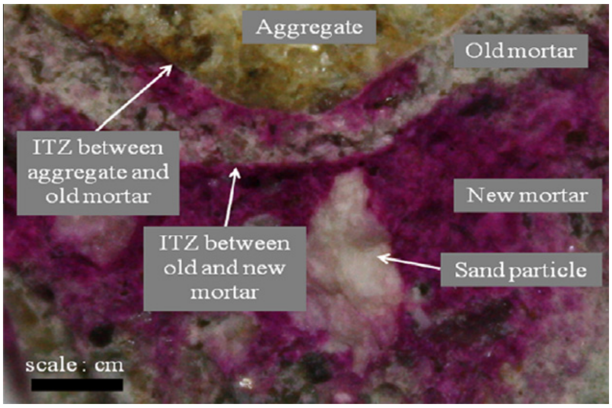

Fig. 1. Classification of aggregate, old mortar and new mortar by discoloration of phenolphthalein solution.

between recycled aggregate and mortar that influence bond strength. Rasheeduzzafar and Khan [8] stated that an interfacial transition zone between recycled aggregate and mortar has little influence on bond strength, which is similar to that for normal concrete. However, Tam et al. [12] and Poon et al. [1] stated that an interfacial transition zone in recycled aggregate concrete makes it weaker than normal concrete. These conflicting results and interpretations are because of the shortage of scientific evidence about recycled aggregate and recycled aggregate concrete. It has also become a major factor that users have a poor understanding and are uncertain regarding the use of recycled aggregate.

To improve the evaluation of recycled aggregate as well as to overcome the poor understanding of this material, researchers need to provide more information about the properties of recycled aggregate and recycled aggregate concrete so that users can believe in and re-evaluate the worthiness of using it. To achieve this, one needs to provide basic information about the strength of recycled aggregate concrete that uses recycled aggregate, and the number of times recycled aggregate can be used, by analysis of properties such as the change in properties of the interfacial transition zone between recycled aggregate and mortar and bond strength by interfacial transition zone. Therefore, the aim of this study is to show the growth shape of mortar on the aggregate surface and the strength change in the interfacial transition zone of aggregate, old mortar and new mortar.

2. Experimental programme and procedure

To study the effect of old mortar on the recycled aggregate (RA) surface in the recycled aggregate concrete (RAC), properties were determined by experimental approaches: the failure shape of recycled aggregate and recycled aggregate concrete was measured by both compressive and tensile tests and interfacial transition zone analysis between aggregate and mortar by a micro-hardness test was undertaken.

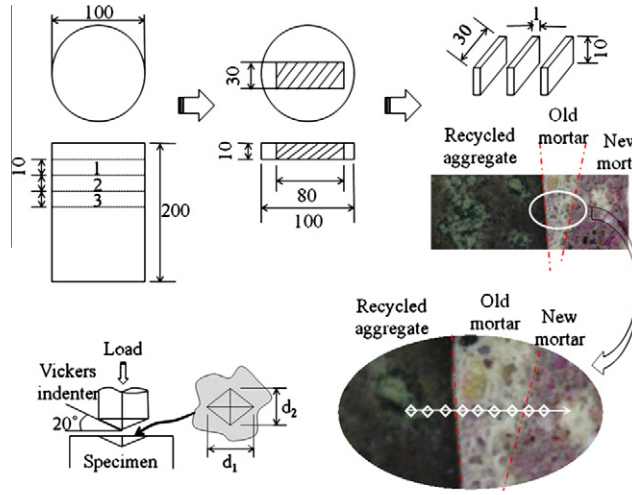

Fig. 2. Specimens and configuration for Vickers micro-hardness test.

To understand the failure shape of recycled aggregate concrete by compressive and tensile tests, ∅ 100 mm × 200 mm cylinder samples with recycled aggregate replacement ratios of 0 and 100% were tested in which 10 samples were prepared at each ratio. As shown in Table 1, the air-entraining agents (neutralised vinsol resin type) were adjusted to achieve a target slump and air content of 180 ± 25 mm and 4.5 ± 1.5%, respectively, and in order to minimize the amount of free water except for water required for hydration of cement and water. Because he free water and voids by it can affect the measured value by indenter of Vickers micro-hardness test. The average compressive strength of the control concrete at the time of the tests was 27 MPa. The cylinder samples were cured in water maintained at 20 ± 2 °C for 28 days after which they were demoulded. Compressive and tensile tests were measured under a load control of 10,000 N/min with a universal testing machine of 500 kN capacity.

A micro-hardness test is a method that measures the hardness of a material at a smaller localized region than the interfacial transition zone by a Vickers indenter [3]. The samples prepared for a micro-hardness test are shown in Fig. 2. As can be seen in Fig. 1, phenolphthalein solution was sprayed on the surface of the sample to effectively distribute old mortar and new mortar. To easily identify the diamond-shaped indentation that is formed on the surface of a sample by the Vickers indenter, the surface is polished by abrasion material of 120 grit using a grinder–polisher from Buehler. The specimens were also washed for 10 min using an ultrasonic cleaner to remove foreign substances on the surface of the sample after polishing. To measure the ITZ of recycled aggregate by the micro-hardness test, cylinder concrete was manufactured and designed with strength of 27 MPa, an air content of 4.0 ± 0.5% and a slump of 180 ± 25 mm. After a curing time of 28 days, the concrete cylinder was cut into a quadrangle of 30 mm × 80 mm after cutting a thickness of 10 mm, and finally, a sample of 10 mm (width) × 30 mm (length) × 1 mm (thickness) was manufactured. Among the prepared samples, a total of six samples (two natural aggregate concrete and four recycled aggregate concrete) were prepared.

The Vickers micro-hardness was measured at 12 and 13 points within a distance of from the 90 μm to 300 μm of the aggregate inner. To evaluate the new interfacial transition zone, the micro-hardness was measured on the interface between aggregate and mortar matrix at the underside of coarse aggregate as this position has the weakest interfacial transition zone due to internal bleed water

Table 1
Mix proportions.

Specimens	W/C (%)	S/A (%)	Unit weight (N/m^3)					
			Cement	Water	Natural sand	Natural coarse aggregate	Recycled coarse aggregate	Admixture
Natural aggregate concrete	50	42	343	171.5	712.5	964.3	0	2.06
Recycled aggregate concrete						0	983.9	

Table 2
Physical properties of aggregates.

Type	Max-aggregatesize (mm)	Water absorption (%)	Density (g/cm^3)	Fineness modulus	Bulk density (kgf/m^3)
Natural coarse aggregate	25	1.63	2.58	6.52	1642
Recycled coarse aggregate		1.93	2.50	6.62	1615
Natural sand	5	2.68	2.53	2.79	1455