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Effects of the old cement mortar attached to the recycled aggregate surface on the bond characteristics between aggregate and cement mortar

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HIGHLIGHTS

- We evaluated the bond characteristics between recycled aggregate and cement mortar matrix.
- Adhered ratio of old mortar is different according to the recycled aggregate size.
- Adequate amounts of old cement mortar attached on the surface of recycled aggregates can improve the bond quality.
- Recycled aggregate should be classified and replaced depending on the size, along with the production of the smaller sizes.

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ABSTRACT

A simple but interesting experiment was carried out to evaluate the bond characteristics between recycled aggregate and cement mortar matrix. The growth shape of mortar generated on the aggregate surface was investigated using image analysis, with the number of uses of the aggregate. The quantity of attached old mortar to the surface depending on the recycled aggregate sizes was analysed. The attached old mortar is a parameter determining the quality between the recycled aggregate and old mortar matrix, but this study showed that adequate amounts of old cement mortar can improve the bond quality, due to providing a fair degree of angularity, contrary to common opinion. Moreover, recycled aggregates of around size 10 mm had old mortar of the proper amount to contribute to the enhancement of the bond quality as aggregate for concrete. This paper suggested that recycled aggregate should be classified and replaced depending on the size, along with the production of smaller sizes than about 20 mm.

1. Introduction

To reduce destruction of the environment and to prevent an exhaustion of resources, the property of fresh and hardened concrete used recycled aggregates has been identified. However, the utilization of recycled aggregates is unsatisfactory; besides taking a lot of time and effort, it does not gain the confidence of users. Recycled aggregates have two kinds of production methods, by either crusher after exposure of the aggregates to about 300 °C, or by crusher only without heating [9]. Recycled aggregates are usually produced by crusher only without heating, due to low production cost, and simple production facilities. The recycled aggregates produced by crusher have a lot of mortar on the surface, and micro-cracks on the inside [8,10]. The recycled aggregates may have significantly changed physical properties, such as the young's modulus, absorption, and porosity, by either the micro-cracks, or the old cement mortar. It was identified that mechanical properties, such as compressive and tensile strength, are much deteriorated by the shape and amounts of micro-cracks [3,4].

In the strength of concrete, the bond between the aggregate and cement paste is an important factor, as the interlocking of the aggregate and cement paste. Nakataki and Tem [10,13] reported that old mortar could have an adverse effect on the bond strength of the aggregate and mortar, by forming a new interface between the old and new mortar in RAC. On the contrary, the old cement paste and/or mortar provides additional hydration in the recycled aggregate and cement paste interface zone, which strengthens the bond between the aggregate and cement matrix [7]. Chen and Wang [14] and Zimbelmann [15] suggested that the bond between the aggregate and mortar matrix depends on three different

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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 aggregate. These conflicting results and interpretations are because of the shortage of scientific evidence about recycled aggregate and recycled aggregate concrete.

Determination of the quality of the bond between the paste matrix and coarse aggregate is very difficult, and no accepted test procedure exists. Even if it is only in an artificial way, to change the perception of this eco-friendly material, as well as to improve the least usage guide of recycled aggregate, this study carried out an evaluation of the bond strength between aggregate and cement mortar, related to the quantity of old mortar on the aggregate surface, and the growth shape of mortar on the aggregate surface, according to the reuse of aggregates.

2. Experimental work

2.1. Materials

The recycled aggregate was obtained by crushing from concrete (20 years old at minimum, with typical design compressive strength of 21–24 MPa), collected at an apartment redevelopment site in Korea. It should be noted that the recycled aggregate used in the test meets the Korean Industrial Standard KS F 2573 for recycled aggregate for structural concrete use. The sand used in this study was blended sand, composed with river sand and crushed sand, and the sands were controlled by grading to 5 mm. Type I Portland cement manufactured locally to meet the ASTM C150 requirements was chosen for the cement mortar.

2.2. Specimens for the bond properties analysis

To analyse the effect of adhered old mortar on the bond strength, the experimental procedure is as shown in Fig. 1. A total of six specimens were manufactured, and the bond strength test was carried out four times per each specimen. The mortar that attached on the specimens surface after every bond strength testing was not removed, and new mortar was settled on the existing mortar, after testing. The size of specimens was 50 mm × 50 mm, and the aggregate used in the experiment was prepared by cutting of rock in a river. The surface of the specimens on which the 1st mortar was poured was maintained in its original condition. All of the specimens were cured in water for 28 days before testing, every time.

Because a primary bond strength test, as shown in Fig. 1, is about the ITZ between the surfaces of raw aggregate and cement mortar that is placed on it, a primary bond test could be considered as an experiment to analyse the ITZ between natural aggregate and mortar. In the case of the 2nd, 3rd and 4th bond test, because new mortar was placed on the adhered mortar on the aggregate surface after the primary bond test, those test methods could be considered as experiments that analyse the properties of the ITZ between recycled aggregate and new mortar. Therefore, to study the properties of the ITZ of NA and recycled aggregate having about the same area and surface properties of aggregate, a series of experiments for each sample was repeated from the 1st to the 4th test, consisting of measuring the bond strength and area of adhered mortar for all six samples. The mortar applied in this experiment was mixed by water/cement = 48.5%, and the amount of sand used was 1.25 kg.

The bond test, as shown in Fig. 2, was applied under displacement control at 0.20 mm/min. After the bond test in each experimental stage, to divide and measure an area of adhered cement mortar on the aggregate surface, phenolphthalein solution was sprayed on the surface of the aggregate, immediately after the experiment. The sample was maintained for about 60 min in air, so that the adhered mortar on the aggregate surface had sufficient time to react with phenolphthalein solution. The phenolphthalein solution on the surface of the aggregate that had not reacted was eliminated by flowing water; and finally, the mortar area discoloured by the phenolphthalein solution was measured. The mortar area attached on the aggregate surface was evaluated by image analysis, using the pixel ratio of adhered mortar area to the section area of aggregate.

2.3. Adhered ratio of old mortar according to the size of recycled coarse aggregates

As shown in Fig. 3, recycled coarse aggregates have much mortar on their surface, and these special characteristics influence the physical properties and/or durability of the recycled coarse aggregates, and concrete made with them [6]. The red colour is discoloured parts by Phenolphthalein Solution of the classification of old mortar and new mortar in hardened concrete. To measure the quantity of old cement mortar on the surface of recycled coarse aggregates, the attachment ratio of old mortar is calculated by the following Eq. (1), applied in the experiments of Choi

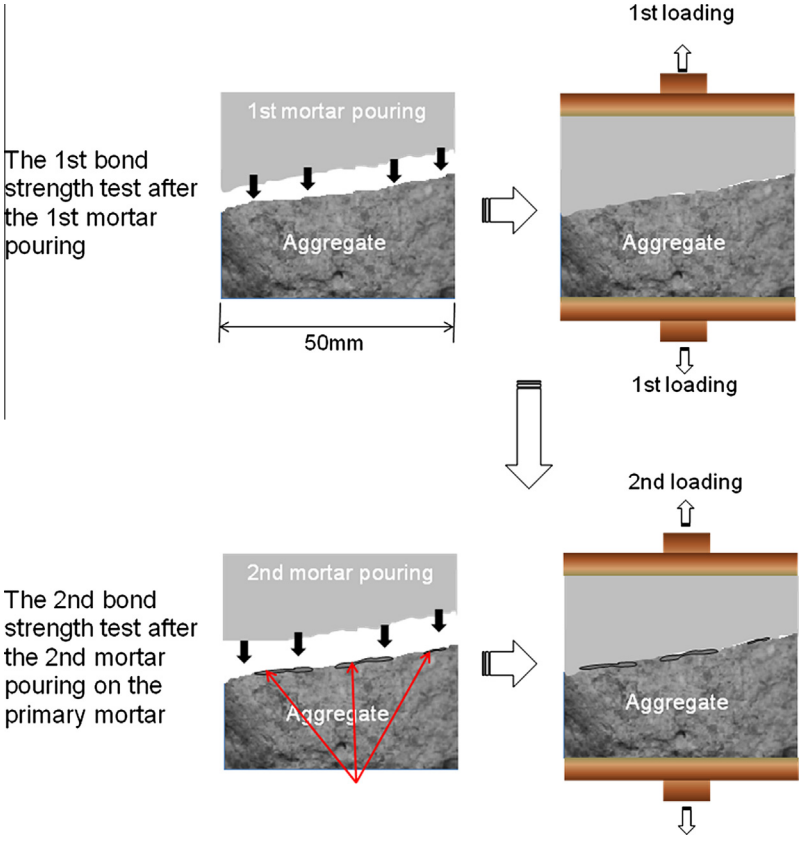

Fig. 1. Specimen shape and bond test process for the effect analysis of adhered old mortar.