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Hybrid techniques for quality improvement of recycled fine aggregate

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HIGHLIGHTS

- The aim of this paper is to improve and verify the quality of recycled aggregate.
- A hybrid method was applied to get the high quality of recycled aggregates.
- The produced recycled fine aggregate was verified through self-compacting concrete.
- It is feasible to use them via partial replacement of natural aggregate.

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ABSTRACT

The objective of this paper is to improve and verify the qualities of recycled aggregates. For this purpose, a hybrid chemical/physical method to get high quality recycled aggregates was applied. After getting the high quality recycled aggregates, the qualities of Self-Compacting Concrete (SCC) produced with recycled fine aggregates were verified through physical, mechanical, and durability testing. The results showed that the absorption rate, ratio of absolute volume, and impurities of New Recycled Concrete Fine Aggregate (NRCFA) were superior to those of Existing Recycled Concrete Fine Aggregate (ERCFA). In addition to the qualities of NRCFA, the results indicate enhanced physical, mechanical, and durability properties of SCC. Therefore, it is feasible to produce much higher qualities of recycled fine aggregates for concrete and to use them as structural materials via partial replacement for natural fine aggregates.

1. Introduction

Self-Compacting Concrete (SCC) is a recent innovation in the construction field and flows under its own weight without consolidation while maintaining sufficient resistance to segregation. Hence, SCC can be used in special situations such as the casting of elaborate shapes, difficult to reach areas, or complex reinforcement. Also, mechanical vibration is required for proper compaction of normal concrete and results in high levels of noise. However, SCC is well known as a "healthy" and "silent" concrete since it does not require vibration to achieve proper compaction. The elimination of this vibration step reduces labor costs and noise [1]. However, it has been reported that aggregates occupy 55–60% of the SCC volume and play a substantial role in the physical, mechanical, and durability properties of concrete [2]. Moreover, aggregates have a significant effect on the cost of SCC. Therefore, inexpensive aggregates are desirable for use in SCC, but there is a serious shortage of natural aggregates in many regions of the world due to construction booms in developing countries and re-building in developed countries [3]. Consequently, the construction industry has been increasing interested in the use of alternative aggregates in the past decade. In addition, recycled aggregates obtained from the re-processing of Construction and Demolition (C&D) waste have been used to produce new types of concrete.

For effective utilization of C&D waste, which is an environmentally desirable process, recycled concrete should be used as aggregate [4–6]. Researchers have attempted to relate the quality of recycled aggregate concrete to the properties of the original concrete and paste, crushing procedure, new mixture composition, and degree of deterioration of the old concrete. These findings have been extensively reviewed and discussed [7–15]. However, the fine fractions of recycled aggregates have not been studied thoroughly since it is believed that its greater water absorption and finer powder may jeopardize the final results of concrete. In comparison with natural normal weight aggregates, recycled aggregates are weaker, more porous, and have many mortars adhered on the aggregate surface, which affects the bonding strength. In general, there are two kinds of methods, drying and wetting methods, that account for the simple crushing and washing of aggregate, respec-

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tively, in order to remove the mortars adhered on their surfaces. And recently, the drying method has been changing to the wetting methods. Nevertheless, aggregates produced by the wetting method still have many adhesion mortars, and their quality is uncertain. In addition, the wash water is repeatedly used for washing of recycled aggregate and does not effectively remove the mortars adhered on the surfaces of recycled aggregates due to the high alkalinity of the water (pH 12–13) resulting from high Ca^{+} ion. To solve these problems, many studies have been performed to convert the high alkalinity water into low pH water by acidification, thus allowing removal of adhesion mortars that induce undesired high absorption rates. However, prolonged immersion in acid solution can result in concrete cracking due to reaction with cement and sulfur or salt.

Therefore, the objective of this paper is to improve the qualities of recycled fine aggregates using a hybrid method. Namely, the first, chemical process removes or softens the adhesion mortars after a short acid-dip. The second, physical process then removes the residual or softened adhesion mortars by applying new Improved Double Log Washer (IDLW) techniques. Also, the recycled fine aggregates produced, whether or not they are feasible for use as structural materials, were verified by comparing and analyzing the experimental results of SCC cast with normal fine aggregates and recycled fine aggregates before and after applying the hybrid method.

2. Hybrid techniques for improving the quality of recycled aggregates

Since recycled aggregates are produced in constant grading with a multi-order crushing procedure, they contain large amounts of fine powders, adhered mortar, and various impurities (e.g. asphalt, paper, wood, glass, brick, plastic, metal, cloth, and other similar construction debris). In general, the fine powders reduce the workability of fresh concrete and the mechanical properties of hardened concrete due to their higher absorption rate compared to normal concrete [16]. In addition to the fine powders, the adhered mortar, which has high absorption and low specific gravity, absorbs relatively large amounts of mixing water. In order to obtain a workability similar to that of normal concrete, and hence, more demanding water and many attentions are required when mix design. Also, impurities that affect mechanical and durability properties of mortar and concrete must be removed.

Therefore, the washing process is generally repeated to separate the fine powders and impurities. The hybrid chemical/physical method is then applied to produce high-quality recycled aggregates.

The first process of acid-dipping water to remove adhesion mortars is an aqueous solution of sulfuric acid and hydrochloric acid. The immersion conditions of the acid-dip are as follows: the ratio of aggregate to acid-dipping water was 1:9, and the dilution ratio of sulfuric acid or hydrochloric acid to water was 1:11, ranges that do not affecting the physical properties of aggregates. The recycled aggregates were immersed in the acid dip for 24 h in order to allow sufficient reaction between them.

The second processing step is the method improved from the existing processing of recycled aggregates. In the previous washing process, crushed recycled aggregates were immersed in a storage tank of pure water, and the fine powders and impurities were then simply removed due to the specific gravity and buoyancy differences between the aggregates and impurities. Fig. 1 shows the processing of general C&D waste after applying the new technique. However, in the case of insertion into a crusher, a large amount of waste concrete is added, which is difficult to remove due to the remaining fine powders and impurities within the mass. Thus, while the quality of aggregates decreases, economic loss increases.

Figs. 2 and 3 show a main detail processing view after inclusion of the hybrid method in the processing of general C&D waste and

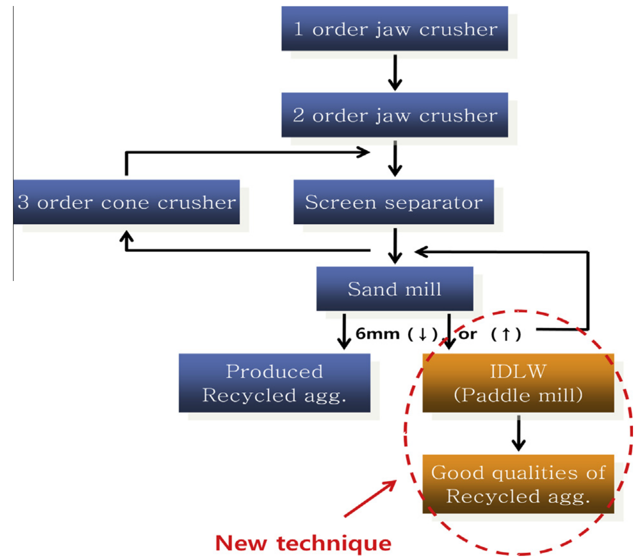

Fig. 1. Circulation system for producing recycled aggregates.

plans for an Improved Double Log Washer (IDLW), impurities remover, and bubble remover, respectively. Crushed recycled aggregates are processed by the IDLW in the following steps: first, the immersed aggregate mass is loaded into the lower part of the IDLW; second, the fine powders adhered on the aggregate surface are separated from the impurities and adhesion mortar by impact and friction actions created by the rotating paddles of the IDLW; third, the separated adhered mortar is removed through the axial lower part of the IDLW, and convey the washed aggregates into the upper part of the IDLW; finally, high-quality recycled aggregates are produced.

The IDLW, which acts as a sorting tank in aggregate washing, is used to eliminate highly buoyant impurities though force-induced water circulation. It also plays an important role in the removal and separation of old mortars adhered to the aggregates though force-induced friction action among the recycled aggregates, created by paddles within the vessel. In addition, the yields of recycled aggregates have been increased by up to approximately 27% and the wash time has been decreased by 30% through improvement of the angle of the vertical paddle from 25° to 30°. These developments have made it feasible to produce massively high-quality recycled aggregates of concrete.

3. Experiments

3.1. Materials used

The concrete mixtures investigated in this study were prepared by mixing Ordinary Portland Cement (OPC), river sand, crushed sand, and coarse aggregates via partial and/or full replacement with Recycled Concrete Fine Aggregate (RCFA), which was improved using the hybrid method. The physical properties of the RCFA obtained from the hybrid method are described in Section 4. In addition, Table 1 presents the chemical compositions and physical properties of OPC and Fly Ash (FA), which were used to improve the workability and water tightness of the concrete. The relative density of the coarse aggregate G_{max} (17 mm) was 2.60, and the water absorption and fineness modulus were 0.86% and 7.30, respectively. Also, a polycarboxylic-based superplasticizer (SP) with a solid content of 1.06 ± 0.05 and specific gravity of 6.55 kg/m^3 was used to reduce the mixing water, and a viscosity agent (VA) with a pH of 8 and specific gravity of 0.5 was used to create resistance to segregation due to adjustment of slump flow.

3.2. Experimental method

To achieve accurate measurements, a mixing trial was performed prior to actual mixing using the secondary regulations of SCC according to the Japanese Society of Civil Engineers (JSCE) code. The SCC specification is presented in Table 2 [17]. The mixture proportion of concrete was performed at a water-cementitious material