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Crushing characteristics of a recycled aggregate from waste concrete

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HIGHLIGHTS

- A three-stage cycle with surface, mortar, and natural aggregate crushing is proposed.
- A crushing load reduction ratio for natural aggregate crushing is proposed.
- The stresses at the initial crack and peak state are 0.1–1.5 MPa and 0.2–3.0 MPa.

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ABSTRACT

A single-particle crushing test was carried out for more than 170 recycled aggregates from waste concrete. Recycled aggregates were sieved into 30- and 40-mm particle size groups, mainly consisting of mortar with 2–10 natural aggregates. At the initial loading of the single aggregate, its irregular surface was close to the loading plate, which eventually crushed it. This first crushing stage is called surface crushing. With further loading, the surface mortar was crushed, and it separated from the aggregate; this process was repeated several times and is called mortar crushing. The natural aggregate was crushed, following several mortar crushing stages, where the load suddenly decreased by more than 50%; this stage is called natural aggregate crushing. As the loading continued, this three-stage crushing cycle was repeated owing to several natural aggregates. The stresses at the initial crack due to the initial natural aggregate crushing and at the peak state seemed to weakly related to the mortar ratio (mass of mortar within each aggregate) and absorption ratio (mass difference before and after soaking). As the number of natural aggregates within each recycled aggregate increased, both stresses slightly increased.

1. Introduction

Production of construction waste in Korea increases every year, and the recycling rate (98%) increases accordingly. Based on the information from the Ministry of Land, Infrastructure, and Transport of Korea [12], 51 million tons of recycled aggregates were produced and 44 million tons were sold in 2012. Although 85% of this was utilized for earth works and road subbases, research has been focused on applying recycled aggregates in concrete manufacturing [8,5,15,10]. Some researchers used recycled aggregates for hardening furnace slag as a catalyst and studied the pH reduction of recycled aggregates [6,4,16,11]. Other researchers attempted to use recycled aggregates for geotechnical purposes, such as backfill for retaining walls, subbase materials, reclaimed soil for pipes, and compaction [14,17,7,3]. Yoon et al. [18] and Lee et al. [9] used recycled aggregates instead of using natural sand for soft soil improvement.

When recycled aggregates are used for backfill or road subbase materials, they could be crushed and become finer owing to interlocking and loading. Their grain size distribution may change, which can influence their compaction efficiency, friction characteristics, and interlocking behavior. The crushing characteristics of each aggregate are fundamental for predicting its load–displacement behavior and selecting suitable recycled aggregates for various earth works. However, such crushing characteristics are not yet fully understood. Therefore, in this study, recycled aggregates from waste concrete were collected and sieved into 30- and 40-mm groups. They consist with mortar and 2–10 natural aggregates. They were loaded in an unconfined compression-testing machine, and their crushing behavior was investigated for geotechnical purposes.

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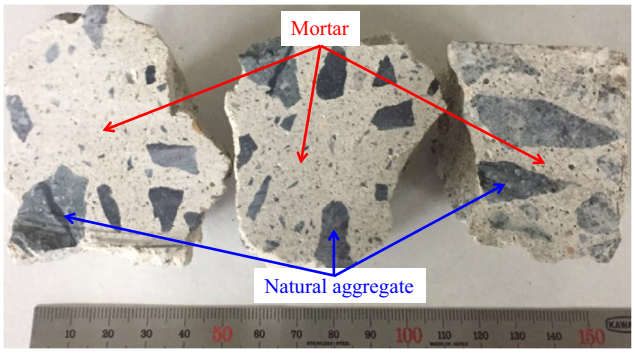

Fig. 1. Cutting planes of a recycled aggregate.

2. Single-particle crushing test

2.1. Material properties

Recycled aggregates were collected from a local waste concrete recycling company located in the Daegu-Kyungpook area in Korea. Their sizes are variable depending on the production process and their potential usage. When the aggregate is small (10–20 mm), it consists predominantly of either mortar or crushed natural aggregate. These recycled aggregates are usually utilized in secondary concrete products, such as bricks or recycled ready-mixed concrete. Such small sizes of aggregates are not suitable for backfill or road subbase materials and are not considered in this study.

Naturally dried recycled aggregates obtained from manufacturers are sieved into 30–40 mm particles for testing because this size range is usually used for road subbase and backfill materials. These aggregates consist of both mortar and natural aggregate as shown in Fig. 1; however, their shapes differ considerably. These recycled aggregates can be visually sorted into (a) rounded, (b) square, (c) triangular, and (d) elongated, as shown in Fig. 2. A series of a single-particle crushing tests [13,19,20] were carried out for more than 170 aggregates with different shapes. The mass of these dried aggregates was in the range of 30–110 g, depending on the amount of natural aggregates and their size.

The Ministry of Land, Infrastructure, and Transport of Korea (2013) suggests specifications for the quality standard of recycled aggregates to be used in road subbase and backfill materials. The material properties based on these specifications are listed in Table 1 and the aggregates used in this study satisfy these specifications.

2.2. Absorption ratio

The absorption ratio is usually used for coarse aggregates to determine the amount of voids in the aggregates and water mix proportion for concrete. Recycled aggregates are soaked for 24 h and then surface dried for mass measurement [1]. The mass difference before and after soaking to the mass before soaking is the absorption ratio. This is calculated for correlation with the mass of mortar within each aggregate (mortar ratio), as well as with the crushing stress of the natural aggregates.

3. Results of single-particle crushing test

Each recycled aggregate was loaded at 1 mm/min in an unconfined compression-testing machine. More than 170 recycled aggregates were loaded to investigate their crushing pattern or mechanism.

3.1. Crushing pattern

As the load increased, the surface of the recycled aggregate contacted the loading plate and proceeded to be crushed by flattening. The mortar on the surface was crushed, and then the natural aggregate broke down. As the loading continued, the broken mortar or natural aggregate was crushed again because it had more than one natural or crushed aggregate. This crushing cycle is defined as shown in Fig. 3. Each stage is described in detail. Initially, an irregular surface of the particle was loaded and, being close to

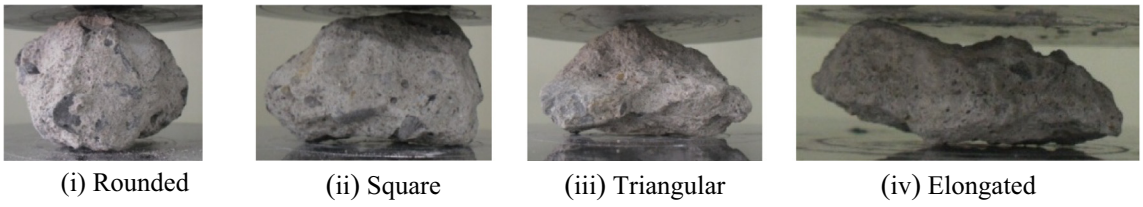

Fig. 2. Shape of single particles in recycled aggregate.

Table 1
Material properties of recycled aggregate for road subbase (RSB).

Plasticity	Mod. CBR	Abrasion loss	Sand equivalent	Optimum water content	Max. dry unit weight
N.P	87%	19%	57%	7.3%	19.81 kN/m^3

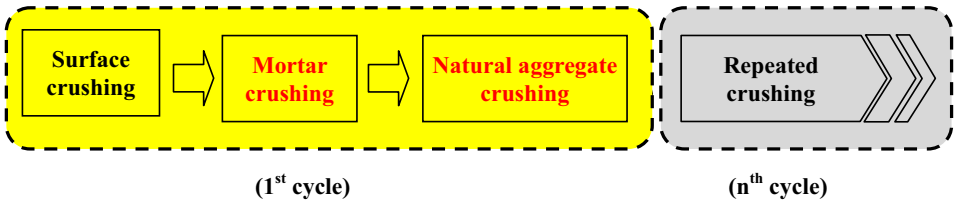

Fig. 3. Crushing process of a recycled aggregate.