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Breakage of waste concrete by free fall

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A B S T R A C T

For producing high-quality recycled aggregates from waste concrete, the characteristics of waste concrete when subjected to breakage by impact were investigated under free-fall conditions at various heights. In general, a lump of waste concrete did not disintegrate by a single impact, but underwent abrasion and occasional chipping before eventually breaking into several pieces. Further, when the sample was pretreated by heat, the number of free falls required for disintegrative fracture reduced markedly. Moreover, the resulting recycled aggregates had less adherent cement mortar due to weakening of the bonding strength between the aggregates and the cement mortar. Therefore, the energy penalty resulting from preheating the sample could be partially compensated for by the production of high-quality recycled aggregates. These results suggest that preheating followed by gentle breakage through free fall is an efficient technique to produce high-quality recycled aggregates from waste concrete.

1. Introduction

Every year, increasing amounts of construction waste are being generated in Korea. According to the Ministry of Environment, approximately 130,000 tons of construction waste was generated per day in 2005 [1]. This accounts for about 50% of the total waste and poses an enormous burden for waste management authorities from both environmental and monetary viewpoints. To deal with this problem, a law for mandatory recycling of construction waste was enacted in Korea in 2005; this law requires that construction waste be collected and processed for future construction work. As a result, the recycling rate has steadily increased from 58.3% in 1996 to 96.7% in 2005 [1]. However, this figure is misleading because it takes into account all the construction waste transported to construction waste processing plants, which is mainly used as backfilling material.

There are about 300 construction waste processing plants in Korea. These plants have typical facilities such as sorting and storage, handling, transporting, crushing, and foreign material removal. However, the recycled aggregates produced by these processing plants are of low quality, since they contain various amounts of adherent cement mortar, which cannot be reused as a substitute for natural aggregate when building concrete structures. Therefore, it is necessary to develop an improved method for producing clean recycled aggregates.

Crushing is the most important step to produce recycled aggregates of various sizes. In general, jaw crushers and/or cone crushers are used. These machines compress particles slowly in a confined space. The stress applied to the particles is sufficiently high for the particles to disintegrate completely. However, at high stress, cracks can propagate across grain boundaries, thereby producing fragments composed of mixing components. Moreover, the resulting fragments can contain residual cracks; consequently, the strength of the recycled aggregates can deteriorate after crushing. This can be avoided if the breakage occurs preferentially along grain boundaries, without stressing the aggregates. Autogenous milling is appropriate for this purpose.

The main mechanism of comminution in autogenous mills is considered to be abrasion and impact. The impact energy received by rocks is relatively lower than the compressive forces exerted by a crusher. Fractures in rocks being impacted develop principally along the grain boundaries due to the relatively gentle action of the mill. Thus, the product size distribution is predominantly of the other of the grain size [2]. This is desirable for producing recycled aggregates from waste concrete because recycled aggregates are released from the cement mortar with minimum degradation. Further, preferential breakage along grain boundaries should be more pronounced if the bonding strength between the cement mortar and the aggregates is weakened. One method to weaken the bonding strength is thermal treatment of waste concrete. The difference between the thermal expansion coefficients of aggregates and cement material can induce fractures along the grain boundaries between the two materials.

Single-particle breakage tests have been used widely to gain a deeper understanding of the complex nature of particle breakage in various grinding devices [3–6]. In this study, the basic breakage patterns of lumps of waste concrete were investigated under free-fall conditions; such breakage resembles gentle breakage under autogenous milling [7–9]. The drop height was varied in order to change the impact energy imparted to the waste concrete, and accordingly to analyze energy utilization. Further, the effect of heat pretreatment was investigated. The ultimate aim of this study is to develop

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an efficient crushing method for producing high-quality recycled aggregates.

2. Experimental

Samples of waste concrete were obtained from a jaw crusher installed at a waste concrete treatment plant in Korea; from these samples, size fractions of 75 mm × 53 mm were selected for free-fall tests. In the free-fall experiment, a lump of waste concrete was dropped on a thick steel plate from heights of 2 m, 2.25 m, 2.5 m, and 3 m. Fig. 1 shows a schematic diagram of the free-fall experiment. In general, a lump of waste concrete did not disintegrate by a single impact, but eventually broke into several pieces as damage accumulated through repeated free fall. At each drop, the fragments were collected for sieve analysis to determine the size distribution and particles larger than 10 mm were separated. These particles were visually examined for the degree of liberation. If not fully liberated, the particles were subjected to further free-fall tests from the same height. This procedure was repeated until all the broken pieces larger than 10 mm were fully liberated; as a result, the testing sequence branched out in the form of a tree, as shown in Fig. 1.

It is known that the bonding strength of concrete can be weakened by dehydration due to heating [10]. Moreover, the thermal expansion coefficient of a natural aggregate ($5–13\times10^{-6}$/°C) is quite smaller than that of cement mortar ($11–20\times10^{-6}$/°C) [11]. Therefore, heating a sample can weaken the interface between grains and thereby promote preferential breakage along the grain boundaries. In this study, a temperature range of 400–500 °C was considered appropriate for avoiding heat damage to aggregates while generating sufficient heat for dehydration and differential thermal expansion. Therefore, a sample was heated simply in a muffle furnace (Korea Furnace Development Co, KF-SA-3000). The heating temperature rose from room temperature to 400 °C for 1 h, and it was maintained for an additional 1 h at 400 °C. The same sequence of free-fall tests at that shown in Fig. 1 was followed for the heat-treated sample.

3. Results and discussion

3.1. Breakage sequence

A particle will break only if the impact energy imparted to it exceeds its fracture energy. However, even if the impact energy is smaller than the fracture energy, it does affect the particle by causing internal damage, which weakens the internal strength of the particle. Therefore, when particles are subjected to repeated impacts, their internal strength continuously weaken, and they eventually break, even if energy imparted to them at each impact is smaller than the fracture energy for a fresh sample.

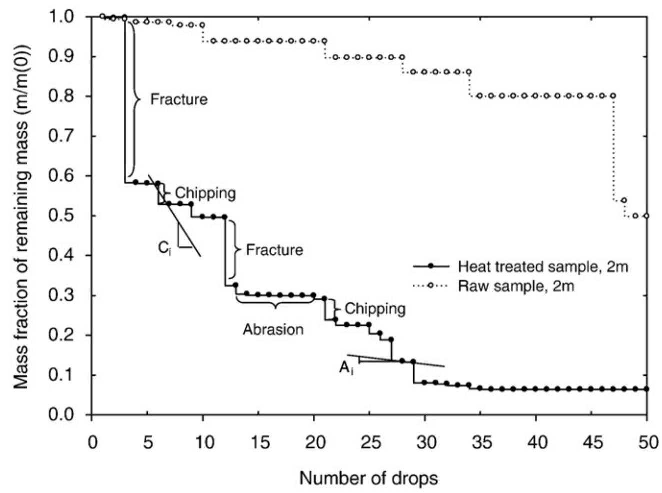

Fig. 2. Mass fraction remaining as a function of number of free falls.

Fig. 2 shows the variation in the fractional mass remaining with the number of free falls. The impact energy as a result of a free fall was indeed too small to induce disintegrative fracture of the waste concrete. Therefore, in general, a lump of waste concrete initially underwent wear, followed by a sudden change in the mass between two consecutive free falls. In this study, this breakage sequence was distinguished into three different breakage mechanisms: abrasion, chipping and disintegrative fracture. Obviously, the abrasion refers to the case where the weight of the lump remained almost the same after impact. The sudden changes were categorized as chipping or fracture depending on the extent of the weight loss. In the chipping process, the fractional weight loss is small (less than 20%) so that most of the mother particles remain intact, and the size of chipped particles is much smaller than the remaining particle. In the disintegrative fracture, the mother particles were broken into several sizeable pieces and the mass of the largest piece was much smaller (less than 50%). Therefore, the size of fragments produced by fracture lies in the middle size range, whereas those produced from chipping lie either in the large size or in the finer size end.

The resistance to breakage was reduced considerably when a sample was pretreated with heat. In the case of a heat-treated sample, disintegrative fracture occurred very quickly, i.e., at the third free falls. As the breakage sequence continued, the size of the fragments decreased rapidly to a progressively smaller size range. On the other hand, a raw sample (i.e., a sample not subjected to heat pretreatment)

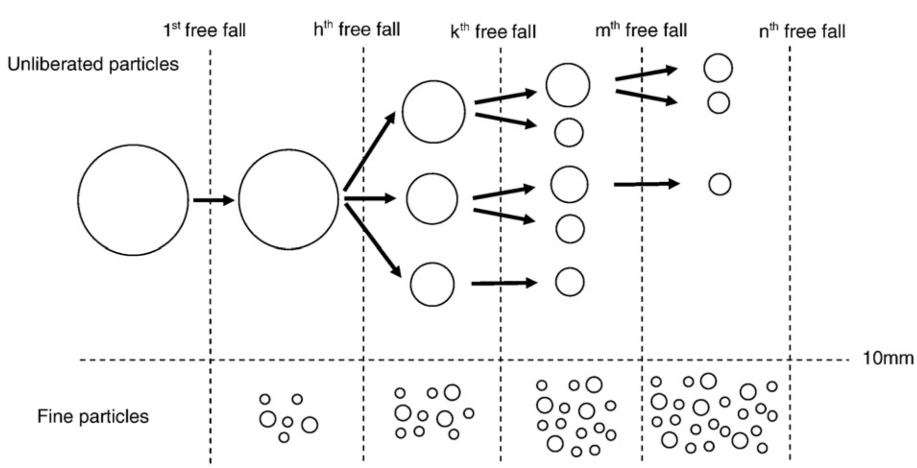

Fig. 1. Schematic diagram of free-fall experiment procedure.