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≫ 硏究論文 ≪

Autogenous mill을 利用한 順換骨材 生產 工程 開發†

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Development of Recycled Aggregate Producing Circuit Using Autogenous mill†

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요 약

건설폐기물 발생량이 매년 급격히 증가함에 따라 건설폐기물 처리의 중요성이 점차 심화되고 있으며, 그 중에서도 가장 많은 비중을 차지하고 있는 폐콘크리트의 처리에 가장 많은 노력을 기울이고 있다. 현재 폐콘크리트는 단순 파쇄를 통해 매움재나 채움재 등의 저급한 용도의 순환골재로 재활용되고 있다. 그러나 부족한 구조용 골재 수급문제를 해결하고 자원의 효율적인 활용을 위해서, 천연골재를 대체하여 구조용 골재로 사용될 수 있는 고품질의 순환골재 생산이 절실히 요구되고 있다. 따라서 본 연구에서는 autogenous mill과 가열처리 방법을 이용하여 고품질 순환골재 생산 공정을 개발하였다. 개발된 공정을 이용하여 약 30분간 파분쇄 과정을 통해 생산된 순환골재의 품질은 밀도 2.5 g/cm^{3}이상, 흡수율 3% 이하로 KS F 2573의 1종 굵은 순환골재 품질 기준을 만족하였으며, 이를 바탕으로 고품질의 순환골재 생산을 위한 연속공정을 개발하였다.

주제어 : 순환골재, 폐콘크리트, Autogenous mill, 가열처리

Abstract

In Korea, reutilization of construction waste is gaining attention as construction waste generated increases continuously. Currently, the concrete waste is simply crushed and used as a low value application such as paving, back filling, etc. To meet the demand of aggregate for construction and the resource efficiently, production of high quality recycled aggregate is necessary. Therefore, in this study, a better process for production of high quality recycled aggregate was developed using combination of heat pretreatment and autogenous milling. Test results showed that the recycled aggregate has a density of 2.5 g/cm^3 and a water absorption ratio of 3.0%, which meet the specification of the first class of KS F 2573. Currently, a pilot scale autogenous mill is being constructed and tests will be further conducted to develop a commerce-scale process.

Key words : Recycled aggregate, Autogenous mill, Waste concrete, Heat treatment

1. Introduction

In Korea, reutilization of construction waste is gaining attention since production of construction waste is expected to increase continuously. In 1996, about 10 million tons of construction waste was generated. But it increased up to 54 million tons in 2004, and is projected to increase to over 300 million tons in 2020, since the life time of buildings is 30 years[1].

Among construction waste, the proportion of concrete waste was about 60% in Korea[2]. Therefore, the recycling of waste concrete is regarded as the most important aspect of waste management. Nowadays, concrete waste is processed at about three hundred

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recycled aggregate producing plants and it was reported that almost 100% of waste concrete were reclaimed for reutilization. However, the products from these plants are of low quality and most of them are downcycled for use as paving material, back-filling material, concrete bricks, etc. It cannot be reused for replacement of natural aggregates because cement paste is not separated perfectly from aggregates. These kind of recycled aggregates tend to be weaker, more porous and have a higher value of water absorption. When these aggregates are used in concrete making, there are problems of higher total water demand, low compressive strength and durability[3-8].

If high quality recycled aggregate can be produced from an advanced processing circuit, it has some merits of not only minimization of construction waste but also resolution of shortage of natural aggregate. Besides, environmental destruction from excavation of natural aggregate is prevented. Therefore, in this study, tests were conducted to develop an advanced processing circuit for production of high quality recycled aggregates, which involves heat-pretreatment and autogenous milling.

2. Material and Method

2.1. Material

Concrete waste used in this study was the product of a primary jaw crusher (200 ton/h) installed at a waste concrete processing plant. Currently, construction and demolition waste are not collected separately in Korea, so the concrete waste collected to the concrete waste processing plant is not homogeneous, because it was containing a complex mixture of concrete blocks, asphalt wastes, wood wastes etc. Therefore tests were conducted after removal of impurities. To analyze the size distribution of concrete waste, the samples were dried and sieved into various size fractions of $\sqrt{2}$ series from the maximum size of 106 mm.

2.2. Pretreatment

The samples were preheated by heating to improve the liberation of aggregate and cement mortar before breakage process. When concrete waste is heated, an inverse reaction of hydration of concrete making was occurred, which may weaken the bonding strength between the cement paste and aggregates. So the possibility of preferential breakage along the boundaries between aggregate and cement paste increase. It is known that the aggregates may get deteriorated if heated at a temperature above 500°C[9]. Therefore in this study, the samples were heated in an oven for 1 hour at 400°C. The test results were compared with results without heat treatment to evaluate the effect of heat treatment.

2.3. Autogenous mill

An autogenous mill was used in this study for the crushing process. Autogenous milling uses a cylindrical-shape mill chamber like a ball mill, and the breakage process occurs by rotating the mill chamber. The major difference between autogenous mill and ball mill is the grinding media. In ball mills, the charge comprises a large volume of steel balls. In autogenous mills, the grinding medium comprises lumps of the ore being ground. Differences also exist between ball and autogenous mills in terms of the breakage mechanism which predominates in each. Feed enters the mill and is subjected to breakage from collision with other particles and/or the mill shell. It is generally regarded that two mechanisms operate within autogenous mills: abrasion/attrition, and impact. Abrasion and attrition result from the scraping of one surface on another against a rigid face of particle against particle, leaving the parent particles largely intact. A rotating drum throws large rocks in a cataracting motion which causes impact breakage of larger rocks and compressive grinding of finer particles. The impact energy that the particle receives is relatively low compared to compressive forces exerted by crusher. Therefore, the specific energy that particles receive may not be sufficient enough to propagate cracks through aggregates in concrete blocks, but along the boundaries between the cement paste and aggregates, especially when the bonding strength between them is weakened by heating. Therefore high quality recycled aggregate can be produced from concrete waste crushed using the autogenous mill due to the enhancement of liberation between aggregate and cement mortar by abrasion and preferential breakage along the boundaries between the cement mortar and aggregates.

The autogenous mill used in this study has a mill chamber with a diameter of 710 mm and a length of 530 mm and has a 1 lifter with a height of 100 mm inside the mill chamber. The rotation speed is fixed at 30 rpm and the percentage of mill volume occupied by the sample is 10%, which is about 48.3 kg. A 5 kg steel ball with a 1 inch diameter was also entered into the mill chamber to enhance the liberation of aggregate from concrete blocks.

2.4 Method

Tests were conducted using a single size fraction (75 mm×53 mm) to investigate the degree of breakage by the autogenous mill. The size distribution and physical characteristics, density and adsorption ratio, were analyzed for the milling products every 10 minutes. Using these results, locked-cycle circuit tests were conducted. After 10 minutes of milling, the products were separated at a certain size, which was determined by the physical characteristics of the milling products. The particles smaller than the cut size were removed from the mill and the size fractions larger than the cut size were returned to the mill. The same amount of mass was replaced using the feed material. This process was repeated until a steady state was reached.

Tests were also conducted using the whole size fractions of the products from a jaw crusher installed at a concrete waste processing plant. To evaluate heat treatment effect, tests were performed with and without heat pretreatment. Milling time was increased from 10 minutes to 30 minutes, and the quality of produced recycled aggregate was analyzed at each cycle of 30 minute milling. Using the test results, a continuous circuit test for recovery of recycled aggregate was conducted.

3. Results

3.1. Single size concrete waste breakage test

Fig. 1 shows the cumulative size distribution of single size concrete waste breakage test result. It is shown that the product size distribution moved towards the finer size range as the milling time increased. But all the size distributions show a plateau in the middle section, indicating the mill products were mainly composed of large particles and fine materials.

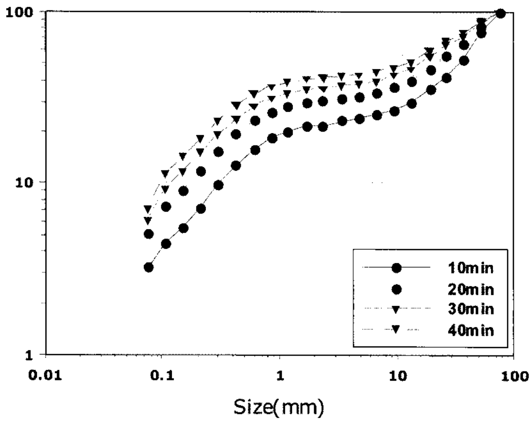

Fig. 1. Cumulative size distribution of single size waste concrete breakage test.

Table 1. Physical characteristics of coarse recycled aggregate from single size waste concrete breakage test

Size Interval (mm)	Heat treatment (40 min)	
	density (g/cm^3)	Adsorption ratio (%)
26.5×19.1	2.45	2.54
19.1×13.4	2.51	1.96
13.4×9.52	2.50	2.16
9.52×6.7	2.51	2.05
6.7×4.75	2.51	2.4

This kind of size distribution is typically found in the grinding condition where attrition is the predominant breakage mechanism. It seems that due to gentle breakage of autogenous milling, the large aggregates do not break and remain intact, and cement paste is chipped or scraped off the aggregates, producing fine materials. This implies that autogenous milling is indeed appropriate for producing clean aggregates along with fine cement paste which can be easily separated by screening.

To evaluate physical characteristics of coarse size recycled aggregate, the milling products were sieved into the size fractions of √2 series. The density and adsorption ratio of each size fraction was estimated according to the Korea Standard (KS F 2573). Table 1 shows the results. It can be seen that almost all the larger size fractions satisfy the specifications for the 1st grade recycled coarse aggregate (density: over 2.5 g/cm^3, adsorption ratio: below 3%). Therefore high quality recycled coarse aggregate can be produced from a single size concrete waste milling test after 40 minutes of milling time. The milling time is rather long. But, it can be reduced substantially by using a larger mill that lifts concrete blocks to a greater height facilitating impact breakage.

Based on these results, a locked-cycle circuit test was conducted to mimic continuous milling process using single size concrete waste. Fig. 2 shows the schematic diagram of locked-cycle circuit test. After milling the single size concrete waste for 10 minutes, the density and adsorption ratio were estimated. By examining the milling products, it was determined that high quality recycled aggregates could be produced if particles smaller than 19.1mm were removed from the mill as a product and large particles were recirculated back to the mill for further breakage. The amount of removed particle was replaced using fresh feed material (75 mm×53 mm), so that the total amount of concrete waste maintained the same.

Locked-cycle test result (Table 2) shows that high

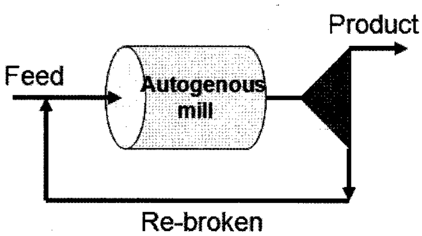

Fig. 2. Schematic diagram of locked-cycle circuit test.

Table 2. Physical characteristics of coarse recycled aggregate from locked-cycle breakage test

Size Interval (mm)	0-10 minute	
	density (g/cm^3)	Adsorption ratio (%)
37.4×26.5	2.07	7.73
26.5×19.1	2.28	4.51
19.1×13.4	2.42	2.98
13.4×9.52	2.46	3.01
9.52×6.7	2.34	4.70
6.7×4.75	2.32	4.70

quality recycled aggregate could be produced at the medium size interval, 9.52 mm×19.1 mm. However, in the case of particles larger than 19.1 mm, the adsorption ratio increased sharply. The aggregate and cement mortar were not liberated sufficiently in large sizes due to insufficient impact breakage. Therefore it is necessary that they be broken further, so these particles were returned to the mill. In the case of particles smaller than 9.52mm, the quality is also not as good as that of the medium-size particles (9.52 mm ×19.1 mm). However, these particles are mixtures of fine aggregates and cement paste, which requires further study on methods of separating the two components.

3.2. Continuous breakage test

Based on the single size concrete waste breakage test, another breakage test was conducted using a primary jaw crusher product for development of an advanced processing circuit. To evaluate the heat treatment method, the tests were performed equally using samples with and without heat pretreatment samples.

As shown in Fig. 3, the milling process was progressed as the milling time increased for both samples. The particle size decreased and cumulative size distribution moved towards the fine particle region as milling time increased. It is also shown that the breakage efficiency of the heat treated sample is superior to the sample without heat treatment. This is because heat treatment lowers the internal bonding

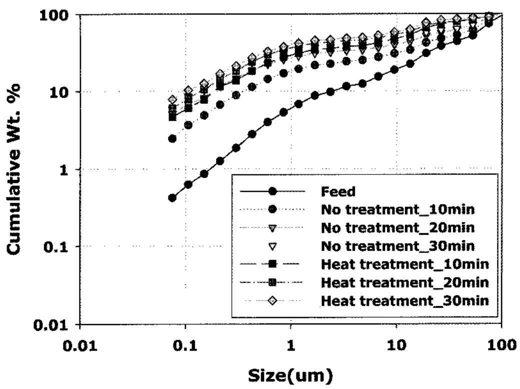

Fig. 3. Cumulative size distribution according to the treatment method and breakage time.

Table 3. Adsorption ratio of crushed particle according to the treatment method

Size Interval (mm)	Adsorption ratio (%)			
	Heat treatment		No treatment	
	10 min	30 min	10 min	30 min
26.5×19.1	3.92	2.31	7.24	3.73
19.1×13.4	3.53	2.03	4.94	2.17
13.4×9.52	3.95	2.38	5.26	2.62
9.52×6.7	4.84	2.71	6.31	2.74
6.7×4.75	6.17	3.64	7.94	3.63

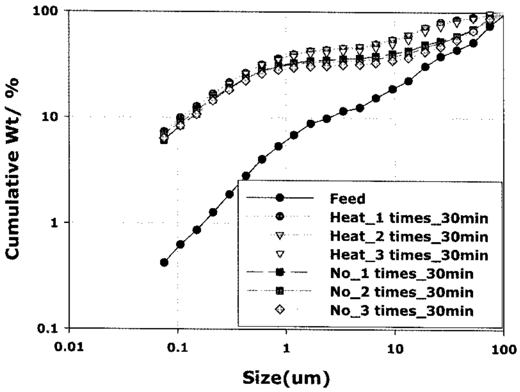

Fig. 4. Cumulative size distribution of continuous breakage test.

strength of concrete waste, resulting in the increased breakage efficiency of the heat treated sample.

The adsorption ratios of produced recycled aggregate for various size fractions of both samples are shown in Table 3. The adsorption ratios of particle were improved as milling time increased for both samples. After 30 minutes of milling, the quality of recycled aggregate met the specification of the first class of KS F 2573. Therefore, 30 minute milling is suitable for the production of high quality recycled aggregate.

Using the above test results, a continuous breakage test was conducted to develop a recycled aggregate producing circuit. After 30 minutes of milling, the -26.5 mm fraction satisfying the 1st grade recycled coarse aggregate standard was removed and the +26.5 mm fraction was returned to the mill for further breakage. The amount of removed particle was replaced by the fresh feed material (primary jaw crusher product). This process was repeated until a steady-state was achieved.

Table 4. Adsorption ratio of crushed particle of continuous breakage test

Size Interval (mm)	Adsorption ratio (%)	
	Heat treatment	No treatment
	3rd circuit	3rd circuit
26.5×19.1	3.62	3.45
19.1×13.4	2.42	2.02
13.4×9.52	2.87	2.07
9.52×6.7	2.99	2.26
6.7×4.75	3.67	2.62

After 3 times of the processing circuit, cumulative size distributions of the crushed product were almost the same (Fig. 4). Therefore it is regarded that steady-state was achieved. The quality of crushed product after 3 times of processing circuit from the continuous test met the specifications of the first class of KS F 2573 (Table 4), indicating that high quality recycled coarse aggregate could be produced from this circuit. Therefore, the circuit developed in this study using an autogenous mill, heat treatment, and size classification was valid and was found to be efficient for producing high quality recycled coarse aggregates.

However the quality difference between heat treatment and no treatment was very small. It is most likely that the scale of the lab autogenous mill in comparison to the commercial one was too small to reveal the heat treatment effect sufficiently. Therefore the effect of heat treatment will be verified by further breakage tests using a pilot scale autogenous mill.

4. Conclusions

An advanced continuous circuit for producing high quality recycled aggregates was developed in this study using a heat pretreatment method and autogenous milling. Using a primary jaw crusher product, heat treatment was conducted and crushed using an autogenous mill. After a 30 minute breakage process, the products smaller than 26.5mm met specifications of the first class of KS F 2573 and larger particles were returned to the mill for further breakage process. This continuous circuit composed of a primary jaw crusher, heat treatment method, secondary autogenous milling, and size classification can produce high quality recycled aggregate and will be further investigated to develop a commerce-scale process circuit.

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