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Recycling of dust wastes as lightweight aggregates

Y. Kim*, J.H. Kim, K.G. Lee and S.G. Kang
Dept. of Materials Engineering, College of Engineering, Kyonggi University Paldal-gu, Suwon, Kyonggi-do 442-760, Korea

Various kinds of industrial dust wastes were recycled by a wet ceramic process. Compounding various dusts gave allowed us compositional variation of dust wastes which originated from various places and conditions. One of the main problems for recycling wastes is caused by compositional variations. Success in recycling depends on how to control compositions and maintain the allowed purity level in the wastes. Grouping of dust wastes into three categories and compounding were introduced to raw material preparation processes for the successful recycling of various dusts. Pretreatment processes were also important to stabilize heavy metals in the raw materials. These processes consist of ion exchange, control of electrolyte concentration and pH etc. After these processes, industrial dust wastes were turned into safe, ecological construction materials such as bricks or lightweight aggregates by a final sintering process.

Keywords: Lightweight aggregates, recycling, ecological construction materials, heavy metal stabilization.

Introduction

The total amount of inorganic waste from Korean industries is estimated to be 70 million tons per year [1]. One of the most serious wastes from among them is fine dust from various sources such as dust collected from electric arc furnaces. Most of these dusts are classified as specific wastes and strictly controlled by the government [2]. The present study has focused on the how to recycle various dust wastes including EAFD (electric arc furnace dust) safely into construction materials. The recycling of dusts into construction materials is promising because not only may a large amount of inorganic waste be recycled but also the components of these dusts are similar to ceramic raw materials [3, 4]. Therefore, hazardous dusts could be turned into environmentally-safe ceramic products.

One of the main obstacles for recycling dust wastes is caused by the compositional variation of wastes [5, 6]. A success in recycling dust waste depends on how to control compositions and maintain the allowed purity level of the waste [7]. Therefore, many researchers have focused their efforts on purifying or classifying wastes from various sources [8-11]. The cost of these purifying or classifying processes have become lower than before; however, these costs are still a main obstacle in recycling of dust wastes [12]. Here a grouping concept was introduced to solve the above compositional variation problem for recycling. A grouping of dust wastes into three categories and compounding gave us some extent in compositional variation which is inevitable when recycling wastes.

The stabilization of hazardous materials such as heavy metals has been intensively investigated using various methods such as solidification, encapsulation, etc. [13-18]. So far, solidification after sintering is known as the safest treatment for the hazardous materials. Fortunately, heavy metals in the wastes can act as flux materials so that an optimum mixture of dust wastes lowers the sintering temperature for the secure capturing of heavy metals in the glassy phases [19]. The glassy phases formed during the sintering process not only capture the heavy metals in the ceramic matrix but also make closed pores, which are necessary for making lightweight aggregates.

In this study, specimens of ecological construction materials were made in the form of bricks and aggregates. The mechanism of stabilization of heavy metals in the specimens and various properties of the specimens were investigated.

Experimental

EAFD, fly ash, stone ash, and clay minerals were used as raw materials. The chemical composition of each dust waste and clay minerals are shown in Table 1. Batch compositions of the brick-shaped specimens are also shown in Table 2. The sizes of the brick-shaped specimens were 190 mm × 90 mm × 55 mm. Table 3 shows batch compositions of three kinds of lightweight aggregates of which the diameters were 5 mm, 8 mm, 10 mm, and 12 mm. The bulk density, compressive strength, and absorption rate were measured for the brick-shaped specimens and bulk density, absorption rate, fracture characteristics, ultrasound velocity etc. were measured for the aggregate specimens.

*Corresponding author:
Tel : +82-31-249-9765
Fax: +82-31-257-8784
E-mail: ytkim@kyonggi.ac.kr

Table 1. Chemical composition of dust wastes

	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	MnO	ZnO	PbO	Cr_2O_3	TiO_2	P_2O_5	C	S	I.L.	Tot.
Fly Ash	4.6	2.7	32.4	3.4	2.5	4.5	2.6	2.5	27.4	2.0	0.3	0.1	0.2	1.9	0.6	11.5	100
Ston Ash	5.5	2.7	42.4	3.3	2.3	4.2	1.0	2.3	11.7	1.2	0.4	0.7	0.2	10.3	0.6	11.5	100
Clay	4.6	2.7	32.4	3.4	2.5	4.5	2.6	2.5	27.4	2.0	0.3	0.1	0.2	1.9	0.6	11.5	100
DAFD	5.5	2.7	42.4	3.3	2.3	4.2	1.0	2.3	11.7	1.2	0.4	0.7	0.2	10.3	0.6	11.5	100

Table 2. Batch compositions of brick-shaped specimens

Specimen No.	Compositions (Wt.%)			
	Fly Ash	Stone Ash	EAFD	Clay
BRK-1	30	30	–	40
BRK-2	30	20	–	50
BRK-3	10	30	–	60
BRK-4	30	20	10	40

Table 3. Batch compositions of aggregates

Specimen No.	Compositions (Wt.%)				
	Fly Ash	Stone Ash	EAFD	Clay	Spent White Clay
AGG-1		30	5	60	5
AGG-2	50	20	–	30	0
AGG-3		25	5	60	10

The microstructures of the specimens were observed and microanalyzed by FE-SEM (field emission scanning electron microscopy) and EDS (energy dispersive spectroscopy).

Brick-shaped specimens were prepared through a conventional ceramic processing (extruding) method with sintering at 950~1050 °C for 3 hours. The aggregate specimens were also prepared by a similar process to that for making the brick-shaped specimens; however, here initially spheres were made and coated to prevent sticking together of the aggregates themselves and a 5 m long rotary kiln was finally used to sinter the aggregates.

A aggregates crushing and impact test (BS 812) for lightweight aggregates was performed by measuring the percentage of fractured aggregates passing through a certain size of mesh after a certain load (225 kg/cm^2) was applied to the aggregates which were placed in a cylindrical metal case. The fracture ratio by the aggregates crushing and impact test is generally accepted as one of the means to measure the compressive strength of aggregates.

Leaching tests for heavy metals were performed by TCLP (toxicity characteristics leaching procedures). All the tests for physical property measurements of secondary cement paste aggregate products were followed using Korean Standards (KS F 2456, KS F 4722, etc.).

Results and Discussion

Mechanism of heavy metal stabilization

A schematic diagram of the processes for making ecological construction materials from dust wastes is shown in Fig. 1. First of all, various dust wastes were classified into three categories according to their compositional characteristics as shown in Table 4; silica group (SG), alumina group (AG), and flux group (FG). These three groups were considered as the main three components of ceramic bodies. Many ceramic products could be made by mixing the appropriate proportion of these three components [20]. Several hundred trials were made on various kinds of wastes and compositions. Eventually, the stabilization and bloating zones were drawn as in Fig. 2 as a large ellipse circle and the frit zone is also indicated in Fig. 1 as a smaller ellipse. It was established that the compositions in the frit zone were not suitable for

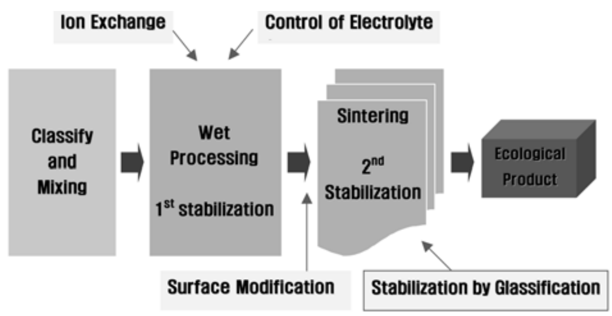

Fig. 1. Schematic diagram of recycling processes for ecological construction materials.

Table 4. Classification of various dust wastes by three categories

	SG (Silica Group)	AG (Alumina Group)	FG (Flux Group)
Wastes	Fly Ash Spent Cast Sand	Stone Ash Paper Ash	EAFD Red Mud Sludge Ash
Characteristics	Basic Materials	Subsidiary Materials	Functional Material
Role (Act as)	Alumino-silicate Minerals	Alumina	Flux or modifier

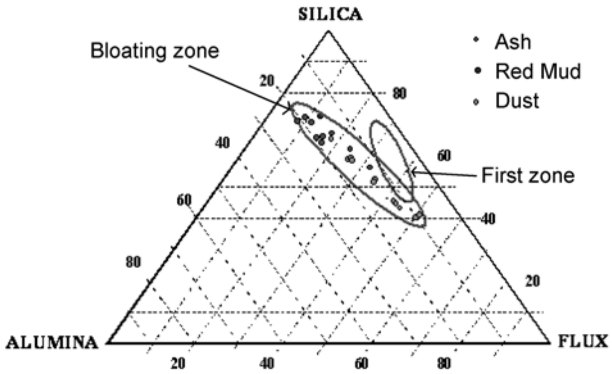

Fig. 2. Stabilization and bloating zones in the SG-AG-FG component system.

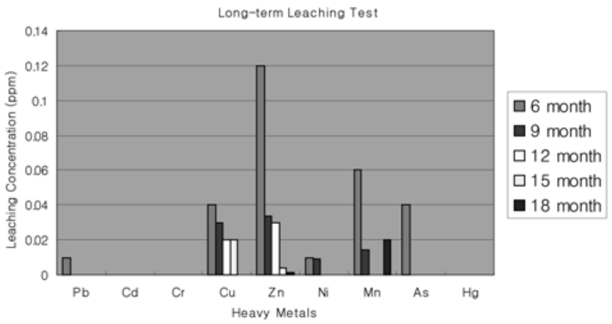

Fig. 3. Long-term leaching test results of ecological bricks by TCLP.

making artificial aggregates because too much glassy phase formed on the surfaces of the aggregates tended to cause the aggregates to stick together during sintering.

The stabilization of heavy metals in the ceramic body could be explained as follows: heavy metal ions were exchanged with alkali ions in the clay minerals during the wet process (first stabilization by cation exchange) and finally captured in the network structures which were formed during the sintering process (second stabilization by glassification). The behavior of heavy metals in the ceramic body which originated from the dust wastes was monitored by various methods such as TG/DTA tests, ion concentration measurements of solution extracted from the dust waste and clay mixture, and leaching tests of specimens which were sintered at various sintering temperatures. The results of these data have been reported elsewhere [21, 22]. The stabilization of the heavy metals in the ecological construction materials was finally confirmed by TCLP (Toxicity Characteristics Leaching Procedures) tests. Fig. 3 shows the results of TCLP tests for the brick-shaped specimens which were exposed to a natural atmosphere for up to 18 months. From this long-term heavy metal leaching test, all the specimens satisfied the leaching limits for the drinking water level in Korea.

Properties of ecological construction materials

Table 5 shows the physical properties of various ecological brick-shaped specimens.

The compressive strength of the brick-shaped specimens was slightly lower than traditional bricks; however, the water absorption rate, absorption coefficient, freeze/melt resistance, etc. were similar or better than traditional bricks. The lower compressive strength values were due to the size of the pores in the bricks because the pore size of the brick-shaped specimens was approximately 15% larger than in the commercial bricks; however, the pore size was not considered when the compressive strength was calculated. The values of compressive strength in Table 5 were simply calculated from the compressive strength divided by the specimen area without considering the pore size. Specimen BRK-1 shows the best physical properties systematically even thought it contains a total of 60 wt.% waste. All the specimens in Table 5 satisfied the KS requirements.

Table 6 shows the physical properties of ecological lightweight aggregate specimens. The physical properties of the ecological lightweight aggregates were similar to or comparable to those of imported material from abroad. The fracture rates of ecological lightweight aggregate specimens by the aggregates crushing and impact test showed lower values than that of those imported; however, these were more than 50% higher

Table 5. Physical properties of bricks specimens having various compositions

Specimen No.	Physical Properties					
	Water Absorption Rate for 5hr (%)	Water Absorption Coeff. (24h WA/5h WA)	Ultrasonic sound velocity (USV) (m/s)	USV after 40 cycle of Freeze/Melt (m/s)	USV Decrease rate (%)	Compressive Strength (kgf/cm^2)
BRK-1	9.4	0.88	2835	2723	4.0	324
BRK-2	9.7	0.90	2920	2674	8.4	288
BRK-3	7.3	0.87	3090	2729	11.7	256
BRK-4	7.74	0.92	2325	2104	9.5	236
BRK-H (H company: commercial)	11.2	0.98	2328	–	–	327
BRK-N (N company: commercial)	12.7	0.92	1937	1565	19.2	353

Table 6. Physical properties of aggregates specimens having various compositions

Aggregates No.	Physical Properties			
	Bulk Density	Absorption rate (%)	Apparent Porosity (%)	Fracture rate (%)
AGG-1	0.86	26.0	22.4	32.0
AGG-2	1.35	15.6	–	30.5
AGG-3	0.69	75.3	52.3	32.5
Imported	0.68	77.8	52.8	35.1
Natural	2.6	1.5	–	20.3

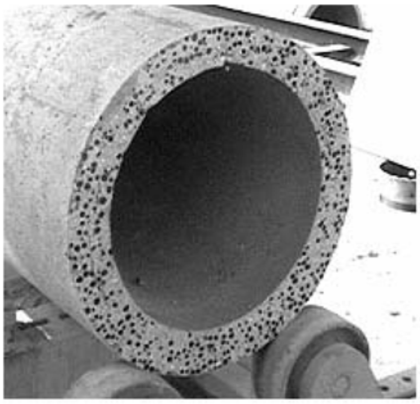

Fig. 4. A vibrated and reinforced cement (V·R) pipe made of lightweight aggregates.

than that of those obtained from the nature, of course. By considering the absorption rate and density, these fracture rates are considered as more than meeting the approved standard.

Ecological lightweight aggregates also satisfied the heavy metal leaching limits for drinking water though a long-term leaching test by TCLP. Fig. 4 shows an example of the application of lightweight aggregates. Ecological lightweight aggregates (AGG-3 in Table 3) were substituted for traditional coarse aggregates to make V·R (vibrated and reinforced concrete) pipes. The total weight of a V·R pipe was reduced by 20% and the flexural strength was slightly increased.

Conclusions

Industrial dust wastes can be recycled by an environmentally benign method through a wet ceramic processing method. Ecological brick-shaped specimens and artificial aggregates which were made of various industrial waste dusts satisfied not only all the regulations for recycled products but also the limits for drinking water through the long-term (up to 18 months) leaching test by TCLP.

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