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Effect of electric arc furnace (EAF) dust on the formation of artificial lightweight aggregate (ALA)

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This study was conducted to evaluate the feasibility of using bottom ash and dredged soil from a coal power plant and EAF dust from the steel industry as primary materials for the production of ALA. The effect of different raw material compositions and sintering temperatures on the lightweight aggregate properties were evaluated. The results indicate that the higher the SiO_2 content, the more bloating below 1100 °C. In contrast, ferrous materials were mainly effective for the bloating of ALA above 1100 °C. The optimum EAF dust contents in coal ash mixtures were 10~15 wt.% and artificial lightweight aggregates having an apparent density under 1.0 g/cm^3 were produced at 1150 °C~1200 °C in 10 minutes.

Key words: Artificial lightweight aggregate, Bloating, Ferrous materials, EAF dust.

Introduction

With the growth of high-rise building construction activities, a shortfall of conventional building material such as bricks, cement etc. have made it imperative to develop new building materials with the aid of modern advanced technologies. Waste materials, when properly processed, have been shown to be effective as construction materials and readily meet the design specifications. Artificial lightweight aggregates(ALA) from industrial and post-consumer wastes are not only adding an extra aggregate source, but also reducing environmental pollution. Fly ash and bottom ash are among the wastes which cause problems of disposal as well as environmental degradation, due to their nature of causing air and water pollution on a large scale. Although applications of fly ash such as portland-fly ash cement, clay-fly ash bricks, sand-lime bricks, etc. have been developed, bottom ash is still unutilized. Using bottom ash and dredged soil from coal power plants still remain a major issue to reduce air and water pollution. The manufacture of ALA from sintered bottom ash is considered to be an appropriate step to utilize a large quantity of bottom ash. Slag is the molten by-product or co-product of many metallurgical operations, that is subsequently cooled(air, pelletized, foamed or granulated) for use or unfortunately in too many cases disposal. The resulting large quantities of slag produced and their potential impact on the environment have caused many researchers to explore the cost-effective and environmentally acceptable use of a wide range of slags, such as slag cement and ALA. Focusing on ALA, black coring is a specific phenomenon sometimes found in ALA, and is characterized by a greyish black coloration of the interior material. The primary cause of black coring has been recognized as the incomplete burning-out of carbonaceous material, which can produce a coke-like residue [1]. Preoccupation with this respect of black coring has led to a number of studies of oxidation kinetics [2] and of the effects of heating time and temperature on the rate of carbon burn-out [3, 4]. Two types of reactions are required for artificial lightweight aggregate formation from heating various raw materials, as agreed by all previous related researchers [5-7]. First, gases serving as bloating agents have to be released to create pores when the raw material is heated at a high temperature, the reaction termed “bloating”. Second, a glassy surface needs to be formed through a sintering reaction when raw material is heated at the high temperature [5-7]. The glassy surface formed by the sintering reaction needs to encapsulate the gases released by the bloating reaction to produce ALA. Riley pointed out that a temperature range of 1,000-1300 °C was most appropriate for sintering and bloating reactions to take place to prepare ALA from a clay mineral [8]. Fe compounds play an important role in the bloating reaction because they have been considered to release gases during the heating process [8, 9]. Riley has considered the following chemical reactions for various Fe compounds in clay to bloat during ALA formation [8]. Fe compounds as bloating components, most studies have agreed that these chemical reactions are responsible for the bloating mechanism:

$$2Fe_2O_3 \rightarrow 4FeO + O_2 \quad (1)$$

$$6Fe_2O_3 \rightarrow 4Fe_3O_4 + O_3 \text{ or } 6Fe_3O_3 \rightarrow 4(Fe_2O_3{\cdot}FeO) + O_2 \quad (2)$$

$$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2 \quad (3)$$

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The bloating mechanism attributed to the chemical reactions involving Fe compounds for ALA formation has been accepted [10]. This study was conducted to evaluate the feasibility of using bottom ash and dredged soil from a coal power plant and EAF dust from the steel making industry as primary materials for the production of ALA. Because EAF dust contains a higher content of Fe components than that required to produce the general ALA, Fe components in the EAF dust is acts as a bloating agent to make lower density ALA. The aim of this study is not only to determine the effect of the EAF dust composition and heating temperature on ALA properties related to the bloating effect but also to establish effective parameters for properties such as bulk density and water absorption.

Materials and Methods

Materials

The bottom ash was collected from Young-hung coal power plant in South Korea that has been embedded in forming clinkers and sticking to hot side walls of a coal-burning furnace during its operation which was dredged and rejected yearly. The EAF (electric arc furnace) dust used in this study was collected from Kangwon iron works furnace. Table 1 shows the elemental compositions, expressed in oxide forms of the raw materials. The mass ratio of bottom ash, dredged soil and EAF dust as a simple controlling parameter to optimize the component for production of ALA and the effect of Fe on the characteristics of ALA under the condition of fixed EAF dust ratios were studied to establish optimum conditions for producing ALA.

Table 1. The elemental compositions, expressed in oxide forms of the raw materials

	Bottom ash	Dredged soil	EAF dust
SiO_2	45.5	70.0	4.1
Al_2O_3	18.6	14.2	1.2
Fe_2O_3	8.1	3.8	49.0
CaO	2.2	0.8	2.0
MgO	.0.8	0.2	2.3
Na_2O	0.2	2.5	0.2
K_2O	0.5	2.7	2.2
TiO_2	1.3	0.8	0
P_2O5	0.2	0.1	0.10
MnO	0.1	0	2.3
ZnO	0	0	25.6
Cr_2O_3	0	0	0.1
C	18.1	0	0
Ig. loss	0	4.0	10.8

*Analysis with XRF
*Loss on ignition after 300 °C for 3 h,
*The sum of the composition is normalized to a sum of 100%

Table 2. The chemical compositions of all specimens

series	Bottom ash	Dredged soil	EAF dust
A	80	20	substituted dredged soil 0~15% ,respectively
B	60	40	
C	40	60	
D	20	80	

Methods

The chemical compositions of specimens are shown in Table 2. Raw materials were crushed to below 100 μm- and dried. The ALA were formed with a diameter of 7-8 mm. The formed specimens were directly inserted into the electric furnace and heated at temperatures ranging from 1050 °C to 1200 °C, with 50 °C increments and they were sintered for 10 minutes. After 10 minutes sintering in the electric furnace, ALA specimens were directly exposed to the air at room temperature by taking them out from the furnace to cool. Water absorption and bulk density were employed to characterize the quality of the sintered specimens. Water absorption and bulk density were determined according to ASTM C127-88 and ASTM C556. Morphological investigations of the ALA at different sintering temperatures were carried out by Camscope^{TM} (optical microscope) and scanning electron microscopy (SEM) observations.

Result and Discussion

Effect of mixture ratio on coal ash based ALA

The apparent particle densities was defined as the ratio between weight and volume of an ALA particle. The individual ALA particle volumes, excluding the pores available to water, was determined based on the Archimedes's principle. Fig. 1 and Fig. 2 shows the bulk density & water absorption of the ALA specimens prepared from coal ash mixtures of different weight ratios and at various

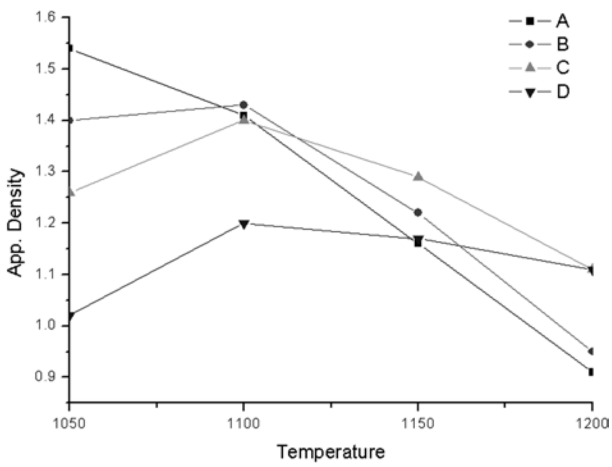

Fig. 1. The apparent density of the ALA specimens prepared from coal ash mixtures of different weight ratios and at different sintering temperature.

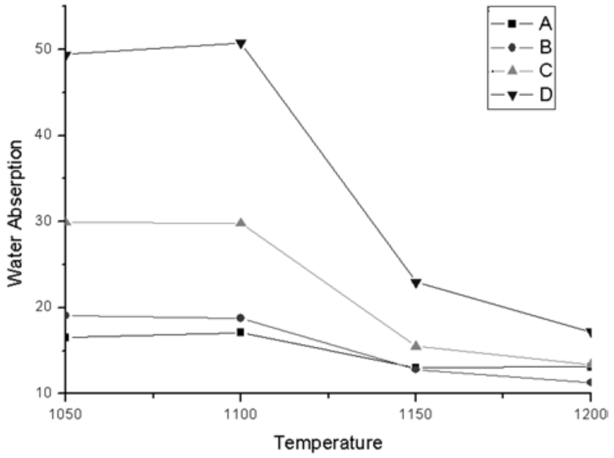

Fig. 2. The water absorption of the ALA specimens prepared from coal ash mixtures of different weight ratios and at different sintering temperature.

sintering temperatures, respectively. The major chemical compositions of these specimens are listed in Table 3. As seen in Fig. 1 and Fig. 2, the bulk density and water absorption tend to decrease with an increase with sintering temperature. Most ceramics, including ALA, sintered at higher temperatures will be more densified and have a lower porosity, which will result in a higher strength and lower hydration rate. The characteristics of these ALA specimens showed the opposite behavior. These results can be explained by "bloating" which was described in the introduction. Gases serving as bloating agents have to be released to create pores when the specimen is heated at a high temperature, and the glassy surface formed by the sintering reaction needs to encapsulate the gases released by the bloating reaction. As a result, pores are formed and the ALA obtained shows an expanded and porous structures. Fig. 1 and Fig. 2 show that the bulk density and water absorption are decreased with an increase in the fraction of dredged soil content between 1050 °C-1100 °C, because the SiO_2 content in the dredged soil is larger than that in the bottom ash. In other words, the higher the SiO_2 content in a specimen, the more easily does the specimen bloat. This would be favorable for the encapsulation of gases produced during the bloating process, leading to less bulk density and water absorption. However, a such trend is not observed for the results from above 1100 °C. To explain this exceptional observation it is suggested that it arrises from the role of Fe. Fe compounds play an important role in the bloating reaction, thus a specimen

Table 3. Major chemical compositions of ALA specimens with various bottom ash and dredged soil contents

	A	B	C	D
SiO_2	50.43	55.33	60.22	65.12
Al_2O_3	17.72	16.85	15.98	15.11
Fe_2O_3	7.21	6.35	5.50	4.64

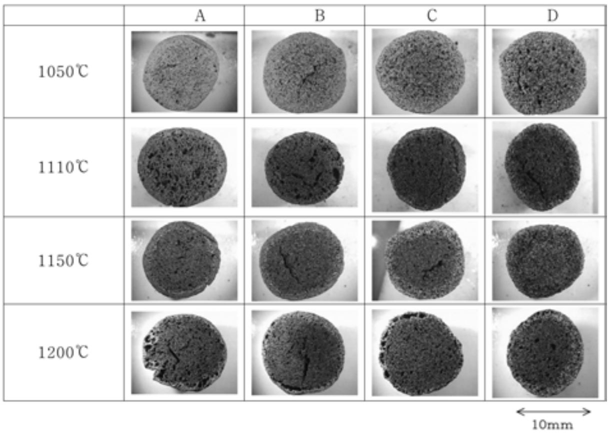

Fig. 3. Cross-sectional view of ALA sintered with various compositions and at various temperatures.

containing more ferrous materials such as Fe_2O_3 is more easily bloated. The cross sectional morphologies of ALA sintered with various compositions and at various temperatures are shown in Fig. 3. The bloating phenomenon as well as black core formation were found at all specimens. The black core formation for the case of the A-series and B-series was clearly observed and the boundary between the shell and black core was also clearly demarcated between 1050 °C-1100 °C. As seen in Fig. 3, black core formation has been recognized as the incomplete burning-out of carbonaceous materials, which can produce a core-like residue. In contrast, the core of ALA specimens heated above 1150 °C becomes glassy with relatively large pores, indicating that the gases released during the sintering process were effectively encapsulated by the glassy shell. Observations of the cross sectional morphology are consistent with the results from the measurements of apparent particle density and water absorption.

Effect of EAF dust on coal ash based ALA

The Fe_2O_3 compositions in the ALA specimens with various EAF dust contents in each series are shown in Table 4.

As seen from Table 4, due to the higher content of Fe compounds in the EAF dust, Fe components acted as a bloating agent to give ALA with a lower density. This is because of specially Fe_2O_3 released oxygen at 1000-1100 °C. Fig. 4 and Fig. 5 show the bulk density & water absorption of the ALA specimens prepared from EAF dust substitution on coal ash mixtures of C-series at

Table 4. The Fe_2O_3 compositions of ALA specimens with various EAF dust contents which substitute for the dredged soil

	A (80%)	B (60%)	C (40%)	D (20%)
0	7.21	6.35	5.50	4.64
5 wt %	9.48	8.62	7.76	6.90
10 wt %	11.74	10.88	10.02	9.16
15 wt %	14.00	13.14	12.28	11.43

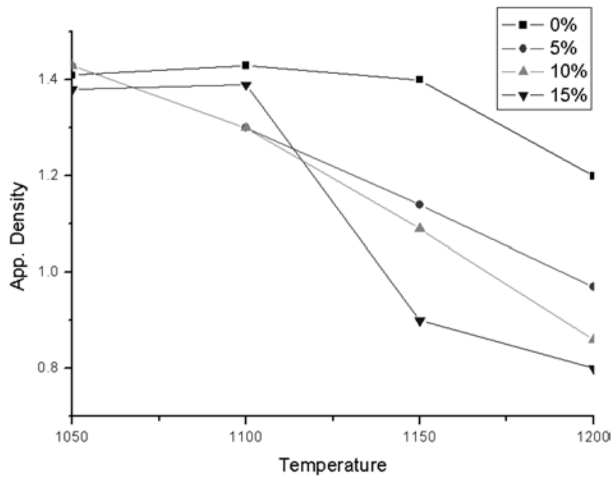

Fig. 4. Apparent density of the ALA prepared from EAF dust substitution on coal ash mixtures of series C(40%) at different sintering temperatures.

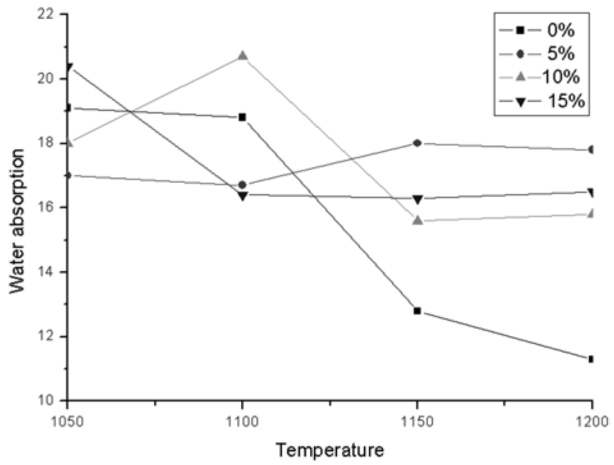

Fig. 5. Water absorption of the ALA prepared from EAF dust substitution on coal ash mixtures of series C(40%) at different sintering temperatures.

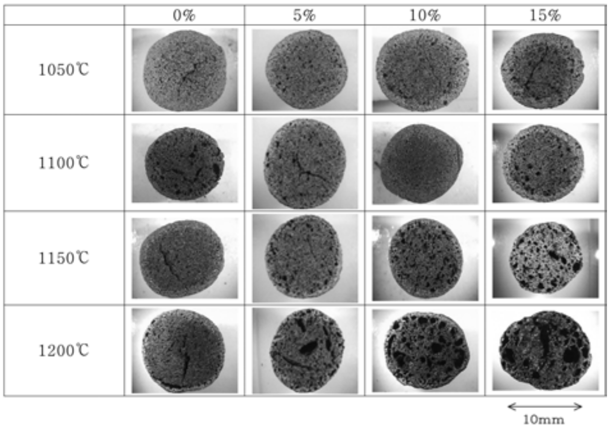

Fig. 6. The cross sectional morphologies of ALA prepared from EAF dust substitution on coal ash mixtures of series C(40%) at different sintering temperatures.

various sintering temperatures. A general trend of decreasing bulk density with an increase in the sintering temperature is observed. This trend is simply explained by the fact that unburned carbonaceous materials are bloat more easily at elevated temperatures. For the specimens sintered above 1150 °C, except the 0% EAF dust sample, the apparent density had a sharp drop below 1.0 which meets the condition of ultra-light ceramics(ULWC). ULWC is generally defined as having bulk densities $\leq 0.5 g/cm^3$ and true densities $\leq 1.0 g/cm^3$, which has more extensive application in civil engineering compare to general ALA [11]. From this sharp drop it could be inferred that the existing content of ferrous material was efficient in bloating the specimens. In other words, there existed ferrous materials, which could bloat the specimens to a maximum. The cross sectional morphologies of ALA prepared with EAF dust substitution of coal ash mixtures of the C-series at various sintering temperature are shown in Fig. 6. As seen in Fig. 6, the sintered product of ALA prepared with EAF dust substitution of coal ash mixtures of the C-series also contained large pores at an elevated temperature. However, as more EAF dust was added, the pores became larger and more irregular. This indicate that increasing the amount of ferrous materials can effectively increase the pore size of the sintered products. Although the processing environment at higher temperature would cause more active movement for an easier sintering reaction, it could also result in more vigorous gas production during the bloating process. The bloating process was so vigorous as to produce gases which cause blistering, and part of gases then escaped to the atmosphere through the sintered shell of ALA. The cross sectional morphologies shows that the pore size in the interior of specimens became bigger with an increase in the EAF dust concentration. There are abundant small pores with a thin boundary and big cracks with no boundaries present in the interior, which are caused by release of the gases and melting of the raw materials. The main differences of the morphology in Fig. 6 are suggested to arise from the difference in the apparent density, because the apparent density is greatly affected by the size and quantity of the pores. Therefore, the morphologies of ALA prepared with EAF dust substitution of coal ash mixtures are significantly influenced by the variation of ferrous materials under the condition of a fixed coal ash mixture ratio.

Conclusions

The apparent density and water absorption of electric arc furnace(EAF) dust on coal ash based ALA are deceased with an increase in the fraction as SiO_2 content between 1050 °C-1100 °C. Thus the more SiO_2 in the specimens, the more easily are the specimens bloated, leading to less apparent density and water absorption. Above 1100 °C, Fe compounds plays an important role in the bloating reaction, the specimens containing more ferrous materials such as Fe_2O_3 are more easily bloated. The optimum EAF substitution in coal ash mixtures was 10-15 wt% and the ALA specimens which were sintered above 1150 °C for

10 minutes were benificial to produce light aggregate with an apparent density under 1.0 g/cm^3.

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References

1. H. Salmang, “Ceramics-Physical and Chemical Fundamentals” (Butterworth, London, 1961) p. 117.
2. P.S. Nicholson and W.A. Ross, J. Amer. Ceram. Soc. 53 (1970) 154-158.
3. W.W. Brownell, J. Amer. Ceram. Soc. 40 (1957) 179-187.
4. C.R. Cheedeman, G.S. Virdi, J. Resources, conversation and Recycling 45 (2005) 18-30.
5. C.C. Tsai, K.S. Wang, I.J. Chiou and J. Hazard. Mater. B134 (2006) 87-93.
6. I.J. Chiou, K.S. Wang, C.H. Chen and Y.T. Lin, Waste Manage. 26 (2006) 1453-1461.
7. A.R. Boccaccini, P. Veronesi and C. Leonelli, J. Eur. Ceram. Soc. 21 (2001) 1073-1080.
8. C.M. Riley J. Amer. Ceram. Soc. 34[4] (1951) 121-128.
9. R. de’Gennaro, P. Cappelletti, G. Cerri, M. de’Gennaro, M. Dondi and A. Langella, Appl. Clay Sci. 25 (2004) 71-81.
10. Y.L. Wei, J.C. Yang , Y.Y. Lin, S.Y. Chuang and H.P. Wang, Mar. Pollut. Bull. 57 (2008) 867-872.
11. Y. Qi, Q. Yue, S. Han, M. Yue, B. Gao, H. Yu, T. Shao and J. Hazard. Mater. 176 (2101) 79-6-84.
12. B.K. Kara-sal, D. Kh. Sat, Yu. D. Kaminskii and A.P. Ochur-ool, J. Glass and ceramics, 65 (2008) 84-87.
13. K.J.D. MacKENZIE and C.M. CARDILE, J. Mater. Sci 25 (1990) 2937-2942.