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Neutralizing capacity of bottom ash from municipal solid waste incineration of different particle size

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Abstract−This study measures the neutralizing capacity of bottom ash from municipal solid waste incineration of different particle sizes. We examine the effect of particle size on the weathering process, a method popularly used for stabilization of heavy metals in incineration of bottom ash. The distribution of particle sizes in municipal solid waste incineration bottom ash is rather broad, ranging from fine powder to as large as 40 mm in diameter. Although considered a by-product highly suitable as a road construction material, the high level of heavy metal leaching is an obstacle to its reuse. Weathering, a method used to reduce heavy metal leaching, is a lengthy process taking over thee months to complete. The chief reaction involved in weathering is carbonation occurring between $Ca(OH)_2$ in bottom ash and $CO_2(g)$ in the atmosphere. During this process, $CaCO_3$ is produced, causing the pH level to drop from over 12 to about 8.2 and reducing heavy metal leaching. In this paper, we attempt to determine the particle size best suited for reducing the period required for weathering bottom ash by identifying characteristics of different particle sizes that affect heavy metal leaching and neutralization.

Key words: Municipal Solid Waste Incineration Bottom Ash, Acid Neutralization Capacity, Recycling

INTRODUCTION

In 2003, some 400 thousand tons of municipal solid waste was discharged in Korea [Korea Ministry of Environment, 2002]. Ash from the incineration of municipal solid waste is distinguished into two types, fly ash and bottom ash, which exist in a weight ratio of 9 : 1. Incineration, offering several advantages over other methods, including a high volume reduction rate and sterilization, is gaining growing importance as a disposal technique and accounting for an increasing share of treated waste. In Korea, about 15% of all waste was incinerated in 2003, substantially above 5% in 1996. This trend is expected to accelerate. In spite of these advantages, disposing of waste through incineration has the downside of generating secondary pollutants such as air pollutants, incineration ash and residual solid waste. Emission of air pollutants from waste incineration became a less serious problem thanks to the progress in combustion and ash collection techniques. Meanwhile, incineration ash is still chiefly disposed of in landfills, and this is raising environmental concerns.

Of the two types of incineration ash, bottom ash contains much less environmentally harmful substances than fly ash, and active research on its reuse is currently underway. In many European countries, bottom ash is already being reused after mechanical separation or other simple treatments. Among many possible reuses of bottom ash, its potential as a construction aggregate for roads and other structures is especially highly praised. For bottom ash to be reused as a construction aggregate, it must meet required standards in physical properties such as wear rate, specific gravity and absorption rate, and in heavy metal and mineral leaching [Wiles and Shepherd, 1999]. Some studies report that the physical properties of bottom ash, including wear rate and specific gravity, are suited for its use as a road construction material such as for road base [Ahn et al., 2001]. Meanwhile, research is continuing on the long-term leaching behavior of unstable heavy metals like Cu and Pb, and minerals present in bottom ash. Hence, the ability to stabilize heavy metals holds the key to the reuse of bottom ash as a road construction material.

There are several methods for stabilizing heavy metals and other harmful substances to prevent leaching: washing, weathering and solidification. Weathering, requiring only a small facility and equipment investment and cheaper to maintain, is the most widely adopted of the three methods. It involves leaving bottom ash exposed to the atmosphere for 1-6 months. During this exposure, a series of reactions occur, including leaching, sedimentation, oxidation and carbonation, lowering the pH level and producing hydroxide and carbonate. This reduces the level of heavy metal leaching from bottom ash.

While there can be many factors which affect the heavy metal leaching behaviors in solid materials, in the case of bottom ash with a broad particle size range, from fine powder to those with diameters over 25 mm, particle size can be an important variable.

The effectiveness of weathering for stabilizing heavy metals present in bottom ash has been confirmed by several studies [Jeannet et al., 2002; Van Gerven et al., 2005]. As leachate generation generally exceeds the limit value to be considered environmentally safe, making bottom ash unsuitable for reuse, the concentration of leachate is lowered as a way of reducing leaching. By letting the ash successively undergo leaching, sedimentation, carbonation and oxida-

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tion in an open-air environment, the pH level is lowered and solubility of heavy metals brought down to the minimum value. The high pH level of incineration ash from municipal solid waste is believed to be caused by $Ca(OH)_2$ contained in bottom ash.

Weathering, a treatment technique consisting simply of leaving the ash exposed to the atmosphere, is more economical and does not require large facility investments. On the other hand, as the standard weathering period can last three to six months on average, a spacious lot is a prerequisite for the process. A large number of variables are involved in the process of lowering the level of pH through chemical reaction with CO_2, including minerals composing the bottom ash and the moisture content. Furthermore, since particles in bottom ash from municipal solid waste incineration range rather broadly in size, from fine powder to particles over 40 mm in diameter, their sizes are likely to be a critical influence factor for reaction with atmospheric CO_2.

Acid-neutralizing capacity test is a technique used chiefly for waste and other solids to predict long-term leaching behaviors of ions in relation to acid rain and other natural changes. As a low liquid-to-solid ratio is used for the leaching test, one is able to measure the pH level and concentration of ion leachate in solids in a state of equilibrium.

In this study, we sorted bottom ash particles according to their size and measured the level of pH at different acid concentrations to determine the particle size capable of shortening the weathering period and identify minerals which act as a buffer neutralizing the acidification process. Our goal was to find out which of the two variables, particle size and composing minerals, produces a greater effect on the process.

SAMPLE AND EXPERIMENTAL

1. Sample

The bottom ash used for this study came from a Korean municipal solid waste incineration plant located in Gwangmyeong, metropolitan city. This facility is a stoker-type plant, incinerating 200-300 tons of municipal solid waste per day, and 20-30 tons of incineration ash is produced daily. The generated bottom ash is stored in an ash bunker after being water-quenched, and magnetic substances are removed by a magnetic separator before being moved at a landfill.

2. Experimental

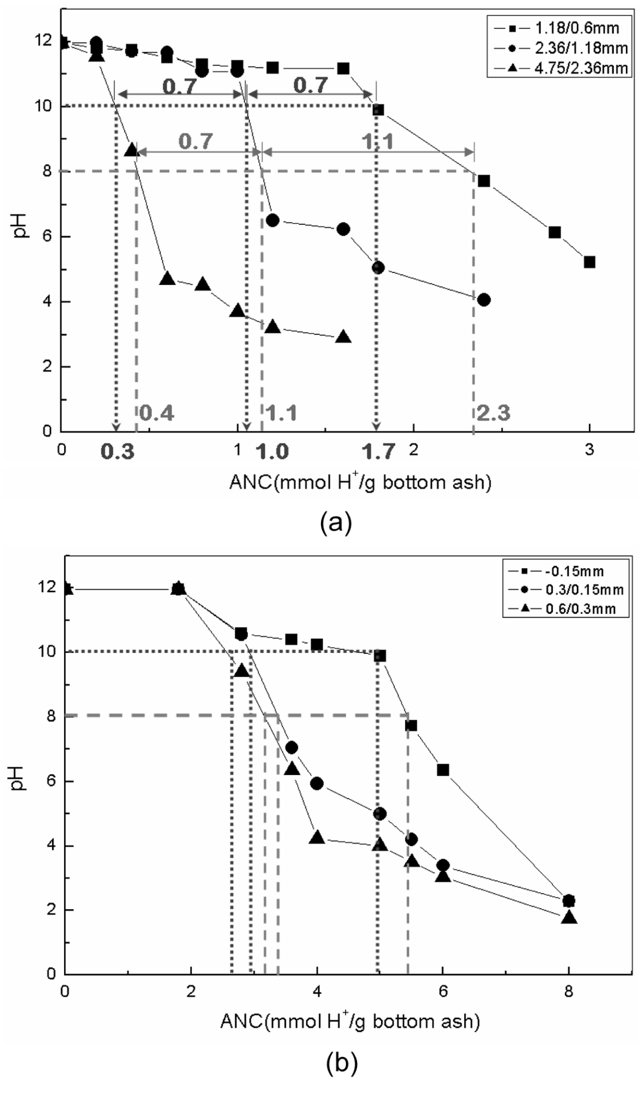
The bottom ash was dried at 50±5 °C for one day, and divided into several size fractions by using Korean standard sieves for different aggregate sizes. Particle size distribution was determined from the weight of each size fraction. For measuring acid neutralization capacity of bottom ash, each bottom ash was mixed with nitric acid solution of determined concentration in a liquid to solid ratio 1 : 20 (10-20 g bottom ash) in a 250 mL Erlenmeyer flask. The flask was sealed to protect from the uptake of CO_2. And then, the samples were shaken by shaker at 200 rpm for 18 hrs.

Acid neutralization capacity (ANC) of each bottom ash was determined for various pH levels. In some cases, nitric acid was added to obtain the concentration required to reach a certain pH value. After 6 hrs of leaching, liquid and solid was separated by using a 0.15 μm pore-size filter. The pH of leachates was determined and cakes separated were dried at 50±5 °C, and mineral phases and compositions were quantified by using XRD (X'pert, Shimadzu).

RESULTS AND DISCUSSION

Bottom ash consists mainly of glasses, ceramics and slag. D_{50} of bottom ash was about 4 mm. The considered particle size was the aggregate size for concrete manufacture in Korea Industrial Standard. Glasses, ceramics and ferrous metals in bottom ash were over 70 wt% in the size fraction above 4.75 mm that is classified as coarse aggregates. Because magnetic separation is carried out in this facility, main matters above 4 mesh are glasses and ceramics. Once the particle size reached 4.75 mm, no significant changes in acid-neutralizing capacity occurred, even when the size was increased. In the case of particles ranging from 4.75-10 mm in diameter, bringing the level of pH down to 8 necessitated 3 mmol of nitric acid per gram of bottom ash. Therefore, acid neutralization capacity (ANC) was carried out on the size fraction below 4mesh in detail.

Fig. 1 shows pH versus acid added curve for each particle size fraction below 4.75 mm. With particle size between 4.75 and 0.6 mm ((a) in Fig. 1), it showed a plateau around pH 12-11. It took 0.7 mmol of nitric acid to lower from initial pH 12.3 to pH 10. To



(a)

(b)

Fig. 1. Acid neutralization capacity curves of bottom ash (a) 4.75 mm-0.6 mm and (b) below 0.6 mm.

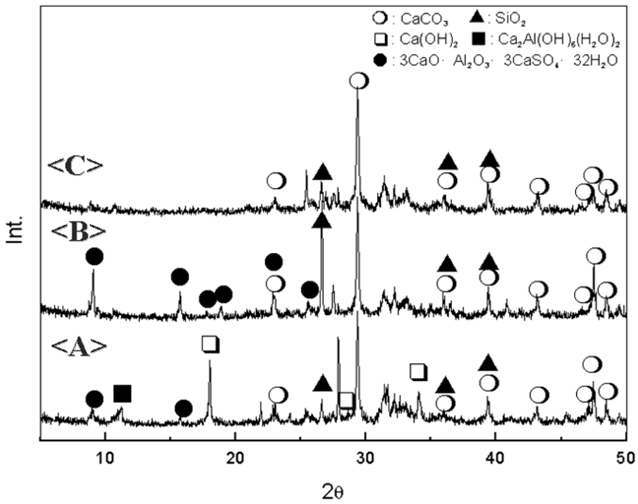


Fig. 2. XRD patterns of raw bottom ash and bottom ash at pH 10.2, and 8.2.

reduce the pH value down to about pH 8, the required amount of nitric acid tended to increase as the particle size decreased. As for particles smaller than 0.6 mm ((b) in Fig. 1), while no significant changes in ANC were observed between 0.6 mm-0.15 mm, a sharp surge was noted with particles below 0.15 mm.

To identify substances which act as a buffer against the acidification process, we performed an XRD analysis on fine powder, which is comparatively easier to measure. The results are given in Fig. 2. The XRD analysis revealed that many minerals composing bottom ash that are below 0.15 mm in particle size had the buffering capacity to prevent the lowering of the pH value. Principal minerals composing bottom ash particles smaller than 0.15 mm include $CaCO_3$, quartz, ettringite, $Ca(OH)_2$ and magnetite. Of these, the mineral capable of buffering actions against lowering of pH at pH values over 12, is likely to be $Ca(OH)_2$. In Figs. 2 and 3, at pH 10.2 and 8.2, the $Ca(OH)_2$ peak is no longer visible in the XRD pattern at pH 10.2, while, in the XRD pattern at pH 8.2, the ettringite peak vanishes.

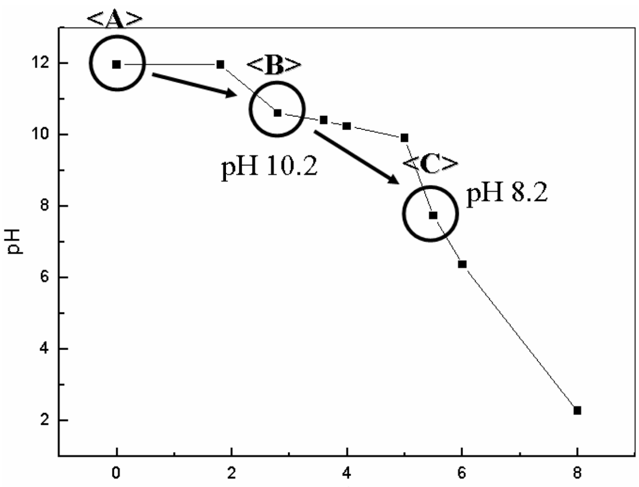


Fig. 3. Relationship of pH and acid neutralization capacity with size fraction below 0.15 mm.

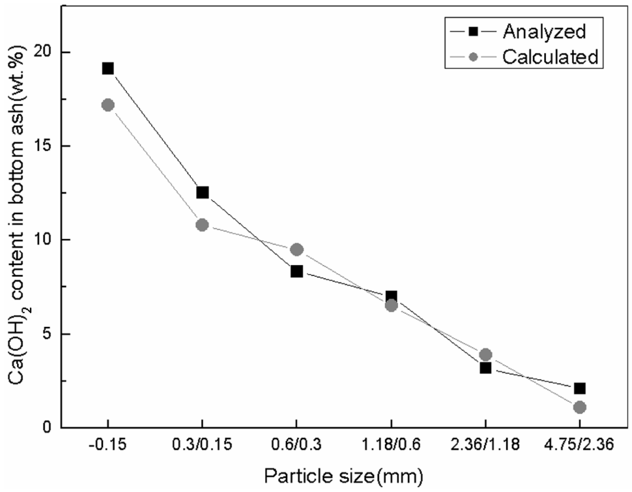


Fig. 4. $Ca(OH)_2$ content calculated and analyzed with different particle size.

This result suggests that the mineral with buffering ability, preventing the pH value from being driven down to 10, is $Ca(OH)_2$, and that the one that acts as a buffer between pH 10 and 7 is ettringite.

The fact that the key mineral phase involved in the acidification process is $Ca(OH)_2$ can be also confirmed through values given in Fig. 4, calculated from the quantification results from XRD analysis and concentrations of nitric acid used, using formula (1). The values obtained were virtually identical to the quantified values of $Ca(OH)_2$ for each of the fractions.

$$Ca(OH)_2+2HNO_3 \rightarrow Ca^{2+}+2NO^{3-}+2H_2O \qquad (1)$$

These results indicate that there exists a concentration of $Ca(OH)_2$ in fine particle bottom ash, and that this mineral plays an important role in the level of pH in bottom ash. Buffering occurring in large particles is likely to be caused by $Ca(OH)_2$ adhering to these particles, rather than by large particles themselves. Hence, what this implies is that, using an appropriate method, for instance, by removing small particles from large ones using a vibrating screen or by efficiently controlling particles, one may be able to effectively reduce the aging period for bottom ash. And we can think that the buffer-

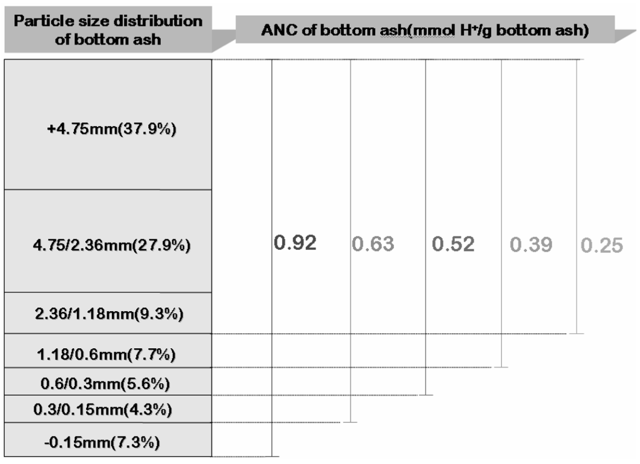


Fig. 5. ANC change in removing fine particle size of bottom ash.

ing mineral interfering with the acidification process between ph 10 and 8 is most probably ettringite.

Fig. 5 provides the ANC required to reduce the pH value to 10, obtained by discarding small particle fractions from calculation. For all size fractions of bottom ash, reducing the pH value to 10 requires 0.92 mmolH$^+$ per each gram of bottom ash, and, when excluding fractions of particles with diameters below 0.15 mm, 0.63 mmolH$^+$ per each gram of bottom ash. When excluding fractions below 0.3 mm, reducing the pH value to the same level requires 0.52 mmolH$^+$ per gram of bottom ash. Thus, when taking into account the portions occupied by each fraction, it appears, as can be noted in Fig. 5, that removing the 0.15 mm fraction, accounting for 7.3% of the overall bottom ash sample, is the most effective for shortening the weathering time. Also, the cycle can be substantially shortened for fractions of particles larger than 4.75 mm, corresponding to the size of coarse aggregate, provided that they are appropriately sorted.

CONCLUSIONS

In this study, the effect of particle size on weathering of municipal solid waste incineration bottom ash was examined. For that, acid neutralization capacity of municipal solid waste incineration bottom ash by about pH 10 and 7 was investigated with different particle sizes. The results of ANC tests offered information on stabilization of bottom ash through the weathering. At first, it showed that the main buffer mineral in lowering pH from initial pH of bottom ash above 12.0 to 10 and 7 is calcium hydroxide and ettringite, respectively. In particular, the contents of calcium hydroxide for each size fraction calculated from ANC result from pH 12.5 to 10.2 agreed nearly with XRD quantification value. And the leaching content of heavy metals considered in this study was the lowest from pH 10 to 6. It showed that lowering pH to stable pH range in leaching of heavy metals is the carbonation of calcium hydroxide in weathering of bottom ash. Secondarily, it revealed that the removal of any size fraction in bottom ash, mainly fine fraction can shorten effectively the period of weathering that is generally used as a stabilization method of the bottom ash. ANC of bottom ash decreased with the increase of particle size. For example, the ANC of fraction below 150 μm was about 12 times higher than the fraction between 4.75 mm and 2.36 mm by pH 10. So if considering each portion in all the bottom ash of each size fraction, ANC of fraction below 150 μm needs about only one third ANC by removing a size fraction below 150 μm that occupies about 7.3% of all the bottom ash by weight, compared with raw bottom ash, which means that it can lead to the stabilization of bottom ash more quickly by simple classification.

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