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Characteristics of Sewage Sludge, Its Incineration Ash, and Sintering Pellet

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This study on the incineration ash and sintering pellet from sewage sludge was carried out to evaluate the possibility of recycling in sewage sludge disposal. The samples used in this experiment were raw sewage sludge, its incineration ash, and sintering pellet. The characteristics of the three sample types were identified using X-ray diffraction(XRD), X-ray fluorescence(XRF), atomic absorption spectroscopy(AAS), and inductively coupled plasma spectroscopy(ICP). The chemical compositions of all three sample types were similar in their clay component, however, the sewage sludge had a high content of organic materials. From an analysis of the mineral content of the three sample types, the conversion of their compositions was found to be relative to temperature. Accordingly, incineration ash and sintering pellet both have potential for use as a functional construction material.

Key words : recycling, sewage sludge, incineration ash, sintering pellet

1. Introduction

The amount of sewage sludge production has been increasing abruptly with urbanization and industrial development. The methods available for disposing of sewage sludge include landfills, ocean dumping, composting,[1] raw material for cement,[2,3] incineration,[4~7] solidification,[8] and melting[9] etc. which depend on regional conditions. Most sewage sludge is disposed of in landfills or by ocean dumping, as shown in Table 1. However, due to the recent imposition of stringent environmental protection laws, these disposal methods are likely to be prohibited by law in future. Some alternative technologies for sewage sludge treatment have already developed in many advanced countries. For example, in Japan, alternative treatment technologies include the conversion of sewage sludge to compost, conversion of sewage sludge to fuel, production of artificial light-weight aggregates from ashes, press burning of incineration ashes, and conversion of sewage sludge to melted slag[10]. In addition, the sintered brick from the incinerated ash of sewage sludge is used as construction material[11,12]. A sewage sludge melting process was developed in the 1980's and is currently being used at about 10 full-scale plants[8,9,13]. In Germany, approximately 60% of sewage sludge is disposed of in landfills, approximately 20-25% used for agricultural purposes, 10% incinerated, and 3-4% used for making compost. In the future, disposal in landfills will significantly decrease, whereas agricultural use and incineration will continue to increase[14].

In incineration treatment, the ideal technology is a small or medium-sized incineration plant, which is both environmentally friendly and economically efficient[15]. As such, the incineration method for sewage sludge disposal is believed to be one of the most promising candidates from the perspective of reducing volume, stabilization, and recycling.[4~7] In Korea, however, there has not been any complete characterization, i.e chemical analysis, of the incineration ash and sintering pellet from sew-

Table 1. Quantity of sewage sludge generated in Korea

(Unit : 1,000 Ton)

Year	Landfill	Ocean dumping	Compost	Incineration	Others	Total sum.
1991	583.9	0.0	16.3	0.0	0.0	600.2
1992	579.4	0.0	31.0	0.0	1.8	612.2
1993	664.8	85.8	19.3	0.0	0.0	770.0
1994	766.1	169.4	26.1	0.0	0.0	961.6
1995	931.7	206.0	33.5	0.0	0.0	1,171.2
1996	1,008.6	243.0	30.2	5.4	11.2	1,298.4
1997	988.7	297.6	43.0	9.3	9.7	1,348.4
Ave. ratio	81.7%	14.8%	3.0%	0.2 %	0.3 %	100.0 %

age sludge.

Accordingly, this paper investigated the characteristics of rural-type raw sewage sludge, its incineration ash, and sintering pellet. In addition, the characteristics of the incineration ash and sintering pellet from the sewage sludge were analysed for their potential as a functional construction material.

2. Experimental

The rural-type sewage sludge was obtained from five sewage treatment plants in the Chungnam region of Korea. The samples used in the experiment were taken from raw sewage sludge, its incinerated ash, and sintering pellet. The incinerated ash and sintering pellet from the raw sludge were obtained after treatment in an electric furnace at 800~850℃ and 1,000~1,100℃, respectively. The component analysis was performed using an atomic absorption spectroscopy (AAS; AAnalyst 300, Perkin Elmer, USA) and inductively coupled plasma-mass spectroscopy (ICP-MS; ELAN 5000, Perkin Elmer, USA). The heavy metal analysis of all samples was performed using an inductively coupled plasma-atomic emission spectroscopy(ICP-AES; JY-38Plus, Jobin Yvon, France). The composition of the mineral matter was analyzed by X-ray diffraction(XRD) measurement using an X-ray diffractometer with Cu-Kα radiation(PW1710, Philips, Netherlands) and X-ray fluorescence(XRF; PW1400, Philips, Netherlands) at room temperature. The compressive strength of the sewage sludge ash and sintering pellets were measured with a compact apparatus(KS L 5105 Korea) using the JIS R 5201 molding method. The measurements of the other physical properties were carried out using the KS L 3114 standard method.

3. Results and Discussion

The average moisture content of the sewage sludge was about 80% and the average organic compound content was about 60% of the total solid sludge weight. The amount of organic material in the rural-type sludge was 10% higher than that from an urban district.[1] The relatively high organic material content indicates that the sewage sludge contained inherent organic compounds plus polymer compounds that had been added as a coagulant material during the treatment of the sewage sludge.

Table 2. Organic element composition of sludge produced from sewage treatment plants in Chungnam region of Korea

elements / sample	T-C (%)	H (%)	O (%)	T-N (%)	S (%)
A	73.2	11.1	2.0	11.4	2.3
B	72.8	10.7	3.2	11.5	1.8
C	51.7	7.7	31.4	7.9	1.3
D	60.0	9.3	18.3	10.1	2.3
E	59.1	8.8	21.5	8.4	2.2
Ave.	63.4	9.5	15.3	9.9	1.9

Table 3. Chemical composition of rural-type sewage sludge, its incineration ash, and sintering pellet from Chungnam, Korea

Sample	Chemical composition (%)										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	P_2O_5	Ig. Loss
Rural type sewage sludge	22.23	10.52	3.23	1.46	0.62	0.34	1.21	0.40	0.38	3.35	56.26
Incineration ash	48.65	24.04	7.47	3.24	1.38	0.74	2.58	1.19	0.79	8.36	1.55
Sintering pellet	52.04	23.99	8.23	2.50	1.45	0.81	2.61	0.27	0.84	6.78	0.48

Table 2 shows the organic elemental analysis data of the sewage sludge. In general, sewage sludge with a high carbon content also has a high heating value, thereby indicating its suitability for incineration treatment.

Table 3 shows the chemical composition of the rural-type sludge, dry sludge incineration ash, and sintering pellets. In the case of the raw sludge, the main contents were found to be SiO_2(22.23%) and Al_2O_3(10.52%). Also, the ignition loss was 56.26%. The CaO content was 1.46%. This indicates that the sewage sludge contained both inherent organic material plus an additional polymer compound as a coagulant material. The chemical compositions of the samples used in this experiment were found to be similar to those in ash from municipal sewage sludge from the Taegu region in Korea[5] and Japan.[6] However, the CaO content in Japan was about 35% compared with about 3% in the current data. Such a high CaO content in sludge ash means it can be used as a replacement for lime in cement. In our case, the incinerated ash and sintering pellet were found to have a similar composition to the clay component of cement.

Figure 1 shows the XRD spectra of the raw sludge, its incinerated ash, and sintering pellets utilizing the ash, respectively. The mineral content of the raw sludge was composed of α-quartz(α-SiO_2), low thermal-type albite($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$), muscovite($K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$), kaolinite($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), and gypsum ($CaSO_4 \cdot 2H_2O$). The mineral content of the incineration ash was identified as α-quartz, high thermal-type albite, muscovite, hematite(α-Fe_2O_3), and anhydrite gypsum($CaSO_4$).

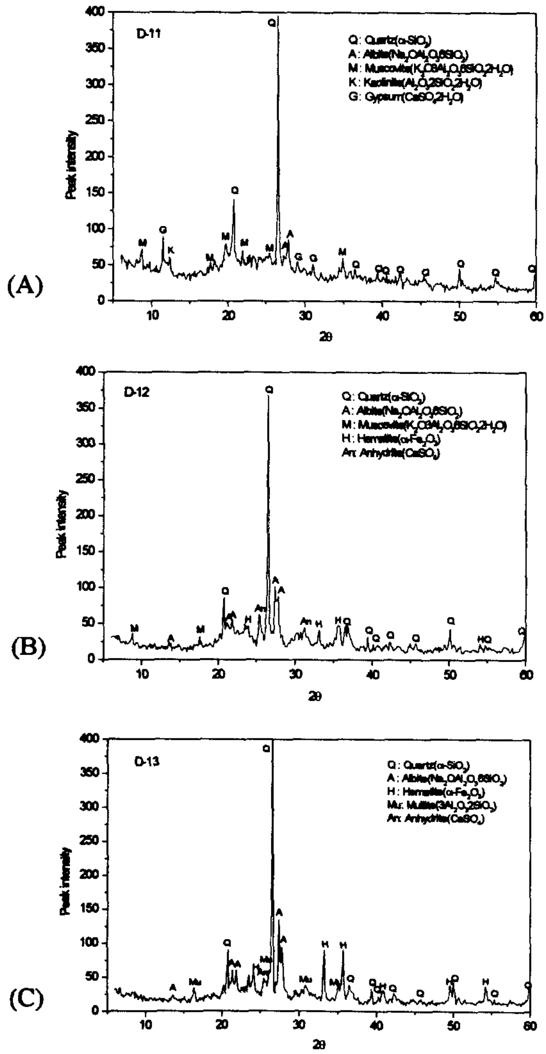

Fig. 1. XRD spectra of (A) dry sewage sludge, (B) its incineration ash, and (C) sintering pellet.

Accordingly this stepinvolved the formation of hematite accompanied by a color change from black to yellow, the formation reaction of which would appear to proceed as $2FeO+1/2O_2 \rightarrow Fe_2O_3$, the transformation of gypsum to anhydrite gypsum, and the disappearance of kaolinite. In the case of the sintering pellets, the XRD spectra indicated the disappearance of muscovite, formation of mullite ($3Al_2O_3 \cdot 2SiO_2$) which is a meaningful component of a fireproof material, enhancement of high thermal-type albite, and remaining anhydrite gypsum. The hematite content in the sintering pellet was higher than that in the incineration ash. A change of color from yellow to dark yellow also proceeded simultaneously. Plus, during the sintering operation at a temperature of approximately 1,000~1,100℃ in a high temperature electric furnace, the mass and volume of the residue were greatly reduced producing a high-density sintered product with a changed physical and chemical state. These results indicate that the incineration ash used in this study is of significant practical interest for application in functional construction materials. Therefore, the recycling of the incineration ash and sintering pellet from sewage sludge should be determined based on their subsequent productive use instead of just disposal. However, a heavy metal leaching analysis of the residual ash and sintering pellets must be done before they can be use in functional construction materials.

Table 4 shows the concentrations of the main heavy metals in each sample type. The three sample types showed a higher concentration of Cu, Cr, and As than the permitted limit. Accordingly, based on the above results, an appropriate treatment needs to be selected to minimize the influence of heavy metals. It is well known that chemical stabilization is one method of reducing the leachability of heavy metals in waste materials.[16] One stabilization agent of recent interest is orthophosphate[17~20] because over 30 elements can react with PO_4^{3-} to form about 300 different naturally-occurring minerals.[21] Especially, phosphate minerals are common controlling solids for Pb^{2+}, Fe^{3+}, Ca^{2+}, Cd^{2+}, Cu^{2+}, and Zn^{2+} in natural soil systems[22,23] and waste sludge in semiconductor fabrication.[24] It is also recommended that a further leaching test should be considered because under extreme conditions an HCl solvent can used for extracting heavy metals. Nonetheless, it is important to take care of heavy metal stabilization.

Table 4. Leaching content of heavy metals from dry sewage sludge, its incineration ash, and sintering pellet. N.D. means not detected

Sample	Heavy metal (ppm)				
	Cu	Cd	Cr	Pb	As
Dry sewage sludge	425	0.03	115	N.D.	8
Incineration ash	1,330	N.D.	161	N.D.	36
Sintering pellet	1,050	N.D.	102	N.D.	31

In contrast, the compressive strength of the incineration ash and sintering pellets was measured to determine whether they had sufficient potential for use as a functional construction material. Table 5 shows the various physical properties of the incineration ash and sintering pellet relative to the conditions of the water mixing ratio. In the case of the incineration ash, the compressive strength was below the Korean industrial standard value (waste ash brick), as shown in Table 5. However, when the incinerated ash was sintered at 1,000℃ for 12 hours the compressive strength was higher than the Korean industrial standard value (fireclay brick), as shown in Table 6. This indicates that sintering pellets can be used as a functional construction material without the addition of a reinforcing material or binder. For example, the sintering pellets from incineration ash could be used as a replacement for natural materials such as crushed stones in construction materials. It may also be possible to use sintering pellets in secondary products, such as interlocking blocks, tiles and bricks.

4. Conclusions

The physical and chemical characteristics of rural-type sewage sludge, its incineration ash, and sintering pellets utilizing incineration ash were all investigated. The findings of this study are as follows:

1. The chemical composition of the rural-type sewage sludge mainly consisted of SiO_2 and Al_2O_3. The organic content of the total solid weight was about 60%.

Table 5. Physical properties of incineration ash and sintering pellet

Samples		Water mixing ratio(%)	Forming pressure (kgf/㎠)	Sintering temp. (℃)	Compressive strength (kgf/㎠)	Appearance porosity (%)	Water absorption (%)	Appearance specific gravity	Vol. Specific gravity
Incineration ash	1	15	23.44	800	75.92	55.6	34.3	3.65	1.62
	2	30	31.25	800	97.29	39.7	24.6	2.68	1.62
	3	45	39.06	800	55.21	44.5	27.0	2.97	1.65
Sintering pellet	1	15	31.25	1,000	401.66	1.2	0.7	1.71	1.69
	2	30	39.06	1,000	426.91	0.8	0.5	1.72	1.70
	3	45	23.44	1,000	265.21	6.6	4.0	1.77	1.65

Table 6. Korean industrial standards of fireclay and waste ash brick

Samples	Compressive strength(kgf/㎠)	Appearance porosity(%)	Water absorption(%)	Appearance specific gravity	Vol. specific gravity
Fireclay brick	> 150	< 24	-	-	> 1.80
Waste ash brick	> 82	-	< 15	-	-

2. The mineral content of the sewage sludge was composed of α-quartz, low thermal-type albite, muscovite, kaolinite, and gypsum. The mineral content of the incineration ash was composed of α-quartz, muscovite, hematite formation, a transformation from gypsum to anhydrite gypsum, and high thermal-type albite formation. In contrast, the sintering pellets showed the disappearance of muscovite, formation of mullite, enhancement of high thermal-type albite and hematite, and remaining anhydrite gypsum.

3. The compressive strength of the sintering pellets utilizing incineration ash and including mullite, which is considered as a fireproof material, was higher than that of the incineration ash.

4. These results prove that the incineration ash and sintering pellet have sufficient potential for use as a functional construction material.

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References

[1] Phae, C. G., J. K. Cho, N. H. Kwak and D. W. Kim, 1998, A study on the evaluation of optimum treatment by analysis of sewage sludge properties, J. Kor. Solid Wastes Eng. Soc., 15(3), 252~260.

[2] Chang, P. K. and Y. H. Kim, 1996, Pozzolanic characteristics of sewage sludge ash from fluidized-bed combuster, J. Kor. Solid Wastes Eng. Soc., 13(3), 386~392.

[3] Asaumi, J., H. Kamiaka and Y. Yamazaki, 1999, Properties of cement made from sewage sludge as raw materials, Inorgnic Materials, 6(Jul.), 268~275.

[4] Park, Y. S., 1994, Incineration characteristics of sludge wastes in a fluidized bed incinerator, J. Kor. Solid Wastes Eng. Soc., 11(3), 347~358.

[5] Won, Y. S., C. H. Lee and S. P. Choi, 1997, Characteristics of composition and incineration of sewage sludge, J. Kor. Solid Wastes Eng. Soc., 14(1), 43~53.

[6] Tanaka, H., T. Suzuki, T. Yoshigae, N. Takehana and T. Kasai, 1993, Producing crystallized slag from sewage sludge ash, R & D Kobe Steel Eng. Reports, 43(2), 17~20.

[7] Takahashi, H., S. Asada, S. Takahashi, S. Ishida, N. Takeuchi and M. Wakamatu, 1997, Formation mechanism of black core in

sintered red brick using incinerated ash of sewage sludge, J. Soc. Mat. Sci., Japan, 46(7), 834~838.

[8] Sakai, S. and M. Hiraoka, 2000, Municipal solid waste incinerator residue recycling by thermal processes, Waste Management, 20, 249~258.

[9] Takeda, N., M. Hiraoka, S. Sakai, K. Kitai and T. Tsunemi, 1989, Sewage sludge melting process by coke-bed furnace : System development and application, Wat. Sci. Tech., 21, 925~935.

[10] Yasuhiro, Y., 1991, Sewage sludge utilization technology in Tokyo, Water Pollution Research and Control Water Science and Technology, 23(10-12), 1743-1752.

[11] Nobuyuki, T., T. Hidenori, I. Shingo, T. Shiro and W. Mitsuru, 1999, Effect of firing atmosphere on extraordinary expansion of sintered brick from incinerated ash of sewage sludge, J. Ceramic Soc. Japan, 107(1246), 551-554.

[12] Hidenori, T., A. Shinji, T. Shiro, I. Shingo, T. Nobuyuki and W. Mitsuru, 1997, Formation mechanism of block core in sintered red brick using incinerated ash of sewage sludge, J. Soc. Mater. Sci., Japan, 46(7), 834-838.

[13] Sakai, S., M. Hiraoka, N. Taketa and T. Tsunemi, 1990, Sewage sludge meeting process: Preliminary system design and full-scale plant study, Water Sci. and Tech., 22, 329-338.

[14] Bergs, C. G., K. H. Linder, 1997, Sewage sludge use in the Federal Republic of Germany, European Water Pollution Control, 7(2), 47-52.

[15] Seier, J., 1999, Small and medium sized incineration facilities, Korea-Germany Environmental Technology Seminar, 167-184.

[16] Crannell, B. S., T.T. Eighy, J. E. Krzanowski, J. D. Eusden Jr., E. L. Shaw and L. A. Francis, 2000, Heavy metal stabilization in municipal solid waste combustion bottom ash using soluble phosphate, Waste management, 20, 135~148.

[17] Eighmy, T. T., B. S. Crannell, J. R. Krzanowski, J. D. Eusden, I. G. Butler, F. K. Cartledge, E. Emery, E. L. Shaw and C. A. Francis, 1996, Abstract ANYL 186, 211th ACS National Meeting, New Orleans(LA), 24~28.

[18] Eighmy, T. T., B. S. Crannell, J. R. Krzanowski, J. O. Eusden, L. G. Butler, F. K. Cartledge, E. Emery, E. L. Shaw and C. A. Francis, 1996, Abstract 169, 70th Colloid and Surface Science Symposium, Clarkson University, Postan(NY), 16~19.

[19] Laperche, V., P. Gaddam and S. T. Traina, 1996, Abstract GEOC087, 211th AES National Meeting, New Orleans(LA), 24~28.

[20] Wright, J., J. Conca, T. Moody and X. Chen, 1996, Abstract GEOC088, 211 ACS National Meeting, New Orleans(LA), 24~28.

[21] Nriagu, J. O., 1984, Formation and stability of base metal phosphates in soils and sediments. Ini Nriagu J. O., P. B. Moore, editors. Phosphate minerals. Berlin: Springer-Verlay, 318~329.

[22] Nriagu, J. O., 1974, Lead orthophosphates, Ⅳ ; Formation and stability in the environment, Geochim Cosmochim Acta, 38, 887.

[23] Santillan-Moohano, J. and J. J. Jurinak, 1975, The chemistry of lead and cadmium in soil; solid phase formation, Soil Sci. Soc. Amer. Proc., 39, 851.

[24] Kang, J. T. and G. H. Jeong, 2000, The removal of heavy metals in aqueous solution by hydroxyapatite, J. Korean Environ. Sci. Soc., 9(4), 325~330.