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Recycling of MSW Incineration Ash by Clay Mixing and Baking Treatment

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Abstract: Municipal solid waste (MSW) incineration bottom ash and soft clay are expected to be used as a composite geomaterial in mechanical and environmental points of view. In this study, a solidification material is developed by mixing clay with MSW incineration bottom ash and baking treatment. Mechanical and leaching properties of the baking solidification material are clarified from the experiments. Furthermore, based on the calculation of CO_2 emission of the solidification material, the recycling efficiency is discussed.

1 INTRODUCTION

Recently, recycle of waste materials has become one of important problems which should be solved in geotechincal engineering. Large amount of municipal solid waste (MSW) is generated and about 80% of them are incinerated, so that the lack of space in landfill sites is serious problem in Japan. Recycling rate of the incineration bottom ash is very low and the reuse as a geomaterial is required. Mixture of MSW incineration bottom ash and soft clay with adsorption ability is considered to decrease the environmental impact such as leaching of heavy metals and become a useful material in mechanical and environmental points of view.

In this study, a solidification material is developed by mixing clay and baking treatment for insoluble of heavy metals and this method is applied to MSW incineration bottom ash (Omine et al., 2002). Leaching test and unconfined compression test are performed and the chemical and mechanical properties of the solidification material are clarified. Emission of CO_2 for the solidification material is also calculated from a viewpoint of life cycle assessment (LCA) and environmental load in a recycle of MSW incineration bottom ash is discussed.

2 LEACHING PROPERTY OF BAKING SOLIDIFICATION MATERIAL FOR HEAVY METALS

2.1 *Samples and Test Method*

Used samples are artificially contaminated soil and Ariake clay. The contaminated soil was made by adding two kinds of heavy metals, Pb and Cd, in Toyoura sand. Maximum release of each heavy metal was adjusted at 10ppm. After drying in the laboratory condition during 24 hours, the contaminated soil was mixed with Ariake clay and the mixture was baked under various temperatures up to 1000°C by using heating furnace. For making clear the effect of insoluble treatment, leaching test in Notification No. 46 of the Japan Environmental Agency was performed on the contaminated soil and the baking solidification material crushed in less than 2mm. In addition, MSW incineration bottom ash being in high alkali condition is assumed here and the solution is controlled in pH=12. Mass of released metals in the leaching test is measured using ICP Mass Spectrometer.

2.2 *Insoluble Effect of Heavy Metals on Contaminated Soil*

Figure 1 shows an influence of baking temperature on the relationship between total mass of released metal and clay content. Insoluble effect of Pb is not found for the baking solidification material without clay (clay content =0%). However, total mass of released Pb decreases remarkably by mixing clay. For example, it is possible to restrain Pb from releasing in the level of about 1/50 at 500°C and about 1/1000 at 1000°C. The baking effect increases as the temperature increases, and it becomes almost constant at the clay content of more than 10%. This tendency of insoluble treatment is also confirmed for Cd.

When MSW incineration bottom ash is reused, release of heavy metal such as lead or cadmium should be controlled in less than environmental standard at least. It is considered that this method by mixing clay and baking treatment is effective for the insoluble of the incineration bottom ash containing heavy metals.

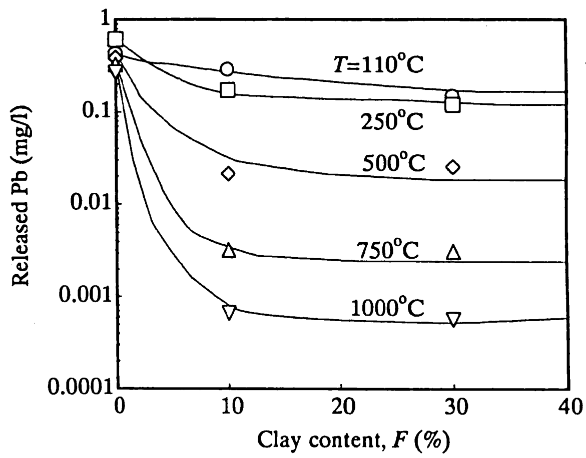

Fig. 1. Relationship between released Pb and clay content.

3 UTILIZATION OF MSW INCINERATION BOTTOM ASH

3.1 *Samples and Test Method*

MSW incineration bottom ash with soil particles of less than 2mm is prepared as a sample and Ariake clay with water content of 170% is used as mixing clay. Physical and chemical properties of the samples are shown in Table 1. Compression process is added for increases of densification and adhesion before baking treatment. At first column specimen in diameter of 20mm is made by compressing mixture of the incineration bottom ash and Ariake clay in rigid mold. This compression process is completed by applied stress of 29.4MPa during 10 minutes using manual hydraulic pump. Solidification material with clay content, F=10 or 30% in percentage of dry weight, is made by baking the mixture during 1 hour under the temperatures of 110, 250, 500 750 and 1000°C.

Leaching test on the solidification material is conducted for measuring values of pH and EC. Unconfined compression test is also conducted in both conditions of submergence and non-submergence. Submergence condition in water is maintained during more than 1 day.

3.2 *Physical and Chemical Properties of Solidification Material*

Relationship between pH and baking temperature on the solidification material is shown in Table 2. The value of pH becomes smaller than that of MSW incineration bottom ash. EC of solidification material decreases in less than a half of the incineration bottom ash. In addition, the effect of decreasing pH and EC becomes relatively high when clay content and baking temperature increase.

Table 1. Physical and chemical properties of samples.

	Ariake clay	MSW incineration bottom ash
Soil particle density (g/cm^3)	2.54	2.43
Liquid limit (%)	105.2	-
Plastic Index	57.8	NP
Initial water content (%)	170	-
pH	8.4	12.7
Electric conductivity *EC* (mS/cm)	0.94	10.7
Ignition loss (%)	9.5	12.43

Table 2. Measured values on pH and EC of solidification material.

Baking temperature,	*pH*		*EC* (mS/cm)	
	F (%)		*F* (%)	
T (°C)	10	30	10	30
110	12.08	11.50	3.60	2.40
250	11.74	11.54	3.30	2.40
500	10.66	10.38	3.10	2.30
750	11.94	11.10	2.50	2.00
1000	11.60	11.01	1.78	1.24

Figure 2 shows a change of dry density of the solidification material at different baking temperatures. The specimen is in a dense state before baking, because it takes a process of high compressive stress. Dry density of the solidification material decreases so that moisture and organic component included in the clay are removed when it is baked. The decrease of dry density becomes much higher as the temperature rises and it is lightweighted up to ρ_d=1.5g/cm^3. The dry density of solidification material with clay content of 10% becomes small so that the percentage of clay particles in void of the incineration bottom ash becomes small when clay content is small. It is therefore expected that the baking solidification material is used as a lightweight geomaterial.

3.3 *Mechanical Property of the Solidification Material*

Relationship between the unconfined compressive strength and baking temperature is shown in Fig. 3. When the baking temperature is low, unconfined compressive strength of the solidification material decreases extremely after submerged. It is considered that, in the condition of low temperature, the strength maintained temporarily by the compression process was lost by submergence. In other words, it seems that the clay had not been solidified sufficiently. Moreover, the high strength is not obtained for the so-

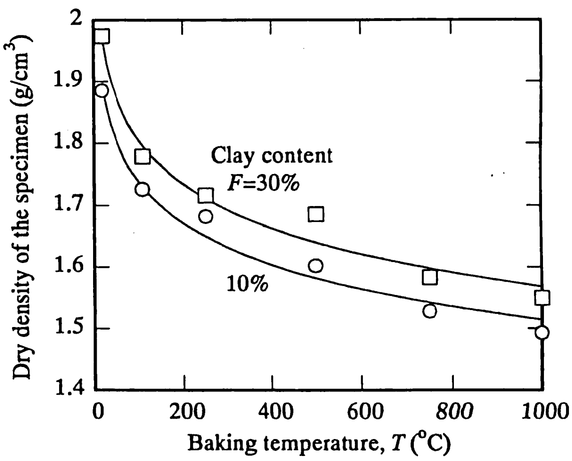

Fig. 2. Relationship between dry density and baking temperature.

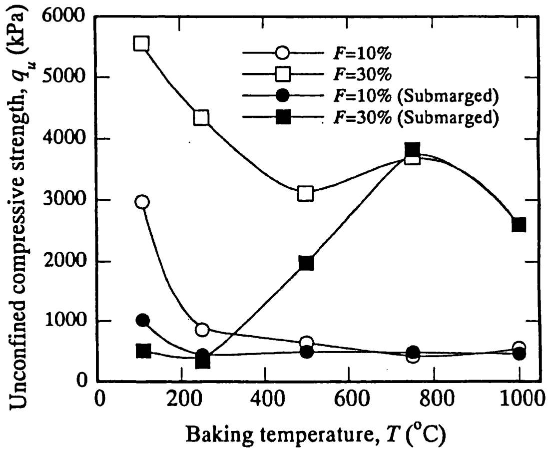

Fig. 3. Relationship between unconfined compressive strength and baking temperature.

lidification material with clay content of 10% even if the baking temperature is high. However, as shown in this figure, the unconfined compressive strength more than 1000kPa can be expected for the solidification material with clay content of 30% and over 400°C of the baking temperature in the submerged condition. It is therefore possible to make the solidification material with lightweight and high strength by this method.

4 EVALUATION OF ENVIRONMENTAL LOAD BASED ON LIFE CYCLE ASSESSMENT

4.1 *Fundamental Concept of LCA*

In the evaluation of environmental load by life cycle assessment (LCA), the following items are considered mainly;

i) Setting of aim and search extent,
ii) Inventory analysis,
iii) Affect assay,
iv) Interpretation of consequence,

where inventory analysis is an item to collect environmental load data and to calculate the impact in a whole life cycle. Although it is better to consider various factors in the affect assay, conventional evaluation method has not been established yet. A lot of data concerning emission of CO_2 is accumulated and the inventory analysis based CO_2, which is called as $LCCO_2$, has been widely used (e.g. Nakamura et al., 2002 or Noda et al., 2001)

As for construction of civil engineering structure, the extent of calculation for the environmental load is generally as follows;

a) Consumption of material,
b) Transportation of material and machine,
c) Construction,
d) Maintenance and patching,
e) Dismantling and disposal.

It is difficult to obtain all precise data concerning environmental load, so that it is important to consider relevantly search extent and collection of main data.

4.2 *Application of $LCCO_2$*

When a waste material is recycled, it is important to evaluate environmental load for recycling material. In this study, $LCCO_2$ is applied to recycling of MSW incineration bottom ash for baking solidification material. Manufacturing flow chart for the solidification materials is shown in Fig. 4. As mentioned above, the solidification material is made in the process of mixing clay and the incineration bottom ash, compression and baking treatment. This method enables to reduce the release of heavy metal from the incineration bottom ash and to make lightweight material. The solidification material with crushing and grading is used as a geomaterial.

Table 3 shows the result of inventory analysis. Emission of CO_2 is calculated for the recycling process of the incineration bottom ash of 1kg. Because MSW ash is common item, CO_2 caused by it is not included. It is assumed that CO_2 unit of clay in a resource is almost same as that of gravel or quarrying stone in which the unit has been already reported. It is assumed that the solidification material is made by mixing clay with water content of 100% in clay content of 30% for total dry weight of the incineration bottom ash. In this condition, the mixing rate of the incineration bottom ash and clay is 1: 0.86 in a weight. It was assumed that the clay is transported from a distance of 20km and the fuel is consumed. CO_2 unit per hour in mixing process was calculated for a small mixing machine with power consumption of 0.75kW and a capacity of 5kg as a mixture (the incineration ash of 4kg). Compression machine and crusher with same efficiency are used. Moreover, in the baking process, small electric furnace with power consumption of 0.5kW can bake the incineration ash of 1kg and it is also assumed that the power consumption is in proportion to temperature. The values of other CO_2 unit were referred to the publication value of LCA subcommittee in Japan Society of Civil Engineers. In addition, because this is a system with much consumption of energy and the environmental load on depreciation of construction services and machine is small relatively, the environmental load for the depreciation is not considered here. Emission of CO_2 in each item is estimated by multiplied the unit and the quantity. Therefore, a total emission of CO_2 of the manufacturing process is calculated by adding the value of CO_2 in each item.

Emission of CO_2 in the solidification material depends on the baking temperature. It is indicated that CO_2 emission in the solidification material increases with increase of the baking temperature. This estimation value is obtained for using small machines in laboratory and it is considered that the value decreases for using large-scale machines efficiently.

4.3 *Evaluation of Recycling Efficiency*

In order to evaluate a recycling efficiency of solidification material, a rate of environmental load causing by CO_2 emission is defined as follows,

$$\alpha_E = \frac{\text{Environmental cost with } CO_2 \text{ emission}}{\text{Waste disposal cost}} \times 100\ (\%) \quad (1)$$

Representative values of environmental cost and waste disposal cost are indicated in Table 4. The environmental cost is obtained from carbon tax and it has been already introduced in European countries. The carbon tax of 11,000 yen/t-C was selected in a relatively low value. Disposal cost means total waste disposal cost. Because the solidification material is made by mixing MSW incineration bottom ash and usual clay or waste clay, the total waste disposal cost depends on the type of wastes and mixing clay and the combination percentage.

Results on the calculation of recycling efficiency are shown in Table 5. The rate of environmental load was calculated in three

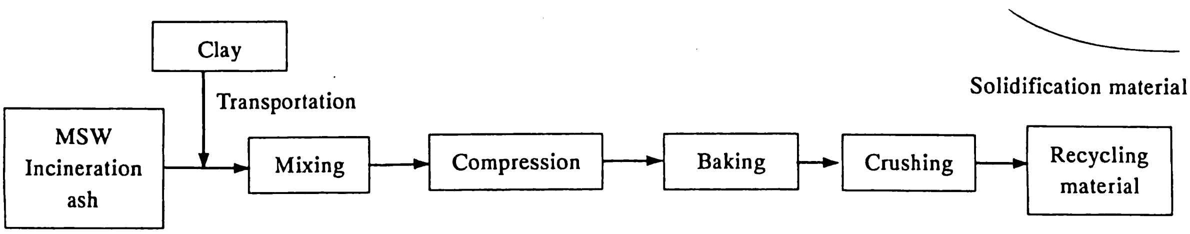

Fig. 4. Manufacturing flow chart of recycling materials.

e 3. Result of inventory analysis.

Item	$LCCO_2$ Unit (kg-C/Unit)	Unit	Amount	CO_2 Emission (g-C)
MSW ash	-	kg	1	
Clay	0.001	kg	0.86	0.86
Transportation	0.093	t·km	0.017	1.58
Mixing machine	0.0242	h	0.17	4.11
Compression machine	0.0242	h	0.17	4.11
Heating furnace	0.0645×T/1000	h	1.00	0.0645×T
Crushing machine	0.0242	h	0.10	2.42
	Total CO_2 emission (g-C)		13.08+0.0645×T	

T: Baking temperature (°C)

Table 4. Representative values of cost for calculation of recycling efficiency.

Environmental load	Carbon tax
(a) CO_2 emission	11,000 yen/t-C
Type of wastes	**Disposal cost**
(a) construction surplus soil	2,000 yen/t
(b) waste of stabilized type	6,000 yen/t
(c) waste of controlled type (MSW ash, waste slurry etc.)	15,000 yen/t

ble 5. Calculation results of recycling efficiency.

	Type of mixing clay	Weight of MSW ash	Weight of mixing clay	Baking temperature	CO_2 emission	Environmental cost with CO_2	Waste disposal cost			Rate of environmental load, α_E
							MSW ash	Mixing clay	Total	
		(t)	(t)	T (°C)	(kg-C)	(yen)	(yen)	(yen)	(yen)	(%)
e-1	Usual clay	1	0.86	400	38.88	428	15,000	0	15,000	2.9
		1	0.86	600	51.78	570	15,000	0	15,000	3.8
		1	0.86	800	64.68	711	15,000	0	15,000	4.7
e-2	Construction surplus soil	1	0.86	400	38.88	428	15,000	1,720	16,720	2.6
		1	0.86	600	51.78	570	15,000	1,720	16,720	3.4
		1	0.86	800	64.68	711	15,000	1,720	16,720	4.3
e-3	Waste slurry	1	0.86	400	38.88	428	15,000	12,900	27,900	1.5
		1	0.86	600	51.78	570	15,000	12,900	27,900	2.0
		1	0.86	800	64.68	711	15,000	12,900	27,900	2.6

s of usual clay, construction surplus soil and waste slurry for ing clay. Emission of CO_2 was estimated from the results of ntory analysis in Table 3. Although the rate of environmental increases with increase of baking temperature in each case, value becomes small in the case of mixing clay with high disl cost under the same temperature. However the rate of environmental load calculated in these conditions is less than 5 %. It ns that this value becomes much larger by considering various environmental loads not only CO_2 emission.

CONCLUSIONS

following main conclusions were obtained from this study.
solidification material is developed by mixing clay and baking treatment and it is effective for reducing release of heavy etals.
t is possible to make the solidification material with lighteight and high unconfined compressive strength more than)00kPa in the condition of clay content of 30% and baking mperature over 400°C.
O_2 emission is calculated in the recycling process for the solification material under the consideration of LCA.
he rate of environmental load with CO_2 emission is obtained and the recycling efficiency of MSW incineration bottom ash is made clearly.

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