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Waste Materials in Construction: Putting Theory into Practice

Overview of MSWI residue Recycling by Thermal Processes

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Abstract

The melting technology reduces the volume of incinerator residues, bottom ash and fly ash, making the melted slag stable and non-toxic. Moreover, this type of treatment allows the melted slag to be used as a resource again. In Japan, the melting process was developed in the 1980's and has been in practical operation at around 24 municipal solid waste (MSW) incineration facilities including scheduled ones. By the melting process, PCDDs/PCDFs in residues are decomposed at temperature of approximately 1,400°C in the furnace and heavy metals are concentrated in the fly ash of melting process. The drafting of an 'effective reuse manual' is introduced, aiming at promoting the safe reuse of incinerator residues, by setting reprocessing technologies, reuse standards and their evaluation methods.

1. Introduction

The gross amount of municipal solid waste (MSW) generated annually in Japan is approximately 50 million tons. Approximately 71.2% of this MSW is incinerated, producing approximately 6 million tons of residue which is then landfilled, with leachate control. Recently it has become more and more difficult to secure landfill locations, particularly in urban areas. Consequently, reducing the volume of incinerated MSW ash and looking for ways in which to reuse residues, are urgent targets to be developed.

Fly ash produced during MSW incineration is classified as "general wastes requiring special controls." One of the following four treatment methods must be applied to the generated fly ash: 1) melting and solidification, 2) solidification with cement, 3) stabilization using chemical agents or 4) extraction using acid or other solvents. The melting technology reduces the volume of incinerator residues, bottom ash and fly ash, making the melted slag stable and non-toxic. Moreover, this type of treatment allows melted slag to be used as a resource again.

The melting operation works by keeping the temperature at approximately 1,400℃ in a high-temperature furnace by electricity or by the combustion of fuel. After the residues' physical and chemical state changes, they are cooled in order to solidify it again. In this way, the mass and volume of the residues is greatly reduced, producing a high-density melted product. By melting the residues at such a high temperature and with the change in physical and chemical state, it is possible to produce a melted slag with high stability. However, this technology needs to be improved in certain areas, e.g. reducing the rate of repairing refractory materials, and improving control technology to ensure stable operation of high-temperature melting.

The melted-solidified slag can be used as construction material, such as for roads, and is also a useful material in land reclamation, since the bulk of the material is reduced by half to one-third of the original incinerator ash. Another advantage of this method relates to the fact that incinerator fly ash contain hazardous substances such as heavy metals, which can cause problems when they leach out into waterways. By this process of melting and solidification, metallic compounds are stabilized in the 'molecular' structure of the waste product, thereby preventing them from leaching out and dispersing into the surrounding environment.

2. Melting Technology

2.1 Present Status of Melting Process Development [1, 2)]

In Japan the sewage sludge melting process was developed in the 1980's and has been in practical operation at around 10 full-scale plants. [3), 4)] In some plants being operated MSW fly ash, along with bottom ash, is melted. The first melting plants used thermal surface melting furnaces,

electric arc-type and coke-bed type melting furnaces. Since then new melting technologies such as plasma melting furnaces, electric resistance melting furnaces and low frequency induction furnaces have been developed and put into practice. At present, 24 municipal solid waste incineration melting-treatment facilities (including scheduled ones) which use the system are shown in **Table 1**. Some of the systems are still at the trial stage of operation. Each company is, however, making efforts to proceed in their research and development and to bring their technology to the marketplace. Melting technology is almost at a feasible stage.
Fusion or vitrification of MSW incinerator residues is not practiced in Europe and North America 5), but detoxification of thermal filter ash has been under development 6).

Table 1 Full-Scale Melting Plants of MSW Incinerator Residues in Japan

	Municipalities	Completion	Capacity ton/d	Unit No.	Manufacturer	Furnace type
1.	Numadzu City	08/1979	20	1	Kubota	Rotating surface
2.	Kashima Town	06/1981	6.5/8h	1	Takuma	Surface melting
3.	Eastern Saitama 2	03/1985	14.4	2	Takuma	Surface melting
4.	Eastern Saitama 1	03/1986	15	2	Takuma	Surface melting
5.	Isahaya City	03/1987	12.3	1	Kubota	Rotating surface
6.	Sayama City	03/1991	15	1	Kubota	Rotating surface
7.	Tokyo Ota	04/1991	250	2	Daido	Electric arc
8.	Anan City	10/1991	4.8	2	Takuma	Surface melting
9.	Handa City	02/1993	24	1	Ebara	Plasma
10.	Omiya City	03/1993	75	1	Daido	Electric arc
11.	Matsuyama City	03/1994	52	1	Ebara	Plasma
12.	Sakado City	07/1994	9.6	1	Takuma	Surface melting
13.	Shirane Regional Center	10/1994	7/16h	1	Kubota	Rotating surface
14.	Tokai City	03/1995	15	1	Nippon Steel	Coke bed
15.	Abiko City	03/1995	10	1	Hitachi Zosen	Surface melting
16.	Eastern Saitama, New 1	09/1995	80	2	Daido	Electric Arc
17.	Kinuura regional center	09/1995	15	2	I.H.I	Coke bed
18.	Sayama City	03/1996	15	1	Takuma	Surface melting
19.	Mima regional center	03/1997	5/16h	1	Kobe Steel	Plasma
20.	Hachioji City	03/1998	18	2	NKK	Electric Joule
21.	Tamagawa regional	03/1998	25	2	Daido	Electric Arc
22.	Togane City	03/1998	26	1	Takuma	Surface melting
23.	Kamo regional center	03/1999	30	2	Hitachi Zosen	Plasma
24.	Yokohama City	03/2001	60	1	NKK	Electric Joule

2.2 Principles of the Melting Systems

At present there are a variety of furnace melting systems that have been developed and are being put into practice. These systems can be divided roughly into two categories: one uses fuels as an energy source and the other uses electricity. The systems can be further classified as follows:

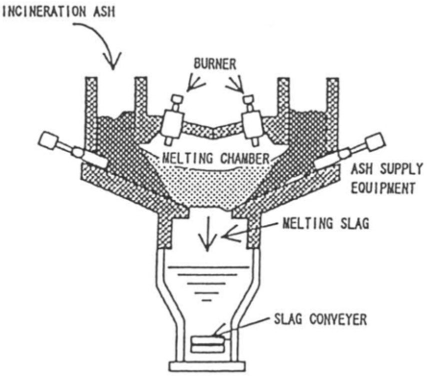
(1) <Fuel-burning melting system>
  o Surface melting furnaces
  o Swirling-flow melting furnaces
  o Coke-bed melting furnaces
  o Rotary kiln melting furnaces
  o Internal melting furnaces
(2) <Electric melting systems>
  o Electric-arc melting furnaces
  o Electric resistance melting furnaces
  o Plasma melting furnaces
  o Induction melting furnace (High-frequency, Low-frequency)

Some of the fuel-burning melting systems, e.g., coke-bed melting and rotary kiln melting, can not only melt the incineration residues, but can also directly melt MSW.
Each of the nine kinds of systems listed has its own particular characteristics. At this stage it is

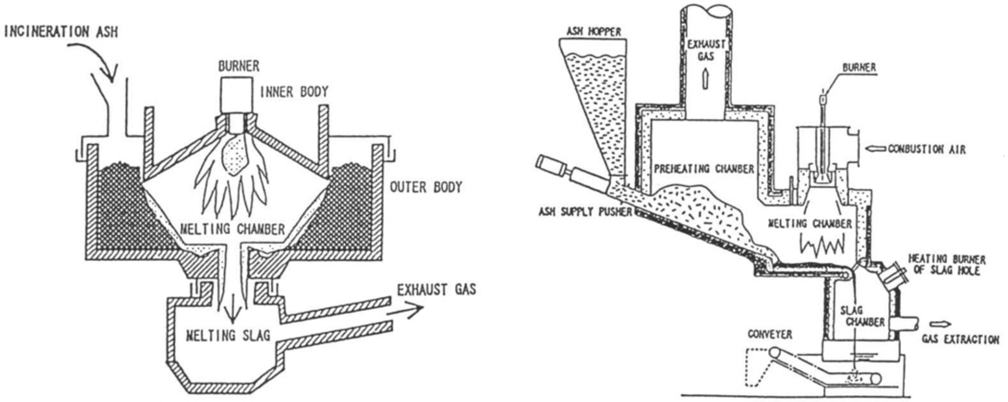
not possible to say clearly which system is the best. It is most important to use the most appropriate system for the particular conditions of each municipality, or to select a system according to a priority setting. Generally, in the case of a large incinerator with a power generation facility, the electric melting system, which can make use of the recovered electric power, can be selected. In case of a comparatively small incinerator without power a generation facility, the fuel-burning melting system will be selected.

2.3 Surface Melting

This is one of the fuel burning-type melting systems. It uses heavy oil, kerosene or gas as the fuel. The structure of the furnace consists of an ash feeding device, main body and burner, as indicated in **Fig. 1** [7, 8, 9]. One type of design has a pair of furnaces with the two systems facing each other. In another design, the furnace itself consists of an outer body and an inner body, with the outer body rotating. The surface melting furnace works in such a way that continuously-supplied incinerator residues melt from the surface by the heat of the fuel burning. It is then discharged via the outlet port. In this way, the melted slag hardly touches the furnace body directly, and the incinerator residues themselves act as an insulator to protect the furnace body. This type of furnace has a rather large exhaust gas volume and is more suitable for the comparatively small capacity range.



(a) Fixed bed type I



(b) Rotating type

(c) Fixed bed type II

Fig. 1 Structures of Surface Melting Furnace [7, 8]

2.4 Electric Arc Melting

The structure of an electric-arc melting furnace is shown in **Fig. 2** 10). It consists of the furnace body, lined with refractory lining, an artificial graphite electrode which penetrates to the inside of the furnace, a power supply to feed electricity, an inlet for the entry of the residues, an exhaust and an outlet port. This type of melting furnace works by the application of alternating current to the electrode, which is arranged so as to generate an arc discharged inside the furnace. The heat produced by arcing causes the residues on the metal base to melt. The arcing generates such a high temperature that even residues containing metal can be melted evenly within a short time. The melted slag is removed continuously via the outlet port. It is quenched with water and taken out by conveyor. Any components in the incinerator residues are burnt completely in this type of furnace, and are then removed by the exhaust gas. The atmosphere in this furnace is oxidative. This technology has been applied in the field of steel making.

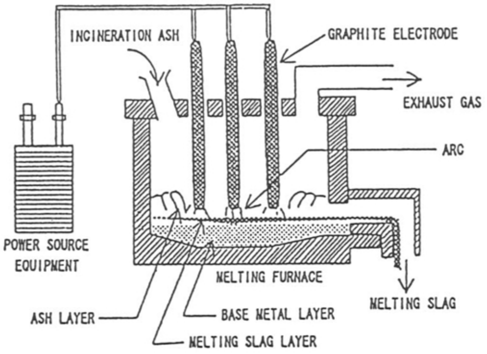
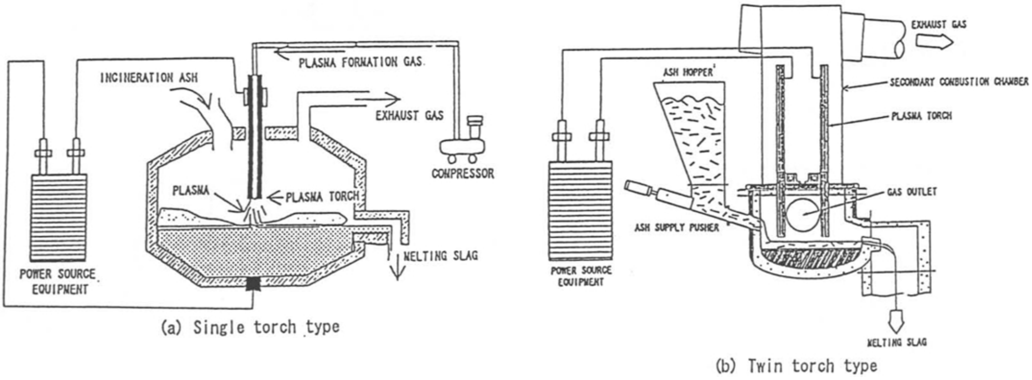


Fig. 2 Structure of Electric Arc Melting Furnace 10)

2.5 Plasma Melting

This is another type of furnace that uses electricity to melt the incinerator residues. The structure of the furnace is shown in **Fig. 3** 11, 12). It consists of the surface body, with refractory lining, plasma torches, and a power supply system. There are a variety of plasma torch designs in use, made by the different manufacturers, and each has its specific character. This type of furnace works as follows: first it makes an arc discharge at the electrode inside the plasma torches. This is then passed through the plasma formation gas (air or inert gas) to produce a high-temperature plasma. This plasma is then directed to the incinerator residues by being continuously supplied into the melting furnace. In this furnace there are two types of atmosphere, oxidation and reduction. The melted slag is continuously removed through the outlet port.



(a) Single torch type

(b) Twin torch type

Fig. 3 Structures of Plasma Melting Furnace 11, 12)

3. Behavior of Heavy Metals and PCDDs/PCDFs in the Melting Process

3.1 Standard Leaching Tests

Leaching of heavy metals from the slag was evaluated using the standard leaching tests defined in Notifications No.13 and No.46 of the Environment Agency (JLT13, JLT46) in **Table 2**. Some points about the standard leaching tests are discussed in the next section. A typical analytical result is shown in **Table 3**. All of the specified substances in the slag leachate were either non-detectable or below the detection limit, demonstrating that the slag satisfies the environmental standards.

In addition, the very low leaching of lead, which has recently become a problem in the effective utilization of recycled materials, is one of the remarkable features of this process.

Table 3 Leaching Test Results for MSW Incinerator Residues and Melted Slag 13)

Sample	Fluidized bed furnace fly ash		Stoker furnace fly ash		Molten slag (hydropulping)		Minimum limit of determination
Item	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l
pH	12.3	-	6.8	-	9.3	-	-
Cadmium, Cd	0.01>	0.1>	33.5	335	0.01>	0.1>	0.01
Lead, Pb	28.3	283	10	100	0.01>	0.1>	0.01
Hexavalent chromium, Cr^{6+}	0.04>	0.4>	0.2>	2>	0.02>	0.2>	0.02
Arsenic, As	0.01>	0.1>	0.01>	0.1>	0.01>	0.1>	0.01
Mercury, Hg	0.0005>	0.005>	0.0005>	0.005>	0.0005>	0.005>	0.0005
Cyanogen, CN	0.1>	1>	0.1>	1>	0.01>	0.1>	0.01
Selenium, Se	0.01>	0.1>	0.01>	0.1>	0.01>	0.1>	0.01
Alkylmercury, R-Hg	0.0005>	0.005>	0.0005>	0.005>	0.0005>	0.005>	0.0005
Organophosphorus, Org-P	0.01>	0.1>	0.01>	0.1>	0.01>	0.1>	0.01
PCB	0.0005>	0.005>	0.0005>	0.005>	0.0005>	0.005>	0.0005
Thiram	0.006>	0.06>	0.006>	0.06>	0.006>	0.06>	0.006
Simazine	0.003>	0.03>	0.003>	0.03>	0.003>	0.03>	0.003
Thiobencarb	0.02>	0.2>	0.02>	0.2>	0.02>	0.2>	0.02
Trichloroethylene	*	*	0.03>	0.3>	0.03>	0.3>	0.03
Tetrachloroethylene	*	*	0.01>	0.1>	0.01>	0.1>	0.01
Dichloromethane	*	*	0.02>	0.2>	0.02>	0.2>	0.02
Carbon tetrachloride	*	*	0.002>	0.02>	0.002>	0.02>	0.002
1,2-dichloroethane	*	*	0.004>	0.04>	0.004>	0.04>	0.004
1,2-dichloroethylene	*	*	0.002>	0.02>	0.02>	0.2>	0.02(0.002)
Cis-1,2-dichloroethylene	*	*	0.004>	0.04>	0.04>	0.4>	0.04(0.004)
1,1,1-trichloroethane	*	*	0.03>	0.3>	0.03>	0.3>	0.03
1,1,2-trichloroethane	*	*	0.006>	0.06>	0.006>	0.06>	0.006
1,3-dichloropropene	*	*	0.002>	0.02>	0.002>	0.02>	0.002
Benzene	*	*	0.001>	0.01>	0.01>	0.1>	0.01(0.001)
Zinc, Zn	5	50	850	8500	0.1>	1>	0.1
Copper, Cu	1>	10>	1>	10>	0.1>	1>	0.1
Chloride ion, Cl	9530	95300	9500	95000	2	20	1
Electric conductivity mS/m	3580	-	3630	-	4.48	-	-

3.2 Behavior of Heavy Metals

(1) Behavior and Mass Balance of Metals 1, 9)

Inorganic compounds like metallic elements, especially in fly ash, are redistributed after the melting treatment according to the boiling temperature. It is considered that metals with high boiling points like Si, Al and Ca, are converted into slag and substances with low boiling points like Cd and Pb are converted into fly ash or melting furnace exhaust gas. As shown in **Table 4**, the concentrations of heavy metals with low boiling points like Cd and Pb in ESP ash from melting furnaces are 5 to 10 times higher than those of fly ash. Based on this analysis, the flow rate of flue gas and the quantity of solids formation, the mass balance and the transfer rate of each constituent are shown in **Table 5,** assuming the input to be 100. SiO_2, Al_2O_3, CaO, Fe, Mg, Mn, T-P, TiO_2, T-Cr and Cu indicate high transfer rates into slag. In contrast, Cd and Pb volatilize into flue gas and are finally concentrated into ESP ash from melting furnace. Na, K, T-S , T-Cl, As and

Table 2. Leaching Test Methods

Test name	Environmental Agency Notification No. 13 (Note 1)	Environmental Agency Notification No. 46 (Note 1)	Ministry of Health and Welfare Tentative draft of slag test (Note 2)	Ministry of Construction Tentative draft of CO_2 method	Availability test (NEN 7341)	pH dependency test (Author et al's commonly used method)	TCLP (EPA Method 1311)
Leaching vessel	Unspecified	Unspecified	Airtight bottle (CO_2 method) or beaker (pH-static method), (1L polyethylene bottle or 1L glass beaker)	Unspecified (1L glass beaker at this test)	1L beaker	1L beaker at this test	Any material compatible with waste, zero-head space container
Sample	< 5 mm	< 2 mm	10-30 mm	20-50 mm (< 50 mm: uncrushed)	< 125 μm	Uncrushed (fly ash, hydropulped slag)	< 9.5 mm
Sample mass	> 50 g	> 50 g	> 50 g	> 50 g	16 g	50 g at this test	100 g
Solvent	Distilled water (Adjusting to pH 5.8-6.3 by HCl or NaOH)	Distilled water (Adjusting to pH 5.8-6.3 by HCl)	1) pH 4, CO_2 saturated water (CO_2 method) 2) Adding HNO_3 to deionized water, and keeping the 1st elution pH 7 and the 2nd one pH 4. (pH-static method)	pH 4 through the way of 20 min-bubbling of deionized water by CO_2 gas.	Adding HNO_3 to deisonized water, and keeping the 1st elution pH 7 and the 2nd one pH 4.	- At this test, distilled water and HNO_3 or NaOH - Using solvent different in acidity (alkalinity) or keeping the leachate a certain pH	1) Acetic acid buffer solution (pH 4.93) 2) Acetic acid solution (pH 2.88) (Note 4)
L/S ratio	10 : 1	10 : 1	10 : 1 (5 : 1 x 2)	10 : 1	100 : 1 (50 : 1 x 2)	10 : 1	20 : 1
Leaching frequency	1	1	1 (CO_2 method), 2 (pH-static method) (Note 5)	1	2 (Note 5)	1	1
Agitation	Horizontal shaking (200 times/m, amplitude: 4-5 cm)	Horizontal shaking (200 times/m, amplitude: 4-5 cm)	- Horizontal shaking, 200 times/m, amplitude: 4-5 cm (CO_2 method) - Stirring and splashing (pH-static method)	Stirring and splashing (200 rpm)	Stirrer	Stirrer	Rotating and shaking (30 ± 2 rpm)
Duration	6 hours	6 hours	24 hrs (CO_2 method), 3 hrs x 2 (pH-static method)	24 hours	3 hours x 2	23 hours at this test	18 hours
Filtration	1 μm GFP	After 20 min centrifugal separation at 3000 rpm, 0.45 μm MF	0.45 μm MF	After 20 min-centrifugal separation at 3000 rpm, 0.45 μm MF	0.45 μm MF	At this test, 0.45 μm MF	0.6 - 0.8 μm GFF
Temperature	Ordinary (approx. 20℃)	Ordinary (approx. 20℃)	Ordinary (approx. 20℃)	Ordinary (approx. 20℃)	Ordinary	Ordinary	22.3 ± 3℃

Note 1 For tri-, tetra-, 1,2-di- and cis-1,2-di-chloroethylene, dichloromethane, carbon tetrachloride, 1,2-di-, 1,1,1-tri- and 1,1,2-tri-chloroethane, 1,3-dichloropropene and benzene (volatile matters), an Erlenmeyer flask with screw cap (500 ml) was used. As for agitation, 4h-stirring by stirrer was implemented. Regarding filtration of elution, the filtrate was extracted by syringe and filter paper was attached to the syringe. This is the same method that is applied to the examination of volatile substances in sludge (Environmental Agency, notification no.13) or soil (Environmental Agency, notification no.46).

Note 2 Test in CO_2 method or in pH-static method is selected.

Note 3 pH targets at this test were 2, 4, 6, 8, 10, 12 and 13.

Note 4 Distilled water is added to the sample of 5 g and they are shaken for 5 min. pH is measured, the solvent of 1) is chosen if pH is over 5. If pH is below 5, 1.0 N HCl of 3.5 ml is added and 10 min-shaking is done at 50℃. If pH 5>, 1) is selected, and if pH 5<, 2) is used.

Note 5 New solvent is added to filter residues and the leaching operation is repeated.

Table 4 Compositions of Solid Materials

Item*		Fly ash	Slag	ESP ash from melting furnace
Moisture	%	0.56		
Heating Value	kcal/kg	580		
Ash	%	89.3		
Combustible	%	10.7		
C	%	5.9	<0.1	1.80
H	%	0.28	<0.1	<0.1
N	%	<0.01	<0.01	<0.01
Volatile-S	%	<0.1		
Volatile-Cl	%	<0.05		
O	%	4.5		
Total-S	%	0.56	0.33	1.8
Total-Cl	%	10.3	0.32	40.5
Si	%	11.3	14.2	<0.01
Ca	%	13.7	19.2	0.20
Al	%	5.4	7.5	<0.01
Na	%	2.1	0.7	17.8
K	%	2.1	0.3	13.8
Mg	%	1.5	2.1	0.01
Fe	%	1.5	2.1	0.38
P	%	0.67	0.96	<0.01
TiO_2	%	1.3	1.7	<0.01
Mn	%	0.06	0.09	0.02
Cd	mg/kg	46	3.0	420
Pb	mg/kg	1600	110	5000
Zn	mg/kg	4900	1200	5000
Cu	mg/kg	440	1300	2500
As		13	5.0	64
Total-Cr	mg/kg	400	1000	42
Total-Hg	mg/kg	2.7	0.13	1.6

* All data are on dry-solid basis except for moisture.

Table 5 Transfer Rate of Each Metal Component

Item	Inputs		Outputs				
	Fly ash from MSWI	NaOH	Slag	Dust in ducts	ESP ash from MF	Flue gas	Total
SiO_2	100		100	0.030	0.000		100
Al_2O_3	100		110	0.063	0.000		110
CaO	100		110	0.33	1.11		110
Fe	100		110	0.50	1.9		110
Mg	100		110	0.091	0.050		110
Mn	100		120	0.000	2.5		120
Na	87	13	21		55	0.20	110
K	100		11	29	49	0.17	77
T-P	100		110	17	0.000		110
T-S	100		46	0.000	24	0.51	91
T-Cl	100		2.5	20	29	8.2	50
TiO_2	100		110	10	0.000	0.00	110
T-Cr	100		200	0.054	0.78		200
Cu	100		230	0.30	42	0.16	290
Cd	100		5.2	17	68	0.24	93
Pb	100		5.4	20	70	0.24	93
As	100		30	7.3	37	0.00	74
Zn	100		19	9.7	38	0.12	67
T-Hg	100		3.8	1.3	4.4	22	31

Zn take the positions in the intermediate, which convert some parts into slag and some parts into dust, depending on their chemical forms. For the slag utilization and the resource recovery from the melting furnace fly ash, heavy metals have to be highly concentrated into melting furnace fly ash.

(2) Recycling of Melting Furnace Fly Ash as Resources

Melting furnace fly ash from melting process is produced about 4% of the total input in case of melted bottom ash only, and 6% to 10% in case of melted bottom ash with fly ash. Melting furnace fly ash contains a considerable amount of Pb and Zn. It is therefore necessary to take care of heavy metal stabilization and control in landfill. In the future the recycling of melting furnace fly ash should be chosen instead of its disposal. We are trying to use it as a non-ferrous smelting material. In any smelter all elements except target metal are treated as impurities, so it is not allowed to apply heavy duty to smelter for removing impurities. Halogens such as chlorine must be restricted to very low levels to prevent equipment corrosion problems. Therefore, resource recovering process should concentrate Pb and Zn separately and reduce the Cl content in the concentrated cake to the upper limit. Following is a kind of resource recovery process, that is the combination process of fly ash melting with bottom ash by furnace, and wet treatment system to recover Pb and Zn.

The 1st stage of the melting process adopts promotive evaporation in the furnace, chloridizing and vaporizing heavy metals by chloride in fly ash, cooling the exhaust gas, and collecting the condensate dust by using a bag filter.

The 2nd stage of wet treatment is shown in **Fig. 4** 10). Dust is mixed with acid solution, transferring Zn, Cu into a liquid state by separating non soluble Pb compounds by filter. The Zn, Cu are changed into hydroxide by neutralization, and then sulfured. After that they are divided to solid and liquid forms. Thus, heavy metals scarcely converted into a liquid state.

By the test plant operation, the following results were obtained, as shown in **Table 6**. About 35% Pb and 31% Zn contained cake are estimated to be usable as raw materials by mixing it with natural concentrate (Pb: 50~70%, Zn: 45~60%), and waste water, satisfying the regulation limits.

3.3 Behavior of PCDDs/PCDFs

Residues from MSW incinerator contains somewhat dioxins (PCDDs/PCDFs). **Table 7** shows analysis results on the dioxin content in melted fly ash with surface melting furnace, containing a rather high concentration of dioxins. Dioxins of 3500 ng/g (10 ng TEQ/g) were contained in fly ash from MSW incineration. However, only 0.063 ng/g (0.00 ng TEQ/g) is detected in slag, 0.74 ng/g (0.00 ng TEQ/g) in fly ash from melting furnace and 23 ng/N (0.25 ng TEQ/Nm^3) in flue gas. The decomposition rate is 99.99% in PCDDs/PCDFs and 99.98% in TEQ 1, 9).

The level of dioxins contained in incinerator residues can be reduced by decomposition due to the heat of the melting process, at the high temperature of approximately 1,400℃. It is suggested, therefore, that waste produced from the melting process will be environmentally compatible.

4. Reutilization of Melted Slag

The technology to turn slag produced from the melting of MSW residues into a reusable resource has been investigated. Some ideas are, to use the slag as a fill for road surfaces, as a component in asphalt mixtures, in concrete structures and in secondary products (e.g. interlocking blocks, tiles, and bricks). There are already established standards in place for these types of natural materials such as crushed stones. In order to develop similar standards for such materials that contain slag, some research has been done. The results have shown that slag can be used in different ways, depending on the particular application and conditions of use, as shown in **Table 8** 14). This does not mean that the use of slag in such existing materials will immediately become widespread. At present, using melted slag as a resource is still at the stage where possibilities are being investigated and the feasibility of operations is being studied. From now on research and development is must concentrate on producing slag that will be acceptable to user's needs. For this reason some standardization of slag products is needed urgently.

To evaluate the possibility of using slag as a resource, economic considerations such as marketing and pricing need to be studied, and the quality of slag-containing products needs to be brought in

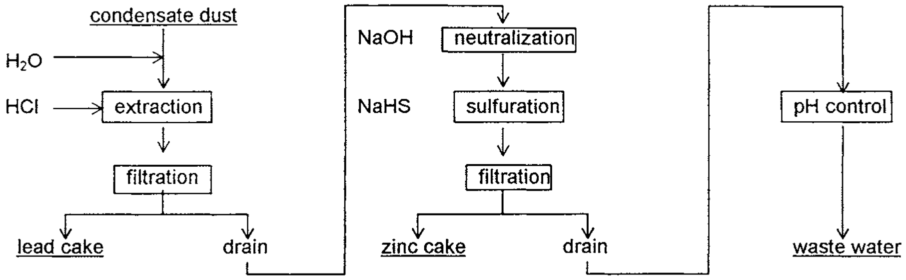


Fig. 4 Pb, Zn Separation and Recovering Process [10)]

Table 6 Chemical Composition of Pb, Zn Cake and Waste Water [10)]

		Pb	Zn	Cu	Fe	Si	Al	Cd	As	Hg	Cr
Dust	[%]	3.14	6.86	1.34	1.43	0.72	0.30	0.073	0.007	2.0 ppm	0.005
Pb cake	[%]	34.71	12.28	0.19	16.43	2.60	1.44	0.0001	0.020	1.6 ppm	0.038
Zn cake	[%]	2.61	31.09	6.93	0.95	2.72	1.02	0.383	0.027	9.5 ppm	0.013
Waste water	[mg/l]	0.03	0.19	0.05	0.18	2.85	4.93	<0.005	0.009	<0.0005	<0.01
Regulation	[mg/l]	0.1	5	3	10	-	-	0.1	0.1	0.005	0.05 (Cr^{6+})

Table 7 Concentrations of PCDDs/PCDFs and TEQ in Solid and Flue Gas Samples

Item	Solids, ng/g			Flue gases, ng/Nm^3 @O_2=12%			
	Fly ash from MSWI	Slag	ESP ash from MF	Inlet of air preheater (S1)	Inlet of gas cooler (S2)	Inlet of ESP (S3)	Outlet of ESP (S4)
T4CDDs	1600	<0.004	0.032	0.45	0.45	1.2	0.23
P5CDDs	910	0.010	0.010	0.63	0.41	1.3	0.31
H6CDDs	640	0.008	0.013	1.7	0.91	3.8	0.97
H7CDDs	110	0.004	0.021	1.7	0.52	9.6	1.8
O8CDD	88	0.020	0.25	3.5	7.0	15	3.5
PCDDs	3300	0.042	0.33	8.0	9.3	31	6.8
T4CDFs	34	<0.004	<0.004	3.5	1.8	8.2	1.3
P5CDFs	43	<0.004	0.007	5.1	1.9	7.0	2.0
H6CDFs	49	<0.004	0.022	4.7	2.5	8.5	3.3
H7CDFs	16	0.004	0.050	3.3	0.91	10	3.4
O8CDF	7.4	0.017	0.3	5.5	4.1	14	5.9
PCDFs	150	0.021	0.41	22	11	48	16
PCDDs+PCDFs	3500	0.063	0.74	30	20	79	23
TEQ	10	0.0	0.00	0.40	0.13	0.54	0.25

line with that of similar existing materials.

Table 8 Properties of a Melted Slag and Commercial Roadbed Materials, and Various Specified Values [14,15]

Property		Slag		Typical commercial products		Specified values for road aggregate				Specified values for concrete aggregate
						Crushed stone for road construction	Guideline for asphalt paving			
		Air cooled	Water cooled	Crusher run (C)	Reclaimed crushed stone (RC-40)	Class 1	Lower sub-grade layer	Upper sub-grade layer	Surface layer/ base layer	Crushed stone for concrete
Specific gravity	dry surface	2.65	2.65	2.66	2.45	>2.45				>2.5
Moisture absorption rate	%	0.12	0.75	1.34	4.43	<3.0				<3.0
Abrasion loss	%	30-35	50-60	20.7	23.0	<35	<50	<50	<30	<40
Stability	%	<1.0	<1.0	10.9	-		<20	<20	<12	<12
Optimum moisture content	%	2.8	3.6	4.5	8.5					
Compensated CBR	%	98-100	15-20	123.0	98.8		>20	>80		

5. 'Effective Reuse Manual' of MSW Melted Slag (draft)

As I mentioned above, high-temperature treatment technologies for incinerator residues (melting and solidification methods) have been developed, and it is becoming possible to reuse the residues effectively by melting. It is important to reuse them as road construction materials or concrete aggregate and so prevent environmental disruption caused by quarrying. Some basic ideas for the effective utilization of incinerator residue products are as follows:

(1) Incinerator residues should be reduced through waste discharge control and recycling,
(2) Incinerator residue products should be positively promoted for reuse, in order to reduce the final landfill volume, and
(3) Incinerator residue products have to be stable in order not to cause environmental pollution, such as soil contamination and ground water pollution.

With this in mind, the Ministry of Health and Welfare is discussing the drafting of an 'effective reuse manual', aiming at promoting the safe reuse of incinerator residues, by setting reprocessing technologies, reuse standards and their evaluation methods. I would like to introduce an outline of the manual here. It deals with the following:

(1) Slag produced by melting MSW incinerator residues under the temperature of 1200 ~ 1400°C or higher,
(2) Slag produced by gasification/melting of MSW under the temperature of 1200 ~ 1400°C or higher, and
(3) Solid substances produced by sintering MSW incinerator residues under the temperature of 1000 ~ 1300°C.

The Ministry of Construction is also considering applying standards for the reuse of melted slag from sewage sludge, and the Environment Agency is examining standards for various recycling flows such as iron slag from steel production or coal ash.

The effective reuse standards have to incorporate physical standards such as strength and durability and quality standards focusing on environmental impact. Within the quality standards, hazardous substances exposure routes to human body should be considered. The routes are roughly classified into three, or food, air, and drinking water. Among them, the most important exposure route is drinking water, that is, hazardous substances leaching from residue products into ground water through rain. Therefore, leaching tests were adopted for quality confirmation and drinking water standards were applied for slag standards. At present, 29 items of drinking water standards are concerned with human health. 23 items including cyanogen and other organic compounds are considered to decompose because melted slag and sintered products are manufactured under the temperature of a thousand and some hundreds degrees centigrade (refer to **Table 2**). Thus, they were left out of the effective reuse standards. For the following six heavy metals, standard values were set;

Cadmium: 0.01 mg/l, Lead: 0.05 mg/l, Hexavalent chromium: 0.05 mg/l, Arsenic: 0.01 mg/l, Total mercury: 0.0005 mg/l and Selenium: 0.01 mg/l.

Non-processed melted slag is used as filling and road-bed materials, concrete and asphalt aggregate and cement materials. Processed-melted slag, secondary products, are used for concrete, asphalt and interlocking bricks. As they are used in many ways it is difficult to identify the places where they are used. Therefore the standards were established to be applied in all cases regardless of place or purpose. Looking at these utilization, it is considered that melted slag products would be more useful than shapeless melted slag. Products like bricks seem to leach smaller amounts of hazardous substances than shapeless melted slag because of the decrease of the rate from surface area, the less permeability and the encapsulation of hazardous substances by solidification. Present leaching tests, however, (JTL13 and JTL46) can be applied only to crushed samples (less than 5 mm on JLT13 and less than 2 mm on JLT46). These tests can not evaluate the effects of solidification, stabilization and formation. Considering the difference in form between shapeless materials and solid products, adequate leaching test methods should be applied for the evaluation. Test methods under discussion are shown in **Table 2**, and the basic ideas are drawn in **Fig. 5**. The test samples were regulated 10~30 mm in size because a certain strength and high reproducibility are required. Taking into account changes of chemical properties, including acidification by acid rain or carbon dioxide, acid solvents have to be used. Reprocessed melted slag is now being used close to our living environment, as opposed to landfill sites. Evaluation of the environmental impact should be carried out as close as possible to our living environment and prior to its use. The further development is expected.

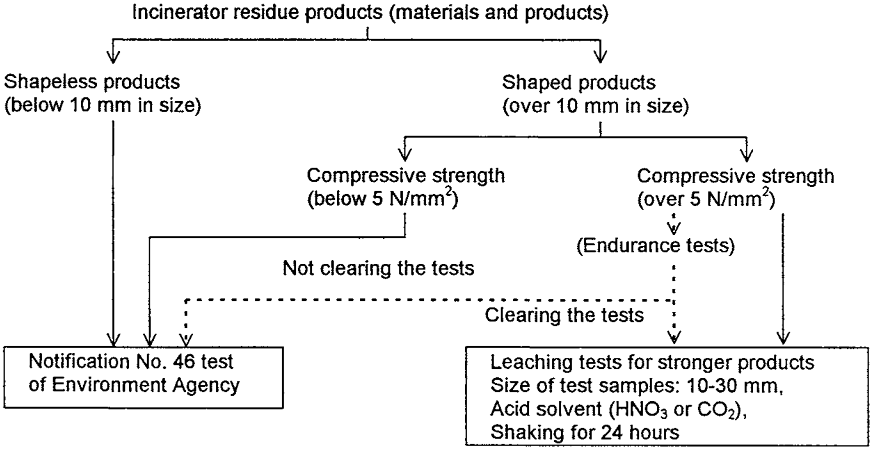


Fig. 5 Frame Work of Leaching Tests by the Form of MSWI Residue Products (draft)

6. Conclusion

The following points should be considered if MSW incinerator residue melting facilities are to share a major role as terminal facilities in municipal waste management and recycling in general.

Firstly, the appropriate technology should be established so that slag should be considered as a recyclable resource. It is necessary to make the quality of slag-containing products equal to that of equivalent existing materials, in order to promote their use.

Secondly, economic aspects need to be carefully considered. Using new processes such as melting will add considerable costs to the existing MSW treatment system. However, even without further treatment after incineration, fly ash still has to be treated, since it has been designated to be 'specially controlled waste'. So currently, the final cost of treatment is higher than it appears. Considering this point, efforts are needed to decrease costs by improving the melting technology to make it more suitable. However, we should always be prepared to pay cost of recycling. From now on, the treatment of incinerator residues should be thought of in terms of the recycling of resources aimed at promoting a more recycle-conscious society. Incinerator residues contain hazardous substances such as heavy metals and dioxins. To use the material efficiently, safety aspects must be well thought out, so as not to leave a negative heritage to future generations. Considering all these points above, we need to proceed further in development of this technology.

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