Utilization of Melt-solidified Slag from Sewage Sludge as Construction Materials

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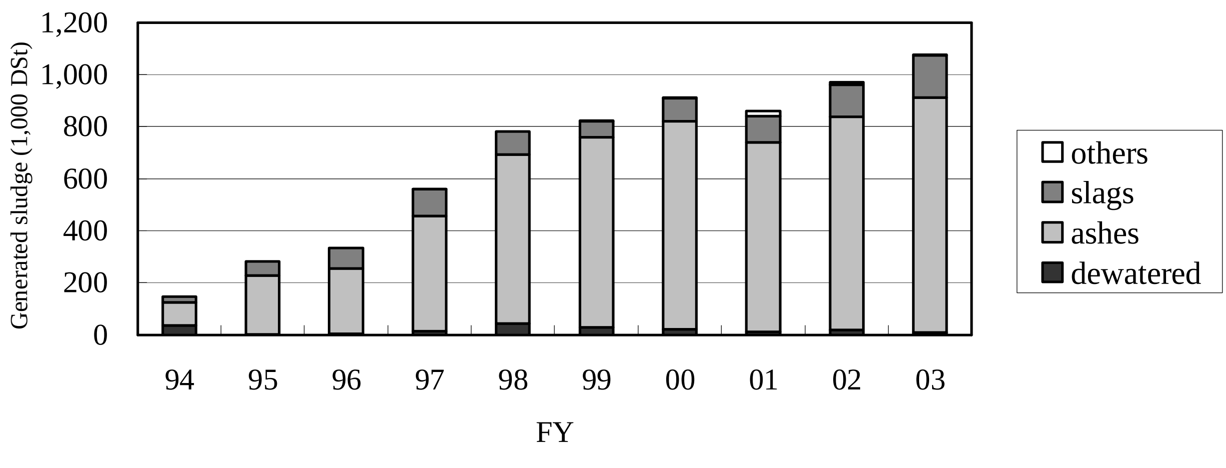
Abstract About 40 thousands tons of slag are produced by melting sewage sludge in Japan, and it has been utilized mainly as landfill for sewer works. Japanese Industrial Standards (JIS) for melt-solidified slag for concrete aggregate and road construction was enacted in July 2006. As acid extractable contents of chemicals have been adopted as criteria for content testing, slag was identified as safe recyclable material. Considering the characteristics of slag made from sewage sludge, standards for coarse aggregate and a new analysis method for metal iron have been added to the JIS. Slag made from sewage sludge can be counted on to be utilized more as construction materials in the near future.
Keywords Acid extractable contents of chemicals; metal iron; particle size distribution

INTRODUCTION

Approximately 2 million dried solid tons of sewage sludge has been generated per year in Japan. In FY2003, 72% of generated sludge was incinerated and 9% was melted with 42% of the generated sludge utilized as incinerated ash and 8% utilized as melt-solidified slag. Recently large amounts of incinerated ash have been utilized in cement production, so about 50% of sewage sludge has been beneficially used as construction material. Figure 1 shows the trend of utilization of sewage sludge as construction material. The vertical line represents the volume of generated sludge (dried solid tons) utilized as construction materials.

Japanese Industrial Standards (JIS) for melt-solidified slag made from municipal solid waste (MSW) and sewage sludge was established in July 2006. This slag is utilized as material for concrete aggregate and for road construction. And slag made from sewage sludge is expected to be utilized more as construction material in the near future.

Figure 1. Trends in the utilization of sewage sludge as construction materials



METHODS

Melting sewage sludge had begun before the standardization. Considering the characteristics of slag made from sewage sludge, standards for coarse aggregate concrete were added to those for fine aggregate in JIS.

Melting sewage sludge

MSW and sewage sludge are continuously generated by urban life. In spite of the reduction, reuse and recycling of these materials, large quantities are used as post-incineration residue for land reclamation. Melting sewage sludge at more than 1,200 degrees produces melt-solidified slag. According to the cooling method, slag is classified as granulated slag, air-cooled slag and crystallized slag. Melting sewage sludge was introduced in the latter half of the 1980s, and had been introduced at most plants by 2000. About 40 thousands tons of slag are produced by melting sewage sludge and they are utilized mainly as landfill material for sewer works.

There are still problems with the melting method. 1) Temperature during operation is extremely high and maintenance cost is relatively high. 2) Prolonged stable operation and higher operating rate are necessary. 3) Slag utilization technology is needed. Regarding the maintenance cost, facilities are improved to save energy through, for example, more efficient heat recovery and prevention of heat radiation. According to one report, the maintenance cost is about 15,000 – 20,000 yen per wet ton of sewage sludge by the melting treatment; a cost relatively high in comparison with that of incineration treatment[1].

To achieve prolonged stable operation, many problems must be resolved. It was observed that its operating rate is lower than that of incineration treatment. The rate tended to be lower at wastewater treatment plants (WWTP) with plural melting plants operating reciprocally. It tended to be higher at WWTP with a single melting plant. According to one report, the rate was 80-90% if periods when the plant was shut down were regarded as operation time[1]. Furthermore, clogging of dust was a characteristic cause of trouble with melting treatment. It is very important to systematically clean dust from the system.

Stabilization of slag

Melting treatment is considered to be one of the most effective methods of utilizing MSW and sewage sludge. It is a method that not only reduces the load on land reclamation by decreasing volume more effectively than incineration treatment, but also lowers environmental load by masking heavy metals. Therefore, its standardization has been strongly requested by stakeholders as a way of utilizing slag.

Investigation of standardization was started by the former Ministry of International Trade and Industry (MITI) in 1999. After the two years investigation, committees were organized to prepare drafts of Technical Reports (TR). Two TRs, one for concrete fine aggregate and the other for road construction, were published in 2002[2, 3]. And melting of MSW has also been introduced as a countermeasure to prevent the emission of chemical substances from facilities. After the TRs were released, many MSW melting facilities started operating. More than 200 thousands tons of slag made from MSW have been produced.

After the TRs were released, committees were formed to prepare JIS drafts. And two JIS were published in 2006[4, 5]. As utilization methods, coarse aggregate and fine aggregate for concrete and hot asphalt mixture, base course material and subbase course material for road construction have been stipulated. Table 1 shows the kinds of melt-solidified slag for concrete aggregate, and Table 2 shows that for road construction.

Table 1. Kinds of melt-solidified slag for concrete aggregate

Kinds	Symbols	Notes
Coarse aggregate	MG	Cool-solidified and mechanical stabilization materials made from melt-solidified slag derived from melt-solidified facilities of municipal solid waste and sewage sludge for utilization
Fine aggregate	MS	

Table 2. Kinds of melt-solidified slag for road construction

Kinds	Symbols	Use (reference)
Single-sized melt-solidified slag (air-cooled slag)	SM	For hot asphalt mixture
Fine aggregate (granulated slag and air-cooled slag)	FM	For hot asphalt mixture
Graded melt-solidified slag (air-cooled slag)	MM	For base course material
Crusher-run melt-solidified slag (air-cooled slag)	CM	For subbase course material

Industrial wastes were not adopted by the JIS because of insufficient data. So the object of JIS is slag from municipal melting plants. A new lot of slag was assumed to begin when its quality changed to a degree that could not be ignored to control its quality. Although the sampling method was stipulated by other JIS (JIS M 8100, Particulate materials - General rules for methods of sampling), additional sampling and storage methods were established in JIS for melting facilities with a stock yard of limited capacity.

In response to the standardization, a sewage sludge melting treatment research group was organized in 2000. The group was formed to: 1) invesigate the quality of slag. 2) assess melting facilities that have been constructed, and 3) exchange information about utilization methods. Core members were municipalities with melting facilities. The Ministry of Land, Infrastructure and Transport (MLIT), Japan Sewage Works Association, Japan Sewage Works Agency and Public Works Research Institute (PWRI) participated. Some facilities produce air-cooled slag from sewage sludge. By providing information about quality investigations of air-cooled slag, the group contributed to the addition of coarse aggregate for concrete aggregate during the drafting of the JIS.

RESULTS AND DISCUSSION

Because the content test method was newly defined by these JIS, the quality of slag made from sewage sludge was investigated. And the drafting of the JIS was done by an investigation focused on metal iron and particle size distribution.

Safety quality standards of slag

JIS characteristically define safety quality levels. Because acid extractable contents of chemicals were defined in the Soil Contamination Counter-measures Law, content testing criteria were defined by JIS along with those for leaching testing. Table 3 shows the both criteria for leaching testing and content testing.

A leaching test method and a method of testing for acid extractable contents of chemicals in slag were established beforehand with JIS[6), 7)]. Until now, under a notification of the Ministry of the Environment (MOE), it has been required that the environmental safety of recycling materials be estimated considering their actual shape and the utilization method, and it also stipulated that if the final products satisfy the specified standards of Soil Contamination Counter-measures Law, there are no problems. But this JIS regulated slag itself and the safety quality level of slag has been defined simply in JIS.

Table 3. Criteria for leaching test and content test

Kinds	Criteria for leaching test	Criteria for content test
Cadmium	Below 0.01mg/L	Below 150mg/kg
Lead	Below 0.01mg/L	Below 150mg/kg
Hexavalent chromium	Below 0.05mg/L	Below 250mg/kg
Arsenic	Below 0.01mg/L	Below 150mg/kg
Total mercury	Below 0.0005mg/L	Below 15mg/kg
Selenium	Below 0.01mg/L	Below 150mg/kg
Fluorine	Below 0.8mg/L	Below 4000mg/kg
Boron	Below 1.0mg/L	Below 4000mg/kg

Adopting the new leaching test method for slag, it was decided that analysis may be performed using small pieces of crushed slag, but actual slag aggregate in principle. Because the acid extractable contents of chemicals were established by the Soil Contamination Counter-measures Law considering its impact on humans directly ingesting these chemicals, it was decided that melt-solidified slag itself should satisfy the criteria conditions. However a countermeasure was also established as a temporary measure if the slag failed to satisfy the content test criteria.

Generally slag derived from sewage sludge satisfies environmental standards for soil in leaching testing. Slag was investigated because acid extractable contents of chemicals were newly established in JIS. The results for 17 kinds of slag are indicated in Table 4[8)]. Hexavalent chromium and total mercury data are not indicated because the former was below the detection limit and the latter was detected at 0.02mg/kg in only one sample. As a result, slag derived from sewage sludge satisfied the content test criteria. This reveals that melting treatment is a technology that can reduce environmental loads.

Table 4. Acid extractable contents of chemicals of slag (mg/kg)

	Detection Limit	Contents of chemicals (n=17)		
		Minimum	Maximum	Average*
Cadmium	0.17	N. D.	1.4	0.5
Lead	0.17	0.4	39.2	13.9
Arsenic	0.17	N. D.	109.7	7.2
Selenium	0.17	N. D.	0.2	0.0
Fluorine	13.3	N. D.	366.7	80.2
Boron	0.17	0.7	70.0	27.8

* Average data were calculated in the conditions that N. D. was 0.0.

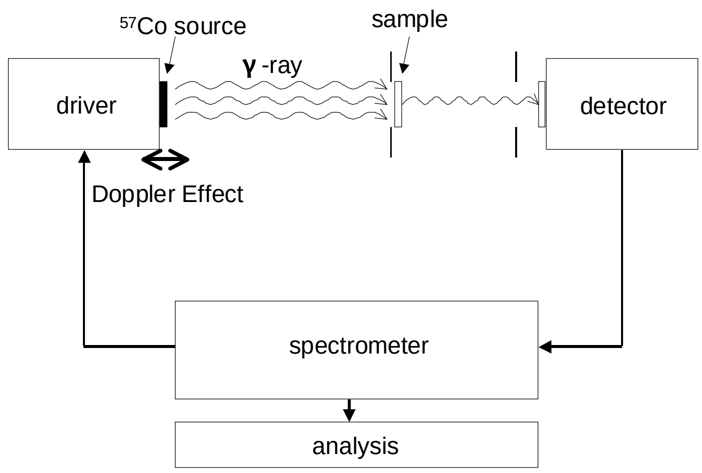
One report states that the heavy metal transition from sewage sludge to slag varied greatly according to the melting method[1)]. Investigating behaviour of heavy metal during melting treatment to perform stable operation of melting plants resulted in the production of good quality slag.

Quality control of slags

Metal iron. Both TRs stipulate that the content of metal iron must be below 1.0%. It was possible that the content of metal iron might be a problem effecting the decision regarding the amount of aggregate added, because the metal iron in slag can be a main cause of the change of density. There was also a risk of aggregate slag that includes metal iron causing iron rust. This could damage the beauty of concrete surfaces by discoloration. Density control has been adopted in JIS for road construction instead of metal iron content. But the metal iron has been stipulated as below 1% in JIS for concrete aggregate.

The wet analysis method in JIS A 5011-2 (Slag aggregate for concrete - part2: Ferronickel slag aggregate) was adopted in the TRs as the metal iron analysis method. The Maessbauer Spectroscopy Method has also been adopted in JIS. The wet analysis method dissolves metal iron in samples using bromic ethanol. But it may detect iron compounds, such as phosphoric, as metal iron. In this case, the metal iron might be overestimated. On the other hand, the Maessbauer Spectroscopy Method uses gamma rays from an atomic nucleus, allowing it to clarify the chemical condition of iron compounds. Figure 2 shows the basic structure of the Maessbauer Spectroscopy Method.

Figure 2. Basic composition of Maessbauer Spectroscopy Method



It is characteristic of slag made from sewage sludge that the iron, phosphorus and sulphur contents are higher than in slag made from MSW. Sometimes the content of metal iron is above 1% according to the wet analysis method. In such cases, it is usually below 1% according to the Maessbauer Spectroscopy Method. Generally most of the iron in slag exists as divalent iron or trivalent iron. It has been hypothesized that it is an oxide of iron or other iron compound.

Small amounts of iron rust have appeared in slag when it has been left outside. It is necessary to detect iron compounds that cause iron rust. And it is also necessary to investigate the possibility of iron rust when slag is used as concrete aggregate.

Particle size distribution. About 65% of MSW melting facilities have post-treatment equipment, such as a magnetic sorter, a crusher and a screen. But sewage sludge melting facilities do not control particle size of slag in most cases, because they have been mainly utilized for the reclamation of sewer works. In such cases, the slag can not satisfy the particle size distribution standard in JIS. The slag could be used mixed with natural crushed stone. But it is required by JIS that the slag itself meets the particle size distribution standard.

As countermeasures at sewage sludge melting facilities, mechanical stabilization facilities are installed when the facilities are reconstructed. Mechanical stabilization is counted on to improve the slag quality in cases of problems with abrasion loss or the solid volume percentage for shape determination. Hereafter, an action plan will be requested to control slag quality of slag from the viewpoint of users.

Additionally durability problems, such as freezing and thawing, have been recognized since the TRs. Future trial works are counted on to confirm long-term durability.

CONCLUSION

As sewage works have been developed in Japan, the demand for slag for these sewer works has gradually decreased. New methods of utilizing slag from sewage sludge must now be developed. Several problems remain unsolved, but the JIS utilization method is counted on to enlarge the slag market.

It is also important to construct a business model that includes an overall plan for the utilization of slag as construction materials from the production stage to the sales stage. With the adoption of acid extractable contents of chemicals as content test criteria, slag has been identified as safe recycling materials. Melting slag is not a sewage sludge treatment but a utilization method that will contribute to constructing a sound material-cycle society.

Acknowledgement

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