Proceedings of the 9ICEG
9th International Congress on Environmental Geotechnics
25-28 June, 2023 | Chania, Greece

https://doi.org/10.53243/ICEG2023-157

Influence of discharge area and year on the geotechnical characteristics of MSW incineration bottom ash in Japan

T. Fujikawa[1], K. Sato[2], C. Koga[3], H. Kubota[4], and H. Sakanakura[5]

[1] *Assistant Professor, Fukuoka University, Fukuoka, Japan, email: takuro-f@fukuoka-u.ac.jp*

[2] *Professor, Fukuoka University, Fukuoka, Japan, email: sato@fukuoka-u.ac.jp*

[3] *Research Assistant, Fukuoka University, Fukuoka, Japan, email: chikashi@fukuoka-u.ac.jp*

[4] *Deputy General Manager, Fujita Corporation, Atsugi, Japan, email: hkubota@fujita.co.jp*

[5] *Section head, National Institute for Environmental Studies, Tsukuba, Japan, email: sakanakura@nies.go.jp*

ABSTRACT

This study focused on variability of geo-environmental characteristics of municipal solid waste incineration bottom ash (IBA) to examine the extent to which these variations would be problematic for the promotion of recycling. Physical, mechanical, and leaching tests were conducted on IBAs from 6 incineration facilities from different discharge areas in Japan. Eight IBAs discharged in different years from one facility were also examined. Results showed that the physical properties of IBA vary depending on the content of combustible waste and the type of incinerator. Regarding the influence of discharge area and year on the quality of IBA, the results suggested that the discharge area has a larger influence than the discharge year. Based on the test results of physical and mechanical properties, IBAs can be used as a base-course material regardless of the discharge area or year. However, immobilizing heavy metals and metalloids as geomaterials is necessary for IBAs, and the target elements and the leached amount of the elements differed depending on the discharge area of IBA.

Keywords: municipal solid waste (MSW), incineration bottom ash (IBA), compaction curve, cone index, California Bearing Ratio (CBR), batch leaching test

1 INTRODUCTION

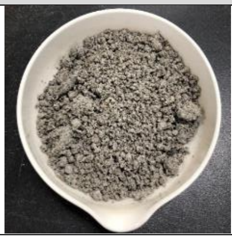
Approximately 43 million tons of municipal solid waste (MSW) is generated annually, most of which is incinerated to reduce its volume and approximately 3.8 million tons of incineration bottom ash (IBA) is discharged in Japan (Ministry of the Environment of Japan, 2020). Most IBA must be landfilled at the final disposal site to avoid environment pollution. However, capacity shortage at the final disposal sites is serious. Therefore, alternative uses of IBA, particularly as a construction and cement raw material, are being explored. By contrast, IBA application after metal recovery is already in progress in Europe as roadbed material for roads and aggregate for cement. Remarkable development of technologies for the recovery and treatment of metals contained in IBA is also observed (Olaf et al., 2016). However, the effective use of IBA has not progressed in Japan due to an enormous concern on heavy metals and metalloids contained in IBA, and the unstable geotechnical characteristics compared to general ground materials (Doi et al., 1999). The material characteristics of IBA generated from MSW also vary according to the regional characteristics (e.g., type of waste, volume, place, and season). Michal et al (2018) reported that bottom ash is a remarkably heterogeneous material because its composition corresponds to that of incinerated MSW, which varies considering the country, the collection area, and season. The practical application of these IBA is still lagging behind in Japan considering physical and mechanical qualities and environmental safety, as well as legal issues. Therefore, studying methods of beneficial utilization of IBA considering the variability of IBA relative to discharge area and year on the geo-environmental characteristics as a ground material is an important issue. This study reports the effects of these influencing factors on the geotechnical characteristics (physical, mechanical, and leaching properties) of IBA using 6 different types of IBA from different discharge areas and 8 IBAs discharged in different years from one facility.

2 TESTING PROCEDURE

2.1 Experimental samples

IBAs collected from 6 different discharge areas (Table 1) were used in the experiment. All incinerator types are mechanical grate-type furnace, DR-1 and DR-2 are dry type ash, and WR-1, WR-2, WR-3, and WN-1 are wet type ash, all of which were discharged in 2018. Wet ash refers to ash removed from incinerated ash after it has been placed in a water tank for cooling during the discharge process. Therefore, wet ash is characterized by higher water content at the time of discharge than dry ash.

Table 1. *Overview of the IBA and incineration facility used in the experiment*

Sample	DR-1	DR-2	WR-1
Photo			
Incineration type	Storker furnace (Dry ash)	Storker furnace (Dry ash)	Storker furnace (Wet ash)
Processing capacity	450 t / 24 h / 3 furnace	—	330 t / 24 h / 4 furnace
Target	Burnable waste, Unburnable waste crushing residue	Burnable waste	Burnable waste, Unburnable waste crushing residue
Sample	WR-2	WR-3	WN-1
Photo			
Incineration type	Storker furnace (Wet ash)	Storker furnace (Wet ash)	Storker furnace (Wet ash)
Processing capacity	235 t / 24 h / 2 furnace	250 t / 24 h /3 furnace	300 t /24 h
Target	Burnable waste, Unburnable waste crushing residue	Burnable waste	Burnable waste

2.2 Experimental methods

The following tests were conducted to reveal the physical, mechanical, and leaching properties of IBA: physical composition, density test of IBA particles (test method for density of soil particles, JIS A 1202), particle size of IBA (test method for particle size distribution of soils, JIS A 1204), compaction test (test method for soil compaction using a rammer, JIS A 1210), cone index test (test method to evaluate the cone index of compacted soils, JIS A 1228), California Bearing Ratio (CBR) test (test method for the CBR of soils in laboratory, JIS A 1211), and batch leaching test (Notifications No. 46 by the Ministry of Environment Japan, herein called JLT 46). In addition, X-ray fluorescence analysis was performed to identify the elements that comprise the IBA.

For physical composition, 2 kg of IBA was magnetically sorted, and the remainder was visually sorted into ash, glass, ceramics, and nonferrous metals. IBA comprises various materials such as iron, glass, ceramics, and nonferrous metals; deaeration via the hot water method may accelerate the chemical reactions of Al and Ca components in the incinerated ash due to heat (Doi et al., 1999). Therefore, instead of the hot water method, the density test was conducted in this study using the vacuum degassing method.

The compaction test was performed by the E-b method (using a 4.5 kg rammer and drying method with a nonrepeating sample) based on JIS A 1210. In adjusting the water content, the IBA particles were watered and mixed and then sealed in a container and left for 24 h to allow full water absorption of the ash particles. The CBR index provides a measurement of the impact resistance of compacted IBA through the E-b method. Table 2 shows the conditions of the CBR test. The water content of the IBA was adjusted to the optimum water content based on the compaction test results. In addition, cone index tests were conducted to investigate the possibility of IBA using the A-a method (using a 2.5 kg rammer and drying method with repeating sample) as an embankment material. Cone indexes are typically used to measure soil strength and identify the compacted soil conditions (Hummel et al., 2004). Table 3 lists the conditions of the cone index test.

Table 2. *Testing conditions of the CBR test*

Sample	E-b method	
	Optimum water content w_{opt} (%)	Maximum dry density ρ_{dmax} (Mg/m^3)
DR-1	20.4	1.462
DR-2	20.0	1.452
WR-3	18.2	1.514

Table 3. *Testing conditions of the cone index test*

Sample	A-a method	
	Optimum water content w_{opt} (%)	Maximum dry density ρ_{dmax} (Mg/m^3)
DR-1	20.8	1.472
DR-2	20.0	1.315
WR-1	35.0	1.297
WR-2	25.4	1.371
WR-3	24.5	1.434
WN-1	25.0	1.475

As a batch leaching test, JLT 46 was used to measure the concentrations of heavy metals in the IBA. Table 4 lists the testing conditions of JLT 46. The samples were sieved to less than 2 mm, and a solvent was added such that the liquid-solid ratio (L/S) was 10. The solvent was deionized water adjusted to pH 5.8-6.3 by adding hydrochloric acid. Inductively coupled plasma atomic emission spectrometry (ICP-AES) was used for analysis of lead (Pb), cadmium (Cd), and boron (B). For the analysis of hexavalent chromium (Cr (VI)), a spectrophotometer (UVmini-1240) was used through diphenylcarbazide absorptiometry. The detection limits of Pb, Cd, B and Cr (VI) were 0.01, 0.001, 0.01, and 0.02 mg/L, respectively. This study focused on these heavy metals and metalloids because they are included in the Japanese environmental standard values for soils and are present in the IBA.

Table 4. *Batch leaching test (JLT 46) conditions*

Sample	Eluent pH	Liquid-solid ratio (L/S)	Maxmum grain size (mm)	Shaking time (hour)	Measurement of heavy metals and metalloids
DR-1 DR-2 WR-1 WR-2 WR-3 WN-1	5.8 - 6.3	10	2.0	6	Pb Cd Cr (VI) B

3 RESULTS AND DISCUSSIONS

3.1 Physical properties

3.1.1 Physical composition of IBA

Figure 1 shows the physical composition percentage of IBA in the 6 areas. Ash content accounts for more than 80% in all areas, followed by iron, glass, ceramics, and nonferrous metals. DR-1 has the highest iron content. The treatment targets shown in Table 1 reveal that DR-1 treats the unburnable waste crushing residue and possibly processes more incombustible waste shredded residues than other areas. The results of the X-ray fluorescence analysis shown in Table 5 also confirm the physical composition results because the highest percentage of Fe and Pb is found in DR-1. No significant differences were observed in the emission regions for Na, Ca, and Cl in any of the samples. These results indicate that the physical composition differs in various IBA discharge areas.

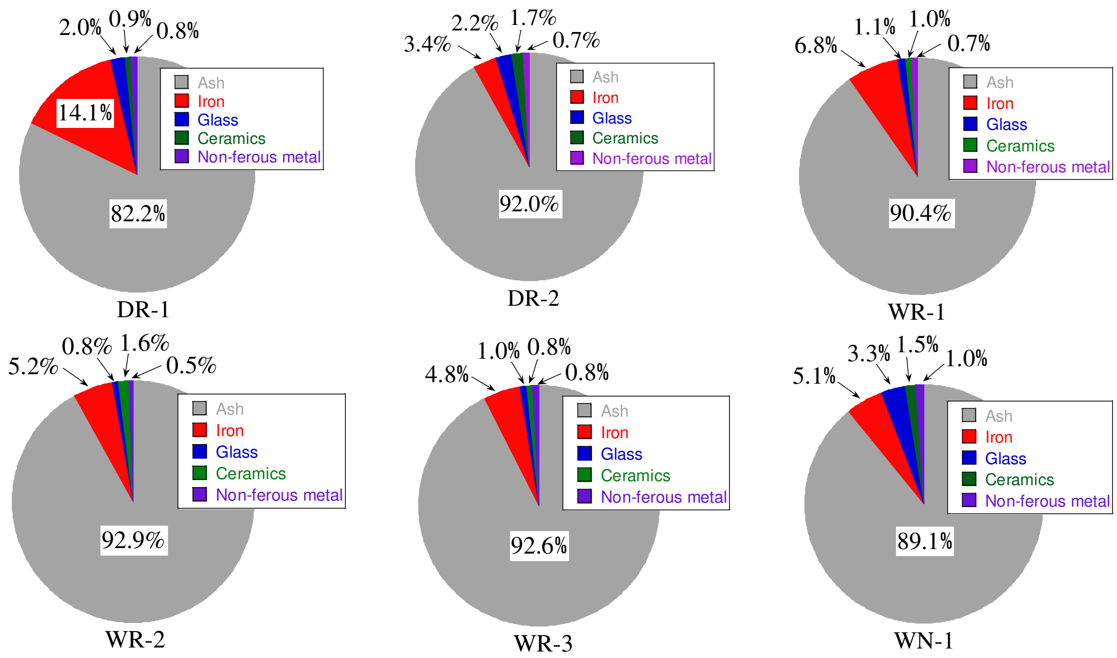


Figure 1. *Mass-percentage of physical composition of IBAs from the 6 areas*

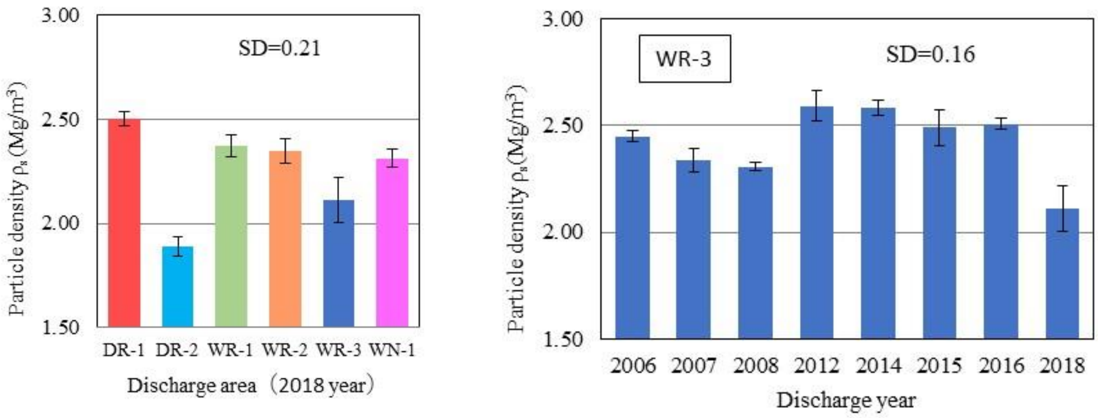
Table 5. *Results of the X-ray fluorescence analysis, represented by converting the measured value as an oxide to the value of a single element*

	DR-1	DR-2	WR-1	WR-2	WR-3	WN-1
Na	30000	28000	21000	31000	16000	22000
Al	37000	43000	66000	65000	38000	57000
Si	130000	140000	71000	130000	88000	81000
Cl	11000	11000	15000	11000	19000	10000
Ca	170000	140000	220000	170000	170000	220000
Cr	630	270	380	370	180	330
Fe	51000	24000	31000	27000	17000	29000
Cu	5100	500	2200	790	990	2600
Zn	3500	1200	2600	1500	2500	2900
Pb	2500	200	250	340	260	380

* Unit: mg/kg

3.1.2 Particle density and grain size of IBA

Figures 2 (a) and (b) show the particle density test results of IBA. The error bars in both figures indicate the error range. The difference in discharge areas in (a) reveal that the particle density of DR-2 and DR-1 is the lowest and the highest, respectively. This finding may be due to the lowest and highest iron contents in DR-2 and DR-1, respectively, based on the physical composition in Figure 1 and the high metal content (Fe, Cu, Zn, and Pb) in Table 5. In addition, focusing on the particle density of IBA at different discharge years in WR-3 shown in (b), some variations in ash particle density ae observed even in the same discharge area due to differences in discharge years. However, the standard deviation is smaller than the difference in discharge area shown in (a). Figure 3 shows the grain size distribution curves of IBA in 6 regions. All IBAs are distributed over a wide range of grain sizes despite differences in the grain size distribution curve depending on the discharge area. Therefore, IBA is considered to be a material with good compaction properties regardless of the discharge area.



(a) Difference of discharge area *(b) Difference of discharge year in WR-3*

Figure 2. *Particle density test results of IBA*

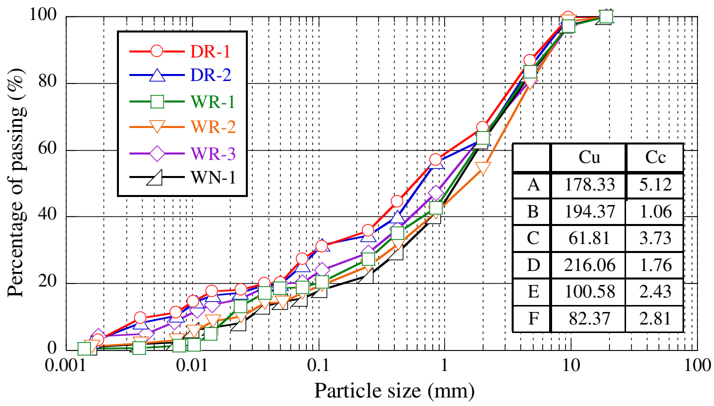
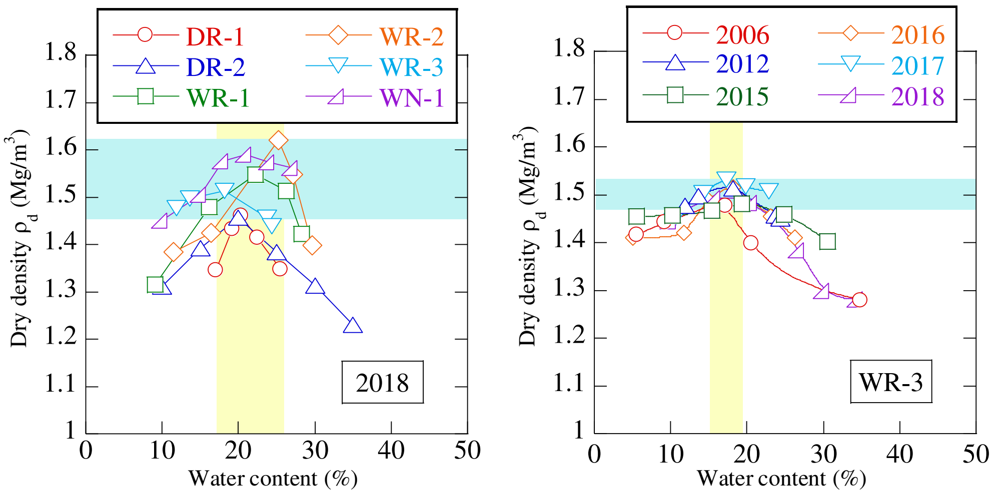


Figure 3. *Grain size distribution curves of IBA*

3.1.3 Compaction characteristics of IBA

Figures 4 (a) and (b) show each compaction curve relationships between dry density of each IBA and water content (E-b method), respectively. As with the grain size distribution, differences in the maximum dry density and optimum water content ratio were observed depending on the discharge area shown in (a). In this study, the maximum dry density difference was approximately 0.2 at the maximum, and the optimum water content was found to have a range of approximately 10%. The large differences in maximum dry density and optimum water content and the stable particle size distribution are possibly due to differences in composition at each particle size, as shown in Figure 1. By contrast, focusing on the effect of different discharge years in the same area (WR-3) on the compaction characteristics shown in (b), The compaction curves are similar in each case, and the variation in the maximum dry density and optimum water content is smaller than that in the discharge area. The maximum differences in maximum dry density and optimum water content in this experiment were found to have a maximum range of 0.05 and 5%, respectively.



(a) Difference of discharge area (b) Difference of discharge year

Figure 4. *Compaction curve relationships between dry density of each IBA and water content (E-b method)*

3.2 Mechanical properties and leaching characteristics

3.2.1 Applicability as embankment material of IBA

The compaction curves (A-a method) shown in Figure 5 and the cone index test results shown in Figure 6 indicate that IBA varies depending on the discharge area. The relatively high cone index values of DR-1 and DR-2, which are dry ashes, suggest that dry ashes have higher strength than wet ashes. The unconfined compressive strength (UCS) generally required for embankment materials is q_u= 200 kN/m^2 or higher. The Cement Association of Japan (2014) reported that the cone index is equivalent to approximately 5 times the UCS. Therefore, focusing on the cone index of the IBA used in this study, the strength converted to UCS is equivalent to approximately 1800 kN/m^2 even for WR-2, which showed the lowest cone index value. Thus, each IBA can be used as embankment material from a mechanical standpoint.

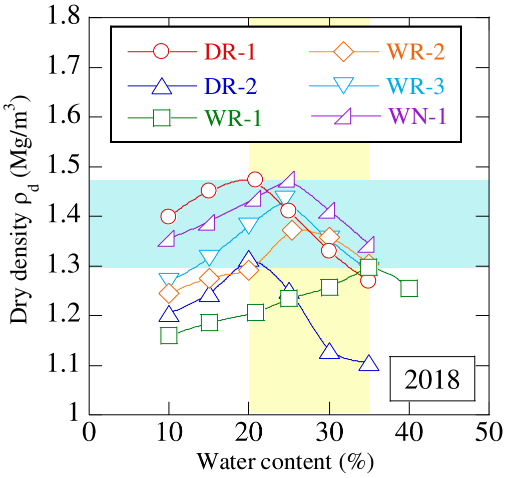


Figure 5. *Compaction curve relationships between dry density of each IBA and water content (A-a method)*

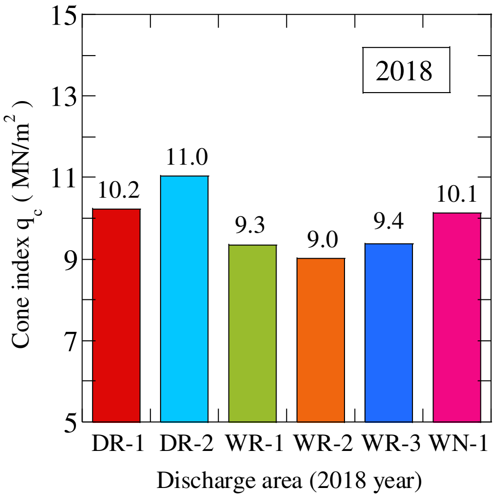
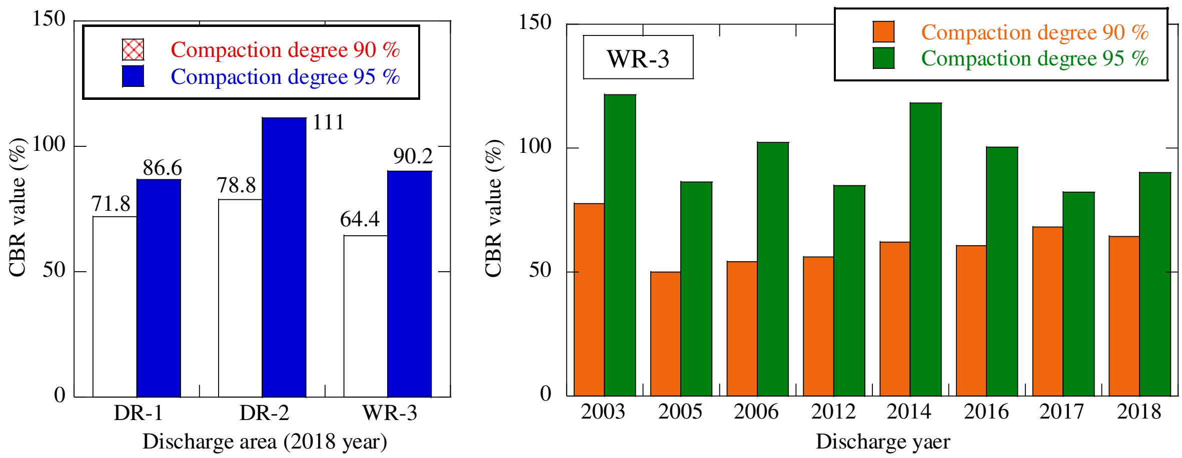


Figure 6. *Cone index test results*

3.2.2 Applicability as base-course material of IBA

Figure 7 (a) shows the results of the CBR tests. The CBR values of DR-1, DR-2, and WR-3 at 95% degree of compaction in different discharge areas were 86.6%, 111%, and 90.2%, respectively, which satisfied the quality criteria (>80%) for the effective use as base-course material (Japanese Geotechnical Society, 2010). The compaction degree at 90% was 71.8%, 78.8%, and 64.4% which satisfied the quality criterion (>30%) for the effective use as subbase-course material. The dry ash of CBR values (DR-1, 2) were relatively larger than the wet ash (WR-3). This finding may be due to the high fine-grain content of the dry ash, which makes the sample remarkably prone to compaction. The composition and physical characteristics of the IBA in the discharge area have a significant influence on these differences in the CBR values. However, the IBA used in this experiment meets the quality criteria for the effective use as base- and subbase-course material at 95% and 90% degrees of compaction, respectively; thus, they can be used as geotechnical materials. Furthermore, regardless of the discharge year, Figure 7(b) shows that the 95% and 90% degrees of compaction meet the quality criteria for effective use as base- and subbase-course materials, respectively, despite some differences in the CBR values due to the different discharge years. These results indicate that the same material properties can be obtained in the same discharge area at different discharge years.



(a) Difference of discharge area

(b) Difference of discharge year in WR-3

Figure 7. *CBR tests results of IBA*

3.2.3 Leaching properties and environmental safety assessment of IBA

Table 6 shows the batch leaching test (JLT 46) results. pH is alkaline in all areas. The pH values of Cd and B satisfy the soil environmental standards in all areas but the elution of Pb and Cr (VI) is observed, indicating that immobilization treatment is necessary for these heavy metals to be used as geomaterials. In particular, the concentrations of Pb and Cr (VI) are both high in dry and wet ash, respectively. Therefore, considering the use of immobilization methods that focus on the combination of aging (Fujikawa et al., 2020), carbonation (Brenne et al., 2015), and water washing (Quek et al., 2016) in the discharge form of incinerator ash to be used. In addition, studies have recently reported that incineration ash absorbs CO_2 and expectations for its contribution to carbon neutrality are high (Fujikawa et al., 2023, Kubota et al., 2020).

Table 6. *Batch leaching test results (JLT46)*

	pH	Cd (mg/L)	Pb (mg/L)	Cr (VI) (mg/L)	B (mg/L)
DR-1	12.6	N.D.	7.9	N.D.	N.D.
	12.6	N.D.	20	N.D.	N.D.
DR-2	12.6	N.D.	0.68	0.04	N.D.
	12.6	N.D.	0.27	0.05	N.D.
WN-1	11.2	N.D.	N.D.	0.10	0.83
	11.3	N.D.	N.D.	0.09	0.86
WR-2	11.5	N.D.	N.D.	0.19	0.78
	11.5	N.D.	N.D.	0.20	0.83
WR-3	12.6	N.D.	0.63	N.D.	N.D.
	12.6	N.D.	0.58	0.02	N.D.
WR-1	12.0	N.D.	N.D.	2.2	0.89
	12.0	N.D.	N.D.	2.2	0.88
Soil environmnetal standard value in Japan	-	<0.003	<0.01	<0.05	<1
Lowe limit of quantification in this experiment	-	0.001	0.01	0.02	0.01

4 CONCLUSIONS

Physical, mechanical, and leaching tests were conducted in this study using IBA from incineration facilities in six regions of Japan and IBA from different discharge years in the same region to investigate the effects of discharge area and year on geotechnical properties. The conclusions are presented as follows.

1) The physical properties of IBA vary depending on the content of combustible waste and the incineration method used in the area where the ash is generated, and these factors affect the ash properties. The physical properties of IBA markedly vary depending on the content of sorted combustible waste and the incineration method in the discharge area. As for the influence of discharge region and year on the properties of incinerated ash, the difference in discharge region had a large influence on quality than that in discharge year.
2) Regardless of the discharge area or year, IBA can be used effectively as base- and subbase-course materials under the 95% and 90% compaction conditions, respectively.
3) Immobilizing heavy metals and metalloids is necessary to use IBA as a geomaterial. Results also revealed that the elements that must be immobilized vary depending on the type of discharge.

Future work should focus on immobilization techniques such as CO_2 gas ventilation and solidification material addition, and investigate environmental safety as a geomaterial.

ACKNOWLEDGMENTS

This research was supported by the Environment Research and Technology Development Fund (3-1804) of the Environmental Restoration and Conservation Agency of Japan.

REFERENCES

Brenne T. and Weigand H. (2015). Stabilization of heavy metals in MSWI bottom ash by dynamic carbonation, Proceedings of the 14th International Conference on Environmental Science and Technology, CEST2005_00227.

Doi, Y., Imaizumi, S., and Yamada, M. (1999). Change of the mechanical properties of MSW-incinerated ash with the lapse of time, Journal of Japan Society of Civil Engineering, 659(52), 103-112. (in Japanese)

Fujikawa, T., Sato, K., Koga, C., and Sakanakura, H. (2020). Effect of Aging on Material Characteristics and Leaching Properties of Incineration Bottom Ash from Municipal Solid Waste, Waste and Biomass Valorization, Vol. 11, 7097-7107.

Fujikawa, T., Sato, K., Koga, C., Sakanakura, H., Kubota, H., and Nagayama, Y. (2023). Evaluation of carbonated incineration bottom ash using exhaust gas and CO2 discharged from waste incineration facilities as ground material, Soils and Foundations, 63, 101270, 1-10.

Hummel, J.W., Ahmad, I.S., Newman, S.C., Sudduth, K.A., Drummond, S.T. (2004). Simulations Soil Moisture and Con Index Measurement, Trans. ASAE 47 (3), 607–618.

Japan Cement Association. (2014). Ground Improvement Manual with cement solidification material, p. 94. (in Japanese)

Japanese Geotechnical Society. (2010). Basic and Companion of Soil test, Doshitsusiken Kihon to Tebiki, p. 89. (in Japanese).

JIS (2020) A 1202: Test method for density of soil particles. Japan Industrial Standard, Japanese Industrial Standards Committee, Tokyo, Japan.

JIS (2020) A 1204: The method for particle size distribution of soils. Japan Industrial Standard, Japanese Industrial Standards Committee, Tokyo, Japan.

JIS (2020) A 1210: Test method for soil compaction using a rammer. Japan Industrial Standard, Japanese Industrial Standards Committee, Tokyo, Japan.

JIS (2020) A 1211: The Method for the California Bearing Ratio (CBR) of soils in laboratory. Japan Industrial Standard, Japanese Industrial Standards Committee, Tokyo, Japan.

JIS (2020) A 1228: The Method for Cone Index of Compacted Soils. Japan Industrial Standard, Japanese Industrial Standards Committee, Tokyo, Japan.

Kubota, H., Shigeizumi, K., Fujikawa, T., Koga, C., Sato, K. (2020). An accelerated, On-Site Bottom Ash Aging and Washing Treatment and Its Effect for Long-Term Leaching. Waste Biomass Valorization. 11, 7067–7077.

Ministry of the Environment of Japan. (2020). Results of actual survey on municipal solid waste: Results of fiscal year 2020 (Accessed on 13th Jan. 2023). https://www.env.go.jp/press/107932.html

Olaf Holm, Franz-Georg Simon （2016） Innovative treatment trains of bottom ash （BA） from municipal solid waste incineration （MSWI） in Germany, Waste Management, 59, 229-236

Quek, A., Xu, W., Guo, L., and Wu, D. (2016). Heavy Metal removal from Incineration Bottom Ash through Washing with Rainwater and Seawater, International Journal of Waste Resources, 6(1), 1000203.