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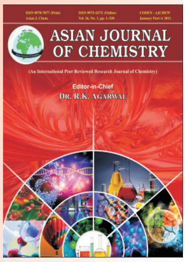

Physical and Chemical Properties of Dry Bottom Ash According to Particle Size Separation for the Development of Light-Weight Artificial Soil†

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A general method to expand the urban green space is to utilize the artificial ground that is unutilized in cities, such as buildings and rooftops. This artificial ground mainly utilizes light-weight artificial soil that in addition to being light-weight has economic feasibility and functionality. The processing technology of bottom ash in thermal power stations shows a tendency to change from the wet process to the dry process. The dry process bottom ash, which arises from the new process, are expected to be utilized as light-weight artificial soil, because they are poor in water, salt and unburned carbon, which are not the characteristics of the existing wet process bottom ash and have a lower density than general aggregate. Therefore, in this study, the suitability of artificial soil composed of dry process bottom ash was evaluated by comparing it to perlite, which is presently predominantly used as artificial soil. This study shows that the coefficient of permeability, saturation bulk density, pH, EC, total amount of nitrogen and organic matter contents of dry process bottom ash are similar to those of perlite. It is concluded that the dry process bottom ash can be utilized as artificial soil.

Keywords: Dry process bottom ash, Light-weight artificial soil, Ground greening.

INTRODUCTION

Population concentration in cities and increase in land utilization has reduced the environment that is inhabited by animals and plants in cities[1,2]. The reduction of this environment has brought about global warming and abnormal climate. Accordingly, the need for creating an environment where nature and human beings coexist in cities has come to the forward. However, securing green spaces in downtown areas is difficult due to the high population density and limited land utilization. One method for solving this is to utilize the artificial ground that is unutilized in cities, such building rooftops, as green spaces[3,4]. This artificial ground greening, in which soil layers and trees are established on artificial structures, requires researchers on the weight of buildings and growth of plants.

The material widely used as artificial soil is perlite, which is the most optimal material considering the growth of plants and weight on buildings due to its light-weight, economic feasibility and functionality[5-7]. However, carbon dioxide is created in the manufacturing process and most of it is dependent on import.

Thermal power stations, which account for more than 60 % of domestic electric power, generate electric power using coal as the raw material and the coal ash, which arise from the generation of electric power, are classified into fly ash and bottom ash and treated[8,9]. Coal ash collected in the air is called fly ash, most of which are used as construction material. Coal ash, which falls in the combustion chamber in lumps, is called bottom ash. Bottom ash cooled with water is called wet process bottom ash and those cooled with air are called dry process bottom ash, most of which is used in foundations or landfills. Because dry process bottom ash has low water, salt and unburned carbon content, unlike wet process bottom ash and has a lower density than general aggregate, this is suitable for utilization as light-weight artificial soil.

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Therefore, in this study, the suitability of dry process bottom ash (hereafter bottom ashes) as a substitute for perlite in light-weight artificial soil according to their distributed particle sizes was verified.

EXPERIMENTAL

Light-weight soil has advantages such as light weight, water permeability, air permeability and nutrient holding capacity. This light-weight soil is placed on the lower drainage layer of the effective soil layer when forming artificial ground. It is also divided into organic and inorganic light-weight soil. Organic light-weight soil is a highly polymerized compound, such as wood and fumic acid light-weight soil and inorganic light-weight soil is a calcareous or rocky light-weight soil, such as perlite.

Organic light-weight soil is light in weight, has a thin soil layer and is unsuitable for tall trees because of its low bearing capacity. Inorganic light-weight soil is more widely used than the organic one because of its highly adjustable soil thickness. The uses and characteristics of inorganic soil are shown in Table-1.

Bottom ash, which generates from thermal power stations, is classified into wet process bottom ash, which is cooled and transported by water on the other hand dry process bottom ash, which is cooled by air and transported by normal vehicles. In the transport method for wet process bottom ash, the ash is cooled by water, crushed to lower than 15 mm in diameter using a crusher and transported to ash disposal facilities. In the transport method for dry process bottom ash, the ash is cooled by air, crushed using a crusher and transported to ash disposal facilities by normal vehicles and their particle sizes range from over 100 mm to a fine powder. The particle pore space of wet and dry process bottom ash shows a porosity of about 20 % and a wide porosity of 20-50 % from fine particles to coarse particles, respectively. The physical and chemical properties of wet and dry process bottom ash are shown in Table-2.

General procedure: In this study, the samples used were distributed according to specific particle sizes after comminuting bottom ash that were discharged from thermal power stations using an impact crusher. In the particle of fine aggregates, the particle sizes of bottom ash are divided into five categories, from 0.15 mm, as shown in Table-3. Except for the particles over 5 mm, the particles were distributed in five stages by increasing by one stage at a time. The perlite and distributed bottom ash of sizes 2.5, 1.25, 0.6, 0.3 and 0.15 mm are used. The measurement items were unit bulk mass,

TABLE-1
CHARACTERISTICS AND USES OF LIGHT-WEIGHT SOIL

Light-weight soil	Use	Characteristic
Vermiculite	Planting soil layer mixing	Biotite or metamorphic rock sintered at high temperatures Has good water holding capacity, air permeability and water permeability due to its porosity Great nutrient holding capacity resulting from great basic exchange capacity pH of about 7.0 Perlite sintered at high temperatures
Perlite	Planting soil layer mixing	Has good water holding capacity, air permeability and water permeability due to its porosity No nutrient holding capacity resulting from small basic exchange capacity Neutrality, weak alkalinity
Volcanic gravel	Drainage layer	Released moisture and volatile components in volcanic eruptive rocks
Volcanic sand	Drainage layer, planting soil layer mixing	Good air permeability, good water permeability due to its porosity
Coal ashes	Drainage layer, planting soil layer mixing	Unburned remaining lumps after combustion of coal Has good air permeability, good water permeability due to porosity, Carbonized reed or moss in cold wetlands in the soil
Peat	Plant soil layer mixing	Good water holding capacity, good water permeability Great nutrient holding capacity resulting from basic exchange capacity

TABLE-2
COMPARISON OF THE PHYSICAL PROPERTIES OF BOTTOM ASH

Item			Wet process bottom ash	Dry process bottom ash (before processing)
Physical properties		Size	15 mm-powder	100 mm-powder
		Shape	Irregular aggregate or powder shape	Irregular aggregate or powder shape
		Porosity of particle	About 20 %	20-50 %
		Moisture state	Wet condition by sea water immersion	Absolute dry condition
		Surface dry density	1.7 kg/L	1.2-1.5 kg/L
		Unit bulk mass	900-1,200 kg/ m^3	350-750 kg/m^3
		Percentage of water absorption	About 10 %	15-30 %
Chemical properties	Oxide analysis	SiO_2	43.5	40.5
		CaO	10.1	13.2
		MgO	2	4.4
		Al_2O_3	17.7	16.7
		SO_3	2.8	0.1
		K_2O	1.5	0.9
	Unburned carbon		1-25 %	Less than 1 %
		Chloride	Contained	Not contained

TABLE-3
EXPERIMENTAL PLAN OF ARTIFICIAL SOIL MATERIALS

Test materials	Experimental plan	
	Physical properties	Chemical properties
Perlite	Air-dried bulk density	pH
(2.5-5.0) mm dBA	Saturation bulk density	EC
(1.25-5.0) mm dBA	Percentage of saturated water content	CEC
(0.6-5.0) mm dBA	Coefficient of permeability	Content of Heavy metals
(0.3-5.0) mm dBA	Particle size distribution	Total amount of nitrogen
(0.15-5.0) mm dBA	–	Content of organic matter

air-dried bulk density, saturation bulk density, coefficient of permeability, particle size, pH, soil salinity (EC), cation exchange capacity test (CEC), content of heavy metals, total amount of nitrogen and content of organic matter.

Detection method

Standard compaction method: For light-weight artificial soil, because the unit bulk mass, bulk density, percentage of water content and coefficient of permeability vary with compaction, a standardized compaction method is required. However, for artificial soil, the compaction does not satisfy the Korean Industrial Standards (KS). Therefore, this test was conducted by compacting the sides of the sample mold 20 times with a rubber hammer, with a weight of 50 N placed on a flat plate (diameter 150 mm) on the upper part of the sample.

Air-dried bulk density: In a water-permeable circular mold used in a ASTM E 2399 (Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems), the weight of artificial soil material was made constant at 105 ± 5 ºC. Furthermore, the sample was compacted using the standard compaction method and the air-dried bulk density of the material was measured by dividing the measured mass by the bulk.

Saturation bulk density: The test piece was fully saturated until bubbles did not arise from the sample using a vacuum saturation device after the air-dried bulk density test, following which, the saturation bulk density was measured after water was drained by gravity for 2 h under natural conditions.

Percentage of saturated water content: The percentage of saturated water content was measured using the sample mass in the air-dried bulk density test and the sample mass in the saturation bulk density test.

Coefficient of permeability: The coefficient of permeability was measured in accordance with the KS F 2322 (Standard test methods for permeability of saturated soils). The coefficient of permeability test method measures the permeating flow rate within a specific time period, maintaining the constant water head difference.

Particle size: The particle size distribution of each sample was measured in accordance with the KS F 2502 (sieve analysis test method of coarse and fine aggregates).

pH: To measure the pH of artificial soil, the pH 1:5 method was used, in which the ratio of soil to distilled water under air-dried conditions is 1:5. 5 g of the analytical sample prepared by the sample preparation method was put into a 50 mL beaker and evenly mixed with 25 mL of distilled water and then left alone for about 1 h and the pH was measured within 1 min of inserting stabilized glass and standard electrodes using a pH meter that was calibrated with a pH standard solution.

Soil salinity (EC): To measure the soil salinity of artificial soil, the pH 1:5 method was used, in which the ratio of sample to distilled water under air-dried conditions is 1:5. 10 g of soil was put into an Erlenmeyer flask along with 50 mL of distilled water. The mixture was shaken for 1 h and filtered with filter paper and the soil salinity was measured within 1 min of inserting a standard electrode using an soil salinity meter.

Cation exchange capacity (CEC): 1 N-NH_4OAc (pH 7) solution was passed through the artificial soil sample to be saturated with replaceable NH_4^+, unabsorbed excess NH_4^+ was cleaned with isopropyl alcohol, absorbed NH_4^+ was replaced with 100 mL of 10 % NaCl solution and the NH_4^+ in the NaCl solution was distilled using the Kjeldahl distillation method and titrated with 0.01 N H_2SO_4 solution to measure the cation exchange capacity.

Content of heavy metals: 3 g of the sample was put into a reaction vessel for decomposing heavy metals, wetted with some purified water, left alone for 2 h after adding 21 mL of hydrochloric acid and 7 mL of nitric acid, decomposed by gradually increasing the temperature and refluxing the reaction mixture for another 2 h, filtered with a Whatman No. 40 filter paper after combining the contents of the absorption cell and the contents of the heavy metals were measured using an ICP-OES.

Total amount of nitrogen: The method used for quantification was the micro-Kjeldahl method, in which organic nitrogen is decomposed with thick sulfuric acid and a catalyst to convert it into ammonia nitrogen which is distilled under alkali conditions for quantification. 1 g of the air-dried sample, which passed a 0.5 mm sieve, was put into a micro-Kjeldahl flask, decomposed by heating for 4 h after sequentially adding 1.1 g of K_2SO_4 mixed catalyst and 5 mL of thick sulfuric acid and the decomposed solution was diluted with distilled water, distilled in a distillation flask and titrated with standard sulfuric acid to measure the total amount of nitrogen.

Content of organic matter: The Walkley-Black method was used to measure the organic matter content. 0.5 g of the air-dried soil, which passed a 0.5 mm sieve, was put into a 500 mL Erlenmeyer flask and mixed with 10 mL of 1 N $K_2Cr_2O_7$ and 20 mL of conc. H_2SO_4. After leaving the sample for 0.5 h, about 200 mL of distilled water was inserted. Subsequently, 4-5 droplets of indicator were inserted and titrated with 0.5 N $FeSO_4$ until the colour changed from red to green or blue-green and finally to murex.

RESULTS AND DISCUSSION

Air-dried bulk density: Fig. 1 shows the measurement results of the air-dried bulk density of artificial soil, 0.09 kg/L for perlite and 0.55-0.67 kg/L, for dry process bottom ash irrespective of particle size. Dry process bottom ash showed very high air-dried bulk densities compared to perlite, which is considered to be affected by the SiO_2 contents.

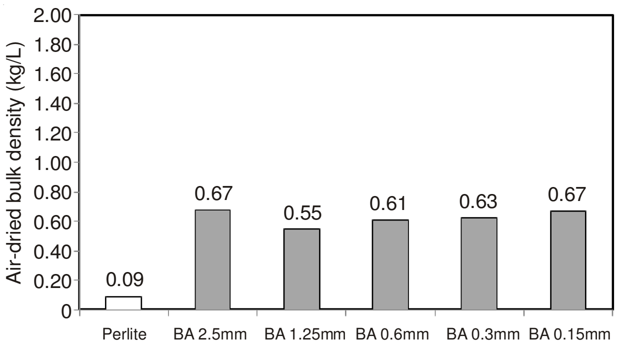

Fig. 1. Air-dried bulk density of artificial soil materials

Saturation bulk density: Fig. 2 shows the saturation bulk densities, 0.71 kg/L for perlite and 0.75-1.22 kg/L, for dry process bottom ash. With respect to the respective particle sizes of dry process bottom ash, as the content of fine particles increases, the saturation bulk density also increases.

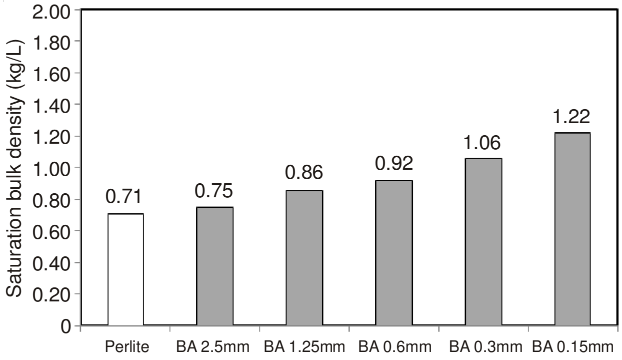

Fig. 2. Saturation bulk density of artificial soil materials

Percentage of saturated water content: Fig. 3 shows the test result of the percentage of saturated water content, 677.8 % for perlite and 36.9-89.7 % for bottom ashes. The basic difference in unit bulk mass and the excellent water holding capacity of perlite are thought to result from its high water content percentage. This percentage of saturated water content is a reference for judging the water holding capacity, which is a very important requirement for the growth of plants.

Coefficient of permeability: Fig. 4 shows the experiment results of the coefficient of permeability, which is 0.04 cm/s for perlite and 0.12 cm/s for bottom ashes, which is similar to perlite. With respect to the respective particles of bottom ashes, the particle sizes from 2.5-5.0 mm show a high coefficient of permeability of 7.90 cm/s and those in the 0.3-5.0 mm and of 0.15-5.0 mm range show coefficients of permeability of 0.52 and 0.12 cm/s, respectively.

Particle size: Fig. 5 illustrates the particle size distribution with respect to the respective particle size stages. These experiment results are expected to be utilized for determining the particle size distribution of components, which are added for adjusting properties such as weight, water holding capacity and coefficient of permeability in the production of artificial soil.

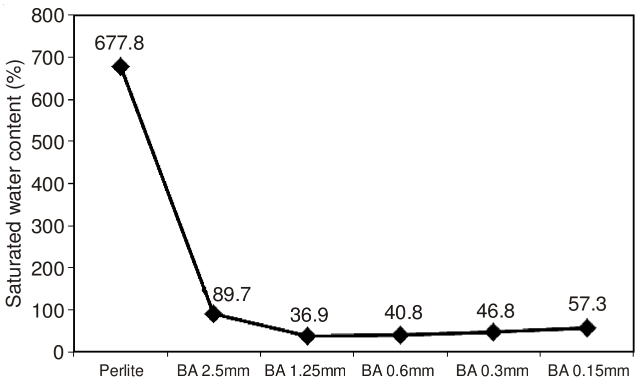

Fig. 3. Percentage of saturated water content of artificial soil materials

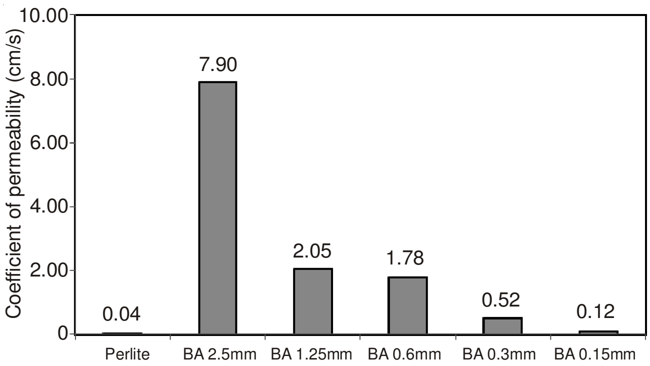

Fig. 4. Coefficient of permeability of artificial soil materials

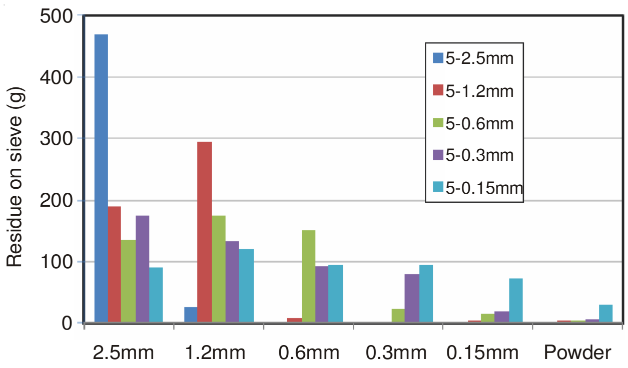

Fig. 5. Particle size distribution of bottom ash

pH test: Fig. 6 shows the pH test results, which are almost similar for both perlite and bottom ashes and located in the middle of the pH range of normal soil of 3-9. No difficulty in adjusting the pH according to the preference of each plant species is expected in future utilizations of artificial soil.

Soil salinity (EC): Fig. 7 shows the measurement result of the soil salinity of test materials, which are much lower for both perlite and bottom ash than the standard values. The low soil salinity of bottom ash is thought to result from cooling and storing in air. The soil salinity influences the growth of plants and bottom ash is expected to be utilized as artificial soil.

Cation exchange capacity (CEC): Fig. 8 shows the measurement results of the cation exchange capacity, 9.96 cmol$^+$/kg for perlite and 0.79-1.96 cmol$^+$/kg for bottom ash, while domestic normal soil shows a cation exchange capacity of 10 cmol$^+$/kg. Although cation exchange capacity value of bottom ash is less than perlite value, utilization of artificial soil is possible because nutrients in soil can be supplemented with fertilizers.

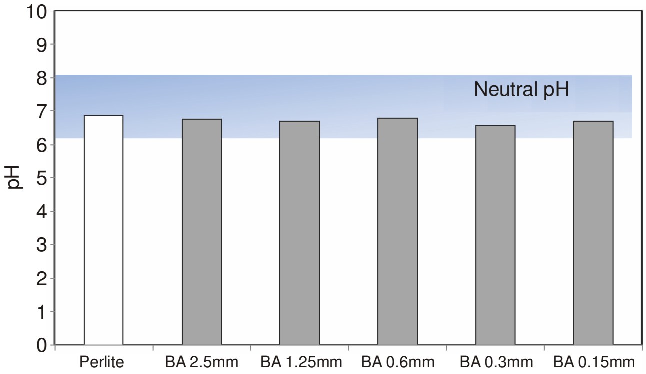

Fig. 6. pH of artificial soil materials

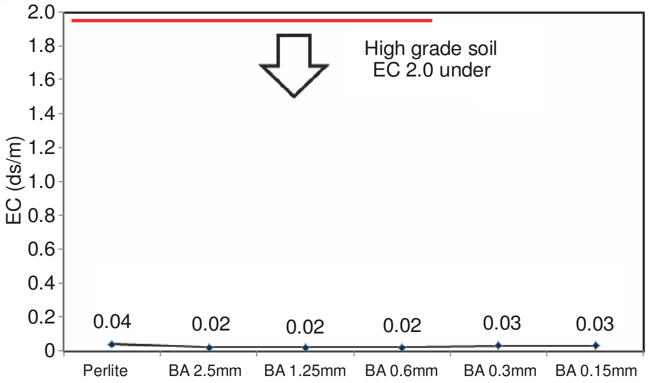

Fig. 7. Soil salinity of artificial soil materials

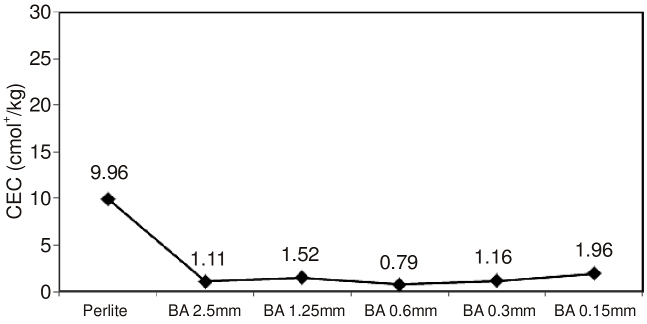

Fig. 8. Cation exchange capacity of artificial soil materials

Heavy metals content: Table-4 shows the test result of heavy metals content. Both perlite and bottom ash meet the official soil contamination test standards. 0.20 and 0.16 mg/kg of cadmium were detected in the perlite and bottom ashes, respectively.

Total amount of nitrogen: Fig. 9 shows the measurement results of the total amount of nitrogen, 154 mg/kg for perlite and 65-105 mg/kg for bottom ashes. With respect to the respective particle sizes of bottom ashes, particles with sizes in the 0.6-5.0 and 0.15-5.0 mm range, which include fine particles, show somewhat larger total amounts of nitrogen than perlite.

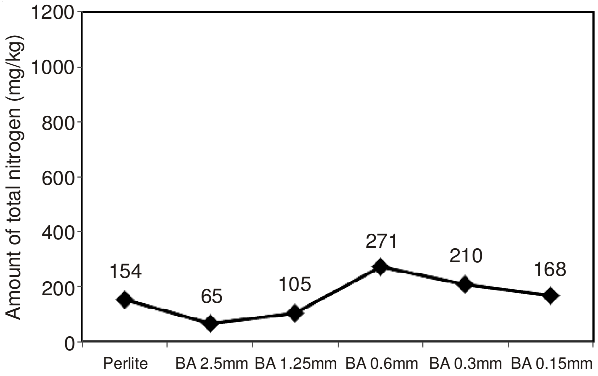

Fig. 9. Total amount of nitrogen of artificial soil materials

Organic matter content: Fig. 10 shows the measurement results of organic matter content, 0.07 % for perlite and 0.13-0.47 % for bottom ash. Perlite is known to be low in organic matter content, but excellent for the growth of general plants. Accordingly, bottom ash, which has similar contents of organic matter to those of perlite, are also thought to facilitate the growth of plants.

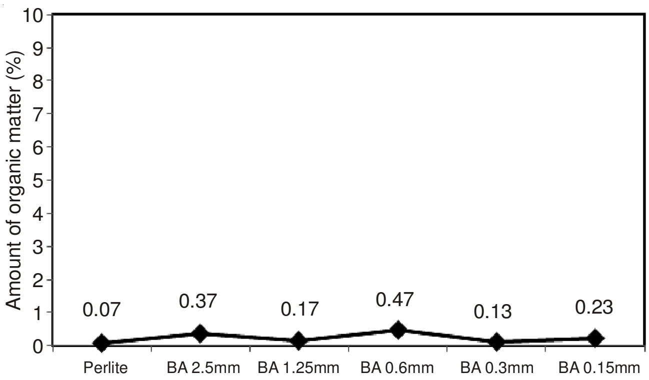

Fig. 10. Content of organic matter of artificial soil materials

Conclusion

As a results of the evaluation of the physical and chemical property of an artificial soil material, we have come to the following conclusions.

- Some physical properties of dry process bottom ash showed differences from those of perlite, for example, of about sevenfold in the air-dried bulk density and more than tenfold in the percentage of water content. However, their saturation bulk density and coefficient of permeability, which are important in artificial soil, were similar to those of perlite. As a result of these experiments, dry process bottom ash is judged to be suitable as artificial soil.
- Among the chemical properties of dry process bottom ash, the cation exchange capacity showed up to a twelvefold

TABLE-4
HEAVY METALS CONTENT OF ARTIFICIAL SOIL MATERIALS

Item	Cd	Cu	As	Pb	Zn	Ni
Perlite	0.20	8.2	N/D	N/D	12.5	12.9
(2.5-5.0) mm dBA	N/D	25.1	N/D	7.6	19.6	11.2
(1.25-5.0) mm dBA	N/D	19.4	N/D	5.0	15.9	13.0
(0.6-5.0) mm dBA	N/D	24.1	N/D	7.0	19.4	13.1
(0.3-5.0) mm dBA	0.16	23.2	N/D	6.7	18.0	15.2
(0.15-5.0) mm dBA	N/D	25.3	N/D	6.9	19.1	16.4

difference compared to that of perlite, while the pH, soil salinity and total amount of nitrogen values were similar to that of perlite. Furthermore, it is thought that since all the official soil contamination test standards (Notification No. 2013-113 of the Ministry of Environment) were met in the heavy metal leaching test, no environmental problems will be encountered from the use of this artificial soil in the future.

Finally, a comparison with perlite showed differences in the air-dried bulk density, percentage of water content and cation exchange capacity. However, it is thought that since the other measurement values were similar to those of perlite, there should be no problems in utilizing dry process bottom ashes as a light-weight artificial soil.

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