Center for
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Utilization

STATUS REPORT

CHARACTERIZATION AND USE OPTIONS FOR ASH PRODUCED BY HERMAN MILLER, INC.

By Tarun R. Naik and Rudolph N. Kraus

Report No. CBU-2007-08
Rep-629
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Submitted to Willie Beattie, Herman Miller, Inc., Zeeland, Michigan

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Executive Summary

TITLE: Characterization and Use Options for Ash Produced by Herman Miller, Inc.

SOURCE: UWM-CBU Report No. CBU-2007-08, REP-629, October 2007

BACKGROUND/PURPOSE: To conduct physical, chemical, mineralogical, and microstructural tests for determining properties of the ash produced at the Herman Miller plant to evaluate the potential options for beneficial recycling.

OBJECTIVE: The primary objective of this project was to recommend alternatives to the normal practice of landfilling by evaluating potential reuse/recycle applications for these materials, especially in durable, construction materials.

CONCLUSIONS:

RECOMMENDATIONS:

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Section 1

Introduction

The scope of this project was to determine physical, chemical, mineralogical, and microscopical (i.e., morphological) properties of the ash produced from daily operations at the Herman Miller. The main objective of this project is to recommend alternatives to the normal practice of landfilling by recommending potential reuse/recycling applications for this material. Background information on the source of the ash materials was obtained from Herman Miller describing the type of boilers, fuel sources, and related data (Table 1).

It has been established by previous projects at the UWM Center for By-Products Utilization (UWM-CBU) that properties of wood and/or coal-combustion products (i.e. different types of ashes) vary from boiler to boiler depending upon the type and source of fuel, how the ash is collected, design and operation of the boiler, and other similar variable based upon the type of fuel and the boiler. Therefore it is important to determine physical, chemical, and morphological properties of the ash for determining their appropriate safe, best-practice, use options, which are environmentally sound and economical.

Before beginning any quantitative testing, the general physical appearance of the ash from the Herman Miller plant was evaluated. Samples were taken by Herman Miller, Inc. on four different dates, July 13, 16, 17, and 18, 2007. Each delivery was evaluated for the general physical appearance of the ash, and a moisture content sample was taken from each (Table 2). The ash consisted of particles nearly black in color, with a wide range of particle sizes, typically from fine ash to pieces over 1-1/2 inches long. Pieces were typically flat, 1/8 to 1/2-inch thick and irregular in shape. Some pieces were over 2 inches long. Ash was delivered with high moisture content, 86 to 181 percent by weight. After the initial characterization, with the approval of Herman Miller, one composite sample was from obtained from all samples delivered. This composite sample was obtained by dry-mixing all samples in a rotating drum concrete-mixer. The composite sample was then placed in a plastic-lined 55-gal steel drum.

In order to evaluate the potential of the Herman Miller ash for various uses as a construction material, such as for aggregate or as a substitute for cement in manufacturing concrete, typical ASTM tests were conducted. ASTM provides standard specifications for both aggregate for use in cement-based products (ASTM C 33) as well as for coal fly ash use in concrete (ASTM C 618). Other specialized test protocols for ash use in construction materials, developed at UWM-CBU, were also used. To judge the suitability of the Herman Miller ash for potential use as a mineral admixture in cement-based materials, tests were performed as described in the following sections. Results obtained were compared to the requirements specified in ASTM C 33 and C 618.

Section 2

Tests of Herman Miller Ash

EXPERIMENTAL PROGRAM

A test program was designed to measure physical, chemical, mineralogical, and microscopical properties of the ash from the Herman Miller plant. In order to test various properties of the ash, the following experiments were carried out.

PHYSICAL PROPERTIES

<u>As-Received Moisture Content</u>

As-received moisture content (MC) of the Herman Miller ash was determined in accordance with the ASTM Test Designation C 311. Table 3 provides the test data on the composite ash sample. The results show that the Herman Miller ash had very high moisture content (180 %) by weight of dry sample. The ash sample received by UWM-CBU would not meet ASTM C 618 requirements for moisture content for a typical coal fly ash (3% max.). It is important to maintain consistent, low moisture contents when using these materials in some proposed future applications since there are some significant negative attributes associated with moisture in any ash:

(1) Moisture/water content leads to cost of shipping water along with the ash to the potential user of the ash. This, of course, increases the cost to the user in obtaining the ash for beneficial recycling.

(2) If the moisture content is not within control, then the variation leads to quality control challenges for the user.

(3) The water content is a critical parameter for manufacturing cement-based products. Therefore, if the user is planning to use the ash in cement-based materials, then the water content must be controlled in a narrow range to control the quality of such products.

(4) Wetting the ash with or soaking it in water would destroy any potential cementitious ability of the ash.

(5) A typical manufacturer of cement-based materials is equipped very well to handle dry or relatively dry materials. Therefore, wet or variable moisture content ash would make it harder for Herman Miller to implement the beneficial uses of the ash for reuse/recycle purposes for cement-based construction materials.

Particle Size Analysis

Ash samples were first oven-dried at 210°F ± 10°F and then were tested for gradation using standard sieve sizes (passing #200), as reported in Table 3, in accordance with ASTM Test Designation C 136. Since less than 5% of the Herman Miller ash passed the No. 200 sieve, a test for material finer than a 325 sieve (45 μm) per ASTM Test Designation C 430 was not conducted. ASTM C 618 for coal fly ash classifies a value of maximum 34% retained on the No. 325 sieve as satisfactory for use in concrete. The Herman Miller ash sample from the ASTM C 136 test results showed that over 97% would be retained for this test, which is out of the acceptable range for this test.

Particle size analysis data in Fig. 2 shows that the ash is very coarse compared with a typical Class C or Class F coal ash, since about 76% of the material is coarser than a No. 30 (0.6mm sieve). The particle size distribution of the Herman Miller ash more closely resembles the particle size distribution of a uniformly graded aggregate. The particle size distribution also shows that the material has more fine particles present than a typical concrete sand (68% of the materials passing a #30 sieve) and a considerable number of larger particles present (approximately 64% retained on a No. 4 (4.75mm) sieve). The gradation indicates that the sample has combined characteristics applicable to both fine and coarse bottom ash. These results indicate that the Herman Miller ash may be suitable for use as a fine aggregate and coarse aggregate and should be useful in CLSM-type of flowable slurry products, as well as cast-concrete products such as bricks, blocks, and paving stones. The presence of fine particles would also be useful in applications such as self-compacting concrete and roller-compacted concrete for pavements for parking areas and/or for storage areas.

Unit Weight

Unit weight (i.e., bulk density) of the ash was determined in accordance with the ASTM Test Designation C 29. Table 4 provides the test results. Bulk density of the Herman Miller ash was 16.9 lb/ft^3. These data indicate that some size fractions contained in the ash may be suitable for replacing regular, light-weight, sand. Determining the bulk density value is also necessary for calculations for establishing and modifying cement-based construction materials mixture proportioning. Percentage of voids in Table 4 indicate amount of free space available for packing of other materials in making cement-based materials. The higher the percent voids, the higher the amount of other materials necessary for making cement-based materials. Over 84% void space was present in the Herman Miller ash.

Specific Gravity

Specific gravity tests for the Herman Miller ash were conducted in accordance with the ASTM Test Designation C 188. The composite Herman Miller Ash sample was first ground (less than 0.5mm) prior to testing. Results are given in Table 5. They show that the specific gravity for the Herman Miller ash is 1.72. This is less than typical Class F coal fly ash (specific gravity approximately 2.50) or typical Class C fly ash (specific gravity approximately 2.60). Specific gravity of typical natural sand is about 2.7. Specific gravity value is necessary for determining relative substitution rate for fly ash versus amount of cement or sand replaced in a mixture; and, also for calculations for establishing and modifying cement-based construction materials mixture proportions.

ASTM C 618 TESTS

Physical Properties per ASTM C 618

ASTM C 618 provides standard specifications for coal fly ash and natural pozzolans for use in concrete. Therefore, to judge the suitability of the Herman Miller ash for potential use as a mineral admixture in cement-based materials, the composite ash sample was ground to a fine powder (passing a No. 50 sieve). Physical tests were performed as described below in accordance with the ASTM Test Designation C 618. Table 6 shows physical properties requirements for coal fly ash and natural pozzolans per ASTM Test C 618. The following physical properties of the Herman Miller ash were determined: (1) Cement Activity Index; (2) Water Requirement; and (3) Activity Index with Lime.

Cement Activity Index

Cement activity index test for the Herman Miller ash was performed in accordance with the ASTM Test Designation C 311/C 109. The ash was first passed through a No. 16 sieve prior to testing. Two-inch mortar cubes were made in the manner prescribed in ASTM C 109 using a mixture of cement, sand, and water, without any ash (Control Mixture). Compressive strength tests were conducted at the age of 1, 3, 7, and 28 days. Actual strength test results are reported in Table 7 for the test specimens made from the Control Mixture. Additional test mixtures were prepared using 80% cement and 20% Herman Miller ash, by weight (instead of cement only without ash as in the Control Mixture). Results are reported in Table 7.

Comparison of the compressive strength for mixtures with and without Herman Miller ash is reported in Table 8. These results are designated as Strength Activity Index with Cement. In this comparison, the Control Mixture was assigned a value of 100, at each age, and all other compressive strength values were scaled from this reference datum at each age.

The compressive strength test results, Table 7, for the Herman Miller ash mixtures were lower than that for the Control Mixture without ash. The Activity Index with Cement data, Table 8, for this ash was 37% at the age of 7 days (much lower than minimum 75% required by ASTM C 618 for coal ash at either the 7- or 28-day age) for the compressive strength, compared with the Control Mixture without ash. However, the actual test data, Table 7, show that although the compressive strength achieved with the Herman Miller ash did not perform as well as the Control Mixture without ash, the material could be used in many lightweight concrete applications. Based upon the compressive strength data, overall, it can be concluded that the Herman Miller ash is suitable for making flowable slurry (which by the ACI Committee 229 Definition has up to 1,200 psi compressive strength), typical lightweight concrete, in low-strength concrete mixtures, and for base course and/or sub-base course for pavement of highways, roadways, runways, driveways, parking lots, and other similar construction applications. This ash source can also be considered very satisfactory for housing construction where typically a compressive strength of 3,000 psi concrete, at the age of 28 days, is used. This ash resource can also be used for in-house concrete construction needs of Herman Miller.

In summary, ASTM C 618 classifies a value at 7-day or 28-day age of 75 or above for the Activity Index with Cement for coal-fly ash as passing. Based upon this criterion only, the Herman Miller ash does not meet this requirement.

Water Requirement

Lime Activity Index

Evaluation with Activators

CHEMICAL PROPERTIES PER ASTM C 618

CHEMICAL COMPOSITION

ELEMENTAL ANALYSIS

SCANNING ELECTRON MICROSCOPY (SEM)

Table 1 - Background Information on the Herman Miller Ash*

Source	Herman Miller
Make of Boiler	Basic Engineering, Inc.
Type of Boiler	Solid Fuel Water Tube Steam Boiler
Age of Boiler	26 years
Type of Fuel	80% Wood, 20% Other (paper, corrugated products, cafeteria waste, plastis)
Maximum Size of Fuel	48" x 42"
Amount of Fuel Used Per Year	12,755 tons 2006 13,890 tons 2005 12,430 tons 2004
Burning Temperature	First Stage: 1,400 ˚F Second Stage: 1700 ˚F Third Stage: 1,300 ˚F Fourth Stage: 1,100 ˚F
Type of Energy	Steam
Amount of Energy	28×10^6 BTU/hr
Wet or Dry Ash Collection	Wet Ash Collection
Amount of Bottom Ash	1,375 tons 2006 1,470 tons 2005 1,050 tons 2004
Amount of Fly Ash	Not Available

* Information supplied by Herman Miller, Inc.

Fig. 1: Herman Miller Ash

AS-RECEIVED MOISTURE CONTENT AND DESCRIPTION OF SAMPLES

Table 2: As-Received Moisture Contents and Description of Individual Samples

Sample Date: 7-13-07 Pail 1/2 Received: 7-17-07 Moisture Content: 160% Sample Description: Sample appears to be mostly composed of charcoal pieces, with some nails visible in the sample. Particles are flat, 1/8 to ½-inch thick and range in size from fine particles to 3-in. long. Most particles appear to be in a size range from 1/8- to 1/2-in. Black in color with some small white particles, tiny specks, visible within the larger pieces.
Sample Date: 7-13-07 Pail 2/2 Received: 7-18-07 Moisture Content: 150% Sample Description: similar as Sample Date 7-13-07, Pail 1/2.
Sample Date: 7-16-07 Pail 1/2 Received: 7-17-07 Moisture Content: 86% Sample Description: More nails visible than the sample pails from 7-13-07 (with some heavy-duty staples for wood visible). Sample also appears to be coarser with most particles in a range from 3/8-in. to 1-in. Otherwise the similar characteristics as material sampled on 7/13/07.
Sample Date: 7-16-07 Pail 2/2 Received: 7-18-07 Moisture Content: 147% Sample Description: similar as Sample Date 7-16-07, Pail 1/2.
Sample Date: 7-17-07 Pail 1/3 Received: 7-20-07 Moisture Content: 183% Sample Description: Particles are flat, 1/8 to ½-inch thick and range in size from 1/8 to 1-1/2-in. long. Black in color with some small white specks visible within the larger pieces. Appears to be slightly darker in color when compared with samples taken on other dates. A larger number of white particles appear to be visible within the larger charcoal pieces.
Sample Date: 7-17-07 Pail 2/3 Received: 7-23-07 Moisture Content: 185% Sample Description: similar as Sample Date 7-17-07, Pail 1/3.
Sample Date: 7-17-07 Pail 3/3 Received: 7-23-07 Moisture Content: 220% Sample Description: similar as Sample Date 7-17-07, Pail 1/3.
Sample Date: 7-18-07 Pail 1/3 Received: 7-20-07 Moisture Content: 182% Sample Description: No nails or staples readily visible. Sample also appears to be coarse with few small particles visible. Flat pieces 1/8 to 3/8-in thick. Average size of ½-in. long, range from 1/8 to 1-1/2-in. Black charcoal pieces with some small (~1/16-in) white particles visible within the charcoal pieces.
Sample Date: 7-18-07 Pail 2/3 Received: 7-20-07 Moisture Content: 126% Sample Description: similar to Pail 1/3 sampled on 7-18. Average size of ½-in. range from 1/8 to 1-1/2-in.
Sample Date: 7-18-07 Pail 3/3 Received: 7-20-07 Moisture Content: 182% Sample Description: Similar to Pail 2/3 sampled on 7-18, but with some larger pieces visible. Flat pieces 1/8 to 3/8-in thick and range in size from ½-in to 3-in. long.

HERMAN MILLER ASH
MOISTURE CONTENT

Table 3: As-Received Moisture Content of the Herman Miller Ash

Source	Moisture Content, % (As-Received Sample)	
	Actual*	Average
Herman Miller Ash	176.2	179.7
	180.7	
	182.1	

$$\text{* Moisture Content, as-received, \%} = \frac{\text{(as-received sample weight – dry sample weight)}}{\text{dry sample weight}} \times 100$$

HERMAN MILLER ASH

PARTICLE SIZE ANALYSIS

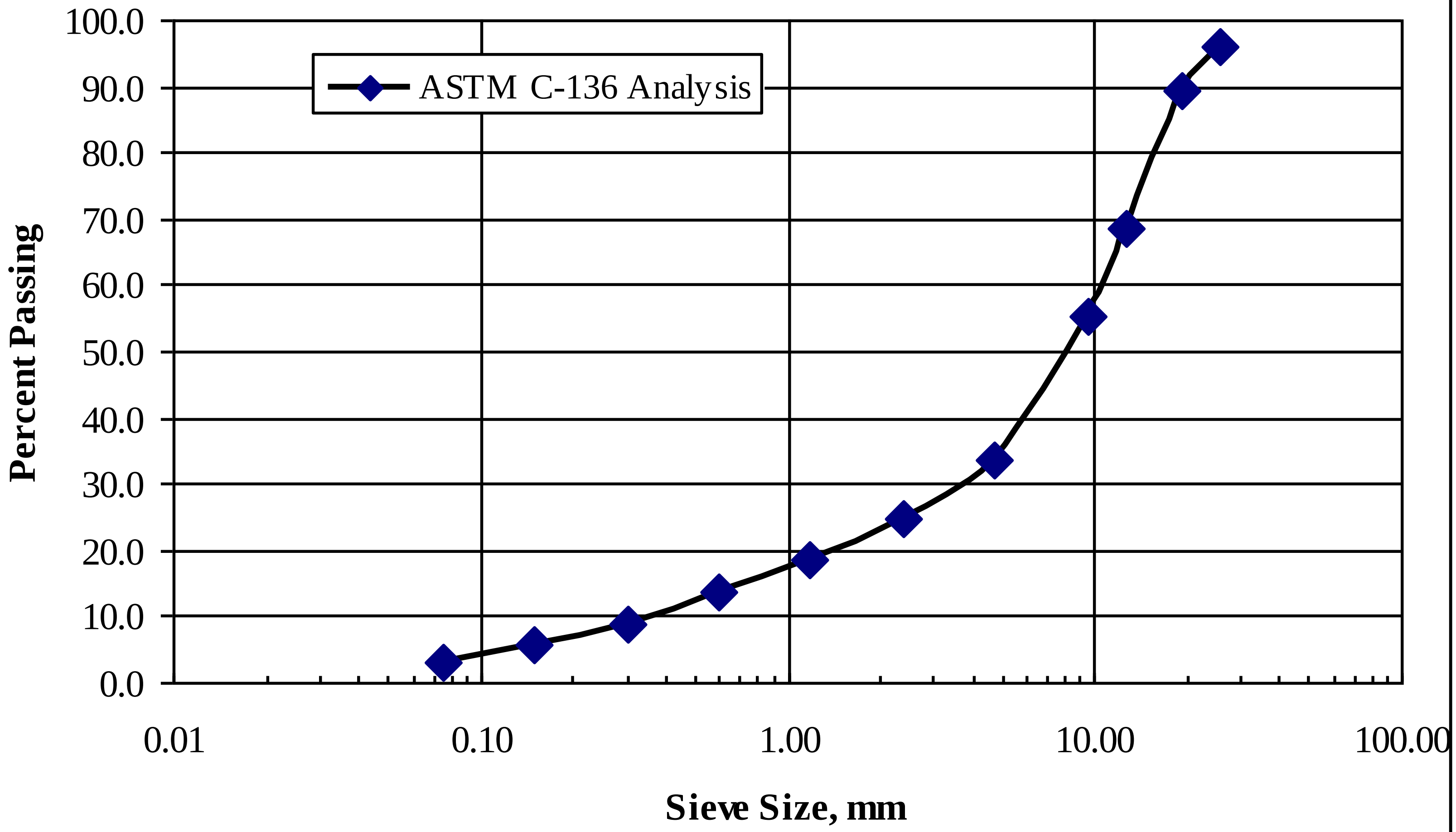

Figure 2: Particle Size Analysis

HERMAN MILLER ASH

UNIT WEIGHT, VOIDS, AND SPECIFIC GRAVITY

Table 4: Unit Weight and Voids
(Tests conducted on as-received samples per modified ASTM C 29)

Source	Unit Weight (lbs/ft^3)		Voids (%)	
	Actual	Average	Actual	Average
Herman Miller Ash	16.7	16.9	84.4	84.2
	17.0		84.2	
	17.1		84.1	

Table 5: Specific Gravity
(Tests Conducted per ASTM C 311/C 188)

Source	Specific Gravity	
	Actual	Average
Herman Miller Ash	1.71	1.72
	1.72	

HERMAN MILLER ASH

ASTM C 618 PHYSICAL PROPERTIES

Table 6: Physical Test Requirements of Coal Fly Ash per ASTM C 618

TEST	ASTM C 618 SPECIFICATIONS		
	CLASS C	CLASS F	CLASS N
Retained on No.325 sieve, (%)	34 max	34 max	34 max
Strength Activity Index with Cement at 7 or 28 days, (% of Control)	75 min	75 min	75 min
Water Requirement (% of Control)	105 max	105 max	115 max
Autoclave Expansion, (%)	±0.8	±0.8	±0.8
Specific Gravity	-	-	-
Variation from Mean, (%) Fineness Specific Gravity	 5 max 5 max	 5 max 5 max	 5 max 5 max

Table 7: Mortar Cube Compressive Strength*
(Tests conducted per ASTM C 311/C 109)

Source	Compressive Strength (psi)			
	1-Day	3-Day	7-Day	28-Day
Control	1565	3160	4025	
Herman Miller Ash	480	1210	1520	

* ASTM C 311 is used in conjunction with ASTM C 618 for evaluation of strength development of mineral admixtures with portland cement. A mineral admixture is added as replacement of cement for the test mixture. Each result is an average of three compressive strength tests. As-received ash was first ground prior to testing.

Table 8: Strength Activity Index with Cement**
(Tests conducted per ASTM C 311/C 109)

Source	1-Day Test %	3-Day Test %	7-Day Test %	28-Day Test %
Control	100.0	100.0	100.0	100.0
Herman Miller Ash	30.7	38.3	37.8	

** Results obtained from the mortar cube compressive strength results, Table 7.

Table 9: Water Requirement*
Tests conducted per ASTM C 311)

Source	Water Requirement (% of Control)	ASTM C 618 Specifications		
		Class C	Class F	Class N
Herman Miller Ash	149	105 max	105 Max	115 max

* Results obtained for the mortar cube mixtures.

Table 10: Pozzolanic Activity with Lime*
(Tests conducted per ASTM C 311/C 109)

Source	Compressive Strength (psi)
	7-Day
Herman Miller Ash	

*Ash was first ground prior to testing.

HERMAN MILLER ASH

EVALUATION WITH ACTIVATORS

Table 11: Mortar Cube Compressive Strength with Activators*
(Tests conducted per ASTM C 311/C 109)

Source	Activator	% Cement Replacement	Compressive Strength (psi)			
			1-Day	3-Day	7-Day	28-Day
Control	N/A	0	1565	3160	4025	
Herman Miller Ash	None	10	970	2215	2825	
		20	480	1210	1520	
	1	10	1145	2410	3345	
	2	10	615			

* ASTM C 311 is used in conjunction with ASTM C 618 for evaluation of strength development of mineral admixtures with portland cement. A mineral admixture is added as replacement of cement for the test mixture. Each result is an average of three compressive strength tests.

Table 12: Strength Activity Index with Cement with Activators*
(Tests conducted per ASTM C 311/C 109)

Source	Activator	% Cement Replacement	Strength Activity Index (% of Control)			
			1-Day	3-Day	7-Day	28-Day
Control	N/A	0	100	100	100	
Herman Miller Ash	None	10	62.0	70.1	70.1	
		20	30.7	38.3	37.8	
	1	10	73.1	76.3	83.1	
	2	10	39.3			

* Results obtained from the mortar cube compressive strength results, Table 11.

HERMAN MILLER ASH

ASTM C 618 CHEMICAL PROPERTIES

Table 13: Chemical Analysis (oxides, LOI, moisture content, available alkali)
(Tests conducted on oven-dried samples)

Analysis Parameter	ASTM C 618 Requirement			
	Herman Miller Ash	Class N	Class C	Class F
Silicon Dioxide, SiO_2	3.1	--	--	--
Aluminum Oxide, Al_2O_3	1.4	--	--	--
Iron Oxide, Fe_2O_3	0.7	--	--	--
SiO_2 $Al_2O_3 + Fe_2O_3$	5.2	70.0, Min.	50.0, Min.	70.0, Min.
Calcium Oxide, CaO	2.4	--	--	--
Magnesium Oxide, MgO	0.5	--	--	--
Titanium Oxide, TiO_2	1.7	--	--	--
Potassium Oxide, K_2O	0.4	--	--	--
Sodium Oxide, Na_2O	0.7	--	--	--
Sulfate, SO_3	1.0	4.0, Max.	5.0, Max.	5.0, Max.
Loss on Ignition, LOI (@ 750 C)	88.0	10.0, Max.*	6.0, Max.*	6.0, Max.*
Moisture Content	4.2***	3.0, Max.	3.0, Max.	3.0, Max.
Available Alkali, Na_2O Equivalent (ASTM C-311)		1.5, Max.**	1.5, Max.**	1.5, Max.**

* Under certain circumstances, up to 12.0% max. LOI may be allowed.
** Optional. Required for ASR Minimization.
*** Dried Sample used for analysis

HERMAN MILLER ASH

CHEMICAL COMPOSITION

Table 14: Mineralogy of Herman Miller Ash

MINERALOGY (% by Weight)	
Analysis Parameter	Herman Miller Ash
Amorphous	94.7
Calcite, $CaCO_3$	2.7
C3A	1.2
Titanite	1.5

HERMAN MILLER ASH

ELEMENTAL ANALYSIS

Table 15: Elemental Analysis (As-Received Sample)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)	
Element	Material
	Herman Miller Ash (ppm)
Aluminum (Al)	
Antimony (Sb)	
Arsenic (As)	
Barium (Ba)	
Bromine (Br)	
Cadmium (Cd)	
Calcium (Ca)	
Cerium (Ce)	
Cesium (Cs)	
Chlorine (Cl)	
Chromium (Cr)	
Cobalt (Co)	
Copper (Cu)	
Dysprosium (Dy)	

* Detection Limit Indicated by "<"

Table 15 (Continued): Elemental Analysis (As-Received Sample)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)	
Element	Material
	Herman Miller Ash (ppm)
Europium (Eu)	
Gallium (Ga)	
Gold (Au)	
Hafnium (Hf)	
Holmium (Ho)	
Indium (In)	
Iodine (I)	
Iridium (Ir)	
Iron (Fe)	
Lanthanum (La)	
Lutetium (Lu)	
Magnesium (Mg)	
Manganese (Mn)	
Mercury (Hg)	

* Detection Limit Indicated by "<"

Table 15 (Continued): Elemental Analysis (As-Received Sample)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)	
Element	Material Herman Miller Ash (ppm)
Molybdenum (Mo)	
Neodymium (Nd)	
Nickel (Ni)	
Palladium (Pd)	
Potassium (K)	
Praseodymium (Pr)	
Rubidium (Rb)	
Rhenium (Re)	
Ruthenium (Ru)	
Samarium (Sm)	
Scandium (Sc)	
Selenium (Se)	
Silver (Ag)	
Sodium (Na)	

* Detection Limit Indicated by "<"

Table 15 (Continued): Elemental Analysis (As-Received Sample)

ELEMENTAL (BULK CHEMICAL) ANALYSIS (Average of two samples unless noted otherwise)	
Element	Material
	Herman Miller Ash
Strontium (Sr)	
Tantalum (Ta)	
Tellurium (Te)	
Terbidium (Tb)	
Thorium (Th)	
Thulium (Tm)	
Tin (Sn)	
Titanium (Ti)	
Tungsten (W)	
Uranium (U)	
Vanadium (V)	
Ytterbium (Yb)	
Zinc (Zn)	
Zirconium (Zr)	

* Detection Limit Indicated by "<"

HERMAN MILLER ASH

SCANNING ELECTRON MICROGRAPHS

FIGURE 2: Herman Miller Ash, 25X Magnification

FIGURE 3: Herman Miller Ash, 50X Magnification

FIGURE 4: Herman Miller Ash, 100X Magnification

FIGURE 5: Herman Miller Ash, 500X Magnification

FIGURE 6: Herman Miller Ash, 1000X Magnification

FIGURE 7: Herman Miller Ash, 5000X Magnification

Section 5

References

[1] Naik, T. R., and Singh, S. S., "Fly Ash Generation and Utilization – An Overview," in Recent Trend in Fly Ash Utilization, Ministry of Environment and Forests, Government of India, Bhopal, India, June 1993 (available from the UW – Milwaukee Center for By-Products Utilization).

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