Beneficial Use of CCBs to Develop an Optimal Mix for Pervious Concrete

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ABSTRACT

Impervious (paved) surfaces are an integral part of development in the form of roads, parking lots, and driveways. However, these surfaces present various environmental difficulties because they typically prevent stormwater from infiltrating back into the subsurface. Alternatively, pervious concrete is an effective means to support “green”, sustainable growth by reusing by-products generated by coal-fired power plants to better manage stormwater runoff. Pervious concrete captures stormwater and allows it to seep back into the ground, which is an essential component of ground water recharge. It also reduces stormwater runoff and is often recommended by the Environmental Protection Agency (EPA) as a Best Management Practice (BMP).

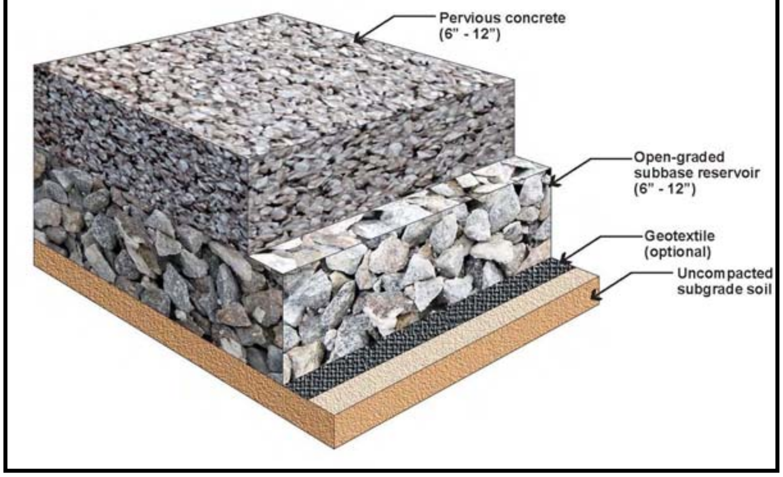
The Maryland Department of Natural Resources Power Plant Research Program (PPRP) is partnering with W. R. Grace and Lafarge to develop a marketable mix design(s) for pervious concrete that maximizes the beneficial use of coal combustion by-products (CCBs), while minimizing the potential for environmental impacts. The physical and chemical characteristics of the candidate CCBs were determined to verify the appropriateness for possible use in pervious concrete mixes. Testing included analyses for total and leachable major elements and trace metals. The candidate CCBs were tested using the American Society for Testing and Materials (ASTM) C618 method to determine suitability as a pozzolan or mineral admixture in concrete. A mix design study will determine the optimal concrete mix for bench scale testing. Bench scale testing will include subjecting trial pervious concrete cylinders to wet/dry leaching cycles.

INTRODUCTION

Traditional impervious surfaces are an integral part of urban, suburban, and rural development in the form of roads, parking lots, and driveways. However, these surfaces present various environmental difficulties because they typically prevent stormwater from infiltrating back into the subsurface. This barrier limits recharge to ground water resources and dramatically increases the amount of runoff that must be managed. Poorly managed runoff can create and/or exacerbate flooding conditions and can carry nutrients, sediment, spilled oil, and other chemicals (e.g., road salts) directly to surface water bodies, such as streams and lakes.

Pervious concrete is an effective means to support “green” sustainable growth by reusing by-products generated by coal-fired power plants, and it is an attractive solution to many of the environmental problems associated with traditional paved surfaces. Pervious concrete captures stormwater and allows it to seep back into the ground, which is an essential component of ground water recharge. It also reduces stormwater runoff and is often recommended by the Environmental Protection Agency (EPA) as a Best Management Practice (BMP). Although pervious concrete is comprised of the same materials as traditional concrete (i.e., Portland cement, aggregate, admixtures, and water), it is mixed in different proportions to create large, interconnected void spaces that allow water to drain through the concrete rather than run off the concrete. More specifically, coarse aggregate (i.e., gravel) with narrow size range is used to minimize packing and maximize void spaces, while greatly reducing the amount of fine aggregate (i.e., sand) from the mixture. A cementitious paste containing Portland cement, pozzolan, and an admixture(s) coats the aggregate particles and binds them together. Figure 1 is a schematic drawing of pervious concrete in cross-section.

Figure 1 Pervious Concrete



Coal combustion by-products (CCBs) have the potential to be used as a part of the mixture for pervious concrete. Bottom ash, which is composed primarily of ash particles that are too large to be carried in the flue gas of coal-fired power plants, can be used as aggregate material. Class F fly ash, which is composed of tiny, glassy, spherical particles, can be used as pozzolan material in the paste. Class C fly ash, which contains residual free lime from the burning of high calcium coals, can also provide supplementary cementitious materials for the paste.

The beneficial use of CCBs to manufacture products such as pervious concrete present environmental and economic advantages, as follows:

1. The disposal of CCBs into landfills is reduced. Landfills consume valuable land space and if not properly managed can leach soluble constituents causing ground water contamination;
2. The CCBs are permanently bound in the cementitious matrix through chemical reactions. Previously published studies by PPRP have shown that, when used in cured concrete mixtures, the metals contained within CCBs are far less likely to leach[1,2,3,4,5];
3. Recycling CCBs into an economically viable product significantly reduces the costs associated with disposing CCBs for power generators and the costs associated with purchasing raw materials for pervious concrete producers;
4. Where CCBs can be used as a surrogate for Portland cement, the greenhouse gas emissions (i.e., carbon dioxide) generated from cement manufacturing can be offset;
5. Finally, the use of recycled materials like CCBs in production processes can reduce the cost of production while also consuming fewer raw materials.

PPRP has partnered with W. R. Grace and Lafarge to develop a marketable mix design(s) for pervious concrete that maximizes the beneficial use of CCBs generated from power plants in Maryland, while minimizing the potential for environmental impacts. The study is proceeding in phases. Phase I includes the identification of a source of CCB materials and the characterization of those materials. Phase II includes the development and physical testing of candidate mixes using varying proportions of CCBs and conventional pervious concrete ingredients. Once an optimal mix has been selected, Phase III, which is a bench scale testing program to evaluate the potential for the pervious concrete mixture to leach under ambient weather conditions, will be initiated.

CCB SOURCE IDENTIFICATION AND TESTING

The first phase of this project involves identifying the source of CCBs to be used for the study and procuring the necessary volumes of ash. Constellation Brandon Shores Power Plant located in Baltimore, Maryland was selected as a source of fly ash and bottom ash for the baseline characterization of the physical and chemical characteristics of the CCBs. Brandon Shores provided 200 pounds of fly ash and 400 pounds of bottom ash for the initial testing. As the project continues, additional Maryland sources of CCBs may be identified for testing and particularly for future full-scale implementation.

CCB CHARACTERIZATION

Methods

Following CCB source identification, the physical and chemical characteristics of the CCBs were determined to verify their appropriateness for possible use in pervious concrete mixes. The fly ash and bottom ash samples were tested using the American Society for Testing and Materials (ASTM) C618 method. Conformance of the tested CCBs to ASTM C618 would indicate that the materials are suitable as a pozzolan or mineral admixture in concrete. This test is more relevant to the fly ash samples, as they would be used as pozzolan, and less relevant for the bottom ash, which would be used as an aggregate material and therefore is not required to be a chemically reactive part of the mixture.

CCB testing also included analyses for total and leachable major elements and trace metals. Although the final pervious concrete product is expected to be far less leachable than the raw CCBs themselves, either because the CCBs have been chemically reacted to form concrete (fly ash) or are encapsulated in concrete (bottom ash), testing the total metal content and leachable metal content of the raw CCB materials gives an initial indication of metals that should be monitored carefully during testing of the final product. The leachate tests were conducted using the EPA's Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP).

ASTM C618 Results

The results of the ASTM C618 test for both the chemical composition and physical requirements for Class F fly ash are shown in Table 1.

The chemical composition requirements include: the sum of silicon dioxide, aluminum oxide, and iron oxide; sulfur trioxide; moisture content; and loss on ignition. The physical requirements consist of fineness, strength activity index, soundness (water requirement), autoclave expansion, and uniformity of fineness and density. The uniformity of fineness and density for both samples could not be tested as only one sample for each material was submitted for testing.

Table 1. Chemical and physical properties of the CCBs according to ASTM C618.

Parameter	Units	ASTM C618 Requirement for Class F	Fly Ash	Bottom Ash
Chemical Requirements				
$SiO_2 + Al_2O_3 + Fe_2O_3$, min	%	70.0	89.3	**69.9**
SO_3, max	%	4.0	0.06	0.59
CaO	%	NS	1.06	2.17
MgO	%	NS	0.97	0.92
Na_2O	%	NS	0.27	0.29
K_2O	%	NS	2.32	1.68
TiO_2	%	NS	1.64	1.12
P_2O_5	%	NS	0.11	0.06
Mn_2O_3	%	NS	0.03	0.03
SrO	%	NS	0.05	0.03
Cr_2O_3	%	NS	0.03	0.01
ZnO	%	NS	0.01	< 0.01
BaO	%	NS	0.12	0.06
Alkalies as Na_2O	%	NS	1.80	1.40
Moisture content, max	%	3.0	0.05	0.41
Loss on ignitions, max	%	6.0	3.49	**23.25**
Physical Requirements				
Fineness, No.325 sieve, max	%	34	17.5	**74.5**
Strength Activity Index, 7 days, min	% of control	75	**65**	**22.0**
Strength Activity Index, 28 days, min	% of control	75	**72**	**25.5**
Water Requirement, max	% of control	105	105	**130**
Autoclave Expansion, max	%	0.8	0.1	**2.5**

< - Compound was not detected. Value indicates the reporting limit..

Values in bold do not meet the ASTM standard for Class F Fly Ash for use as pozzolan.

The fly ash meets all of the ASTM C618 requirements for Class F fly ash except for strength activity index. The strength activity index is used to determine whether the material develops an acceptable level of strength when used with hydraulic cement in concrete. The strength of the samples was tested after allowing the samples to cure for 7 and 28 days. The measured strengths were then compared to the strength of the control specimens (made with all Portland cement). The samples must be at least 75% of the strength of the control specimens after 7 and 28 days of curing. After 7 and days of curing, the strength activity indices calculated for the fly ash were 65% and 72%, respectively. Both the 7 day and 28 day strength activity index values for the fly ash fall below the 75% requirement. However the project team believed that the reported values are sufficient to warrant further inclusion in the preparation of candidate mixes.

The bottom ash was found to contain a wide range of particle sizes, including a relatively large proportion of fine particles, making it unsuitable for use as a coarse aggregate. The bottom ash can still be used as fine aggregate. The bottom ash does not meet the ASTM C618 requirements for Class F fly ash for several parameters; however, as the bottom ash would be used as aggregate material and not pozzolan, these characteristics are less critical. Therefore the bottom ash will also continue to be used in the preparation of candidate mixes as fine aggregate.

Total and Leachable Metals Results

A summary of the TCLP and SPLP leachate test results is presented in Table 2.

Table 2. Total and Leachable Metals and Ions Results.

Parameter	**Total Screening Level [1] (mg/kg)**	**TCLP Screening Level [2] (mg/kg)**	**SPLP Screening Level [3] (mg/kg)**	**Fly Ash**			**Bottom Ash**		
				Total (mg/kg)	**TCLP (mg/kg)**	**SPLP (mg/kg)**	**Total**	**TCLP**	**SPLP**
Metals									
Aluminum	55,000	NS	37	12,000	--	4.35	1,760	--	0.655
Antimony	0.27*	NS	0.006*	< 6.13	--	0.033	<1.99	--	<0.011
Arsenic	0.29*	5.0	0.01*	**20.8**	<0.100	**0.214**	<2.49	<0.100	<0.056
Barium	82*	100.0	2.0*	**161**	<2.00	0.243	25.6	<2.00	0.115
Beryllium	3.2*	NS	0.004*	**4.08**	--	< 0.011	0.649	--	<0.011
Boron	23	NS	7.3	< 6.7	--	1.07	3.61	--	<0.056
Cadmium	0.38*	1.0	0.005*	< 0.307	<0.020	< 0.011	<0.099	<0.020	<0.011
Calcium	NS	NS	NS	3,280	--	48.1	1,160	--	5.97
Chromium	180,000*	5.0	0.1*	39.2	0.292	< 0.111	5.23	<0.100	<0.111
Cobalt	0.49	NS	0.011	**14.4**	--	< 0.011	<4.97	--	<0.011
Copper	46*	NS	1.3*	42.9	--	< 0.056	6.46	--	<0.056
Iron	640	NS	26	**7,330**	--	< 0.011	**7,030**	--	0.091
Lead	14*	5.0	0.015*	**19.4**	<0.100	< 0.006	1.83	<0.100	<0.006
Magnesium	NS	NS	NS	953	--	1.68	276	--	<0.555
Manganese	57	NS	0.88	**58.6**	--	< 0.022	**169**	--	<0.022
Mercury	0.1*	0.2	0.002*	< 0.185	<0.0008	< 0.0008	<0.195	<0.0008	<0.0008
Nickel	48	NS	0.73	30.3	--	< 0.022	5.64	--	<0.022
Potassium	NS	NS	NS	2,080	--	18.3	<274	--	<0.611
Selenium	0.26*	1.0	0.05*	< 12.3	<0.100	< 0.111	<3.98	<0.100	<0.111
Silver	1.6	5.0	0.18	< 2.15	<0.020	< 0.022	<0.696	<0.020	<0.022
Sodium	NS	NS	NS	356	--	8.35	<274	--	0.803
Thallium	0.14*	NS	0.002*	**0.78**	--	< 0.022	**0.178**	--	<0.022
Vanadium	2.6	NS	0.0026	**68.9**	--	**0.399**	**5.59**	--	<0.011
Zinc	680	NS	11	32.2	--	< 0.044	31.7	--	<0.044
Other									
pH (s.u.)	NS	NS	NS	9.09	4.97	8.38	7.16	5.09	7.39
Chloride	NS	NS	NS	< 48.6	--	--	<62.3	--	--
Sulfate	NS	NS	NS	3,020	--	--	83.0	--	--
Bromide	NS	NS	NS	< 9.94	--	--	<12.0	--	--
Nitrate-Nitrogen	NS	NS	10	< 19.4	--	--	<24.9	--	--
Nitrite-Nitrogen	NS	1NS	1.0	< 19.4	--	--	<24.9	--	--

[1] EPA Region III Protection of Ground water Risk-based or MCL-based SSLs[6].

[2] Table 1 Maximum Concentration of Contaminants for the Toxicity Characteristics. 40 CFR 261.24. Revised July 1, 2004.

[3] EPA Maximum Contaminant Level (MCL) or Region III Risk-Screening Level for Tap water[6].

* MCL or MCL-based SSL.

NS - No Standard available.

-- - Sample was not analyzed for specified metal or ion.
< - Metal or ion was not detected, value represents the reporting limit.
Values in bold represent exceedance of screening value.

The results of the total metals analysis indicate that both the fly ash and bottom ash contain several metals that could potentially leach from the raw materials. For reference, the results were compared to the EPA Region III Protection of Ground water Soil Screening Levels (SSLs)[6], and provide a theoretical concentration for a chemical in soil that is meant to be protective of ground water quality in ground water use areas. The screening value represents the theoretical migration of a chemical from soil to ground water assuming a standard dilution/attenuation factor. Several of the detected metals in the fly ash sample exceed their respective EPA SSL, including arsenic, barium, beryllium, cobalt, iron, lead, manganese, thallium, and vanadium. Iron, manganese, thallium, and vanadium were also detected in the bottom ash sample at concentrations that exceed the EPA SSL.

The TCLP analysis simulates landfill conditions (i.e. exposure to organic acids) and was conducted to affirm that the candidate CCBs are not characteristically hazardous, as defined by the Code of Federal Regulations, Title 40, Part 261 (40 CFR Part 261). The TCLP test results confirm that both the fly ash and bottom ash are not characteristically hazardous.

The SPLP tests were conducted to determine the potential leaching of constituents from the raw CCBs under simulated rainfall conditions. The SPLP test uses low concentrations of nitric and sulfuric acids to simulate acid rain, and is routinely used to assess the potential for materials to leach metals and other constituents when exposed to ambient weather conditions. For reference, the results were compared to the EPA’s Maximum Contaminant Levels (MCLs) or Region III Tapwater Risk-screening Levels (RSLs) in the event that an MCL was not available for the specified chemical. Although several metals were detected in the fly ash and bottom ash leachate samples, only two metals, namely arsenic and vanadium that were detected in the fly ash sample, were reported at concentrations that exceed their respective MCL or RSL. Arsenic and vanadium were detected in the fly ash leachate sample at concentrations of 0.214 and 0.399 mg/L, respectively. The SPLP results for the bottom ash did not exceed either an MCL or RSL.

DISCUSSION

The baseline characterization results suggest that for both materials (fly ash and bottom ash) certain physical and chemical characteristics will need to be taken into consideration when designing and testing the optimal mix for use in pervious concrete.

Brandon Shores Power Plant Fly Ash

The fly ash material met or very nearly met all of the requirements for Class F fly ash to be used as pozzolan in concrete. This material will therefore continue to be used in the design of candidate pervious concrete mixes for further testing.

The TCLP test results confirmed that the fly ash material from the Brandon Shores Power Plant is not characteristically hazardous. The total metals analysis revealed that the fly ash material contained some metals that could be of concern in regards to ground water impacts. The SPLP test results suggest that only arsenic and thallium may leach from the raw fly ash at levels that may cause concern with regards to ground water quality. However, it is important to note that the SPLP tests were run on unstabilized fly ash, which is not representative of the intended use of fly ash in pervious concrete. Rather, it is anticipated that the leachability of these constituents would be greatly reduced when the fly ash is used as a reacted pozzolan material that is a component of a pervious concrete final product. Once candidate mixes have been designed, their potential to leach metals will be determined.

Brandon Shores Power Plant Bottom Ash

Although the bottom ash did not meet several of the ASTM C618 requirements for Class F fly ash, its anticipated use as fine aggregate, rather than pozzolan, make these characteristics less critical in evaluating its suitability for use in the pervious concrete final product.

The TCLP test results confirmed that the bottom ash material from the Brandon Shores Power Plant is not characteristically hazardous. The total metals analysis revealed that the bottom ash material contained several metals that could be of concern in regards to ground water quality. However, the SPLP test results show that none of these metals would be expected to leach from the raw bottom ash at levels that would be of concern for ground water quality. If the bottom ash were to be used as aggregate in pervious concrete, the material would be coated with a concrete paste and leaching of metals from the bottom ash material would be expected to be reduced even further.

DEVELOPMENT AND TESTING OF CANDIDATE PERVIOUS CONCRETE MIXES

METHODS

Mix Designs

Mixtures of pervious concrete were proportioned and mixed in laboratory batches to cast cylindrical test specimens that were 4-inches (10.2 cm) tall and 4-inches (10.2 cm) in diameter. For each set of mixture proportions, a set of 5 cylinders was cast at the desired void content (20% for most of the mixtures). From each set of 5 cylinders, 3 were used for surface durability testing while 2 were reserved for future testing for water quality impact potential. Additionally, for 4 of the mixture proportions (mix 3, 13, 16 and 19), an extra 3 cylinders were cast at a secondary void content to confirm the validity of the casting procedure. A total of 21 mixtures were cast and tested, the proportions used for each mixture are described in Table 3.

Table 3 Pervious Concrete Mixture Proportions.

Mix #	Fly Ash %	Bottom Ash %	Void Content %	Water Demand
1 (Control)	0	0	20	0.33
2	10	0	20	0.33
3	20	0	20[1]	0.33
4	30	0	20	0.33
5	50	0	20	0.41
6	70	0	20	0.41
7	10	10	20	0.41
8	20	10	21.2	0.45
9	30	10	20	0.49
10	50	10	20	0.54
11	70	10	20	0.59
12	0	5	20	0.40
13	0	10	20[2]	0.44
14	0	15	20	0.48
15	0	20	20	0.48
16	0	10	18[3]	0.40
17	0	10	22	0.46
18	0	10	25	0.48
19	20	0	18[4]	0.33
20	20	0	22	0.33
21	20	0	25	0.33

[1] Three additional cylinders were prepared for mix 3 at 25% initial void content, rather than 20%.
[2] Three additional cylinders were prepared for mix 13 at 25% initial void content, rather than 20%.
[3] Three additional cylinders were prepared for Mix 16 at 20% initial void content, rather than 18%.
[4] Three additional cylinders were prepared for Mix 19 at 20% initial void content, rather than 22%.

Mix Testing

For each pervious concrete mixture, the fresh properties were tested and documented. The density and void content were tested by ASTM C 1688. Slump was tested by ASTM C 143. Furthermore, for each mixture the workability was measured by recording the number of blows of the Marshall Hammer that were required to achieve the desired void content as the specimens were cast. Lower blow counts correlate to enhanced workability.

Surface durability potential testing followed the procedure described in ASTM WK 23367 (01-11). After a 7-day curing period, sets of three specimens were turned for 500 revolutions in the apparatus commonly used to determine Los Angeles Abrasion Resistance (ASTM C 131). Mass loss was calculated as a percentage of initial specimen mass. Low values of mass loss correlate to high surface durability potential.

RESULTS

The results of the tests on the pervious concrete mixtures are detailed in Table 4.

Table 4: Results of Pervious Concrete Mixture Testing

Mix #	Slump (in)	Slump cm	Density (pcf)	Density (g/cm^3)	Fresh Void Content (%)	Diff. in Void Content (%)[5]	Blow Count	Mass Loss (%)
1	7.75	19.7	116.2	1.86	26.7	6.7	10	31.9
2	6.75	17.1	114.3	1.83	27.6	7.6	10	35.6
3[1]	0	0	113.9	1.82	27.5	7.5	11	36.3
4	0	0	113.8	1.82	27.2	7.2	9	35.6
5	7.5	19.1	119.6	1.91	20.5	2.9	5	46.8
6	8	20.3	113.5	1.82	26.3	6.3	3	94.7
7	0	0	116.6	1.87	25.8	4.8	5	**27.5**
8	0	0	114.8	1.84	25.6	4.4	5	40.6
9	7.75	19.7	118.7	1.90	22.7	2.9	3	41.9
10	7.75	19.7	122.7	1.96	19.6	-0.4	3	54.3
11	7.75	19.7	116.7	1.87	23.0	3	3	100
12	7.24	18.4	116.1	1.86	25.1	6.1	9	**28.7**
13[2]	5.5	14	121.3	1.94	22.1	2.1	3	**21.7**
14	0	0	120.9	1.93	21.5	1.5	2	**30.2**
15	6	15.2	121.2	1.80	20.5	0.5	1	34.0
16[3]	7.25	18.4	124.4	1.99	19.8	1.8	3	**29.5**
17	7	17.8	116.8	1.87	25.3	3.3	3	36.4
18	5.5	14	114.7	1.84	27.2	2.2	3	42.8
19[4]	0	0	119.9	1.92	23.3	5.3	9	**30.4**
20	0	0	114.6	1.83	27.5	5.5	7	36.8
21	0	0	109.8	1.76	31.1	6.1	9	46.5

in – inches.
cm - centimeters.
pcs – pounds per cubic foot.
g/cm^3 – grams per cubic centimeter.

[1] Three additional cylinders were prepared for Mixture 3 but compacted to 25% void content rather than 20%. The blow count and mass loss for the additional cylinders were 5 and 44.1%, respectively.

[2] Three additional cylinders were prepared for Mixture 13 but compacted to 25% void content rather than 20%. The blow count and mass loss for the additional cylinders were 2 and 28.9%, respectively.

[3] Three additional cylinders were prepared for Mixture 16 but compacted to 20% void content rather than 18%. The blow count and mass loss for the additional cylinders were 1 and 31.3%, respectively.

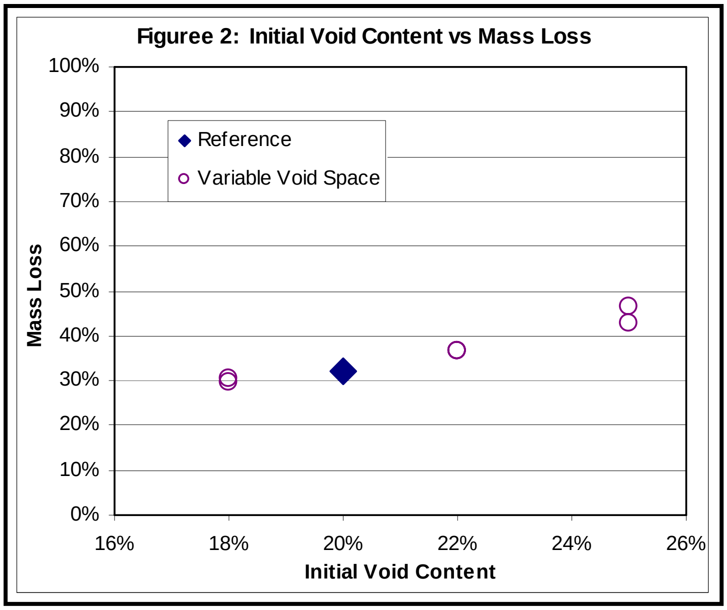
[4] Three additional cylinders were prepared for Mixture 19 but compacted to 20% void content rather than 18%. The blow count and mass loss for the additional cylinders were 5 and 31.5%, respectively.

Bold values indicate mass loss results that are lower than the mass loss of the reference sample (i.e. higher durability than the reference sample.

[5] The difference in void content between the theoretical mixture proportions and the ASTM C 1688 test results on the fresh concrete.

Initial Void Content and Durability

The optimal initial void content of pervious concrete is a balance between the ability of the mixture to allow water to drain through and resist clogging and resistance of the cured mixture to breaking apart under stress (i.e. “raveling”). An initial void content of 20% was selected based on past experience; however some of the mixes were tested at lower or higher initial void contents to confirm that this level was appropriate. Figure 2 shows the variability in mass loss as a function of initial void content. While reducing the initial void content to 18% did not significantly improve the durability of the concrete, increasing the void content to 25% did decrease the durability of the material slightly. Thus, 20% is believed to be the optimal void content for these pervious concrete mixtures.



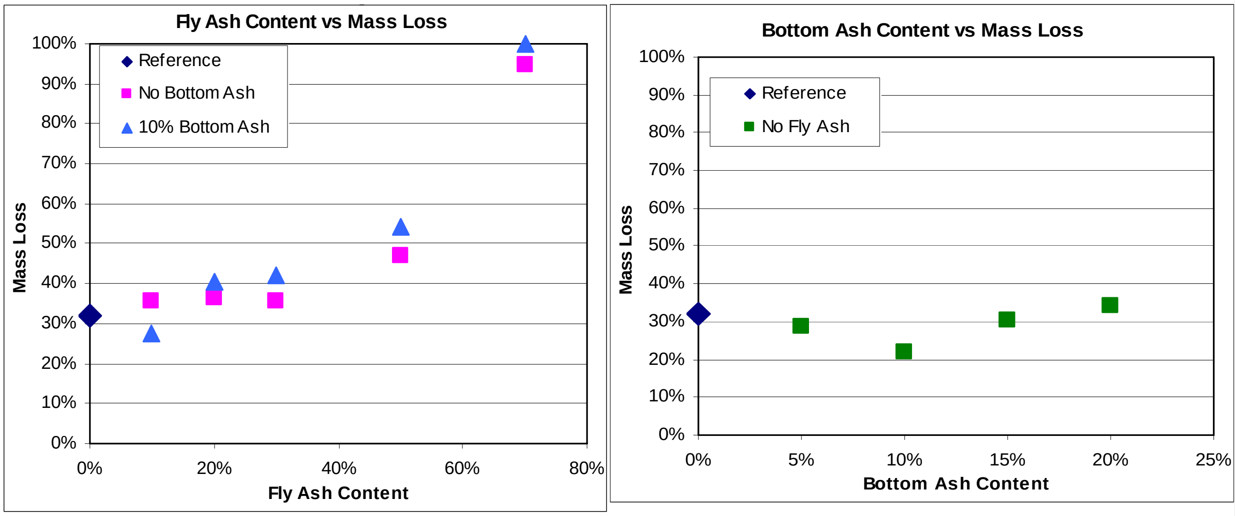
Figuree 2: Initial Void Content vs Mass Loss

CCBs and Durability

Figure 3 shows the variation in the durability of the pervious concrete mixtures as a function of their fly ash and bottom ash content.

While varying the proportion of bottom ash present in the mixture had very little effect on the durability of the pervious concrete sample, high proportions of fly ash decreased the durability. The pervious concrete mixes containing 10% to 20% fly ash performed similarly to the control.

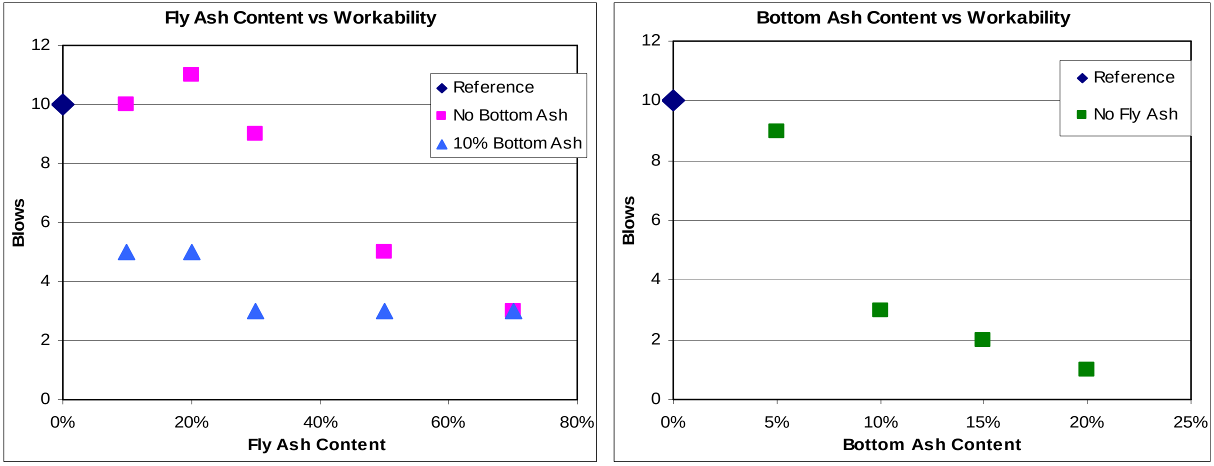
Figure 3 CCB Content and Mass



CCBs and Workability

Figure 4 shows the workability of the pervious concrete mixes as a function of the proportions of CCBs included in the mixture. The workability of the pervious concrete mixtures improved with increasing proportions of both fly ash and bottom ash.

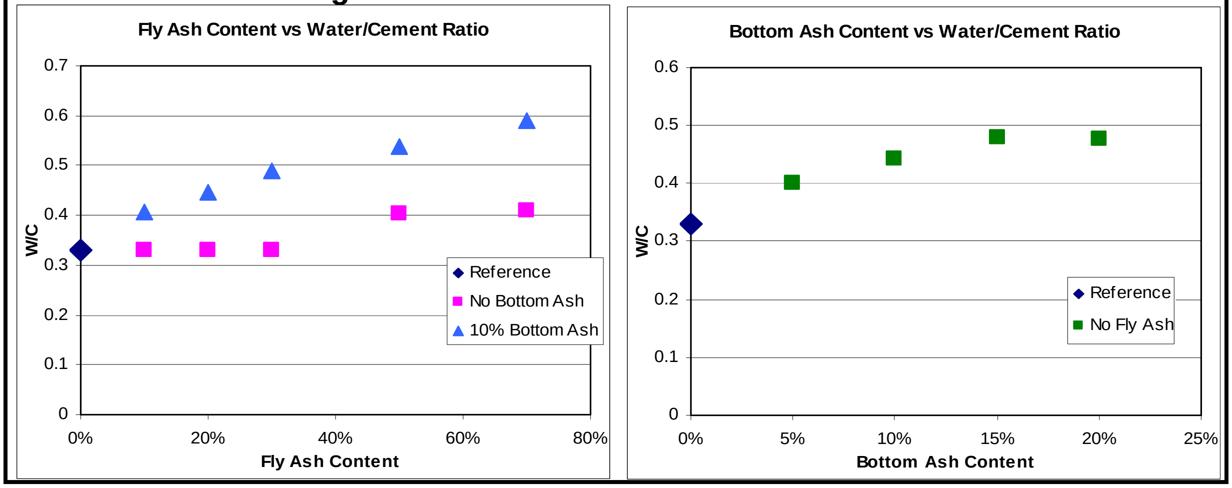
Figure 4 CCB Content and Blow



CCBs and Water/Cement Ratio

Figure 5 shows the water/cement ratio of the various pervious concrete mixes as a function of CCB content. The water/cement ratio of the pervious concrete mixtures was impacted by the addition of both fly ash and bottom ash to the mixture. The ratio increased significantly with the addition of high concentrations of fly ash. The ratio also increased with the addition of bottom ash, though the change was less significant.

Figure 5 CCB Content and Water/Cement



Discussion

While the initial intent for including bottom ash in the pervious concrete mixes was to use it in place of gravel as coarse aggregate, the bottom ash was found to be too variable in particle size and contained too many sand-sized particles for use as coarse aggregate. It was found to be suitable for use as fine aggregate. However, since pervious concrete by nature, contains very little fine aggregate, this limited the amount of bottom ash that could be used in the test mixtures.

While including fly ash in the mixtures had a negative impact on their durability, it had a beneficial impact on the mixtures' workability. It should be noted that the test cylinders were cured for only seven days, which approximates the traditional installation of pervious concrete in the field. It is possible that longer curing times for high-fly-ash mixtures would improve the durability of the final product. Although longer curing times are not representative of current typical installation procedures, it is possible that specific projects in the future could accommodate longer curing times; therefore this possibility will be tested in future bench scale testing.

The bottom ash content of the pervious concrete mixtures appears to have had little effect on their durability and a positive effect on the workability of the mixtures. It was also noted that the non-homogeneous nature of the bottom ash and the fact that it is generally shipped wet (because it is frequently stored in ponds) makes it difficult to use, from a production standpoint, particularly at the low proportions (10% - 20%) that would be used. Therefore, at present, the use of bottom ash in a commercially viable pervious concrete seems unlikely. Nevertheless, future mix refinement or operational changes could make the use of bottom ash more favorable; therefore some of the bottom-ash containing pervious concrete specimens will still be carried forward into the next phase of testing, for informational purposes.

MOVING FORWARD

The initial proposal for the development of pervious concrete mixes divided the project into three phases:

- Phase I – CCB Procurement and Baseline Characterization;
- Phase II – Mix Design; and
- Phase III – Bench Scale Testing.

The activities detailed in this paper represent the completion of Phases I and II for CCBs from one source (the Brandon Shores Power Plant). Work is slated to begin on Phase III – Bench Scale Testing in the near future. This phase will involve leaching tests of the selected pervious concrete mixes. Rather than standard TCLP or SPLP test procedures, flow-through leaching over a longer period of time including wet and dry cycles will be used to more accurately simulate leaching of the pervious concrete by rain water as it would ordinarily be installed. The Final Engineering Design of a field-scale demonstration of the optimal pervious concrete mix or mixes will include identification and procurement of necessary federal, state, and local permits, as well as the preparation of a conceptual engineering design for bid by qualified contractors.

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