

## HIGH-STRENGTH PORTLAND CEMENT CONCRETE CONTAINING MUNICIPAL SOLID WASTE INCINERATOR ASH

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### ABSTRACT

A variety of methods are being examined by numerous organizations to render hazardous solid residues non-hazardous and to create beneficial uses for ash from municipal solid waste incinerators. One method for both purposes is the replacement of a portion of the fine aggregate in Portland cement concrete. The strength of the concrete drops significantly as the portion replaced increases, even with normal additives. This paper presents the greatly improved strengths obtained with ash, which has been exposed to a new additive. These results show that up to 35% of the concrete can be made up of ash, while still obtaining compressive strengths of over 5000 psi (34.5 MPa). Micrographs of the original ash, ash and additive, concrete with ash but without additive, and concrete with ash and additive indicate the role of the additive. TCLP extractions of this novel new concrete have yet to be conducted. The economics, commercialization and extension of the development to other situations are discussed.

### INTRODUCTION

As landfill space becomes more limited, it becomes more attractive to reduce the volume of materials being disposed there. Recycling is one approach, waste minimization is a second method, and combustion for energy production is the third, and ultimate, one. Ash from municipal solid waste (MSW) combustors can have less than 10% of the original volume entering the facility. A further reduction in landfilling, though, can be realized by developing a beneficial use for the ash. The most commonly considered beneficial use of ash is as an aggregate in either bituminous or Portland cement concrete. This method has the further advantage of displacing sand and gravel, which must be mined from sometimes environmentally sensitive locations. Another short-term advantage of this method is its ability to bind the toxic metals, entering with the MSW [1], into the concreted mass. Controversy over the long-term implication of the presence of these metals in the concrete has arisen, however. The Environmental Defense Fund has expressed vigorous concern for the long-term release of these metals as the concrete eventually degrades or is reduced to rubble [2].

Utilizing MSW incinerator ash in Portland cement concrete has been investigated by several organizations. At a number of locations, bottom ash (slag) from high-temperature combustors is utilized as coarse aggregate in regular concrete (see for example References 3 and 4). Utilization of low-strength concretes containing either

fly ash or mixed fly and bottom ash (combined ash) are moving toward commercial use in three directions.

One of these directions is to make block secondary products, such as artificial reef blocks, construction blocks, and shore protection devices [5]. Artificial reef blocks consist of 85% combined ash and 15% Portland (Type II) cement and have compressive strengths of about 1000 psi (6.9 MPa). By comparison, standard precast Portland cement concrete contains 40% coarse aggregate, 40% fine aggregate and 20% Portland cement and has a compressive strength of over 3500 psi (24.2 MPa). Construction blocks consist of 35-60% combined ash, 25-50% sand, 15% Portland (Type I) cement, and sufficient Acme-Hardesty superplasticizer to allow the mix to flow easily. Compressive strengths vary from 1600 psi (11.0 MPa) to 2600 psi (17.9 MPa). A boathouse, built recently at the State University of New York at Stony Brook from 14,000 such construction blocks, is being evaluated for structural and environmental acceptability. Finally, shore protection devices require the use of a patented admixture, Chloranan (manufactured by Hazcon, Inc., of Brookshire, Texas) at a ratio of cement to admixture of 10:1. Using cement percentages between 17 and 33, compressive strengths up to 4200 psi (29.0 MPa) are reported.

A second approach is the accretion of combined ash with Portland cement (8-14%) into coarse aggregate for use in roadbeds and concrete [6]. This level of concretization provides aggregate with strengths of about 1200 psi (8.3 MPa), similar to the material, described in Reference 5. Finally, a third approach is the stabilization of combined ash with Portland cement (6-10%) to create land fill covers [7]. In all of these approaches, the ability of Portland cement concrete to reduce the leachability of trace metals from the concreted mass to meet TCLP standards has been a key element of their development.

A major area which these projects do not address is the precast concrete market. For entrance into this arena, compressive strengths between 3500 psi (24.2 MPa) and 5500 psi (38.0 MPa) must be achieved. In addition, extensive physical testing must be applied and minimum standards met. These tests include tensile strength, freeze-thaw, deicing, and abrasion. As the preceding brief review shows, obtaining the compressive strengths required by precasters has proven impossible with significant amounts of combined ash, even with standard additives. Only those concretes made with the addition of large amounts of Chloranan enter this range.

The School of Engineering at the University of Pittsburgh has recently discovered an inexpensive method which permits high-strength concrete to be produced, containing large amounts of combined ash from a MSW combustor. The method, which has just been disclosed to the University as the first step in the patent process, will now be described as thoroughly as possible within the limits imposed by that process.

#### PORTLAND CEMENT CONCRETE MANUFACTURE

In October 1988 the University of Pittsburgh began to study the utilization of MSW combustor ash in Portland cement concrete. Four 750-lb (1650-kg) samples of ash have been obtained during the past two years from the MSW combustor at Poughkeepsie, New York, operated by the Dutchess County Resource Recovery Agency by Dutchess Resource Energy, a subsidiary of the Resource Energy Systems

Division of Westinghouse Electric Corporation. The primary combustor in this facility is an O'Conner water-wall rotary kiln. The bottom ash drops into a water-filled pit, from which it is reclaimed past a grizzly to take out large particles, and a magnet for iron removal. The hot gases from the primary combustor pass through a secondary combustor, a boiler, and a dry scrubber. The fly ash and spent limestone (injected in the scrubber for acid gas removal) are added to the bottom ash just before the combined ash is loaded into trailers for hauling to a land disposal site.

The first two samples of ash were composited from 5-pound (11-kg) sub-samples of combined ash, collected six times daily for 25 days. Ash Sample #1, combined ash collected from mid-July to early September 1989, contained 8-21% moisture, 15.1% calcium oxide, 2.21% sulfur trioxide and 7.2% iron oxide and exhibited a 7.26% loss of ignition. Ash Sample #2 was bottom ash collected during January 1990. Ash Samples #3 and #4 were bottom ash collected in essentially one quick draw on May 24-25, 1990, and March 1-2, 1991, respectively. Ash Sample #3 contained 11.9% calcium oxide, 2.58% sulfur trioxide and 9.8% iron oxide and exhibited a 8.04% loss of ignition.

Six batches of concrete were made with Ash Sample #1 and fifteen batches with Ash Sample #2. The basic recipe was 17% coarse aggregate, 40% ash and 43% Portland cement. An air entrainment additive, a water reduction additive and a silica fume additive were all tried individually with certain of these batches. The slump of each batch was held as close as possible to 1.75 inches (4.45 cm) by varying the water content. Concrete batches were produced in a small commercial mixer in the Concrete Laboratory of the Civil Engineering Department, following standard procedures. A number of cylinders (3 inches (7.6 cm) in diameter and 6 inches (15.2 cm) long) were formed from each batch. Cylinders were stored in an environmentally controlled room. Compressive strengths were measured on a Baldwin hydraulic compression tester, also located in the Concrete Laboratory of the Civil Engineering Department. Sets of four cylinders were cracked, and the load at breaking were averaged to obtain reported values of compressive strength.

Compressive strengths were generally in the range of 1000 psi (6.9 MPa) to 2300 psi (15.9 MPa). The ash in the first six batches of concrete were subjected to the Standard Extraction Procedure Method (the EP TOX procedure). The extractions were performed in the Environmental Laboratory of the Civil Engineering Department and leachates were sent to a commercial laboratory for analysis. Neither the ashes nor the concretes exceeded the EP TOX limits for any constituent. However, the ash and one of the six concrete batches (which happened to contain a lower amount of Portland cement a higher amount of coarse aggregate than according to the usual recipe, and which also contained some sand) exceeded the NYCRR limits for cadmium and lead. The presence of fly ash in Ash Sample #1 appeared to cause a number of "popouts". A white crystalline material, identified as a physical assemblage of aluminum chloride and calcium oxide crystals, was found at the focal point of all the popouts examined.

As Ash Sample #2 was running out, it was decided to attempt to modify the chemical and/or physical makeup of the surface of the ash particles to increase the strength of the bond between the ash and the cement. Two different commonly available chemicals were tried as additives in the last two batches of concrete made from Ash Sample #2. One of these novel additives did, in fact, yield compressive

strengths of nearly 4000 psi (36.0 MPa). Therefore, a set of batches with varying amounts of this effective, inexpensive, novel additive were prepared with ash from Ash Sample #3. The results are shown in the Table 1. The amount of additive is given as a percentage of the weight of cement present in each batch. A second batch of concrete, Batch Number 44, was made with the last portion of Ash Sample #3, using the same recipe as Batch Number 32.

Samples of ash and concrete were examined in the Scanning Electron Microscope (SEM) in the secondary electron imaging mode. The phases present were also compared using X-ray microanalysis in the SEM. Figures 1 and 2 are examples of micrographs for Batches Number 42 and 44, respectively, in the secondary electron imaging mode. It appears from an examination of these micrographs that, even with a 12-fold increase in additive from Batch Number 42 to Batch Number 44, the same basic cement structure is present in both concretes.

Figures 3 and 4 are SEM micrographs of ash. Figure 3 is for Ash Sample #4 as received. Figure 4 is for Ash Sample #3, which has been mixed with an aqueous solution of the chemical additive, using the same amounts of ash and additive as was used in preparing Batch Number 32. It may be observed from an examination of these micrographs that the surface of the as-received ash is heavily contaminated with fine particles, which are not present on the treated ash.

It is hypothesized from the observations reported above that the elimination of the fine particles in the concrete formulations with the chemical additive renders the surface of the ash particles (serving as fine aggregate) more amenable to strong bonding with the hydrated Portland cement, yielding high-strength concrete as a product.

A preliminary cost analysis of one ton (4400 kg) of concrete (dry basis), composed of

- 420 pounds (930 kg) coarse aggregate
- 750 pounds (1650 kg) of ash
- 830 pounds (1830 kg) of Portland cement
- chemical additive at the level of Batch Number 32

shows that purchase of the materials for its manufacture would require \$23.50. The cost of materials for a 2:2:1 precast concrete is \$10.00. The ash-containing concrete with the formulation of Batch Number 32 would be \$13.50 more expensive than the standard concrete. Since the former contains 750 pounds of ash, the ash would have to be forced into this beneficial use with a tipping fee of \$36.00 per ton, which is less than one-third of the current tipping fee at landfills.

#### FUTURE WORK

One final technical step in developing concrete with the same recipe as Batch Number 32 needs to be taken. Durability tests (tension strength, expansion, freeze/thaw, deicing and abrasion) and a TCLP extraction need to be carried out. When these results are available, precasters in the vicinity of the MSW combustor, operated by the Dutchess County Resource Recovery Agency, can make an informed technical decision on the use of the ash from this combustor in their products.

Regulatory permission for this use of the MSW combustor ash would then have to be sought from the State of New York.

Several other aspects of the beneficial use of MSW combustor ash in Portland cement concrete should be examined. First, the current 0.5:0.9:1 recipe may not be the optimal one for commercial use. A range of formulations should be explored. Second, additives similar to the one used in these first experiments could be tried, especially if durability and TCLP tests uncover any problems. Third, ash from other types of combustors could be tested for the applicability of the new additive. These combustors would include other MSW combustors with different methods for ash removal from the unit. They could also include industrial and hazardous waste combustors.

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TABLE 1. Variation of Compressive Strengths with Additive

<u>Batch Number</u>	<u>Additive (%)</u>	<u>90-Day Compressive Strength, Psi (MPa)</u>
29	3.47	0 ( 0 )*
30	1.73	4940 (34.1)
32	0.87	6200 (42.8)
36	0.65	3750 (25.9)
37	0.43	3210 (22.1)
34	0.17	2260 (15.6)
42	0.07	1560 (10.8)**

- \* All cylinders of this batch broke apart by 90 days.
- \*\* 14-day compressive strength.



FIGURE 1. SEM micrograph of the fractured surface of Batch Number 42, made with 0.07% additive; the bar is 10 micrometers.

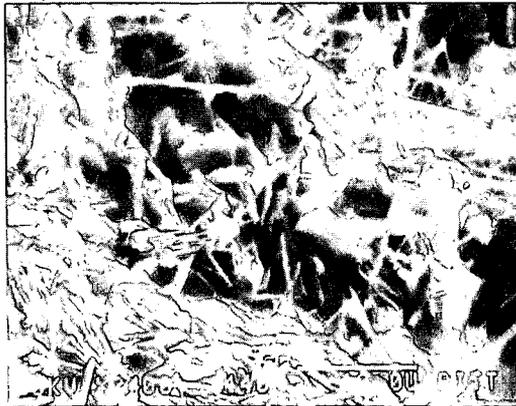


FIGURE 2. SEM micrograph of fracture surface of Batch Number 44, made with 0.87% additive; the bar is 10 micrometers.

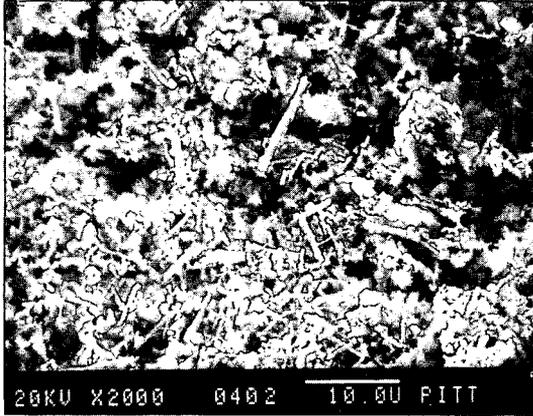


FIGURE 3. SEM micrograph of Ash Sample #4 as received; the bar is 10 micrometers.

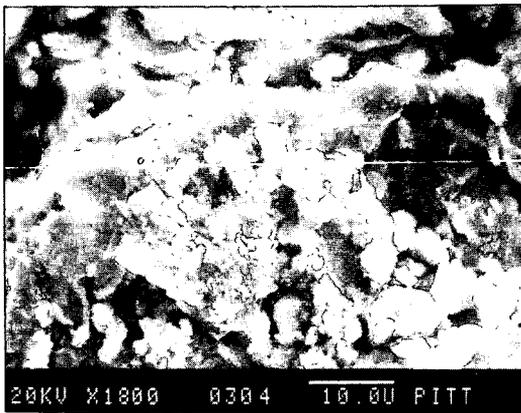


FIGURE 4. SEM micrograph of Ash Sample #3, mixed with additive; the bar is 10 micrometers.