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INTERACTIONS OF STABILIZED INCINERATION RESIDUE WITH THE MARINE ENVIRONMENT

FRANK J. ROETHEL AND VINCENT T. BRESLIN
MARINE SCIENCES RESEARCH CENTER
STATE UNIVERSITY OF NEW YORK
STONY BROOK, NEW YORK 11794-5000

ABSTRACT

This paper presents the results of a research program designed to examine the feasibility of stabilizing particulate incineration residues for artificial reef construction. Particulate incineration residues were combined with Portland cement to form solid blocks using conventional block making technology. The resultant stabilized incineration residue (SIR) blocks were used to construct an artificial habitat in Conscience Bay, Long Island Sound, New York.

Divers periodically returned to the site to monitor the interaction of SIR blocks with the marine environment. Results show that the SIR blocks retain their strength after prolonged seawater exposure. Metals of environmental concern, including lead and cadmium, are retained within the cementitious matrix of the SIR blocks after 12 months submersion in seawater. In addition, organisms growing on the surfaces of the SIR blocks are not accumulating metals from the blocks.

INTRODUCTION

Disposal of residential and commercial solid waste presents a rapidly growing problem to many metropolitan areas. In the New York metropolitan area alone 18 million tons of solid waste is collected each year and greater than 90% of the waste is landfilled (Schubel et al. 1985). Due to the large volumes of waste collected and the lack of suitable landfill space, municipalities nationwide are turning to energy recovery incineration as a means of handling the ever increasing volume of municipal solid waste.

Incineration of solid waste produces particulate residues which are often rich in lead, cadmium, copper and zinc (Roethel et al. 1987). Results of leaching studies show that metals of environmental concern are released from particulate residues resulting in the need for incineration residues to be disposed of in an environmentally acceptable manner (Sawell et al. 1986). Stabilization of particulate residues with cement into blocks has been shown to effectively prevent the release of metals and may provide an alternative method for the disposal of incineration residues (Roethel et al. 1987).

In urban coastal areas where landfills are few and increasingly distant, ocean disposal of stabilized incineration residues may provide an

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acceptable alternative to current landfill practices. Previous studies have demonstrated that the stabilization of combustion residues (coal fly ash, oil ash) using additives (lime, sodium carbonate, portland cement) can be used to produce solid blocks that are environmentally acceptable in the sea (Parker et al. 1981; Kalajian et al. 1987).

In May 1985 a research program was initiated at the Marine Sciences Research Center to examine the feasibility utilizing stabilized incineration residues for artificial reef construction in the ocean. Results of these studies showed that particulate incineration residues could be combined with cement to form a solid block possessing physical properties necessary for ocean disposal (Roethel et al. 1986). The stabilized residues were subjected to regulatory extraction protocols and in no instance did the metal concentrations in the leachates exceed the regulatory limits for toxicity (Park, 1987). Bioassays revealed no adverse impacts to the phytoplankton communities exposed to elutriate concentrations higher than could be encountered under normal disposal conditions (Roethel et al. 1986). The success of the laboratory studies resulted in securing the necessary permits for the placement of an artificial habitat constructed using stabilized incineration residue in coastal waters.

During April 1987 stabilized incineration residue blocks and cement blocks were submerged in eight meters of water in Conscience Bay, Long Island Sound, New York. Since then divers have periodically returned to the reef site to study the interactions of stabilized incineration residue with the marine environment. Stabilized incineration residue blocks were retrieved from the reef site for physical and chemical testing. Compressive strengths of the reef blocks were measured to monitor the strengths of the blocks with prolonged seawater exposure. Samples of blocks exposed to seawater were analyzed for metals to determine if metals associated with particulate residues are effectively retained within the stabilized blocks. In addition, divers removed biomass from the surfaces of the blocks for analysis of the tissues for possible uptake of metals by organisms attached to the surfaces of the stabilized incineration residue blocks.

MATERIALS AND METHODS

ASH SAMPLES

Incineration residues for block making were collected from the Westchester Resource Recovery Facility, Westchester County, New York in November 1986. Combined ash, a mixture of bottom ash and fly ash, was collected. Prior to block making, the combined ash was sieved to particle sizes less than 3/8". The residue >3/8" was crushed with a jaw-crusher and resieved. Screening the combined ash was necessary to prevent large particles from damaging the block making equipment. This processed material is refered to as crushed ash. The physical properties of the combined ash and crushed ash are detailed elsewhere (Roethel et al. 1987).

BLOCK PRODUCTION

Block manufacturing was conducted in December 1986 at the research facilities of the Besser Company at the Alpena Community College, Alpena, Michigan. Block fabrication employed conventional block making machines currently used by the industry.

The block mix components (combined ash, crushed ash, and Portland type II cement) were fed in weighed amounts from hoppers into a mixer. Water is then added to adjust the moisture content of the mix. The mix formulation consisted of 63.8% combined ash, 21.2% crushed ash, and 15% portland type II cement, with a total mix moisture content of 10.2% (Roethel et al. 1987). The well mixed materials are the fed into the loader of the block making machine. A block making machnine uses vibration and pressure to mold the mixture into blocks. The block mold (8"x8"x16", hollow core) rests on a steel pallet during the molding process and the material is fed into the mold box by vibration. Shoes then descend on top of the mold to exert pressure and a second cycle of vibration begins as the mold consolidates the material into blocks. After compaction, the mold lifts and the pallet holding the blocks emerges from the machine while a new pallet is pushed under the mold box for the next molding cycle. The pallets of blocks are loaded on racks and cured in steam kilns. Block making is fast, a block machine can process 128 tons of material per hour.

REEF PLACEMENT

The "Narrows" region of Conscience Bay, Long Island Sound was selected as the site for the in situ investigations of the interactions of stabilized incineration residues with the marine environment (Figure 1). Conscience Bay is a small embayment immediately west of the Port Jefferson Harbor channel on the northern shore of Long Island. Tidal currents within the "Narrows" can exceed 10 Km/hr (Roethel 1981). As a result, the sediments of Conscience Bay at the reef site are predominantly composed of poorly-sorted gravel and course sand. The salinity within Conscience Bay varies between 25.5 to 29.7 ppt and the water temperatures range from 0 - 24.5°C (Roethel 1981).

Stabilized incineration residue blocks and standard cement blocks were submerged in about 8 meters depth (mean high tide) on April 27 and 28, 1987. The blocks were arranged underwater to produce two separate structures, one incineration residue and one cement, approximately 2 meters apart (Figure 2). Each reef was designed to maximize the surface area exposed to seawater and to provide numerous crevices to facilitate biological colonization.

Sample collection on the reef was performed by certified SCUBA divers. Due to strong tidal currents within Conscience Bay, diving activities were restricted to forty-five minutes prior to and after slack water.

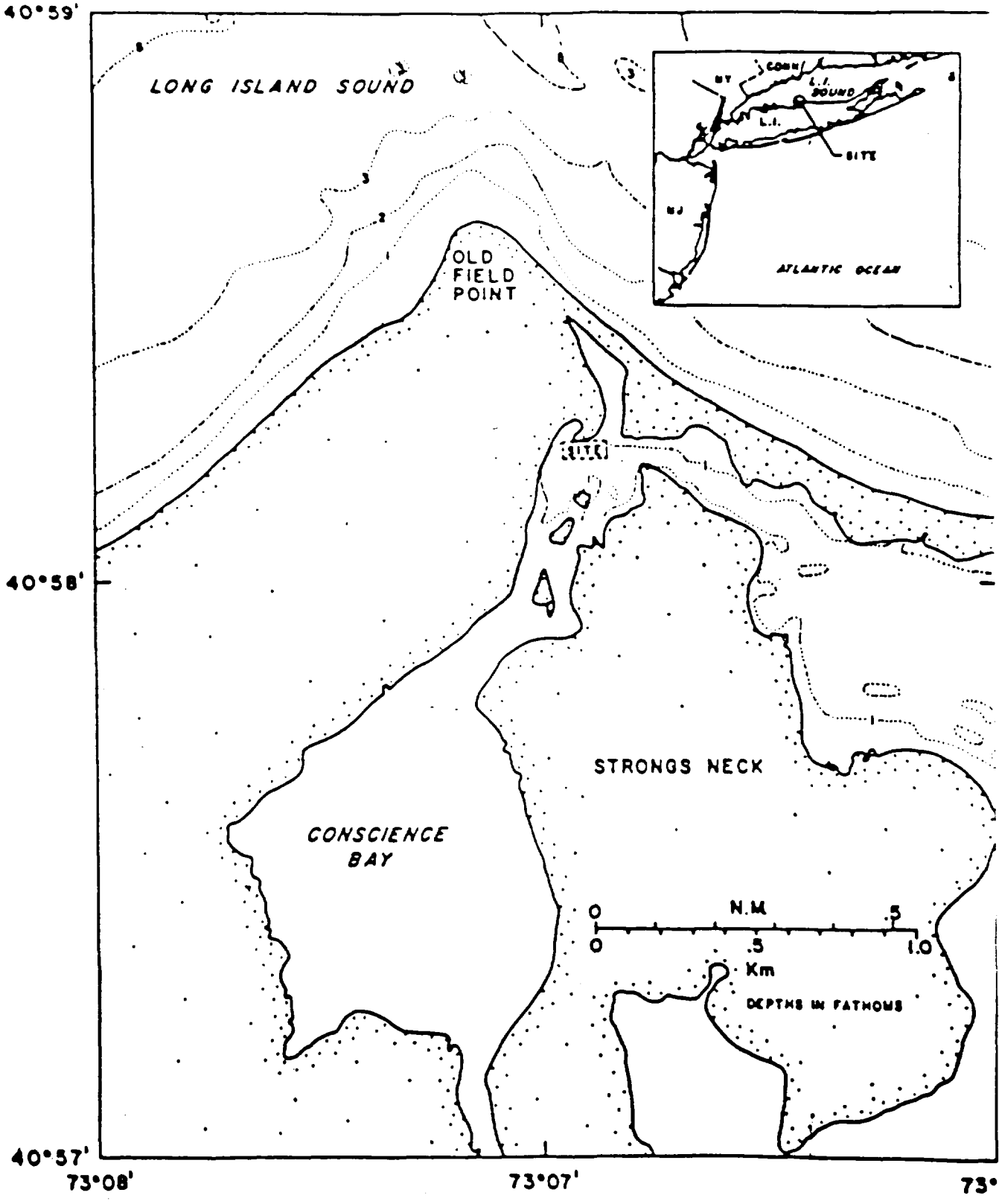
40°59'
40°58'
40°57'
73°08'
73°07'
LONG ISLAND SOUND
OLD
FIELD
POINT
SITE
STRONGS NECK
CONSCIENCE
BAY
0
N.M.
.5
1.0
Km
DEPTHS IN FATHOMS
NY
CONN
L.I.
SOUND
L.I.
SITE
NJ
ATLANTIC OCEAN

Figure 1.

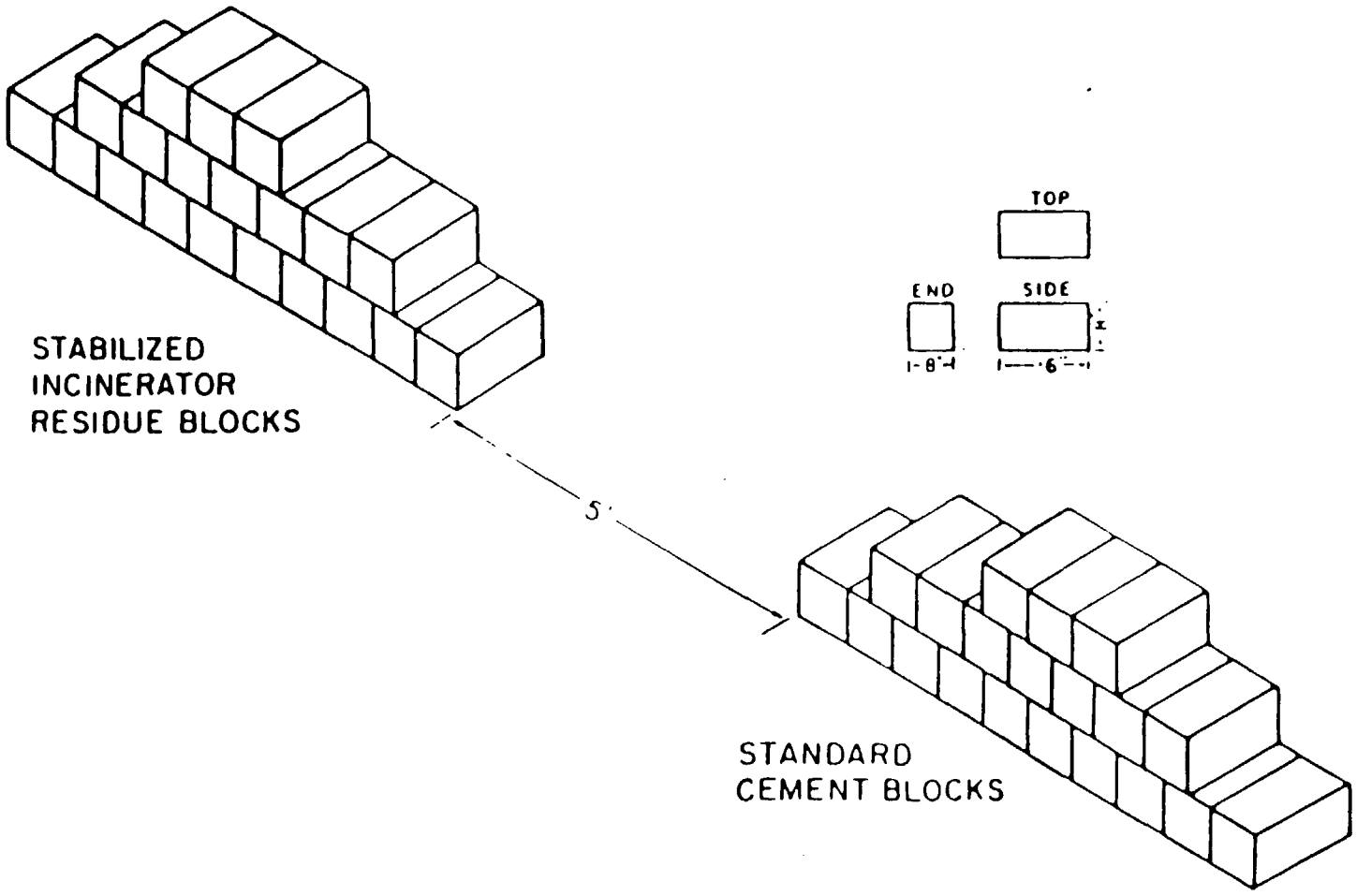
STABILIZED
INCINERATOR
RESIDUE BLOCKS
5'
STANDARD
CEMENT BLOCKS
TOP
END
SIDE
8"
6"
4"

Figure 2.

INSTRUMENTATION

Metal analyses were performed using a Perkin-Elmer Zeeman/5000 atomic absorption spectrophotometer (AAS) equipped with an HGA 500 atomizer and an AS-40 autosampler. Calibration curves were prepared from dilutions of Fisher Scientific atomic absorption standards which were prepared with reagent concentrations equivalent to those in the samples.

Compressive strengths of the stabilized incineration blocks and cement blocks were determined using a Reihle Universal Testing apparatus following ASTM method C-39 (ASTM).

All glass and plasticware were soaked in a 10% HCl-10% HNO_3 acid for 24 hours, rinsed with distilled-deionized (DID) water, soaked in 1% Ultrex® HNO_3 acid for 24 hours, and again rinsed with DID water. Acid cleaned glass and plasticware were then air dried in a laminar flow hood and stored in plastic bags prior to use.

ACID DIGESTION OF INCINERATION RESIDUES

Samples of the combined and crushed residues were oven dried at 110°C, ground using a mortar and pestle, and sieved to obtain a powder <425 μm.

Samples of the stabilized incineration residue blocks, both retrieved from Conscience Bay and those not exposed to seawater, were analyzed for metals. Side sections (>800 g) of the blocks were broken with a hammer and chisel. The exposed surfaces of the submerged blocks were carefully scraped to remove the attached biomass while minimizing the removal of any of the block surface. The block sections were then ground with a mortal and pestle, oven dried at 110°C for 24 hours, and sieved to a particle size <425 μm.

Samples (0.500 ± 0.001 g) were placed into a 125 ml HDPE bottle followed by the addition of 10 ml DID water. After the addition of 10 ml of concentrated Ultrex® HF the mixture was mechanically shaken for 24 hours. Then 70 mls of saturated (45°C) H_3BO_3 solution were added. The mixture was shaken for an additional 24 hours. The digests were then filtered through a 0.40 μm Nuclepore® membrane filters and transferred into 100 ml volumetric flasks. The volume was adjusted to 100 mls with DID water.

The digests were then analyzed by flame AAS for calcium, sodium, potassium, magnesium, iron, zinc, copper, manganese, lead, cadmium (air-acetylene) and aluminum, silicon, chromium (nitrous oxide-acetylene).

ACID DIGESTION OF BIOMASS MATERIAL

Divers periodically removed the biomass material from both the concrete and the incineration residue blocks. The samples were primarily composed of hydroids, *Tubularia sp.* and *Sertularia sp.* and were carefully removed *in situ* with plastic scissors to avoid removing any block material along with the biomass. Biomass samples were then placed into acid washed plastic bottles and returned to the laboratory. Once in the laboratory, the samples were rinsed with DID to remove salts and particles adhering to the organisms and freeze-dried for 24 hours.

Freeze-dried biomass samples were ground to a fine powder using a mortar and pestle. Samples (0.500 ± 0.001 g) of the powdered tissue were transferred into 125 ml Erlenmeyer flasks and covered with a watch glass. To these samples, 10 mls of Ultrex® HNO_3 were added and the samples were allowed to digest at room temperature for 2 hours followed by digestion at 60°C on a hot plate for 4 hours. The samples were removed from the heat and allowed to stand overnight. The samples were again heated to 60°C on the hot plate, then filtered hot through Whatman No.42 ashless filter paper into 100 ml volumetric flasks. The samples were brought to volume with DID water.

The digests were analyzed by flame AAS for Si, Al (nitrous oxide-acetylene), Fe, Mn, Zn and Cu (air-acetylene). Graphite furnace AAS was used for the analysis of Cr, Pb and Cd.

RESULTS AND DISCUSSION

EFFECTS OF SEAWATER EXPOSURE ON BLOCK STRENGTH

One day net unconfined compressive strengths of the blocks fabricated in Alpena, Michigan averaged 697 psi which increased to 1118 psi after 28 days curing. Details of the physical properties of the blocks are given in (Roethel et al. 1987). These values far exceed the minimum unconfined compressive strength criteria of 300 psi necessary for marine disposal of stabilized products (Woodhead et al. 1984).

Stabilized incineration residue blocks destined for reef construction were placed in flow through sea tables at the Flax Pond Laboratory during January 1987 to determine the change in unconfined compressive strengths of the blocks due to prolonged seawater exposure. Results of these tests show that the strengths of the stabilized incineration residue blocks increased with increasing seawater exposure (Figure 3). During January 1988, after 358 days of seawater exposure, the strengths increased from 985 psi to 1372 psi.

After placement during April 1987, both stabilized incineration residue and cement blocks were periodically retrieved from the Conscience Bay reef site for unconfined compressive strength testing. Blocks were last retrieved during May, 1988 and results show that after 380 days of seawater exposure, the strengths of stabilized incineration residue blocks increased to 1103 psi. The strength of the cement blocks, shown for comparison, decreased from 1087 psi to 779 psi after 380 days of seawater exposure (Figure 3).

Results of the laboratory seawater exposure studies and the Conscience Bay field studies show that the stabilized incineration residue blocks retain their structural integrity after prolonged seawater exposure.

ELEMENTAL COMPOSITION OF PARTICULATE AND STABILIZED INCINERATION RESIDUES

For the purpose of classification, major elements are defined as those elements present in concentrations >1 mg g^{-1}; minor elements are those in the range 1 mg g^{-1} to 100 μg g^{-1}; and trace elements are those present in concentrations <100 μg g^{-1} (8).

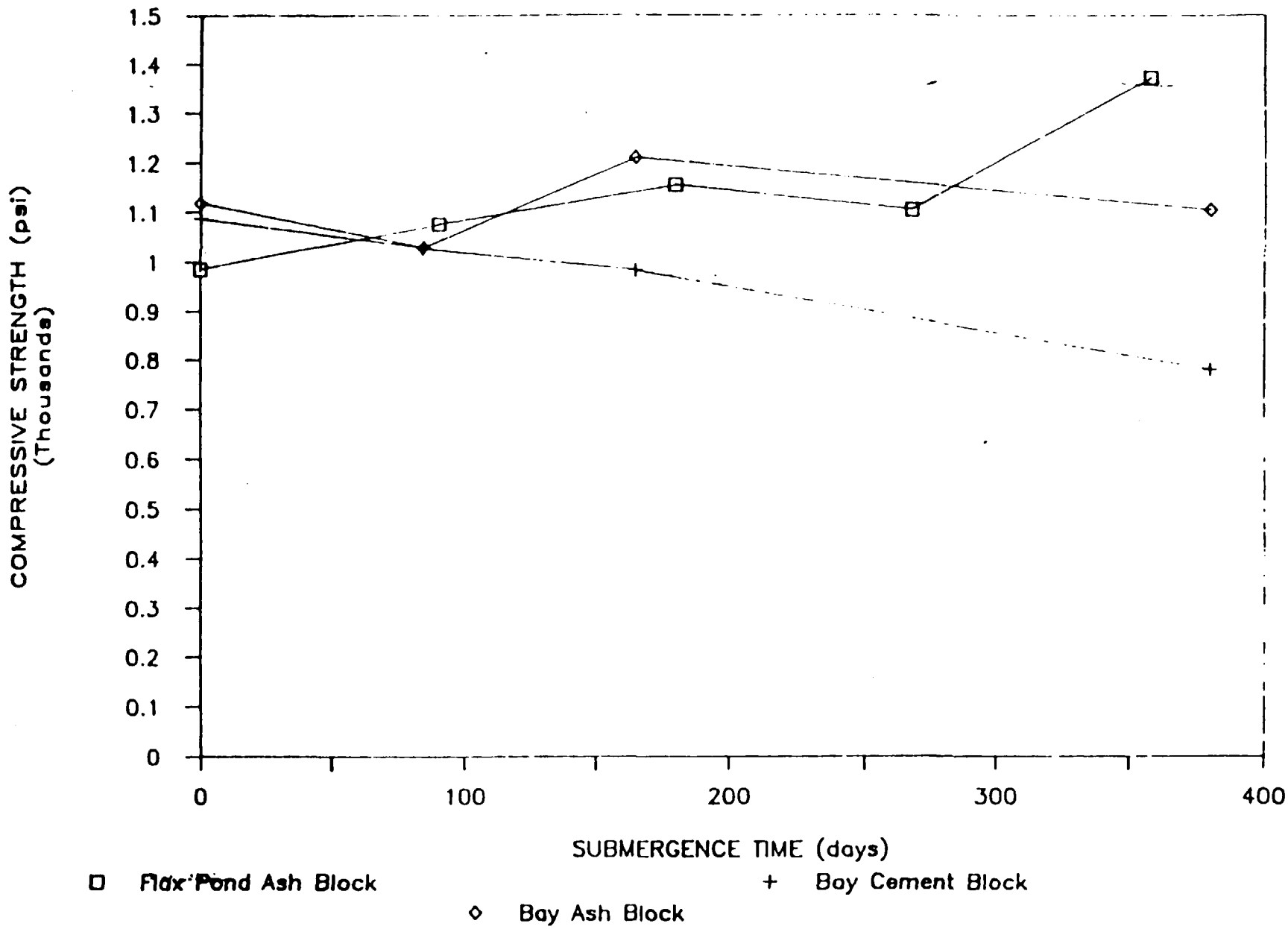
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
SUBMERGENCE TIME (days)
Flax Pond Ash Block
Bay Cement Block
Bay Ash Block

Figure 3.

Major elements found in both combined residues and crushed residues include Si, Al, Fe, Zn, Mn, Pb and Cu (Table 1). Chromium was present in the residues in minor amounts and cadmium was present in trace amounts.

The elemental composition of the stabilized residue blocks generally reflect the elemental composition of the 3:1 mix ratio of the combined and crushed particulate residues (Table 1). However, due to the presence of Portland type II cement, the metal content of the stabilized blocks are slightly less than the metal content of the particulate residues.

Major elements in the stabilized residues include Ca, Mg, Na, K, Al, Si, Fe, Pb, Zn and Cu (Table 2). Manganese and chromium were present in minor amounts and cadmium was present as a trace component.

EFFECTS OF SEAWATER EXPOSURE ON THE ELEMENTAL COMPOSITION OF CONSCIENCE BAY REEF BLOCKS

Analyses of the elemental composition of blocks submerged in Conscience Bay were performed to detect any release of block components to the surrounding seawater and to identify chemical reactions that take place within the blocks that could effect their success in the marine environment.

Of the thirteen metals analyzed, only an enrichment of magnesium and a depletion of potassium in the submerged stabilized incineration residue blocks was observed when compared to the corresponding metal content of the unsubmerged stabilized incineration residue blocks (Table 2).

Magnesium enrichment in stabilized waste products exposed to seawater has been observed in both laboratory and field studies (Woodhead et al. 1984; Breslin, 1986; Edwards and Duedall, 1985). Brucite formation and ion exchange processes may account for the observed magnesium enrichment in stabilized incineration residue blocks.

Precipitation of brucite [$Mg(OH_2)$] has been observed in the pore spaces of both stabilized incineration residue blocks and coal waste blocks after prolonged seawater exposure (Roethel et al. 1987; Parker et al. 1981). The equilibrium pH of brucite in seawater is 9.55 (Pytkowicz et al. 1966). The estimated pore water pH of the residue blocks was shown to exceed pH 11.0, which may result in the removal of magnesium from seawater via the precipitation of magnesium hydroxide (Park, 1987).

Another mechanism which may contribute to the enrichment of magnesium in the stabilized residue blocks is the exchange of magnesium for calcium in calcite resulting in high magnesium calcite on the surfaces of the blocks. X-ray diffractograms of coal waste material exposed to seawater consistantly showed a shift in the main calcite (211) peak, which indicates some substitution of magnesium for calcium in the calcite (Milliman, 1974).

Potassium is a major element in the stabilized incineration residue blocks and a decrease in the potassium concentration was observed in the submerged blocks (Table 2). Potassium loss was also observed in stabilized coal waste blocks with prolonged seawater exposure (Woodhead et al. 1984). The loss of potassium may be due to soluble potassium compounds in the stabilized residue blocks.

Table 1. Elemental composition of particulate incineration residues.

Element	Combined Ash	Crushed Ash
Si (%)	18.9 (0.02)[a]	19.8 (1.5)
Al (%)	5.53 (0.43)	4.11 (0.15)
Fe (%)	8.0 (1.3)	19.5 (4.8)
Cu (μg/g)	2240 (590)	1710 (720)
Mn (μg/g)	1330 (120)	1420 (140)
Zn (μg/g)	5520 (920)	2030 (37)
Pb (μg/g)	3960 (300)	4450 (1420)
Cr (μg/g)	207 (14)	400 (37)
Cd (μg/g)	37.5 (3.1)	BDL[b]

[a] Values in parenthesis denote the standard deviation (n=3).

[b] Below method detection limit of 10 μg/g.

Table 2. Elemental composition of stabilized incineration residue reef blocks submerged in seawater: $HF-H_3BO_3$ acid digestion.

Metal	Unsubmerged[a] Block t = 0 days	Submerged[b] Block t = 165 days	Submerged[c] Block t = 380 days
Ca (%)	15.70 (1.6)	15.93 (1.5)	14.27 (1.6)
Mg (%)	1.13 (0.08)	1.41 (0.09)	1.44 (0.09)
Na (%)	2.39 (0.03)	2.34 (0.26)	2.37 (0.21)
K (%)	0.82 (0.05)	0.69 (0.04)	0.63 (0.02)
Al (%)	4.17 (0.23)	4.15 (0.08)	4.44 (0.26)
Si (%)	16.76 (0.22)	16.73 (0.50)	16.95 (0.78)
Fe (%)	7.25 (0.23)	6.60 (0.38)	7.03 (0.98)
Pb (μg/g)	3580 (160)	3520 (260)	3550 (440)
Zn (μg/g)	3760 (170)	3838 (180)	4090 (180)
Cr (μg/g)	178 (15)	200 (23)	193 (24)
Cu (μg/g)	1260 (230)	1560 (420)	1400 (120)
Mn (μg/g)	1020 (70)	969 (35)	1100 (50)
Cd (μg/g)	23.6 (1.5)	24.5 (2.6)	26.2 (3.3)

Data shown are the means and standard deviations of replicate analyses of residue block samples: [a] unsubmerged ash block (n=8); [b] ash block collected on 9 October, 1987 (n=10); [c] ash block collected on May 13, 1988 (n=10).

The metals of environmental concern, lead, chromium, copper, zinc and cadmium were effectively retained within the stabilized incineration residue blocks (Table 2). The high alkalinity of the particulate residues, the Portland type II cement additive, and the alkalinity of the seawater combine to create a favorable environment within the blocks for the retention of metals.

The estimated pore water pH of the stabilized incineration residues in seawater exceeds pH 11.0 (Park, 1987). The high alkalinity within the stabilized incineration residue blocks favors the formation of metal precipitates such as lead hydroxides and copper carbonates (Theis and Richter, 1979). Incineration residues are also rich in iron and manganese which form hydrous oxide phases at high pH resulting in the adsorption or coprecipitation of other metal ions in solution (Swallow, 1978; Johnson, 1986).

Cement is not only an important additive for block strength development, it may also act to reduce metal leaching. Portland cement has been demonstrated to contribute to the effective retention of metals within stabilized waste blocks (Breslin, 1986; Young et al. 1983; Shively et al. 1986). Metal binding may be due to a combination of entrapment of metal precipitates in pore spaces within the cementitious matrix and adsorption of metals to silica and oxyhydroxide surfaces within the cement matrix (Brown and Bishop, 1985).

BIOLOGICAL COLONIZATION

Diver and photographic surveys were conducted to document the organisms colonizing the two reef structures. Preliminary results suggest that no differences are observed in the species composition of the stabilized incineration residue blocks and the concrete blocks. Table 3 lists the organisms which are common to both reef structures. Both reef structures were colonized rapidly, with hydroids attached to all sides of the reef structures within six weeks of placement. As the summer progressed, bryozoan colonies replaced the hydroids as the dominant species growing on the surfaces of the reef structures. In addition, the reef structures attracted several fish species (Table 4). Blackfish, cunner and winter flounder were commonly observed in and around the reef sites.

ELEMENTAL COMPOSITION OF ATTACHED REEF BIOMASS

Samples of the attached biomass, primarily the hydroids *Tubularia sp.* and *Sertularia sp.*, were removed from both the stabilized incineration residue blocks and the cement blocks on 8/25/87 and 9/11/87 for metal analysis of the digested tissue to determine if the attached biomass were accumulating metals as a result of their association with the stabilized incineration residue blocks. Hydroids were chosen for these studies since these organisms attach themselves to the surfaces of the blocks and are the dominant organisms present during these sampling periods. The hydroids also serve as a food source for other members of the reef community.

A one-way analysis of variance (ANOVA) was used to determine if the metal contents of the hydroids growing on the stabilized incineration

Table 3. Organisms observed by divers on the surfaces of incineration residue blocks during six months of submersion in Conscience Bay.

Species No.	Organism
	Phylum Chlorophyta (green algae)
1	*Codium fragile*
2	*Ulva sp.*
	Phylum Rhodophyta (red algae)
3	*Chondrus crispus*
4	*Polysiphonia sp.*
5	*Polyides rotundus*
	Phylum Coelenterata (hydroids)
6	*Tubularia crocea*
7	*Obelia dichotoma*
8	*Sertularia sp.*
9	*Metridium dianthus*
	Phylum Bryozoa
10	*Membranipora pilosa*
	Phylum Annelida (segmented worms)
11	*Serpula sp.*
12	*Nereis sp.*
	Phylum Arthropoda (lobsters)
13	*Homarus americanus*
	Phylum Mollusca (snails and bivalves)
14	*Crassostrea virginica*
15	*Littorina littorea*
16	*Mercenaria mercenaria*
	Phylum Echinodermata (starfish and sea urchins)
17	*Asterias forbesi*
18	*Arbacia punctulata*

Table 4. Fin fish observed near incineration residue blocks during twelve months of submersion in Conscience Bay.

Common Name	
Blackfish	*Tautoga onitis*
Silversides	*Menidia menidia*
Toadfish	*Opsanus tau*
Cunner	*Tautogalobrus adsperus*
Winter flounder	*Psuedopleuronectes americanus*
Killifish	*Fundulus heteroclitus*

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residue blocks were significantly different from the metal contents of the hydroids growing on the cement blocks (Table 5). Results show that the metal contents of the hydroids collected from the stabilized incineration residue blocks and the cement blocks structure were not significantly different on each of the two sampling dates.

Metal contents of the hydroids were significantly different for Zn, Cr, Cu, Mn and Cd in the hydroid biomass collected on 9/11/87 as compared to hydroids collected on 8/25/87 for each respective reef structure (Table 3). A similar pattern was observed for hydroids growing on coal waste and cement blocks in Conscience Bay (Roethel, 1981). Factors such as changes in the water quality surrounding the reef site, maturity of the hydroids at the time of collection, and sample inhomogeniety may account for the observed differences in the metal contents of the hydroids on the different sampling dates.

CONCLUSIONS

Particulate incineration residues, when combined with Portland cement, can be successfully stabilized into solid blocks using conventional block making technology. On April 27-28, 1987 thirty stabilized incineration residue blocks and thirty cement blocks were successfully transported and placed in Conscience Bay, Long Island Sound, New York.

The establishment of the Conscience Bay reef site constructed using stabilized incineration residues has provided a unique opportunity to study the *in situ* interactions of stabilized incineration residue blocks with the marine environment. Results of this study have shown that the stabilized incineration residue blocks have retained their strengths even after prolonged seawater exposure. Metals of environmental concern, including lead and cadmium, are retained within the cementitious matrix of the stabilized incineration residue blocks after 12 months of submersion at the reef site. In addition, the organisms growing on the surfaces of the stabilized incineration residue blocks are not accumulating metals from the blocks.

To date, no adverse environmental impacts have been observed at the Conscience Bay reef site due to the presence of stabilized incineration residue blocks. Continued monitoring of the reef site is planned and will provide data to more clearly define the long-term effects of stabilized incineration residue in the marine environment.

ACKNOWLEDGEMENTS

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Table 5. Elemental composition of attached reef biomass.

Element	Collection Date	Concrete Block[a] (X_c)	Reef Block[a] (X_r)	ANOVA[b] Result
Al (%)	8/25	0.82 (0.09)	0.76 (0.08)	N.S.
	9/11	0.83 (0.01)	0.80 (0.08)	N.S.
Fe (%)	8/25	1.52 (0.09)	1.45 (0.05)	N.S.
	9/11	1.54 (0.09)	1.51 (0.03)	N.S.
Pb (μg/g)	8/25	35.3 (2.6)	34.4 (0.8)	N.S.
	9/11	36.8 (1.1)	36.1 (2.0)	N.S.
Zn (μg/g)	8/25	174 (7.8)	173 (9.2)	N.S.
	9/11	184 (15)	187 (6)	N.S.
Cr (μg/g)	8/25	31.2 (1.7)	30.4 (1.0)	N.S.
	9/11	34.6 (2.1)	35.1 (1.6)	N.S.
Cu (μg/g)	8/25	57.2 (4.0)	60.8 (1.5)	N.S.
	9/11	65.3 (4.7)	67.0 (4.8)	N.S.
Mn (μg/g)	8/25	4970 (300)	4610 (400)	N.S.
	9/11	7040 (450)	6790 (200)	N.S.
Cd (μg/g)	8/25	0.44 (0.04)	0.41 (0.04)	N.S.
	9/11	0.51 (0.04)	0.53 (0.04)	N.S.

[a] Data shown are the means and standard deviations of replicate analysis of samples collected on 25 August and 11 September, 1987. For 8/25 concrete block n=7; 8/25 reef block n=8; 9/11 concrete block n=4; 9/11 reef block n=7.

[b] The hypothesis $H_0: X_c = X_r$ was tested for each metal on each date using a single classification analysis of variance (Sokal & Rohlf, 1969), where X_c and X_r are the mean metal concentrations measured on replicate analyses of samples obtained from concrete and incineration residue block surfaces, respectively. N.S. indicates no significant difference observed.

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