MARINE SCIENCES RESEARCH CENTER
STATE UNIVERSITY of NEW YORK
STONY BROOK, N.Y.

The Fixation of Incineration Residues

Final Report - August 1986

Frank J. Roethel
Victor Schaeperkoetter
Ruth Gregg
Kyeong Park

Waste Management Institute
Marine Sciences Research Center
State University of New York
Stony Brook, New York 11794

The Fixation of Incineration Residues

Final Report - August 1986

Frank J. Roethel
Victor Schaeperkoetter
Ruth Gregg
Kyeong Park

Prepared for

New York State Legislative Commission on the
Water Resource Needs of Long Island

Working Paper # 27

Reference 86-11

Approved for Distribution

Donald W. Pritchard
D. Pritchard, Acting Director

ABSTRACT

Incineration ash from three operational facilities within the New York Metropolitan area were stabilized with various portions of additives (lime, gypsum, Portland cement and sodium carbonate) to produce a concrete-like material suitable for both marine disposal and use in the construction industry. Curing parameters were adjusted to maximize the structural integrity of the experimental mixes. Certain mix and curing designs produced proctor sized samples exhibiting a compressive strength of approximately 1,600 psi.

Stabilized composite residues (containing both fly ash and bottom ash) did not exceed EPA leachate limits. New York City fly ash, stabilized without any bottom ash did exhibit significantly higher elemental concentrations and exceeded EPA leachate limits for cadmium and lead.

Permeabilities of the stabilized mixes ranged from 10^{-5} - 10^{-8} cm/sec with the stabilized composite residues yielding the lowest permeabilities. Following submersion in seawater, stabilized composite residue samples experienced no decline in their structural integrity while significant expansion and loss of strength was observed for the New York City fly ash samples.

The results of this investigation indicate that incineration ash possesses significant pozzolanic activity and may be a suitable substitute for aggregate in the manufacture of cement blocks for use by the construction industry in this region. In addition, blocks having excellent structural properties relative to marine disposal have been fabricated.

Table of Contents

Table of Contents (continued)

Section 6

Section 7

Section 8

Section 9

Section 10

Table of Contents (continued)

List of Figures

List of Figures (continued)

List of Figures (continued)

List of Tables

List of Tables (continued)

List of Tables (continued)

ACKNOWLEDGEMENTS

Our sincere thanks to Mr. Andrew Szurgot, Signal Environmental Systems, Mr. Michael White, Town of Huntington and Mr. Nick Cavagnaro, New York City Department of Sanitation for their cooperation and making available the incineration residue utilized in this investigation. We are pleased to acknowledge the help of Mr. George Proios, New York State Legislative Commission on Water Resource Needs of Long Island for his valuable comments and active involvement in this investigation. We are especially indebted to Senator Caesar Trunzo whose early interest and participation in this investigation was directly associated with the funding of this project by the New York State Legislature.

Section 1

INTRODUCTION/OVERVIEW

PROJECT DESIGN

This project, entitled "The Fixation of Incineration Ash: Physical and Leachate Properties", is a one year laboratory study which began in May 1985. This work is sponsored by the New York State Legislature with the New York State Legislative Commission on the Water Resource Needs of Long Island as the lead agency. Investigators at the Waste Management Institute of the Marine Sciences Research Center of the State University of New York at Stony Brook are conducting the investigation. Motivation for the project stemmed from a desire to examine the feasibility of fixating incineration ash and demonstrate the use of the stabilized material in a constructive manner as an alternative to landfilling.

PROJECT OBJECTIVES

This project focussed on two main objectives:

Objective 1 - To investigate incineration ash fixation by means of chemical additives and controlled curing environments.

Objective 2 - To determine the permeability and leachate characteristics of several "optimum" mixtures of incineration ash and fixation additives.

Objective 1 was addressed during the first stage of the project. The incineration ash utilized in this study was secured from three operational incinerators. New York City's Southwest Brooklyn facility twice provided a source of fly ash. On two separate occasions the Town of Huntington incinerator located in East Northport, Long Island was visited to remove composite samples of both bottom and fly ash. Composite ash samples were also acquired from the Westchester Resource Recovery facility in Peekskill, New York.

The incineration wastes were initially characterized by determining the moisture content of the samples, particle size distribution and pH. The concentration of organic constituents was determined by measuring the loss on ignition and X-ray diffraction provided information as to the major mineral phase found within the incineration wastes.

Calcium hydroxide (lime), Portland cement (Type 1), gypsum and sodium carbonate served as fixation additives during the fabrication of ASTM proctor sized cylinders of incineration ash. The proctors were cured in various controlled temperature-humidity environments for varying periods of time.

At the end of the curing period, proctors were subjected to compressive strength testing (ASTM C39). Relative compressive strengths were used as a criterion for comparing various mixes of incineration wastes and fixation additives in order to determine an optimum formulation. Mixes containing 15% Portland cement were selected as optimum.

The next stage of the project addressed the second objective; to determine the permeability and leachate characteristics of the optimum mixes. Portions of proctors were sealed into PVC pipe. The rate and quantity of water which permeated through the proctors was recorded, enabling calculations of permeability constants.

The leachate characteristics of starting materials and optimum mixes were studied using both EPA and ASTM protocols. Additional physical tests were performed on the optimum mixes and starting materials. Density/ porosity (ASTM C 642) of the optimum mixes was measured. Optimum mixes and starting materials were analyzed for major, minor and trace components. Samples were digested in hydrofluoric acid prior to analysis by atomic absorption spectroscopy. X-ray diffraction was used to identify the principal cementatious phases. Table 1.1 summarizes the overall scope of the project.

Table 1.1. "The Fixation of Incinerator Residues: Physical and Leachate Properties" - A summary of activities.

Objective 1:	To investigate incineration residue fixation by means of chemical additives and controlled curing environments. - Initial research and development of proctor fabrication techniques, - determination of physical properties of incinerator residues, - determination of optimum water content for making proctors, - full scale production of test proctors for all of the test mix types studied, - selection of an "optimum" mix to be used during the investigation of the second objective.
Objective 2:	To determine the permeability and leachate characteristics of optimum mixes of three incinerator residues plus fixation additives. - Darcy falling head permeability measurements of the optimum mixes, - EPA and ASTM chemical leachate tests of optimum mixes and starting materials, - determination of the bulk chemical composition and mineralogy of the optimum mixes and starting materials, - additional physical testing of the optimum mixes and starting materials, - preliminary fabrication of "cement blocks" incorporating incineration residue in place of natural aggregates, - determination of the flux of calcium from the optimum mixes and a preliminary evaluation of block longevity, - initial evaluation of the impacts from marine disposal of fixated incineration residues.

PROJECT RESULTS

This report is the final product of the first phase of this investigation. It includes a tabulation of all data and a description of methods. A brief discussion of the results with suggestions for future work is included.

Section 2

PROJECT SUMMARY AND CONCLUSIONS

STATEMENT OF PRINCIPAL CONCLUSIONS

This project provided data to support the following principal conclusions:

- Incineration residues contain sufficient pozzolanic ingredients to support lime fixation.

- Fixation additives affect the physical and chemical properties of proctors.

- Both physical and chemical properties of proctors determine the chemical composition of leachate.

- Higher temperature generally accelerates the curing process. Compressive strength increases with curing time.

- Chemical fixation of incineration residue is capable of reducing the rate of release of trace metals.

- Structural integrity is significantly affected by particle size and organic content of the residue.

- Proctors of stabilized combined ash maintain their structural integrity following their placement in the sea.

- For fixated combined ash proctors, EPA leachate limits were not exceeded for parameters which were tested.

- For fixated incinerator fly ash, EPA leachate limits were exceeded for Cadmium and Lead.

- Preliminary results indicate that stabilized blocks of combined incineration residue will maintain their structural integrity in the marine environment for prolong lengths of time.

- Incineration residues may be a suitable substitute for natural aggregates in the production of cement blocks.

- Proctors fabricated with New York City fly ash and Portland cement experience significant expansion upon seawater submersion resulting in failure of the samples structural integrity.

- If the New York Metropolitan region were to elect marine disposal of all the projected incineration residue (2.2×10^6) it would require 10 years to construct one artificial fishing reef.

A SUMMARY OF PHYSICAL AND CHEMICAL OBSERVATIONS

Fabrication Techniques and Mix Types

Proctor fabrication was accomplished following the ASTM D698 method "Standard Test Moisture-Density Relations of Soils and Soil-Aggregate Mixtures using 5.5 lb. Rammer and 12 inch Drop". While modifications of this test were investigated, proctor fabrication could not be improved.

A water content of 17% was found to be optimum for fabrication of proctors containing Westchester residue. In general optimum water content is a function of median particle size, increasing as particle size decreases.

The maximum observed compressive strength was 1592 psi for a 67% Westchester residue and 15% Portland cement mix with 18% water content cured for 21 days at ambient temperatures. Additions of sodium carbonate (Na_2CO_3) found to improve the structural integrity in fixated coal ash, resulted in no improvement for the incineration ash proctors. Gypsum, calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) another commonly used additive significantly deteriorate the compressive strength and produced the lowest compressive strengths measured during this investigation.

The three optimum mixes selected for additional physical and chemical testing were:

- 62% New York City fly ash with 15% Portland cement and 23% moisture cured at 49°C for 72 hours. [Proctor series COA2].
- 67% Huntington combined residue with 15% Portland cement and 18% moisture cured for 14 days at Ambient temperatures. [Proctor series HA3].
- 68% Westchester combined residue with 15% Portland Cement and 17% moisture cured at 49°C for 24 hours. [Proctor series WAE6].

Physical and Chemical Tests

Tables 2.1 and 2.2 summarize the results of the physical, chemical and mineralogical tests performed on optimum mixes.

Physical testing disclosed the need for either calcium hydroxide (lime) or Portland cement and increased curing time to insure the development of sufficient reaction products to insure the physical integrity of the stabilized mix. No significant differences were observed in either the top or bottom portions of the proctor with the one exception that the bottom edges of the New York City proctors were sometimes chipped in removal from the mold. Basically uniform values for both porosity and permeability suggest that the compaction effort was homogeneously distributed during proctor fabrication. For each of the optimum mixes, the permeability initially declined very rapidly, then stabilized experiencing a minor trend toward lower values during the four week period of the investigation.

Mineralogical and chemical analyses provided an interesting comparison of the fly ash and composite residues used in this study. Elemental constituents were found in higher concentration in the fly ash, when compared to the composite residues.

Comparison of the chemical composition of the ASTM and EPA leachate revealed that:

- EPA leachate concentrations were significantly higher than the ASTM values. It is important to note that the pH of the EPA leachate is adjusted with acid prior to the test.

- For composite ash proctors leachate concentrations did not exceed EPA limits for those parameters which were examined.

- Modelling of leachate diffusion from a hypothetical disposal site indicates that water column chemistry is unaltered beyond 1000 meters from the disposal site. For most elements the distance is less than 100 meters.

Table 2.1. Summary of physical tests performed on optimum mixes.

Test	New York City Fly Ash	Huntington Composite Residue	Westchester Composite Residue
Proctor fabrication data (Modified ASTM D698 method)	62% Ash 15% Portland Cement 23% Moisture	67% Residue 15% Portland Cement 18% Moisture	68% Residue 15% Portland Cement 17% Moisture
Proctor compressive	228 (±43)	455 (±51)	1230 (±59)
Proctor wet density, ASTM D698 (modified) (kg/m^3)	1533	1712	1744
Darcy falling head permeability (cm/sec)	Top of Proctor: 10^{-7} Bottom of Proctor: 10^{-5}	T: $<10^{-7}$ B: $<10^{-5}$	T: 10^{-8} B: 10^{-8}
Density/porosity, ASTM C642:			
Apparent specific gravity 2.32	2.53	2.51	
Water absorption	36%	21%	18%
Voids	47%	39%	36%

Table 2.2. Summary of chemical and mineralogical tests performed on optimum mixes.

Test	Optimum Mixes
<u>Bulk Chemical Composition</u>	
Major Constituents	Aluminum Silicon Magnesium Iron Calcium Zinc
Minor Constituents	Cooper Chromium Lead Manganese
Trace Constituents	Cadmium Arsenic Cobalt Mercury Nickel
<u>Mineralogy</u>	
Major Crystalline Phases	Anhydrite Gypsum Quartz Calcite
Minor Crystalline Phases	Ettringite

SUGGESTIONS FOR FUTURE WORK

The following suggestions are provided as an aid for planning future investigations:

- undertake toxicity bioassays on selected organisms representative of the project site following the procedures described by the US EPA for the ocean disposal permit program,

- develop methods for the mechanical, high speed fabrication of SAI blocks using existing equipment and technology provided by the concrete block industry,

- construct small test structures, simulating an artificial fishing reef, at our marine test site located in Conscience Bay, an embayment of Long Island Sound,

- examine the chemical, physical and biological interactions of SAI blocks submerged in Conscience Bay as a function of marine exposure,

- evaluate the suitability and engineering properties of construction grade cement block using incineration residues as a substitute for natural aggregate.

Section 3

INCINERATION WASTE CHARACTERISTICS

INCINERATION RESIDUES USED IN THE PROGRAM

Ash from three operational New York State facilities was utilized in this study. The Southwest Brooklyn plant operated by the City of New York, the Signal - RESCO facility in Westchester County, and the Town of Huntington incinerator located in East Northport were selected. Ash was collected on two separate occasions from each site and returned to our facility in steel 55 gallon drums. The total amount of residue collected from each site was, approximately, 4,200 lbs from Westchester, 600 lbs from the New York City plant and 1,200 lbs from the Town of Huntington facility. Distinction between the use of first and second trip ash is indicated in the remaining sections of the report.

Composite ash, a combination of bottom and fly ash, was collected at the Westchester and Huntington facilities, and only fly ash was collected at New York City. Different types of ash are produced due to the varied descriptive parameters of the plants, and some of these parameters can be found in Table 3.1.

BULK PROPERTIES

Particle-size Analysis

The distribution of particle size in the incineration wastes was determined by sieving a sample of approximately 6 kg of Huntington residue, 1 kg of Westchester residue and 0.5 kg of New York City fly ash. We secured ash twice from Huntington and New York City and following each collection event particulate size distribution analysis was undertaken. The analysis followed ASTM D422-63 using a series of U.S. Standard Sieves 3 in, 1.5 in, 0.75 in, Numbers 4, 10, 18, 40, 60, 100 and 200. For the three larger size sieves the residues were sieved dry and shaken by hand. The smaller sieves were placed into a Ro-Tap sieve shaker.

Table 3.1. Comparison of incineratón ash facilities.

Statistics	Westchester	Huntington	NYC Southwest Brooklyn
Start-up	1984	Unit#1-1956 #2-1960 #3-1962	1961
Area served	Westchester Cty 850,000 people	Huntington 210,000 people	Varies ~300-500,000
Plant capacity	2250 tons/d	***	750 tons/d
Average throughput	1800 tons/d	Unit#1&2-100tons/d #3 -200tons/d	600 tons/d
Combustion temp.	2500°F+	1400°F+	1400-1600°F
Type of system	Mass burning with waterwall boilers	Mass burning	Mass burning
Operation	24 h/d 7 d/week	24 h/d 6 d/week	24 h/d 7 d/week
Materials recovery	Ferrous, Aggregate	Aggregate[1]	None
Precipitators	Electrostatic, 3	Electrostatic, 1	Electrostatic,4
Power generation	Electric power	None	None
Power generation capacity	60 MW,ongoing	***	***
Customer	Consolidated Edison Co.	***	***

[1] Material is sorted at the plant before burning and the metallic fraction is disposed of in a landfill located on the premises.

The results of the particle-size analysis are illustrated in Figures 3.1 - 3.3 which shows the composition of the different size fractions. The composite ash from Westchester and Huntington was more heterogeneous than the New York City fly ash, as expected. In the larger size groups glass was predominant. In the Huntington samples fragments of rags, paper and wood shaving were observed.

The quantitative contributions of the different size fractions to the samples are given in Table 3.2. From the grain size distribution curve (Figure 3.4) it can be concluded that the New York City fly ash sample obtained during our second visit to that facility is predominantly of silt size having a mean grain size of 0.09 mm. This is significantly finer than the first sample that was collected which has a mean grain size of 0.25 mm. Sand sized particles are dominant in the Westchester ash; the mean particle size is 0.6 mm. The largest particle size is represented by the two Huntington samples which compare very well. Huntington ash has the highest fraction of gravel sized particles and a mean particle size of slightly less than 2.0 mm.

Moisture Content and pH

Moisture content was determined in replicate (n=10) on 30 - 40 g samples of fresh residue ash following each collection event. Samples were dried to constant weight in an oven at about 90°C, Tables 3.3 - 3.5. Moisture contents were fairly uniform, despite the heterogeneity of the materials and the large solid inclusions. New York City fly ash and Westchester residue were significantly dryer than the Huntington ash which has a moisture content of approximately 24%.

The pH of the various residues was determined using an Orion Research Model 701A pH meter attached to a standard glass electrode. Table 3.6 presents the data.

Figure 3.1. Particle size fractions, New York City incineration ash.

Illustration	Sample Retained by Seive Number	
A	18	(1.00 mm)
B	40	(425 μm)
C	60	(250 μm)
D	150	(100 μm)
E	200	(75 μm)
F	Pan	(<75 μm)

Figure 3.1

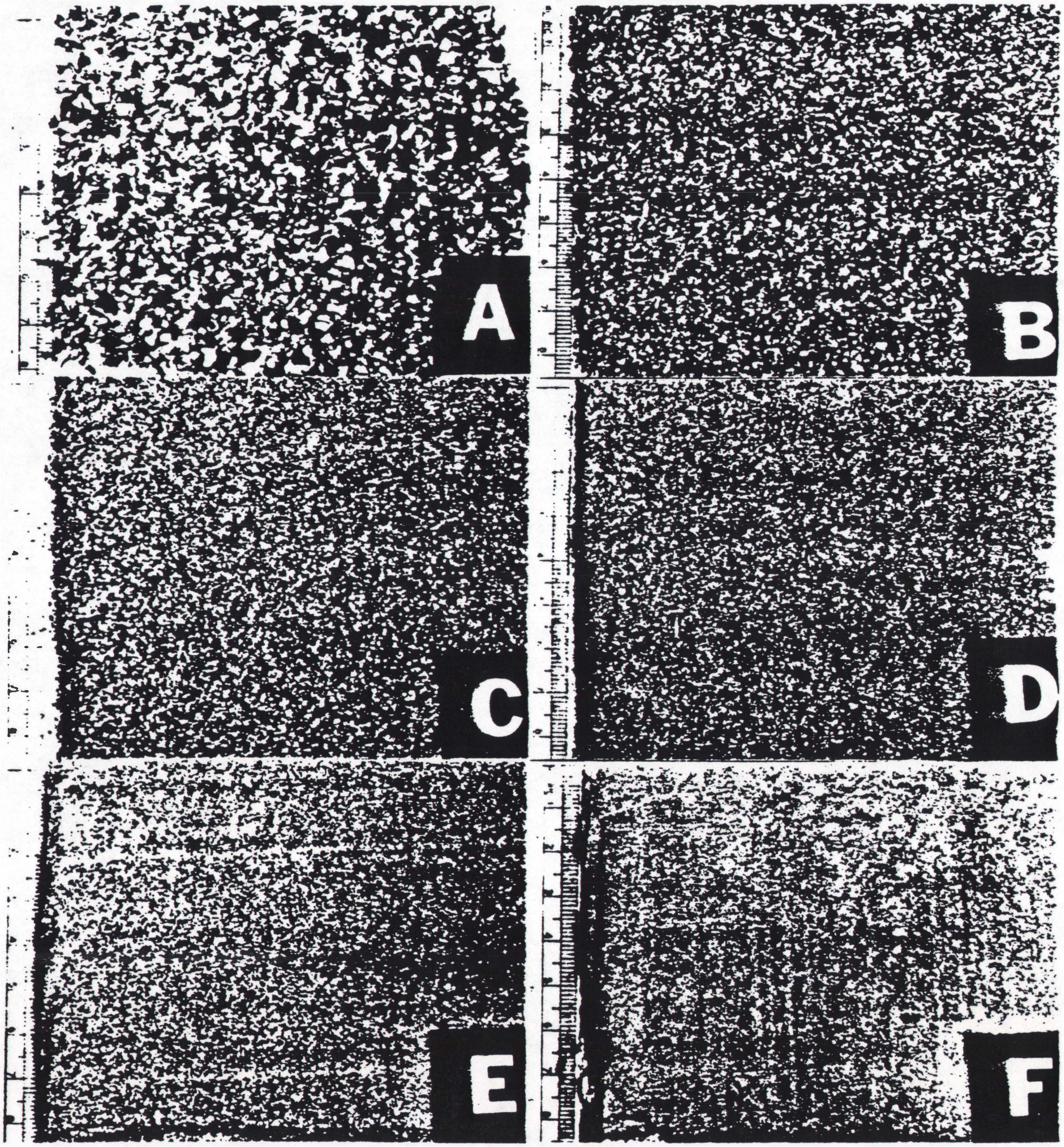


Figure 3.2. Particle size fractions, Huntington incineration residue.

Illustration	Sample Retained by Seive Number	
A		(3/4")
B		(1/2")
C	4	(4.75 mm)
D	18	(1.00 mm)
E	60	(250 μm)
F	Pan	(<75 μm)

Figure 3.2

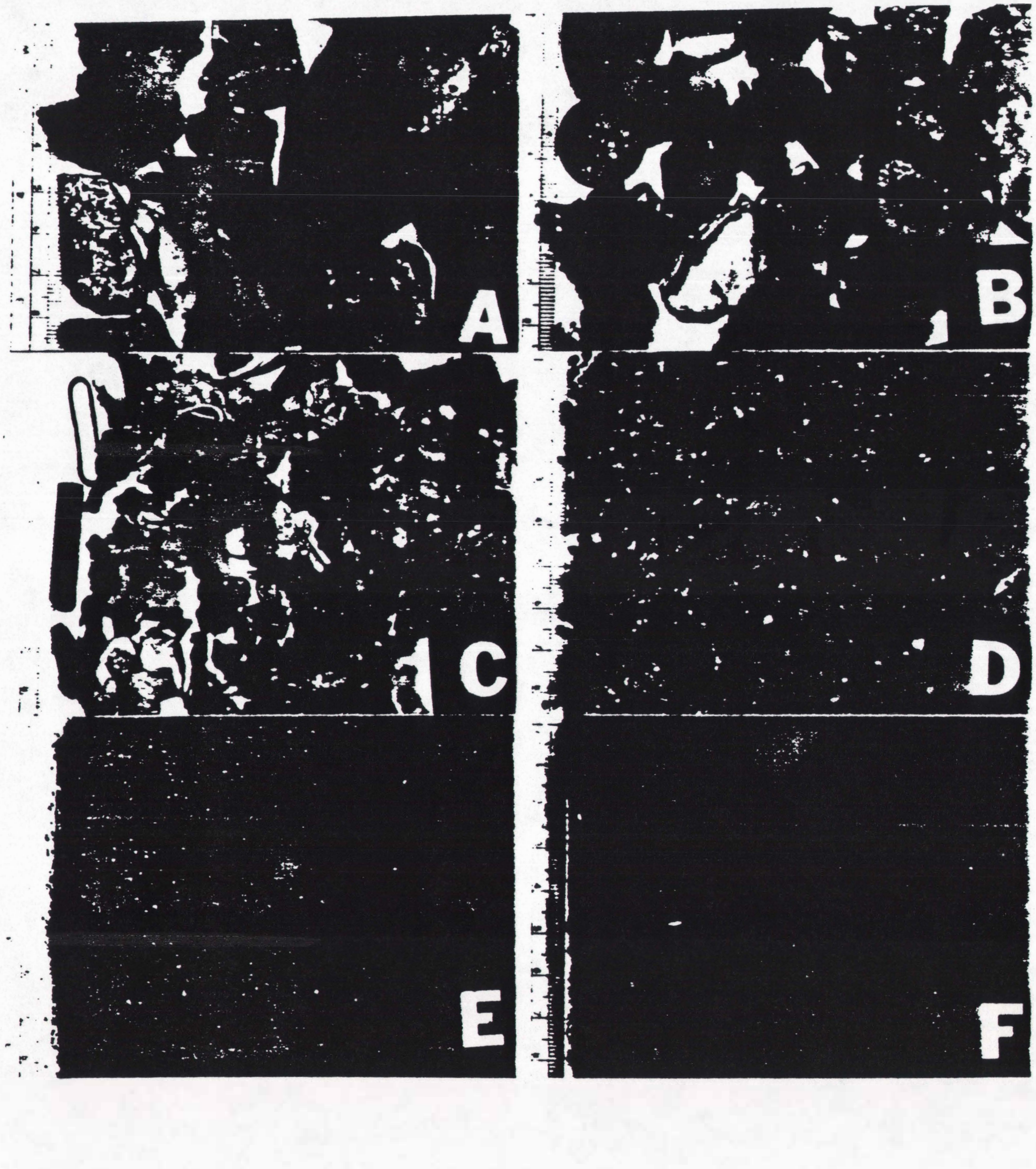


Figure 3.3. Particle size fractions, Westchester incineration residue.

Illustration	Sample Retained by Seive Number
A	4 (4.75 mm)
B	10 (2.00 mm)
C	18 (1.00 mm)
D	60 (250 μm)
E	200 (75 μm)
F	Pan (<75 μm)

Figure 3.3

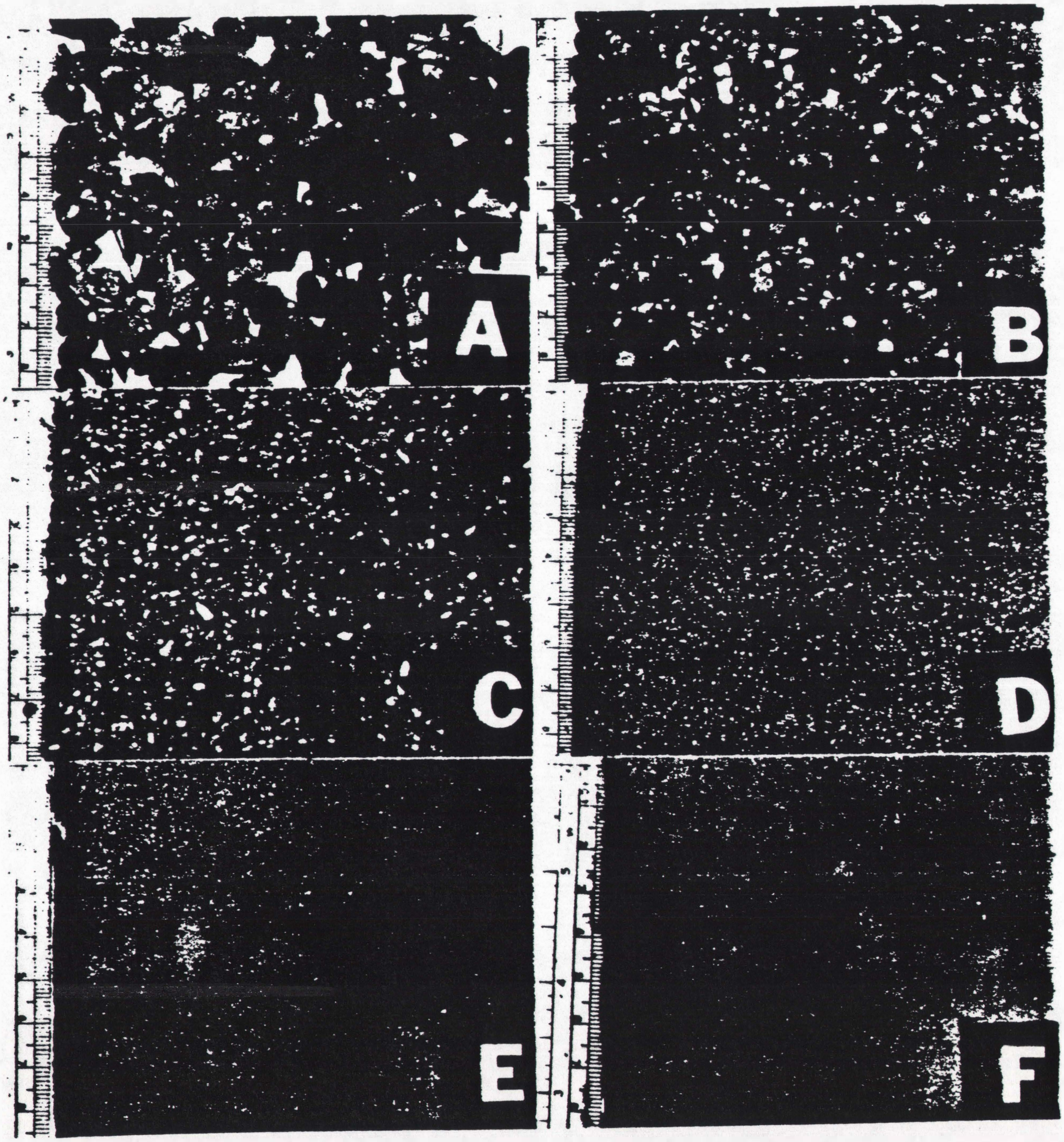


Table 3.2. Size fraction of residues.

PARTICLE SIZE ANALYSIS

		HUNTINGTON COMPOSITE ASH		NEW YORK CITY FLY ASH		WESTCHESTER COMPOSITE ASH		NEW YORK CITY FLY ASH*		HUNTINGTON FLY ASH*	
SIEVE NUMBER	OPENING SIZE	GRAMS RETAINED	% RETAINED	GRAMS RETAINED	% RETAINED	GRAMS RETAINED	% RETAINED	GRAMS RETAINED	% RETAINED	GRAMS RETAINED	% RETAINED
	.75"	239.1	4.08	0.0	0.00	0.0	0.00	0.0	0.00	88.3	4.76
	.50"	324.5	5.54	0.0	0.00	0.0	0.00	0.0	0.00	128.98	6.96
	.375"	451.5	7.70	0.0	0.00	47.2	4.47	0.0	0.00	139.08	7.50
4	4.75 mm	866.2	14.78	0.0	0.00	72.5	6.87	0.0	0.00	294.32	15.87
10	2.00 mm	844.6	14.41	0.6	0.11	111.4	10.56	4.0	0.69	254.77	13.74
18	1.00 mm	779.9	13.30	3.7	0.70	183.1	17.36	5.0	0.86	212.48	11.46
40	425 µm	1108.8	18.91	74.2	14.12	310.8	29.46	16.3	2.80	315.01	16.99
60	250 µm	487.6	8.32	174.0	33.13	136.3	12.92	29.8	5.10	162.73	8.78
100	150 µm	262.8	4.48	149.0	28.37	73.0	6.92	78.4	13.45	106.46	5.74
200	75 µm	186.9	3.19	84.3	16.04	54.6	5.18	185.6	31.84	75.04	4.05
	<75 µm	310.3	5.29	39.5	7.52	66.1	6.27	263.8	45.25	77.13	4.16
	TOTAL WEIGHT:	5862.1		525.3		1055.0		582.9		1854.3	

* Represents ash collected on a second visit to the facility.

Figure 3.4

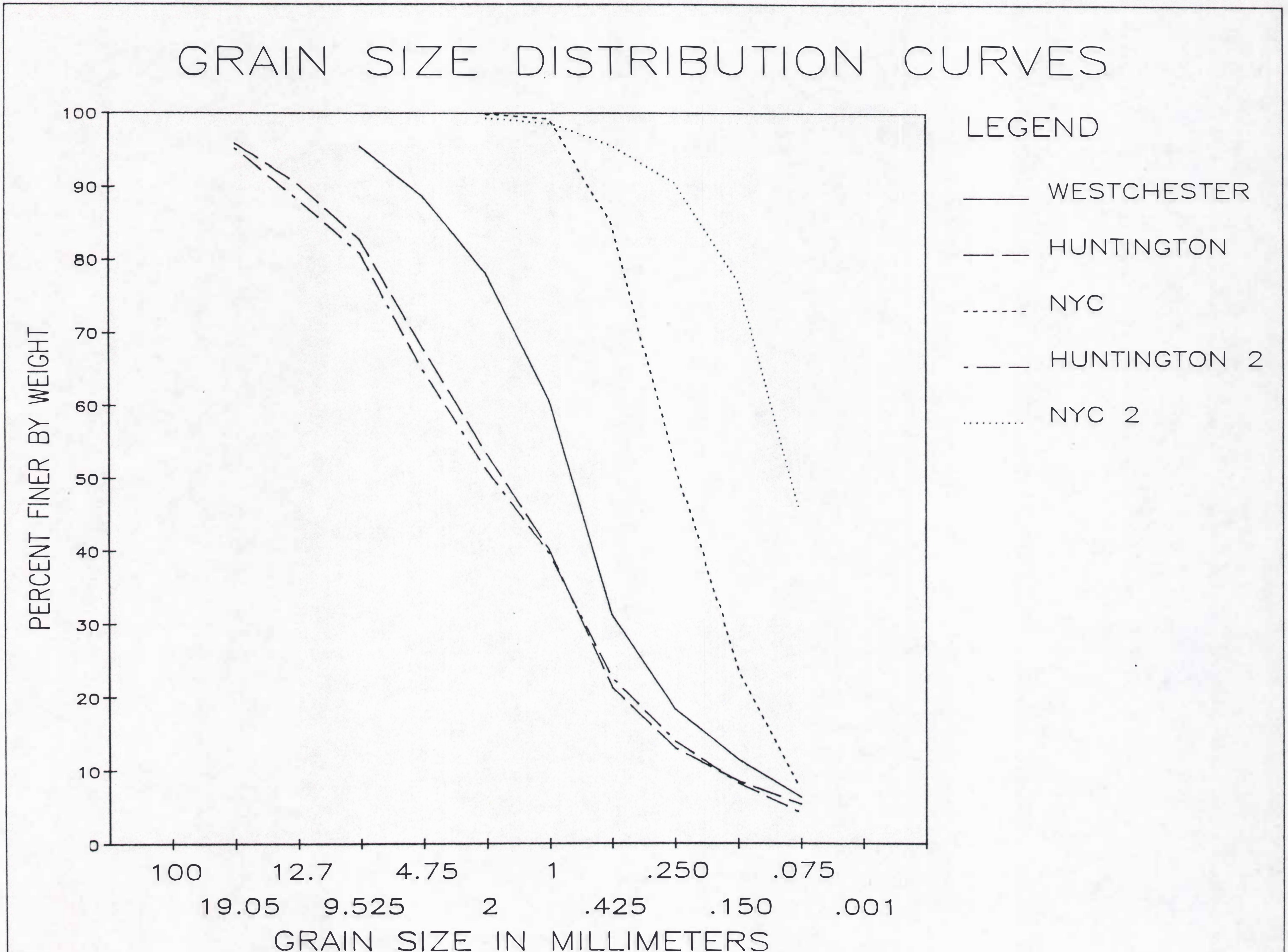

GRAIN SIZE DISTRIBUTION CURVES
LEGEND
WESTCHESTER
HUNTINGTON
NYC
HUNTINGTON 2
NYC 2
PERCENT FINER BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
100
19.05
12.7
9.525
4.75
2
1
.425
.250
.150
.075
.001
GRAIN SIZE IN MILLIMETERS

Table 3.3. Moisture content of Huntington incineration ashes.

WEIGHT	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
BEAKER	27.74	27.28	27.93	27.21	27.50	28.89	28.05	27.39	48.81	49.48
BEAKER + ASH	59.56	58.13	61.31	60.65	62.78	60.31	64.99	62.33	87.28	89.27
WET ASH	31.83	30.85	33.38	33.43	35.29	31.43	36.94	34.94	38.46	39.79
BEAKER + ASH (DRY)	51.62	50.15	52.41	52.15	54.11	52.70	56.37	53.49	77.63	79.17
DRY ASH	23.89	22.87	24.48	24.94	26.61	23.81	28.31	26.10	28.81	29.69
MOISTURE CONTENT	7.94	7.98	8.90	8.50	8.67	7.62	8.62	8.84	9.65	10.10
% MOISTURE	24.94	25.87	26.66	25.41	24.58	24.24	23.34	25.30	25.09	25.39
AVE. MOISTURE	25.08									
VARIANCE	0.74									
STD. DEV.	0.86									

WEIGHT	H1*	H2*	H3*	H4*	H5*	H6*	H7*	H8*	H9*	H10*
BEAKER	49.92	50.31	50.13	49.96	49.96	48.74	50.56	49.59	49.96	51.50
BEAKER + ASH	90.19	91.14	81.01	77.71	76.40	72.70	83.49	87.55	79.62	83.48
WET ASH	40.27	40.83	30.88	27.75	26.44	23.95	32.93	37.96	29.66	31.98
BEAKER + ASH (DRY)	81.08	80.98	74.42	71.34	69.84	67.23	75.63	79.77	72.61	77.02
DRY ASH	31.16	30.68	24.29	21.38	19.88	18.49	25.07	30.18	22.65	25.52
MOISTURE CONTENT	9.11	10.16	6.60	6.37	6.56	5.46	7.86	7.78	7.01	6.46
% MOISTURE	22.63	24.88	21.36	22.96	24.80	22.81	23.87	20.49	23.62	20.21
AVE. MOISTURE	22.76									
VARIANCE	2.43									
STD. DEV.	1.56									

* Represents ash collected on a second visit to the facility.

Table 3.4. Moisture content of New York City incineration ashes.

WEIGHT	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
BEAKER	30.08	27.10	27.32	28.01	29.48	30.00	28.05	29.00	51.50	49.56
BEAKER + ASH	46.82	46.40	47.00	45.52	48.43	50.37	45.92	48.45	76.11	76.56
WET ASH	16.74	19.30	19.68	17.51	18.94	20.37	17.87	19.45	24.61	27.00
BEAKER + ASH (DRY)	45.94	45.23	45.83	44.53	47.26	49.12	44.71	47.19	74.48	74.77
DRY ASH	15.86	18.13	18.51	16.52	17.78	19.12	16.66	18.19	22.98	25.20
MOISTURE CONTENT	0.88	1.17	1.17	0.99	1.16	1.25	1.21	1.26	1.63	1.79
% MOISTURE	5.25	6.07	5.96	5.64	6.13	6.14	6.75	6.49	6.63	6.64
AVE. MOISTURE	6.17									
VARIANCE	0.21									
STD. DEV.	0.45									

WEIGHT	C1*	C2*	C3*	C4*	C5*	C6*	C7*	C8*	C9*	C10*
BEAKER	50.04	51.60	48.29	49.57	48.82	51.30	49.46	50.85	48.75	48.99
BEAKER + ASH	67.67	67.17	68.31	66.70	70.21	69.54	66.88	69.60	66.90	66.36
WET ASH	17.63	15.57	20.02	17.14	21.39	18.23	17.41	18.75	18.15	17.37
BEAKER + ASH (DRY)	67.37	66.90	67.96	66.40	69.81	69.22	66.58	69.28	66.58	66.05
DRY ASH	17.33	15.30	19.66	16.83	20.99	17.91	17.12	18.43	17.83	17.06
MOISTURE CONTENT	0.30	0.27	0.35	0.30	0.40	0.32	0.30	0.32	0.32	0.31
% MOISTURE	1.70	1.76	1.77	1.78	1.87	1.75	1.72	1.70	1.75	1.79
AVE. MOISTURE	1.76									
VARIANCE	0.002									
STD. DEV.	0.048									

* Represents ash collected on a second visit to the facility.

Table 3.5. Moisture content of Westchester incineration ashes.

WEIGHT	W1	W2	W3	W4	W5
BEAKER	51.60	48.29	49.57	48.83	50.63
BEAKER + ASH	89.17	82.98	82.53	84.27	86.33
WET ASH	37.57	34.69	32.96	35.44	35.70
BEAKER + ASH (DRY)	88.38	82.18	81.82	83.43	85.47
DRY ASH	36.78	33.89	32.26	34.60	34.84
MOISTURE CONTENT	0.78	0.79	0.70	0.83	0.86
% MOISTURE	2.08	2.29	2.14	2.35	2.40
AVE. MOISTURE	2.25				
VARIANCE	0.01				
STD. DEV.	0.12				

Table 3.6. pH values for the various residues.

Residues	pH
New York City Fly Ash	10.89
New York City Fly Ash*	6.59
Huntington Composite Ash	7.72
Huntington Composite Ash*	7.71
Westchester Composite Ash	12.74

* represents ash collected on a second visit to the facility

Once again the two New York City samples differed considerably, the first sample was alkaline while the second sample collected was slightly acidic. The two Huntington samples were virtually identical and the most alkaline residue was obtained from the Westchester facility.

Loss on Ignition

The dried samples of residue used for determination of moisture content were used to measure loss on ignition (LOI). In this method the samples were ignited in a covered crucible in a muffler furnace at controlled temperature. Separate determinations were made for LOI at two temperatures, 500 ± 50°C and 900 ± 50°C. LOI is frequently determined at temperatures of 900 to 1,000°C but biogenic organics are burned off at 500°C and this was a materials group of interest for the present characterization.

Figure 3.5 and Tables 3.7 - 3.11 clearly illustrate that Huntington ash possessed the highest amount of uncombusted material, approximately 14% at 900°C. The second sample of New York City ash was significantly higher in organics when compared to the first sample and Westchester composite ash lost only 1.8% of its dry weight after being heated to 500°C.

Figure 3.5 Loss on ignition

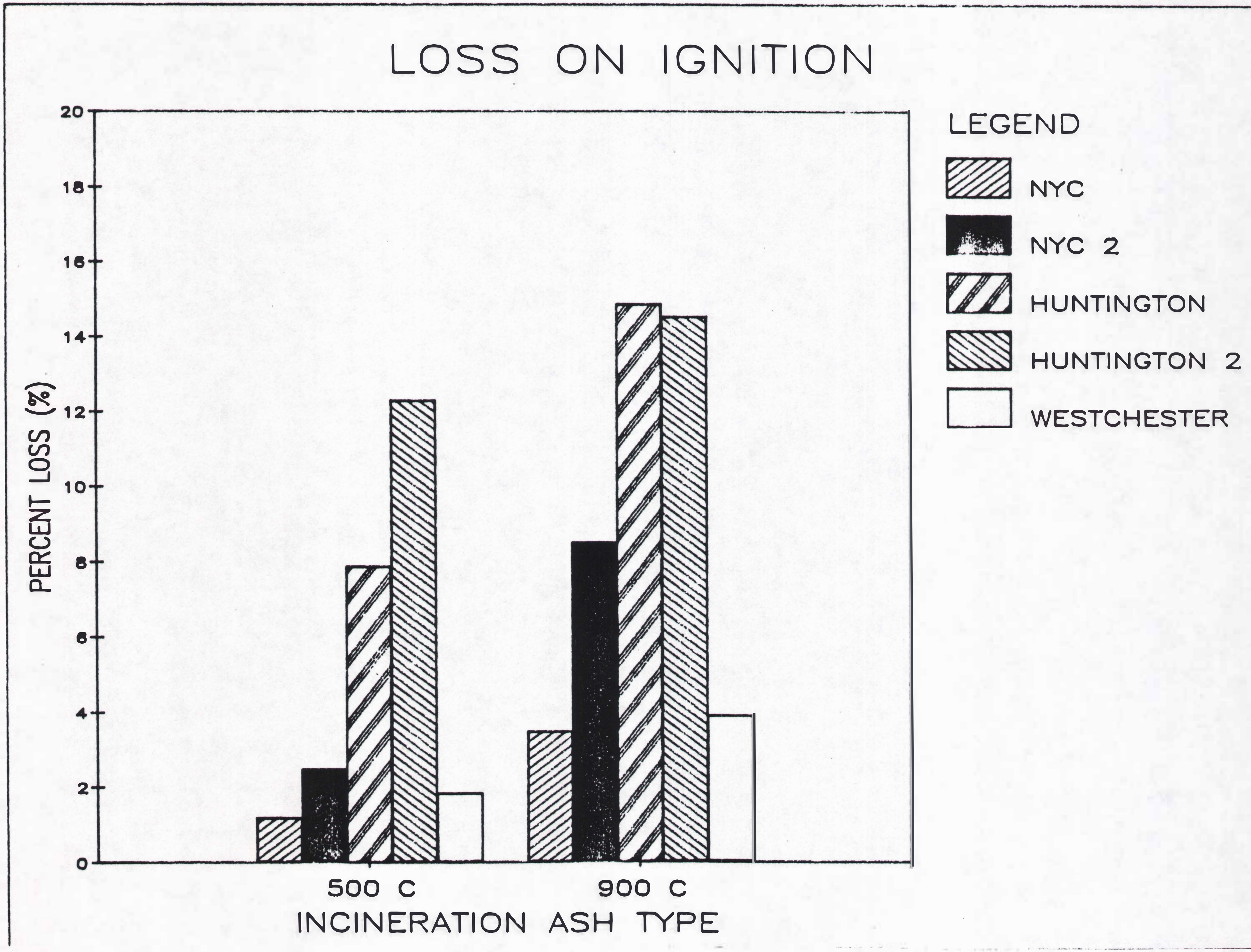


Table 3.7. New York City fly ash, loss on ignition 500°C, 900°C.

WEIGHT	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
CRUCIBLE + COVER	13.86	14.13	13.60	13.76	13.86	13.96	14.03	13.76	14.01	50.83
CRUCIBLE + ASH	20.38	19.49	19.30	18.67	18.52	18.04	19.06	19.03	19.22	68.57
ASH (PREIGN.)	6.52	5.36	5.70	4.91	4.67	4.08	5.03	5.27	5.20	17.74
CRUCIBLE + ASH (POST)	20.31	19.44	19.24	18.63	18.49	17.99	18.98	18.94	19.14	68.40
ASH (POSTIGN)	6.46	5.30	5.63	4.87	4.63	4.03	4.95	5.18	5.13	17.57
LOI (@500)	0.07	0.06	0.06	0.05	0.03	0.05	0.08	0.09	0.08	0.17
% LOI (@500)	1.01	1.09	1.09	0.94	0.75	1.28	1.62	1.78	1.48	0.96
AVG. % LOI (@500)	1.20									
VARIANCE	0.10									
STD. DEV	0.31									
CRUCIBLE + ASH (POST)	20.17	19.31	19.10	18.51	18.37	17.89	18.88	18.84	19.03	67.95
ASH (POSTIGN)	6.31	5.18	5.50	4.75	4.51	3.93	4.85	5.09	5.02	17.13
LOI (@900)	0.21	0.18	0.20	0.16	0.15	0.16	0.18	0.19	0.18	0.62
% LOI (@900)	3.23	3.42	3.42	3.35	3.32	3.83	3.64	3.55	3.56	3.47
AVG. % LOI (@900)	3.48									
VARIANCE	0.03									
STD. DEV.	0.17									

Table 3.8. New York City fly ash*, loss on ignition 500°C, 900°C.

WEIGHT	C1*	C2*	C3*	C4*	C5*	C6*	C7*	C8*	C9*	C10*
CRUCIBLE + COVER	13.6097	14.2302	13.8725	13.9815	13.759	13.89	13.9099	13.7816	14.0237	50.3976
CRUCIBLE + ASH	15.1298	15.5602	15.4956	15.7813	15.3532	15.2704	15.7026	15.2201	15.8605	55.4538
ASH (PREIGN.)	1.52	1.33	1.62	1.80	1.59	1.38	1.79	1.44	1.84	5.06
CRUCIBLE + ASH (POST)	15.09	15.5271	15.455	15.7343	15.3141	15.2342	15.6586	15.183	15.8207	55.3301
ASH (POSTIGN)	1.48	1.30	1.58	1.75	1.56	1.34	1.75	1.40	1.80	4.93
LOI (@500)	0.04	0.03	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.12
% LOI (@500)	2.62	2.49	2.50	2.61	2.45	2.62	2.45	2.58	2.17	2.45
AVG. % LOI (@500)	2.49									
VARIANCE	0.02									
STD. DEV	0.13									
CRUCIBLE + ASH (POST)	14.9945	15.4446	15.3506	15.6178	15.2695	15.1392	15.4961	15.0866	15.7357	55.0947
ASH (POSTIGN)	1.38	1.21	1.48	1.64	1.51	1.25	1.59	1.31	1.71	4.70
LOI (@900)	0.14	0.12	0.14	0.16	0.08	0.13	0.21	0.13	0.12	0.36
% LOI (@900)	8.90	8.69	8.93	9.08	5.25	9.50	11.52	9.28	6.79	7.10
AVG. % LOI (@900)	8.51									
VARIANCE	2.69									
STD. DEV.	1.64									

* Represents ash collected on a second visit to the facility.

Table 3.9. Town of Huntington composite ash, loss on ignition 500°C, 900°C.

WEIGHT	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
CRUCIBLE + COVER	50.23	23.76	24.47	87.27	88.82	49.34	24.65	23.64	24.47	85.57
CRUCIBLE + ASH	71.30	45.83	44.78	127.90	136.55	65.02	40.14	40.38	42.50	127.40
ASH (PREIGN.)	21.07	22.07	20.31	40.63	47.73	15.68	15.49	16.75	18.03	41.83
CRUCIBLE + ASH (POST)	70.05	44.40	43.43	125.18	133.66	63.75	38.47	38.68	40.45	124.65
ASH (POSTIGN)	19.82	20.64	18.97	37.91	44.84	14.41	13.82	15.04	15.98	39.07
LOI (@500)	1.25	1.43	1.35	2.72	2.89	1.27	1.67	1.71	2.05	2.75
% LOI (@500)	5.93	6.48	6.62	6.69	6.06	8.09	10.76	10.19	11.37	6.59
AVG. % LOI (@500)	7.88									
VARIANCE	3.96									
STD. DEV	1.99									
CRUCIBLE + ASH (POST)	68.41		42.08	121.92	130.16	62.68	37.58	37.76	39.60	120.89
ASH (POSTIGN)	18.18		17.61	34.65	41.34	13.34	12.94	14.12	15.13	35.32
LOI (@900)	2.89		2.70	5.98	6.39	2.34	2.56	2.63	2.90	6.51
% LOI (@900)	13.74		13.29	14.72	13.39	14.91	16.50	15.68	16.09	15.57
AVG. % LOI (@900)	14.88									
VARIANCE	1.25									
STD. DEV.	1.12									

Table 3.10. Town of Huntington composite ash*, loss on ignition 500°C, 900°C.

WEIGHT	H1*	H2*	H3*	H4*	H5*	H6*	H7*	H8*	H9*	H10*
CRUCIBLE + COVER	6.9482	7.0982	24.6426	23.6228	24.3341	23.7857	23.6358	24.47	23.8519	6.82
CRUCIBLE + ASH	12.2523	11.5105	40.3781	36.3578	40.803	43.304	43.0079	40.3944	37.7056	9.0541
ASH (PREIGN.)	5.30	4.41	15.74	12.73	16.47	19.52	19.37	15.92	13.85	2.23
CRUCIBLE + ASH (POST)	11.6332	11.1526	38.3832	34.7655	38.1904	41.3771	40.6259	38.1368	36.1448	8.7287
ASH (POSTIGN)	4.69	4.05	13.74	11.14	13.86	17.59	16.99	13.67	12.29	1.91
LOI (@500)	0.62	0.36	1.99	1.59	2.61	1.93	2.38	2.26	1.56	0.33
% LOI (@500)	11.67	8.11	12.68	12.50	15.86	9.87	12.30	14.18	11.27	14.57
AVG. % LOI (@500)	12.30									
VARIANCE	4.64									
STD. DEV	2.15									
CRUCIBLE + ASH (POST)	11.4773	11.0448	37.988	34.34	37.8947	40.9061	40.6232	37.8298	35.8675	8.6594
ASH (POSTIGN)	4.53	3.95	13.35	10.72	13.56	17.12	16.99	13.36	12.02	1.84
LOI (@900)	0.78	0.47	2.39	2.02	2.91	2.40	2.38	2.56	1.84	0.39
% LOI (@900)	14.61	10.55	15.19	15.84	17.66	12.29	12.31	16.10	13.27	17.67
AVG. % LOI (@900)	14.55									
VARIANCE	5.16									
STD. DEV.	2.27									

* Represents ash collected on a second visit to the facility.

Table 3.11. Westchester composite ash, loss on ignition 500°C, 900°C.

WEIGHT	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
CRUCIBLE + COVER	14.1611	13.9618	13.7895	13.9748	13.6363	13.88	13.7186	13.882	14.0202	50.2386
CRUCIBLE + ASH	19.5761	18.5713	17.7568	18.481	18.7635	19.6731	18.8331	19.211	18.5563	64.32
ASH (PREIGN.)	5.42	4.61	3.97	4.51	5.13	5.79	5.11	5.33	4.54	14.08
CRUCIBLE + ASH (POST)	19.4894	18.4794	17.6902	18.3855	18.6658	19.5552	18.7476	19.1046	18.4778	64.0927
ASH (POSTIGN)	5.33	4.52	3.90	4.41	5.03	5.68	5.03	5.22	4.46	13.85
LOI (@500)	0.09	0.09	0.07	0.10	0.10	0.12	0.09	0.11	0.08	0.23
% LOI (@500)	1.60	1.99	1.68	2.12	1.91	2.04	1.67	2.00	1.73	1.61
AVG. % LOI (@500)	1.83									
VARIANCE	0.03									
STD. DEV	0.19									
CRUCIBLE + ASH (POST)	19.3654	18.3944	17.6114	18.2983	18.5707	19.4201	18.6532	19.01	18.3612	63.766
ASH (POSTIGN)	5.20	4.43	3.82	4.32	4.93	5.54	4.93	5.13	4.34	13.53
LOI (@900)	0.21	0.18	0.15	0.18	0.19	0.25	0.18	0.20	0.20	0.55
% LOI (@900)	3.89	3.84	3.66	4.05	3.76	4.37	3.52	3.77	4.30	3.93
AVG. % LOI (@900)	3.91									
VARIANCE	0.06									
STD. DEV.	0.25									

Section 4

PROCTOR FABRICATION

INTRODUCTION

The proctor fabrication stage of this project dealt with four major tasks:

- Initial research and development of proctor fabrication techniques.

- Determination of optimum water content for making proctors.

- Production of test proctors for all of the mix types studied.

- Comparison of proctor compressive strengths in order to select optimum mixes.

In order to accomplish these tasks the following types of equipment were used. Proctor compaction was done with a Soil Test, Inc. model CN-4230 Mechanical Compactor equipped with a 4 inch replacement mold, Soil Test model CN-4230-100. Mold dimensions were 4.6 inches height by 4.0 inches diameter for a volume of 1/30 cubic foot. The mechanical compactor permitted operator selection of either a 5.5 or 10 pound, 2 inch diameter circular face rammer as well as a 12 or 18 inch drop height. Hot Pack Corporation model 435300 Bench Top Steady-State Humidity Chambers were used for accelerated cures at different temperature and 98-100 % relatively humidity. Compressive strength testing was performed using a Model FS 160 Riehle Universal Testing Machine which conformed with ANSI/ASTM C39-72 standards.

ADDITIVES

Additives such as sodium carbonate (Na_2CO_3), lime ($Ca(OH)_2$), calcium sulfate ($CaSO_4 \cdot 2H_2O$) and Portland cement (type 1) were used in this study. These additives were obtained from Fisher Scientific, Inc. except Portland cement which was supplied from local supplier.

According to Fisher Scientific, Inc. 1983, Na_2CO_3 (Fisher CERTIFIED) used in this study contains only 0.01% insoluble matters and 0.005% silica (SiO_2), 0.003% sulfur compounds (SO_4), 0.01% calcium and magnesium ppt, and 0.5 ppm heavy metals (as Pb). For $Ca(OH)_2$ (Fisher CERTIFIED), it shows 0.03% insoluble in hydrochloric acid and contains 0.1% sulfur compounds (SO_4), 1.0% magnesium and alkali salts, and 0.003% heavy metals (as Pb). Fisher CERTIFIED gypsum ($CaSO_4 \cdot 2H_2O$) was used in this study. Portland cement (designated as type 1 by the ASTM) is the most important of the inorganic cementing materials by far. There are three predominant compounds in common portland cement, i.e., dicalcium silicate ($2CaO \cdot SiO_2$), tricalcium silicate ($3CaO \cdot SiO_2$), and Tricalcium aluminate ($3CaO \cdot Al_2O_3$).

FABRICATION TECHNIQUES

ASTM D698-78 provided guidelines for proctor fabrication techniques. These conditions in general require the compaction of the sample using:

- a 5.5 pound rammer falling a distance of 12 inches,
- 3 compactions of material per proctor,
- a total of 75 compactions per proctor.

The appropriate components of a test mixture were mixed on a weight basis and in the sequence: incineration wastes (first), calcium hydroxide (lime), additives (cement, gypsum, sodium carbonate) and water (last). Hand mixing was used to distribute the materials as they were added. After thoroughly mixing the dry components, water was added to the mix and vigorously stirred to achieve a uniform distribution. In some cases additional water was added to the mix prior to final hand mixing. Subsamples of the wet mix were taken in order to determine the total moisture content prior to compaction and curing. Prior to mixing particles larger the 0.75 in were screened out.

The ASTM D698 method was used for proctor fabrication. Approximately 600 grams of mix were placed in a mold and a 5.5 pound rammer was dropped twenty five times from a height of 12 inches. Between each drop the mold was automatically rotated 36 in order to assure uniform compaction of the proctor surface. A second 600 gram portion of mix was added to the mold and the process repeated. After addition and compaction of a third 600 gram sample, the extension collar of the mold was removed. The proctors surface was trimmed and leveled prior to weighting. After extrusion from the mold, the proctor was ready for curing.

Three curing temperatures were studied. Ambient (approximately 23°C), 49°C and 71°C. Proctors cured at 23°C in air were wrapped in 1 ml thick plastic bags to prevent premature dehydration. These samples were air cured for intervals of 7, 14 and 21 days. The accelerated cures at 49°C and 71°C were performed in controlled humidity chambers for two time intervals, 24 and 72 hr.

After curing, proctors were permitted to cool to room temperature or were removed from the double wrapped plastic bags. Their weight, height, diameter and physical appearance were recorded prior to unconfined compressive strength testing.

Cured proctors were tested for unconfined compressive strength on a Model FS160 Riehle Universal Testing Machine. The FS160 was equipped with a 7 inch diameter self-aligning compressive head and spherical seat which conforms to the requirements of ANSI/ASTM C39-72, "Standard

Methods for Compressive Strength Testing of Cylindrical Concrete Specimens". The rate of loading was 3200 pounds per second. The total load withstood during testing was divided by the cross sectional area of the proctor to calculate unconfined compressive strength in pounds per square inch.

DETERMINATION OF THE OPTIMUM MIX

The first formulation of proctors were fabricated using lime portland cement and sodium carbonate, three additives that were shown in prior investigations to enhance stabilization. While holding relatively constant the concentrations of incinerator residue and additives, moisture content was altered between 13 and 25% for the three different residues. Following compaction, the proctors were subdivided into three groups and each group cured at different temperatures [49°C, 71°C, and air (23°C)]. The duration of the cure was also altered for each of the groups. For the proctors being cured at elevated temperatures, curing time was either 24 or 72 hours. For the air cured samples, the curing time was either 168, 336 or 504 hours (7, 14 or 21 days). The data in Tables 4.1 and Figures 4.1-4.3,in concert with the detailed fabrication information found in Appendixes A, B and C reveals the following information:

a) Huntington residue produced proctor samples having the lowest compressive strength,
b) in order to achieve a maximum compressive strength, as the particle size of the residue increased, moisture content also increased
c) increased curing time resulted in improved structural integrity,
d) proctors fabricated using Westchester residue yield the highest density, while New York City samples exhibited the best compressive strength.

The effects of increasing the lime concentration was examined by fabricating a series of proctor samples having a 9% lime content.

Table 4.1. Results of proctor fabrication using 6% lime, 3% cement, 0.5% Na_2CO_3.

NEW YORK CITY INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
CA	17	18.6	438 - 875
CB	19	19.4	458 - 1134
CC	21	22.1	601 - 903
CD	23	22.2	430 - 688
CE	24	23.6	386 - 637

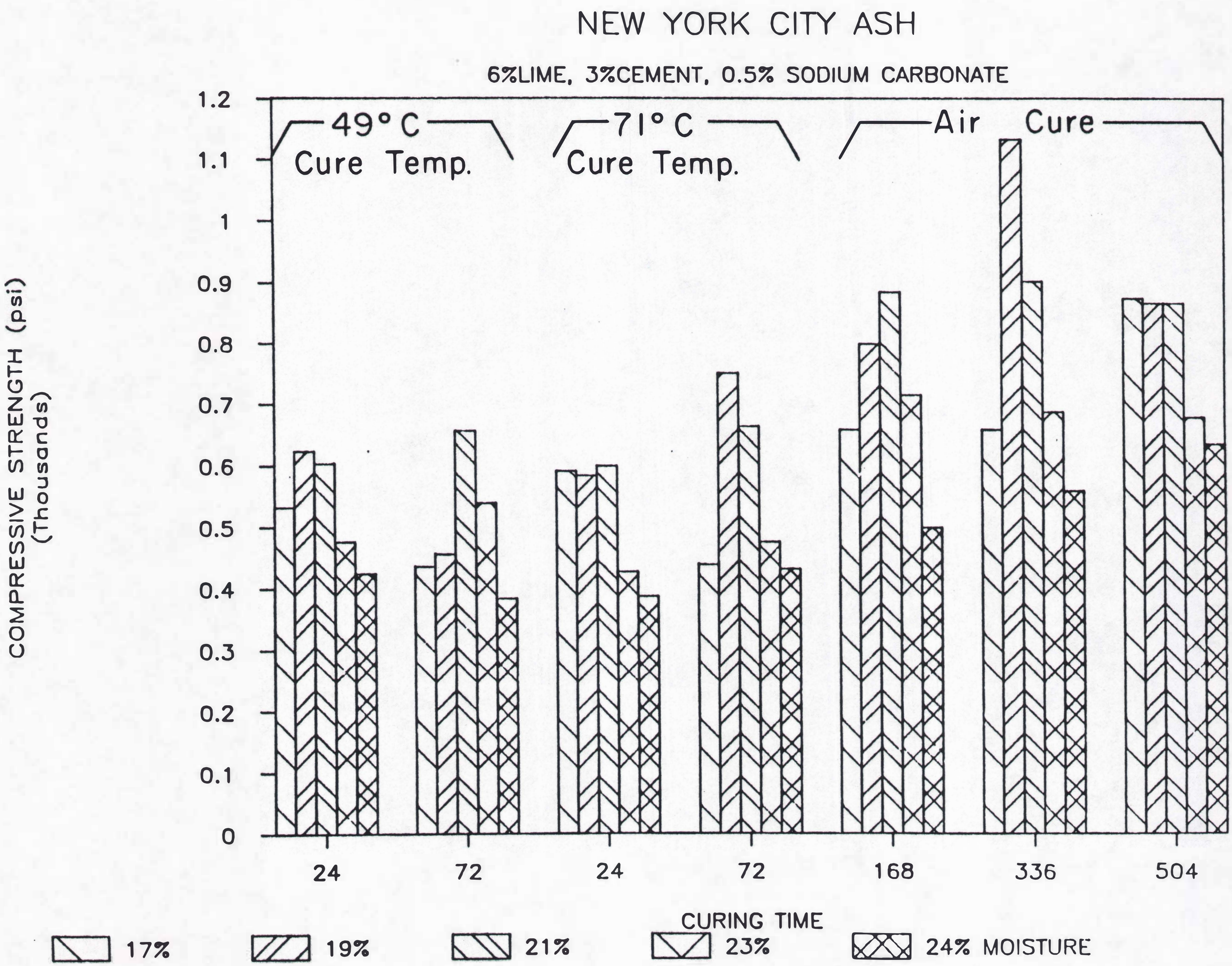
WESTCHESTER INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
WA	17	17	251 - 446
WB	15	14.8	394 - 533
WC	13	13	161 - 521
WD	11	11.5	84 - 414
WE	19	19.5	139 - 398

HUNTINGTON INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
HA	18	21.5	115 - 254
HB	22	23.7	96 - 217
HC	24	25.1	62 - 183
HL	20	21.6	203 - 386
HM	18	19.2	219 - 314
HN	16	18.8	219 - 330
HO	14.6	16.3	171 - 235

Figure 4.1



NEW YORK CITY ASH
6%LIME, 3%CEMENT, 0.5% SODIUM CARBONATE
49° C Cure Temp.
71° C Cure Temp.
Air Cure
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
24
72
24
72
168
336
504
CURING TIME
17%
19%
21%
23%
24% MOISTURE

Figure 4.2

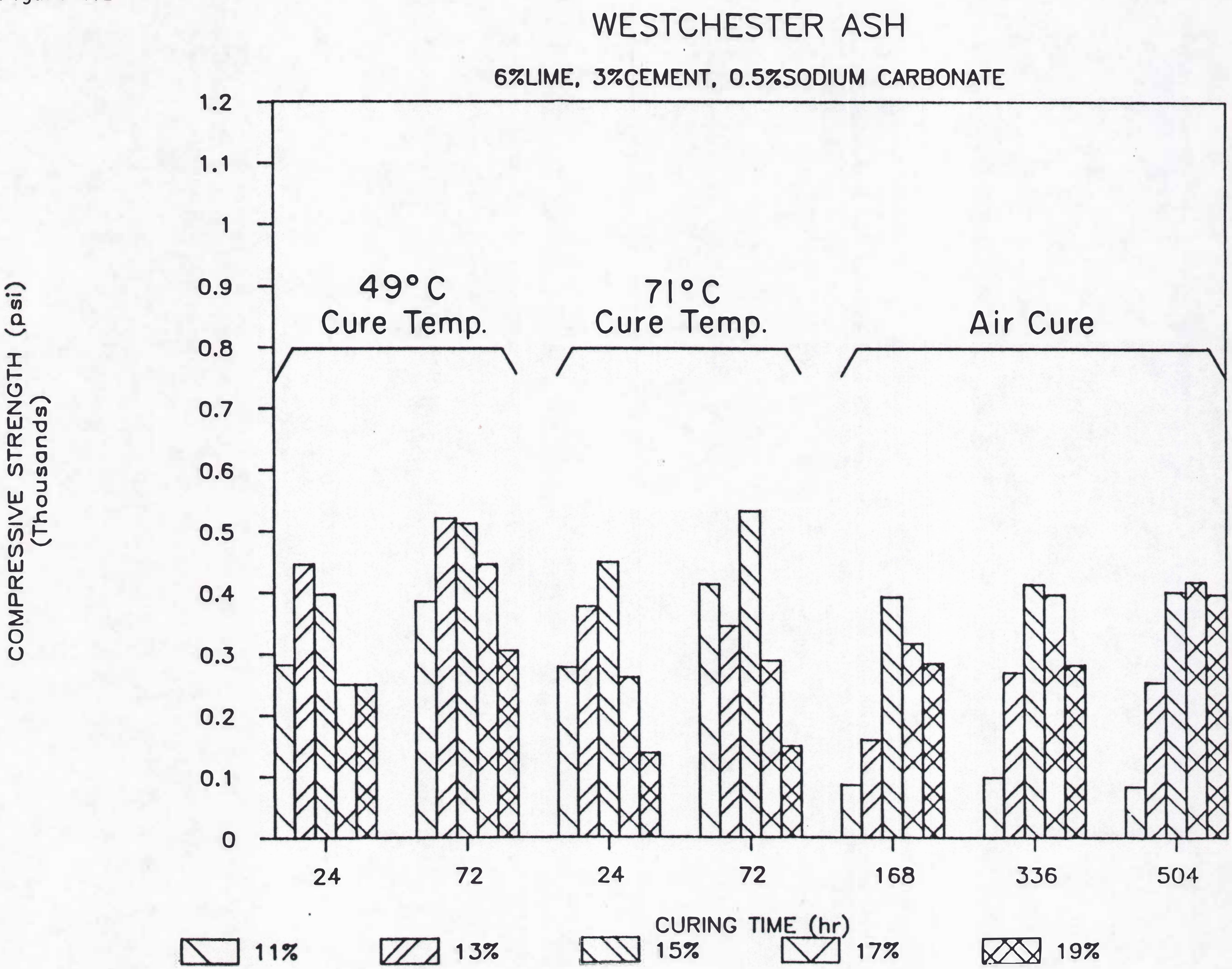

WESTCHESTER ASH
6%LIME, 3%CEMENT, 0.5%SODIUM CARBONATE
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49° C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
11%
13%
15%
17%
19%

Figure 4.3

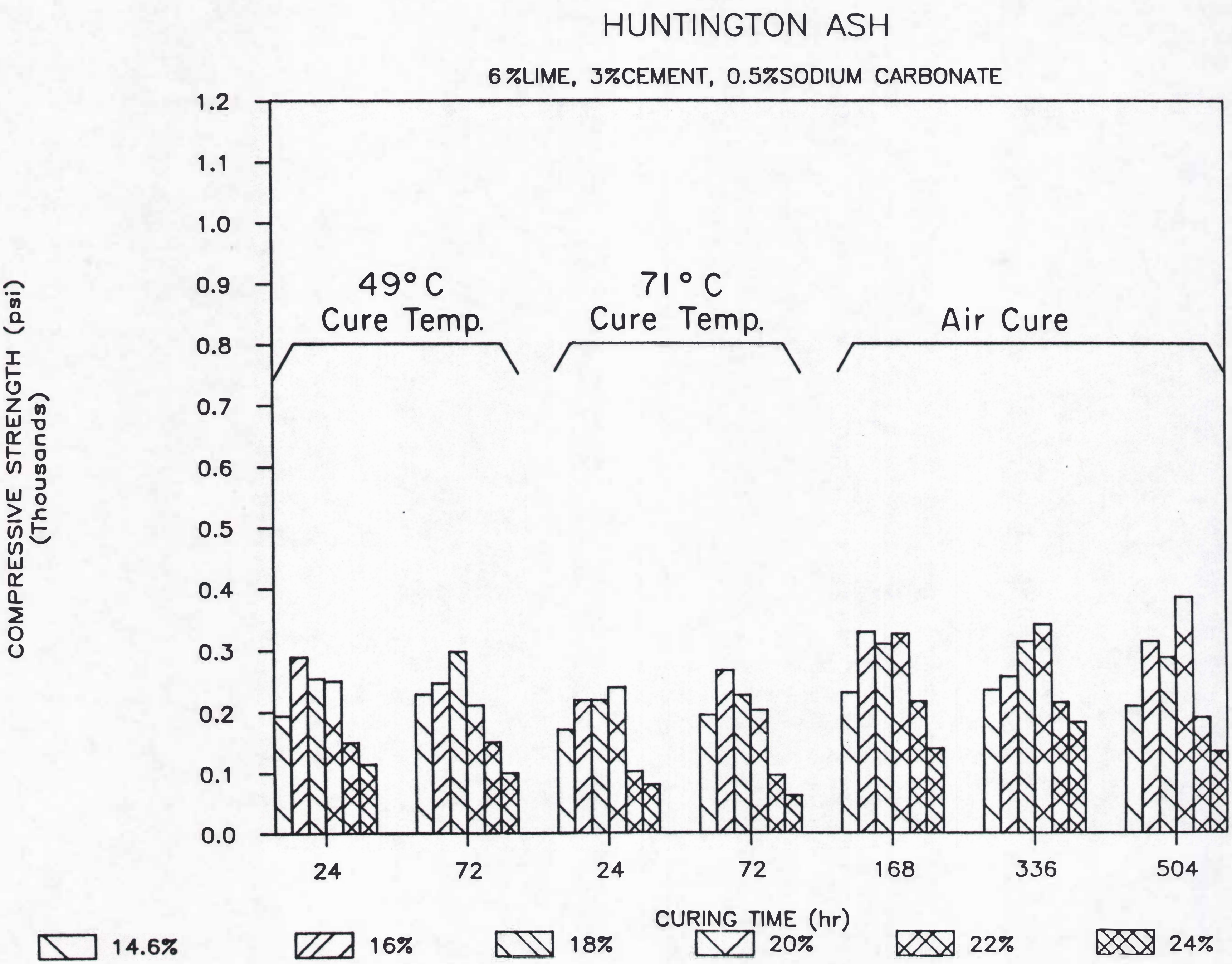

HUNTINGTON ASH
6%LIME, 3%CEMENT, 0.5%SODIUM CARBONATE
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
49°C
Cure Temp.
71°C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
14.6%
16%
18%
20%
22%
24%

Table 4.2 and Figures 4.4 - 4.6 illustrates that little benefit with respect to the structural integrity is realized by increasing lime concentration. New York City and Huntington proctor samples exhibited a decline in compressive strength and only a slight increase in strength was noted for the Westchester samples. In all cases increasing the lime content did not alter the pH of the mix. It can be concluded that lime content in excess of 6% offers no significant structural improvement.

Sodium carbonate (Na_2CO_3), was used in this research for prior investigations by Harder et al., 1981, Vincent et al., 1961 and Roethel et al., 1985 has shown that this additive accelerates the strength gain of various coal ash mix designs. This investigation reveals that sodium carbonate has no effect on the compressive strength of stabilized incineration ash samples. Table 4.3 and Figures 4.7 - 4.9 indicates that New York City samples without sodium carbonate exhibit a slight increase in strength.

Portland cement (type 1) was added to the mix design and yielded proctor samples having the highest compressive strength. Samples fabricated using Westchester residue and 15% cement achieved a compressive strength of 1592 psi. Unfortunately by this time we were using the second batch of New York City fly ash which possessed properties that significantly reduced the structural integrity of the samples. Strengths measured for the New York City samples reached 400 psi, significantly lower than earlier samples though still acceptable for marine disposal. Data pertaining to this mix design is presented in Table 4.4 along with Figures 4.10 - 4.12.

One of the possible reasons the proctors fabricated using second batch of New York City fly ash failed to achieve a higher compressive strength was the significantly lower pH of the ash. In an attempt to improve the compressive strength a series of proctors were fabricated with 15% cement and 4% lime. While the lime did elevate the pH of these samples, no significant improvement in compressive strength was obtained. Table 4.5 and Figure 4.13 presents the data obtained from this investigation.

Table 4.2. Results of proctor fabrication using 9% lime, 3% cement, 0.5% Na_2CO_3.

NEW YORK CITY INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
CF	17	15.9	386 - 625
CG	19	18.0	489 - 780
CH	21	20.3	637 - 949
CI	23	21.9	450 - 844

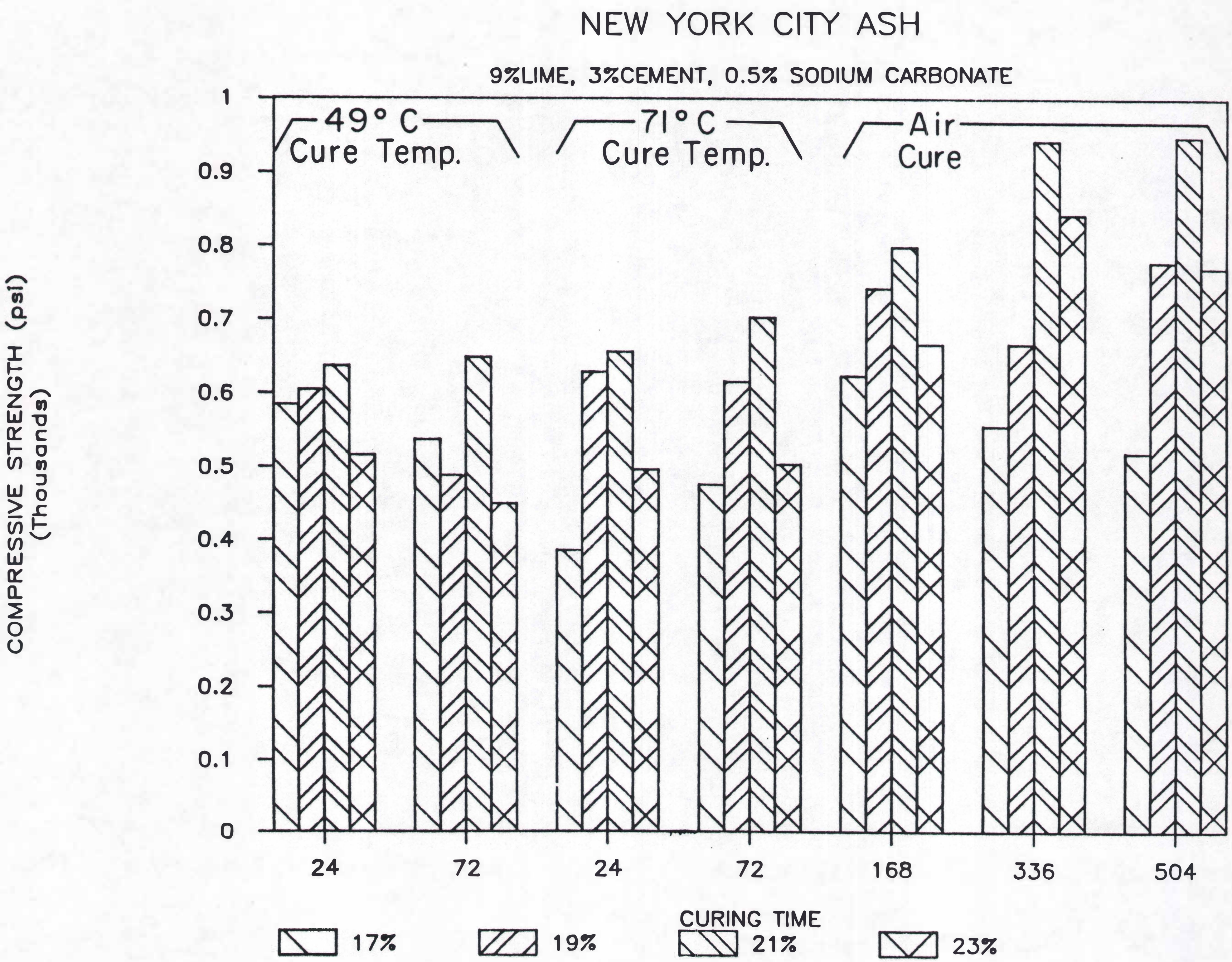
WESTCHESTER INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
WF	17	17.9	183 - 454
WG	15	16.2	517 - 688
WH	13	14.7	269 - 645

HUNTINGTON INCINERATION ASH

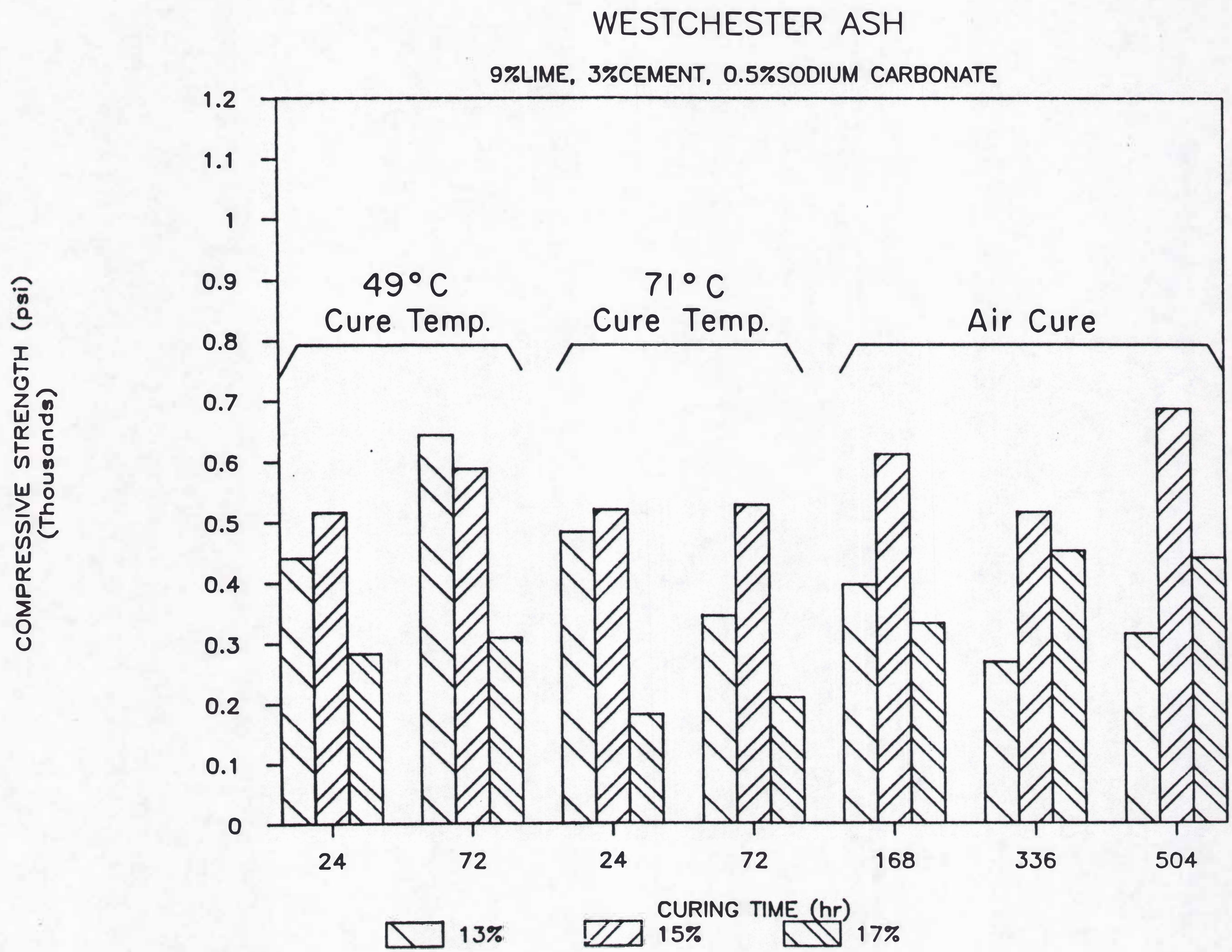
PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
HD	20	23.4	68 - 255
HE	22	27.4	80 - 147
HH	22	25.0	76 - 247
HJ	18	21.9	167 - 318
HK	16	20.2	171 - 285
HI	20	24.2	119 - 318

Figure 4.4



NEW YORK CITY ASH
9%LIME, 3%CEMENT, 0.5% SODIUM CARBONATE
COMPRESSIVE STRENGTH (psi)
(Thousands)
49° C
Cure Temp.
71° C
Cure Temp.
Air
Cure
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
24
72
24
72
168
336
504
CURING TIME
17%
19%
21%
23%

Figure 4.5



WESTCHESTER ASH
9%LIME, 3%CEMENT, 0.5%SODIUM CARBONATE
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49°C
Cure Temp.
71°C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
13%
15%
17%

Figure 4.6

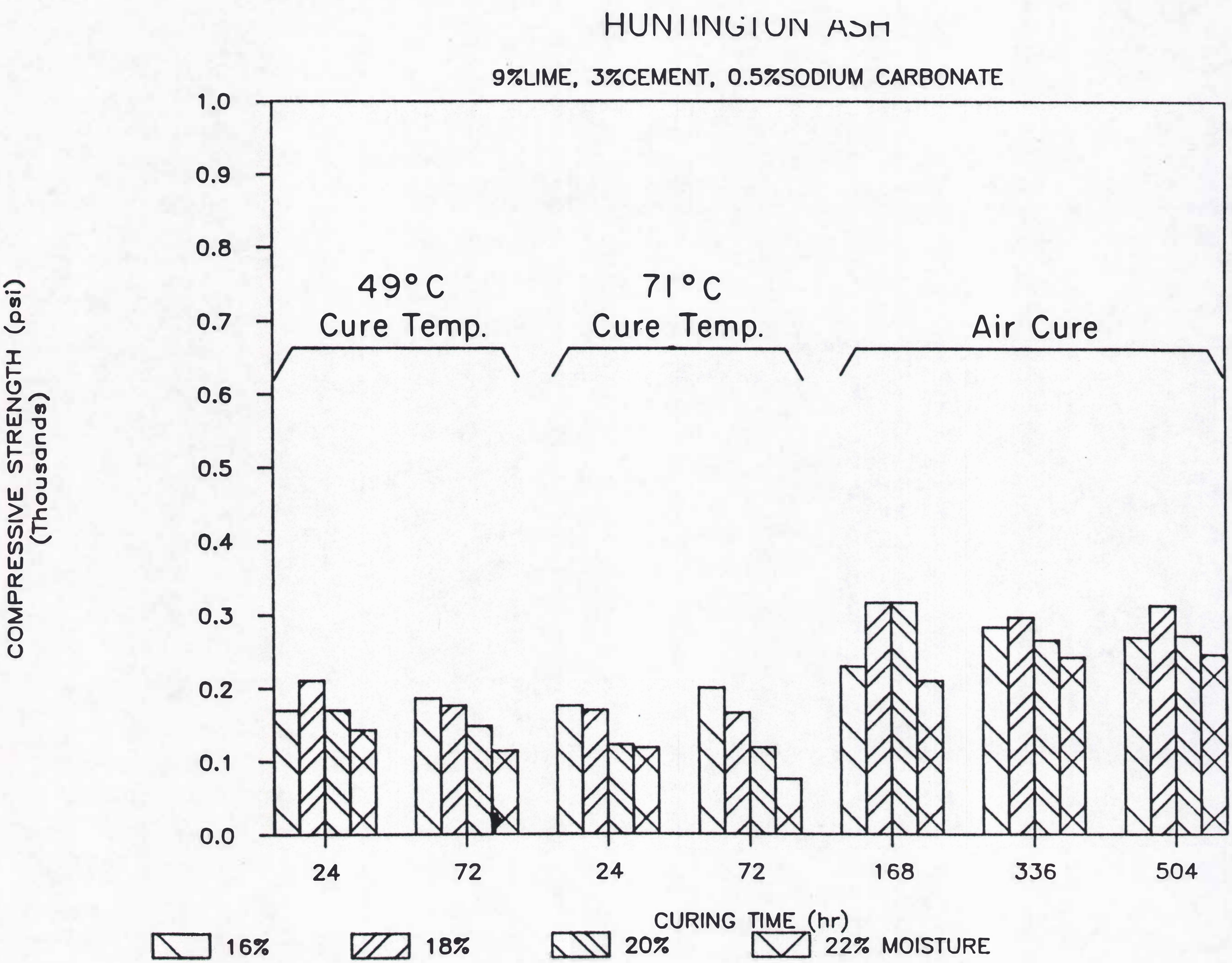

HUNTINGTON ASH
9%LIME, 3%CEMENT, 0.5%SODIUM CARBONATE
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
49°C
Cure Temp.
71°C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
16%
18%
20%
22% MOISTURE

Table 4.3. Results of proctor fabrication using 6% lime, 3% cement.

NEW YORK CITY INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
CJ	15	15.4	537 - 1122
CK	17	17.4	557 - 1194
CL	19	18.4	454 - 955
CM	21	20.5	312 - 891
CN	23	22.9	157 - 660

WESTCHESTER INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
WI	17	16.3	199 - 450
WJ	15	14.9	217 - 410
WK	13	14.5	287 - 454
WR	11	10.5	101 - 398

HUNTINGTON INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
HP	16	17.2	175 - 231
HQ	18	21.7	219 - 306
HR	20	22.0	163 - 314
HS	22	24.2	92 - 231

Figure 4.7

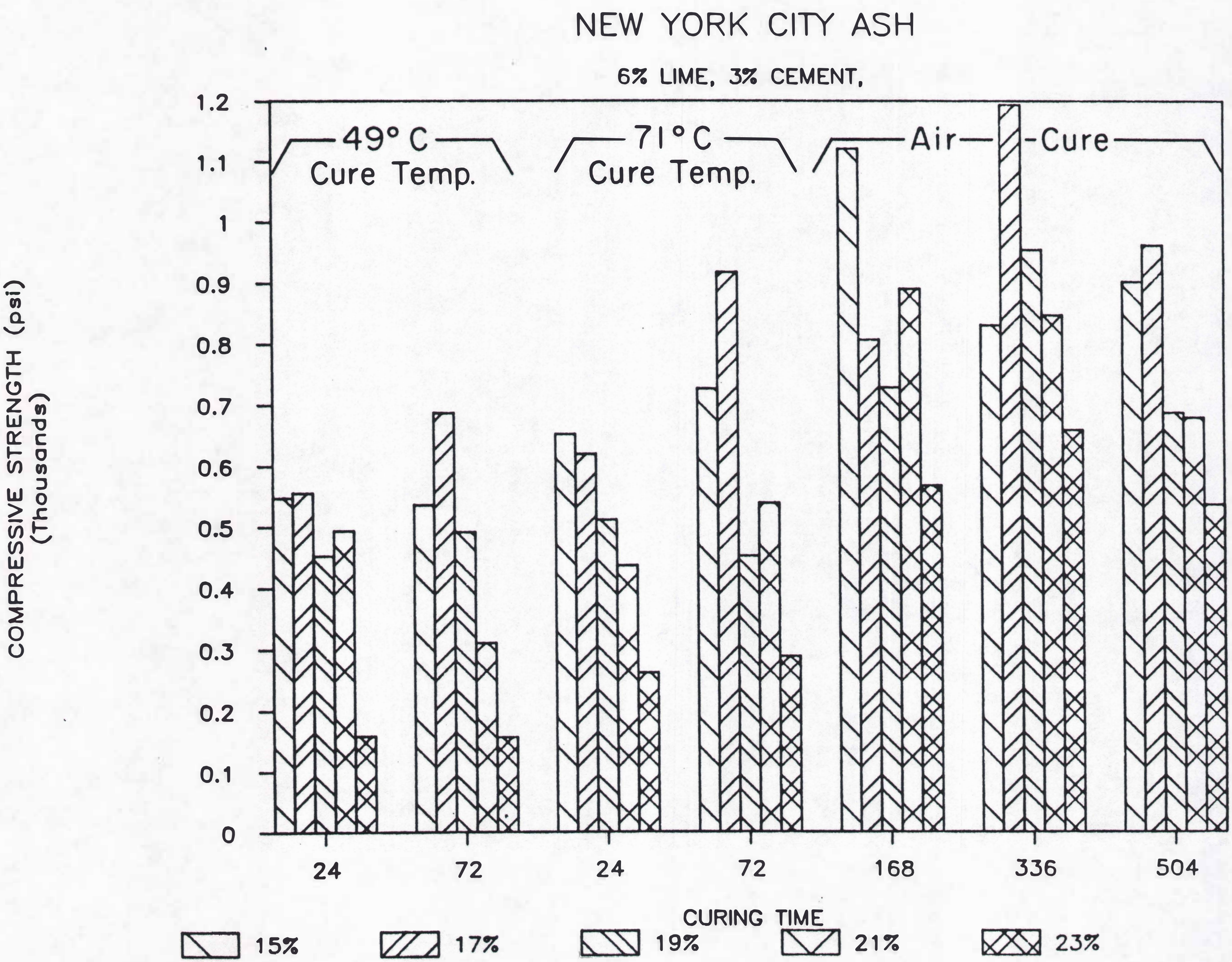

NEW YORK CITY ASH
6% LIME, 3% CEMENT,
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49° C
Cure Temp.
71° C
Cure Temp.
Air-Cure
24
72
24
72
168
336
504
CURING TIME
15%
17%
19%
21%
23%

Figure 4.8

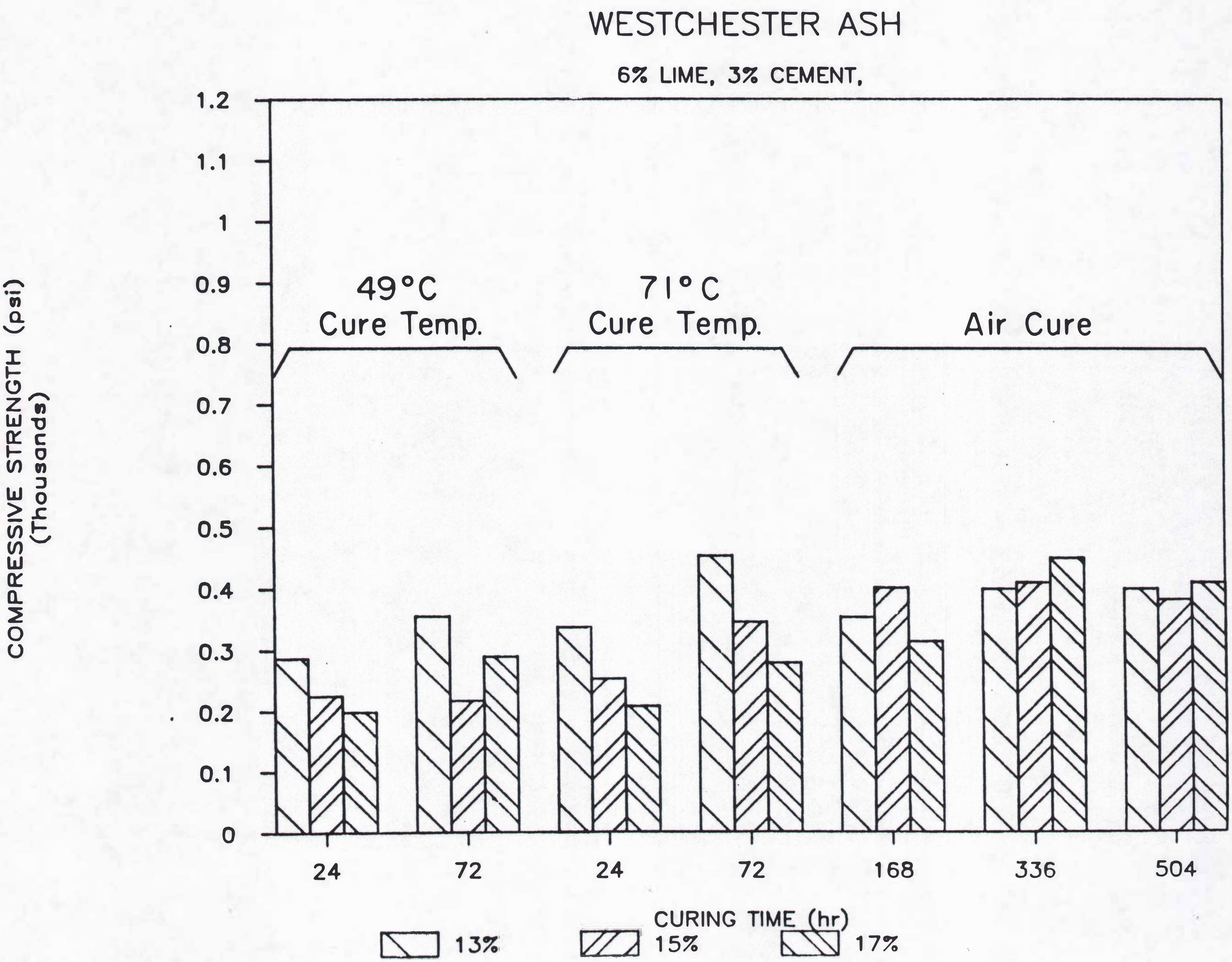

WESTCHESTER ASH
6% LIME, 3% CEMENT,
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49°C
Cure Temp.
71°C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
13%
15%
17%

Figure 4.9

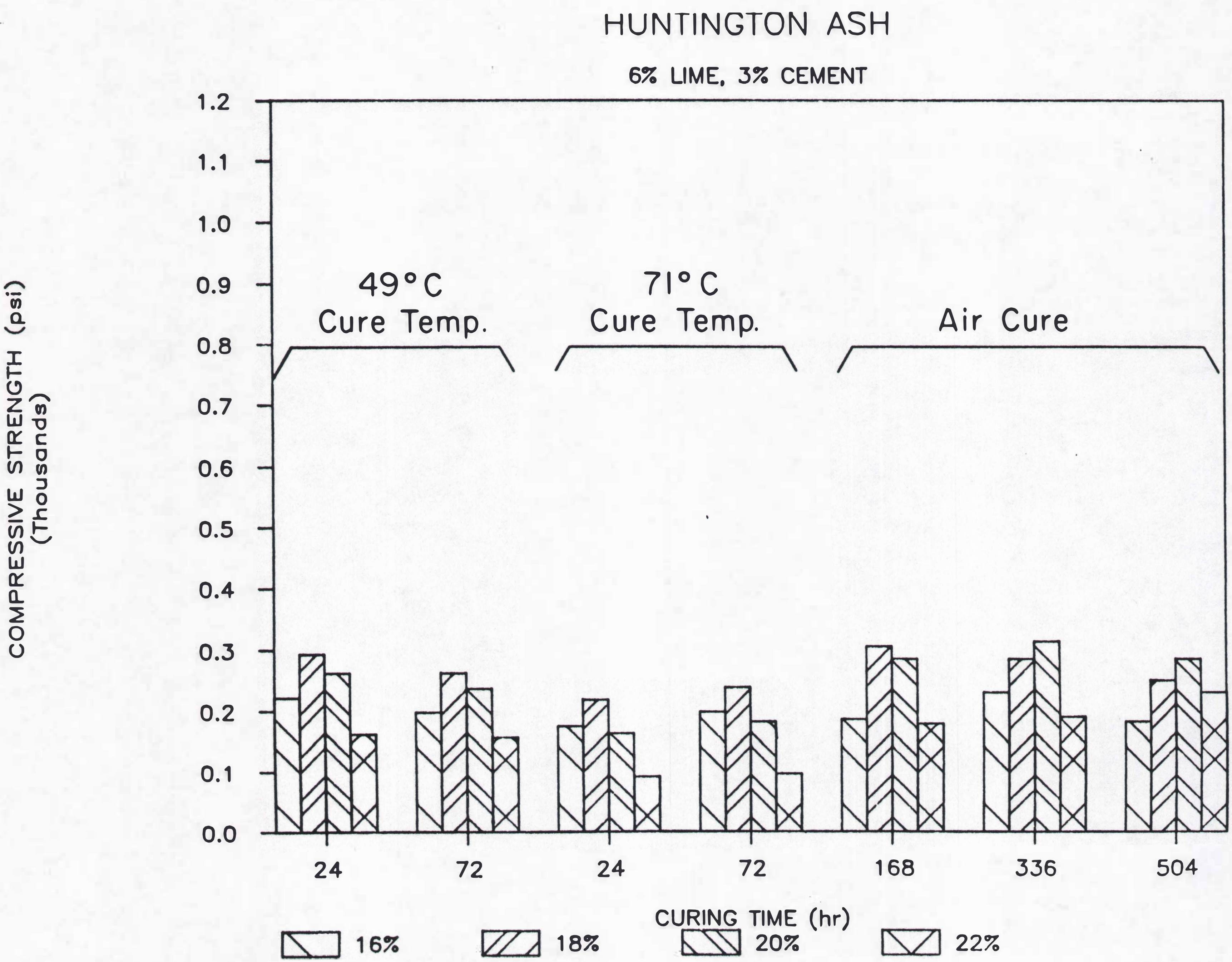

HUNTINGTON ASH
6% LIME, 3% CEMENT
49°C Cure Temp.
71°C Cure Temp.
Air Cure
COMPRESSIVE STRENGTH (psi) (Thousands)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
24
72
24
72
168
336
504
CURING TIME (hr)
16%
18%
20%
22%

Table 4.4. Results of proctor fabrication using 15% cement.

NEW YORK CITY INCINERATION ASH*

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
CQ	15	14.4	251 - 398
CR	17	16.0	197 - 292
CS	19	18.2	119 - 247
CT	21	20.4	119 - 211
CY	23	22.4	88 - 390

HUNTINGTON INCINERATION ASH

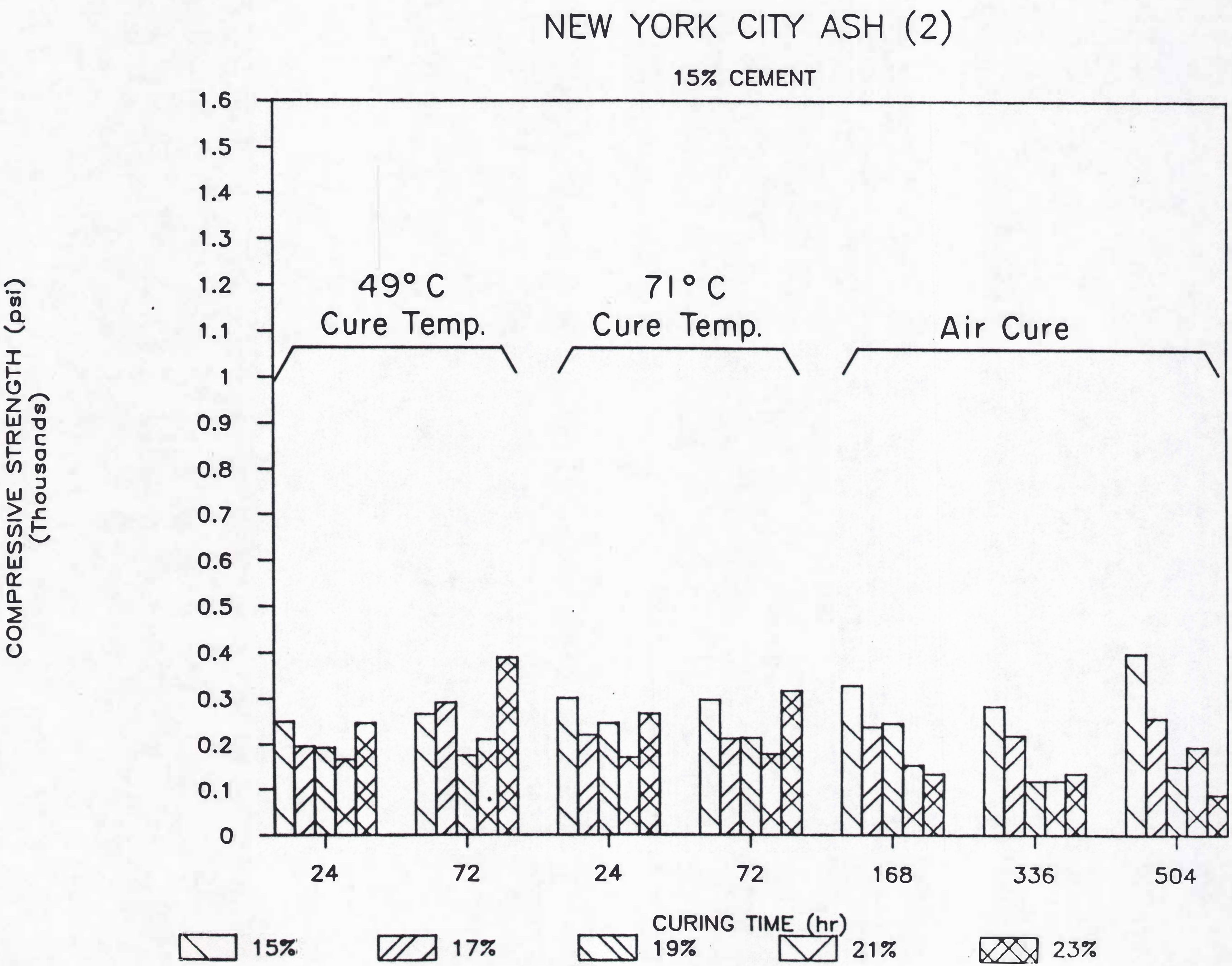
PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
HX	20	23.8	235 - 611
HY	18	22.1	330 - 569
HZ	16	19.1	322 - 466

WESTCHESTER INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
WO	13	12.3	462 - 816
WP	15	14.1	513 - 1241
WQ	17	16.2	736 - 1377
WT	19	18.0	593 - 1592

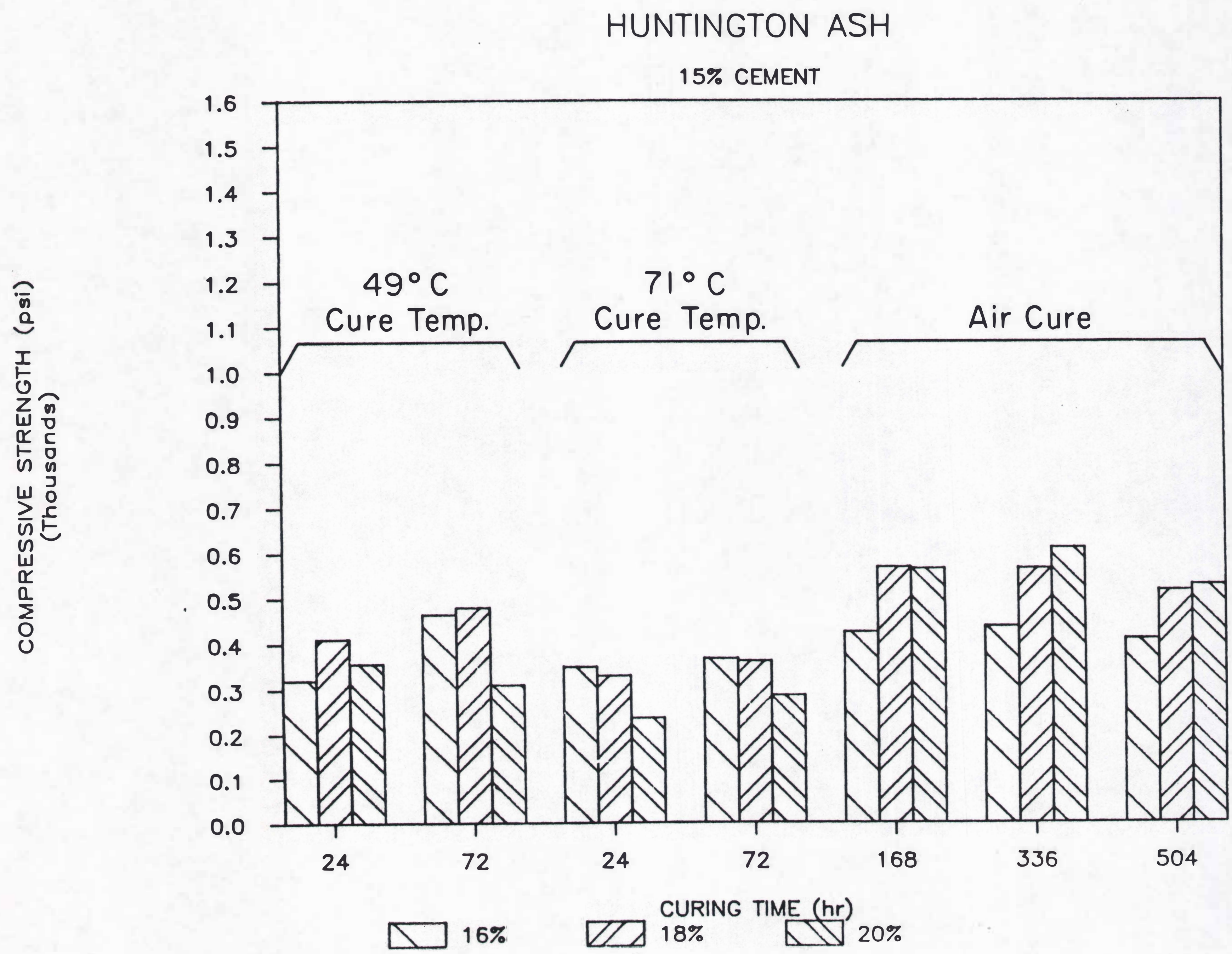
* Represents ash collected on a second visit to the facility.

Figure 4.10



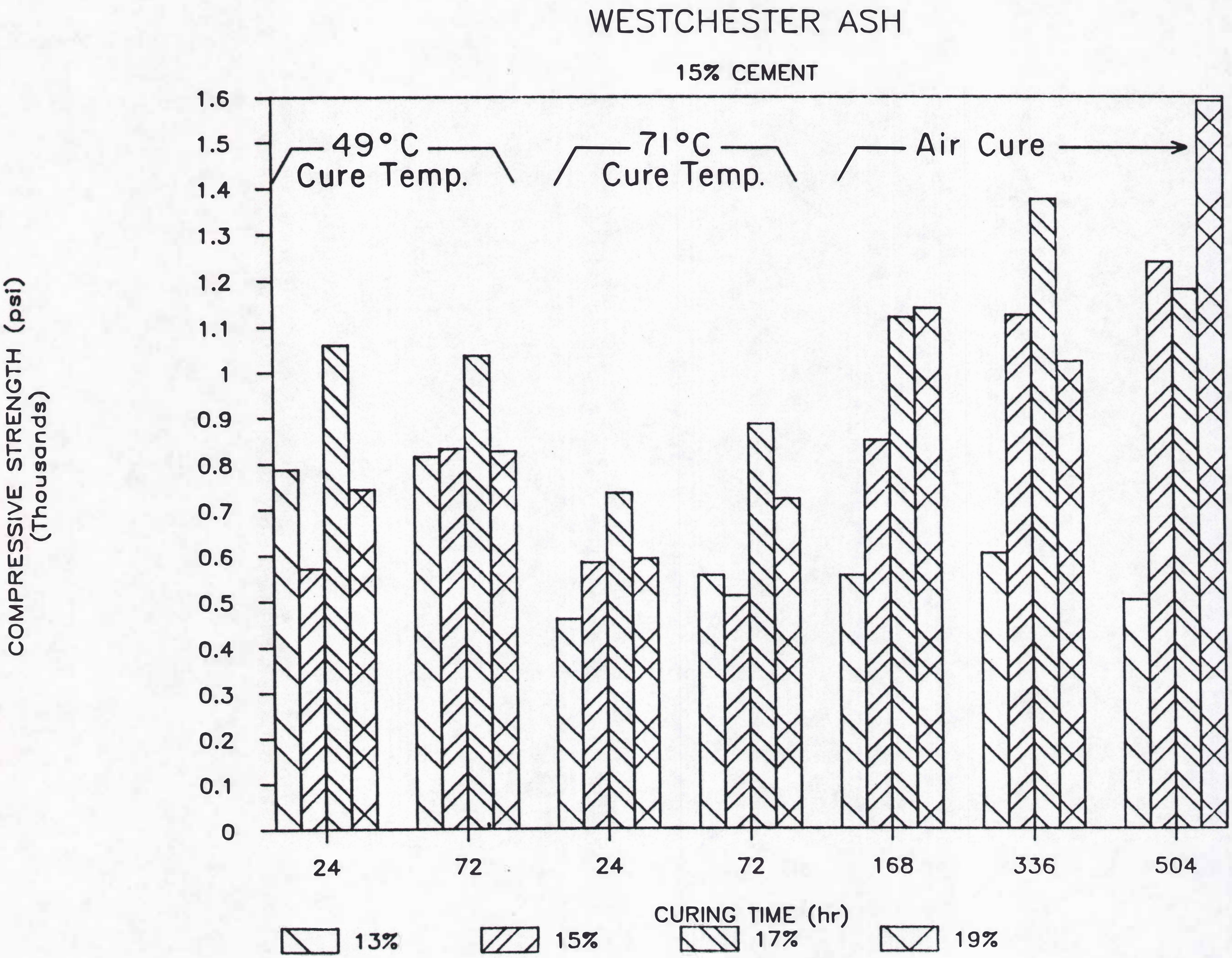
NEW YORK CITY ASH (2)
15% CEMENT
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49° C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
15%
17%
19%
21%
23%

Figure 4.11



HUNTINGTON ASH
15% CEMENT
COMPRESSIVE STRENGTH (psi)
(Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
49° C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
16%
18%
20%

Figure 4.12



WESTCHESTER ASH
15% CEMENT
49°C Cure Temp.
71°C Cure Temp.
Air Cure
COMPRESSIVE STRENGTH (psi) (Thousands)
1.6
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
24
72
24
72
168
336
504
CURING TIME (hr)
13%
15%
17%
19%

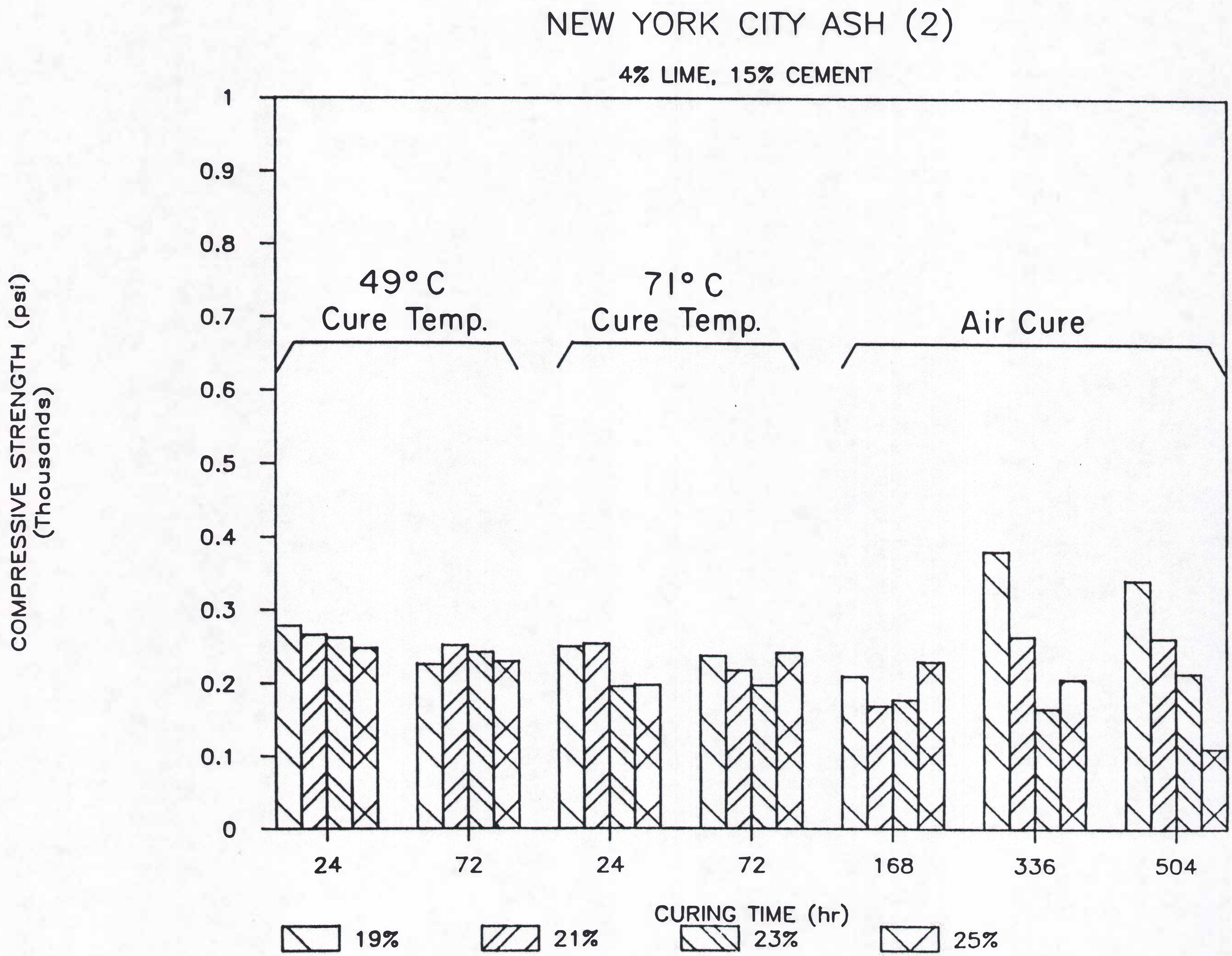
Table 4.5. Results of proctor fabrication using 4% lime, 15% cement.

NEW YORK CITY INCINERATION ASH*

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
CZ	19	17.9	211 - 382
CAA	21	19.1	171 - 267
CAB	23	21.3	167 - 263
CAC	25	23.5	111 - 249
CAD	29	27.2	80 - 207
CAE	31	29.8	24 - 195

* Represents ash collected on a second visit to the facility.

Figure 4.13


NEW YORK CITY ASH (2)
4% LIME, 15% CEMENT
COMPRESSIVE STRENGTH (psi)
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49° C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
19%
21%
23%
25%

Prior investigations with coal ash has shown that small amounts of gypsum ($CaSO_4 \cdot 2H_2O$) can significantly improve compressive strength. A series of proctor samples were fabricated using all three ashes and 6% lime, 6% gypsum and 3% cement. Significant deterioration in the structural integrity of the samples was observed. Table 4.6 and Figures 4.14 - 4.16 indicates that none of the samples achieved a strength of 300 psi, the minimum strength we accept for marine disposal.

GRAVEL ADDITIONS

The effects of adding small amounts of natural aggregates to the structural integrity of the proctor samples was examined. Two mix designs were fabricated; for both, Westchester residue and 15% Portland cement were added. For one mix design 15% of the total weight was represented by gravel sized aggregate. Proctor sized samples of both mix designs were fabricated following the same procedures described above. Once fabricated, the proctors were placed in constant temperature and humidity chambers for 24 h. They were then removed and allowed to air dry for a period of four days after which their compressive strength was tested.

Results are shown in Table 4.7. Strengths for the gravel addition proctors ranged from a 0% to 100% increase over blocks of the same ash and cure regime with no gravel addition. Optimum strength was achieved with 15% gravel and 11% water, a decrease from the 16% water used in optimum mixes without gravel.

Undoubtedly addition of gravel provides increased strength with lower optimum moisture content for the same mix and cure conditions. This would be expected since the stone that is added has a higher strength and nearly zero moisture content per unit volume. In addition, a greater percentage of the added cement is incorporated with the decreased ash fraction of the block as the relative volume of the added gravel increases. This results in better cementation of the ash which in part accounts for the enhanced structural integrity.

Table 4.6. Results of proctor fabrication using 6% lime, 3% cement, 6% $CaSO_4 \cdot 2H_2O$.

NEW YORK CITY INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
CU	17	16.5	115 - 199
CV	19	18.5	143 - 251
CW	21	20.9	135 - 219
CX	23	22.8	183 - 243

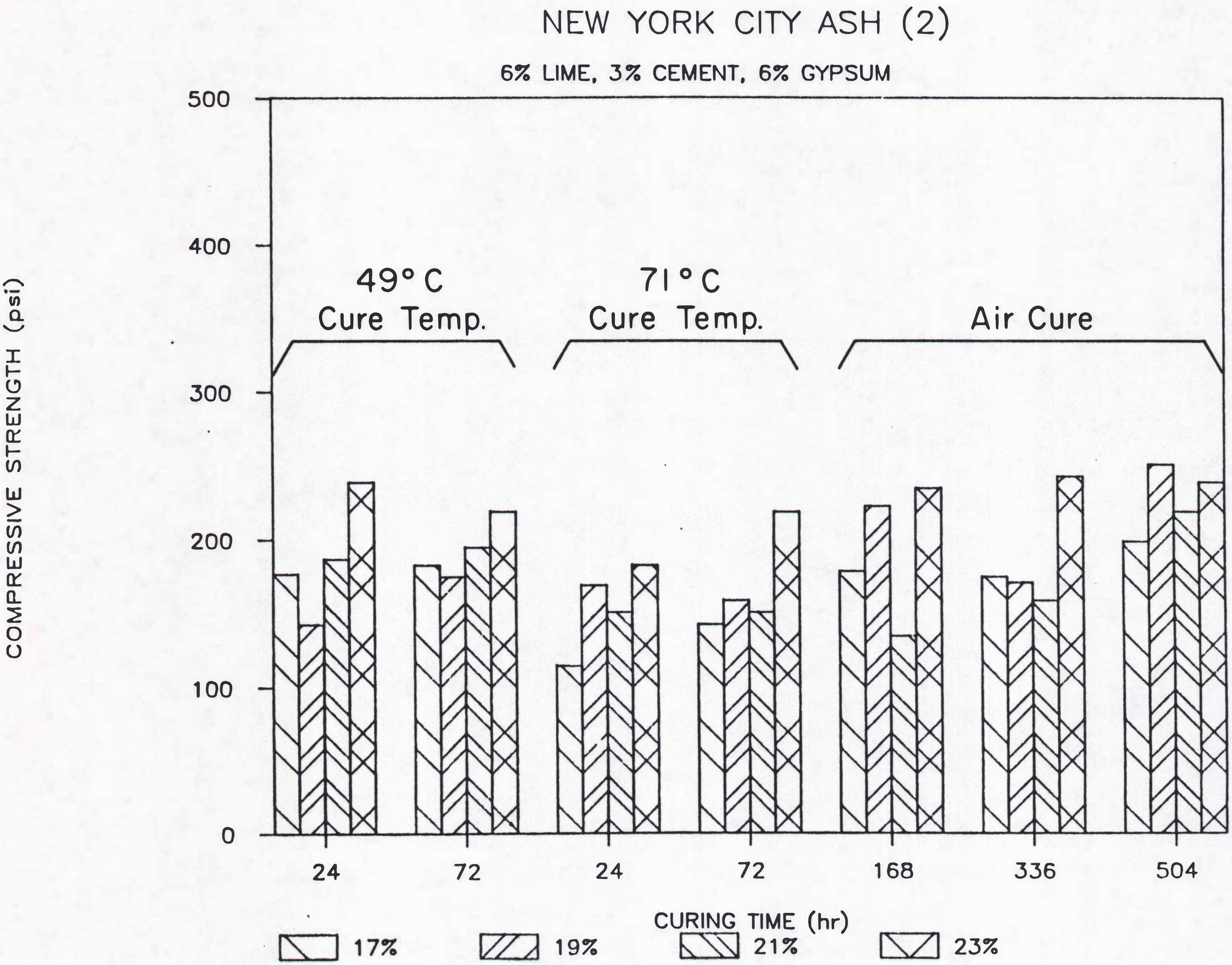
HUNTINGTON INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
HT	20	21.0	199 - 294
HU	22	21.0	179 - 239
HV	24	25.6	147 - 199
HW	17	19.9	191 - 286
HAA	16	16.2	203 - 277
HAB	18	20.4	235 - 348
HAC	20	21.3	183 - 286

WESTCHESTER INCINERATION ASH

PROCTOR I.D.	CALC. MOISTURE	MEAS. MOISTURE	COMPRESSIVE STRENGTH
WL	13	12.8	0 - 231
WM	15	14.5	0 - 217
WN	17	16.1	0 - 255

Figure 4.14



NEW YORK CITY ASH (2)
6% LIME, 3% CEMENT, 6% GYPSUM
COMPRESSIVE STRENGTH (psi)
500
400
300
200
100
0
49° C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
17%
19%
21%
23%

Figure 4.15

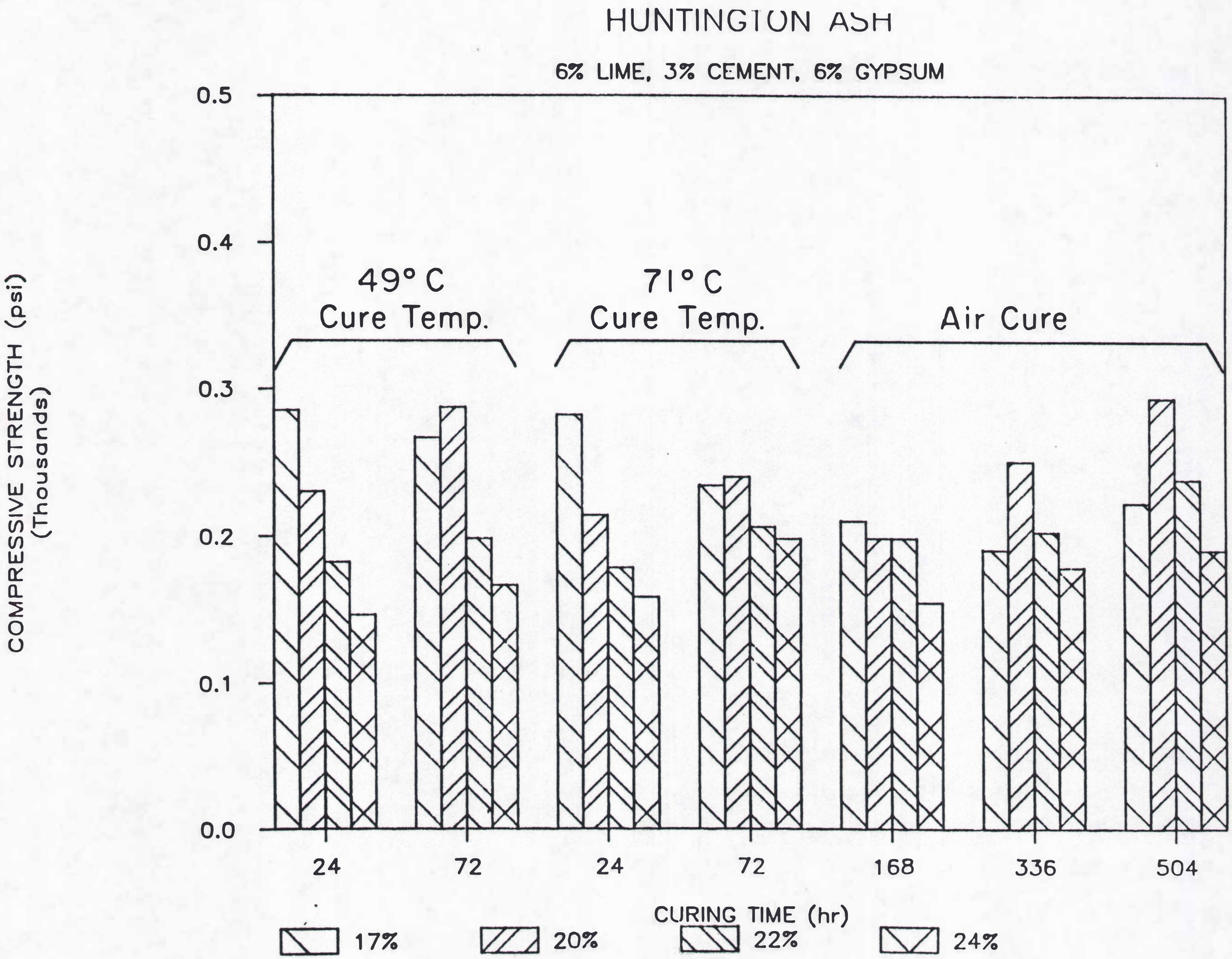
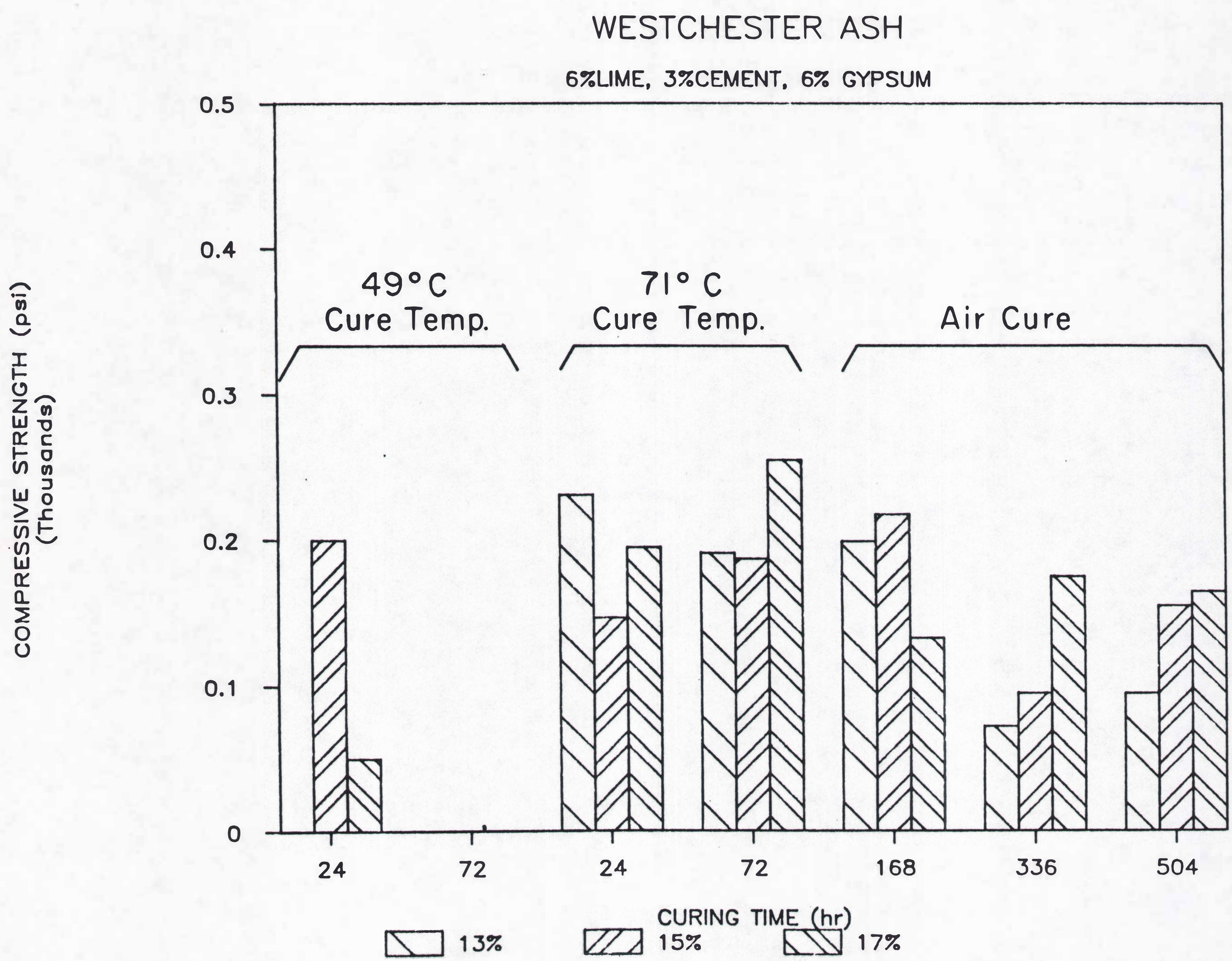

HUNTINGTON ASH
6% LIME, 3% CEMENT, 6% GYPSUM
COMPRESSIVE STRENGTH (psi)
(Thousands)
0.5
0.4
0.3
0.2
0.1
0.0
49° C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
17%
20%
22%
24%

Figure 4.16



WESTCHESTER ASH
6%LIME, 3%CEMENT, 6% GYPSUM
COMPRESSIVE STRENGTH (psi)
(Thousands)
0.5
0.4
0.3
0.2
0.1
0
49°C
Cure Temp.
71° C
Cure Temp.
Air Cure
24
72
24
72
168
336
504
CURING TIME (hr)
13%
15%
17%

Table 4.7. Results of proctor fabrication using gravel additions.

WESTCHESTER PROCTOR STRENGTHS WITHOUT GRAVEL

PROCTOR I.D.	WO3	WP3	WQ3	WT3
INCINERATION RESIDUE (%)	72	70	68	66
CEMENT (%)	15	15	15	15
CALC. MOISTURE (%)	13	15	17	19
MEAS. MOISTURE (%)	13	14	16	19
GRAVEL (%)	0	0	0	0
COMPRESSIVE STRENGTH (psi)	462	585	736	593

WESTCHESTER PROCTOR STRENGTHS WITH GRAVEL

PROCTOR I.D.	WEG	WFG	WDG	WBG
INCINERATION RESIDUE (%)	59	58	56	61
CEMENT (%)	15	15	15	15
CALC. MOISTURE (%)	11	13	15	17
MEAS. MOISTURE (%)	11	14	16	9*
GRAVEL (%)	15	14	14	7
COMPRESSIVE STRENGTH (psi)	1029(±14)	752(±28)	736(±24)	511(±26)

* Value lower than calculated due to a large percentage of gravel in the moisture sample.

FULL SCALE PRODUCTION OF TEST PROCTORS

Having developed methods for fabricating proctors of acceptable quality, the next task was to begin full scale production of test proctors to be used in the second phase of this investigation. Thirty proctor sized cylinders of each residue were fixated with 15% Portland cement. Table 4.8 describes the mix design and proctor curing conditions for each residue examined and the resulting compressive strength measured for three randomly selected samples. All three solidified samples are presented in Figure 4.17.

These mixes will be subjected to additional physical and chemical tests including permeability, porosity, ASTM and EPA leachate tests, bulk chemical composition and x-ray diffraction.

Table 4.8. Formulation of the optimum mixes.

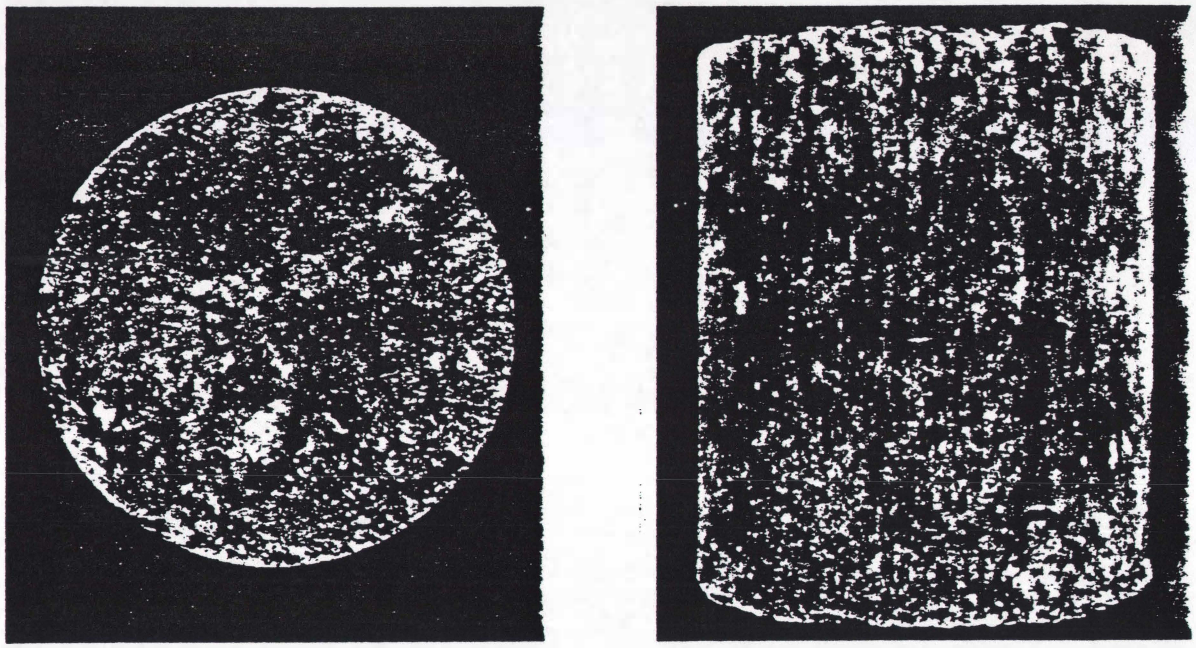
RESIDUE	NEW YORK CITY*	HUNTINGTON	WESTCHESTER
INCINERATION RESIDUE (%)	62	67	68
CEMENT (%)	15	15	15
MOISTURE (%)	23	18	17
CURING TEMPERATURE (^{o}C)	49	AIR (23)	49
CURING TIME (h)	72	168	24
COMPRESSIVE STRENGTH (psi)	228(±43)	455(±51)	1230(±59)

Figure 4.17. Solidified proctors of the three optimum mixes.

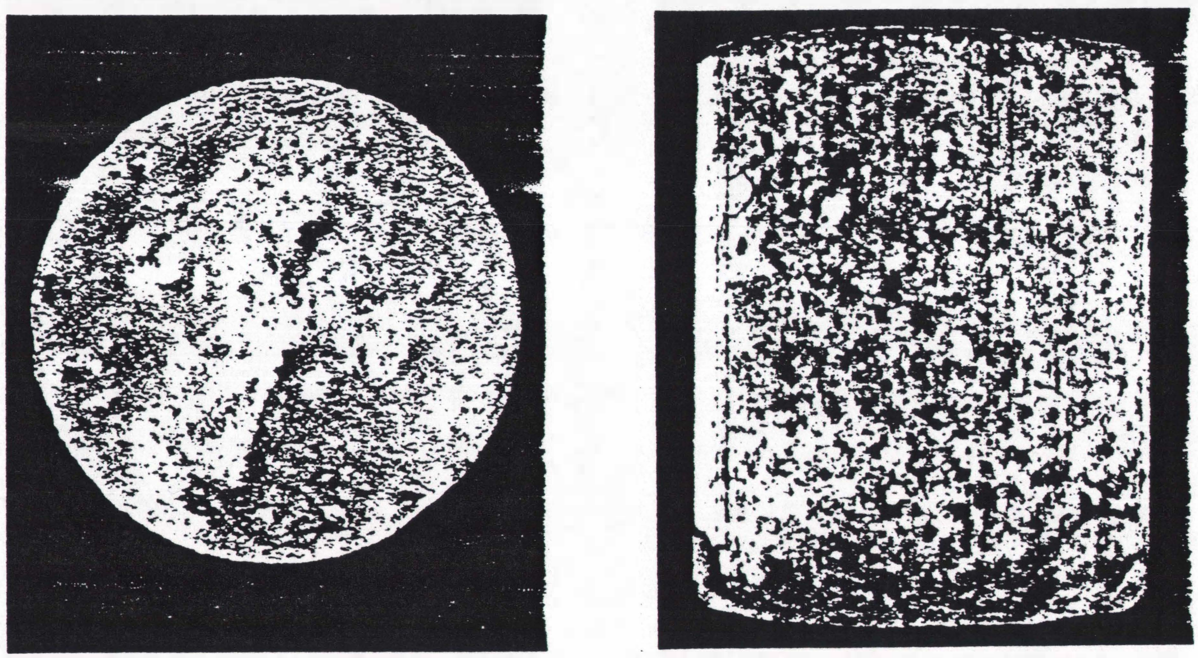
a) Stabilized Huntington Incineration Residue

b) Stabilized New York City Incineration Ash

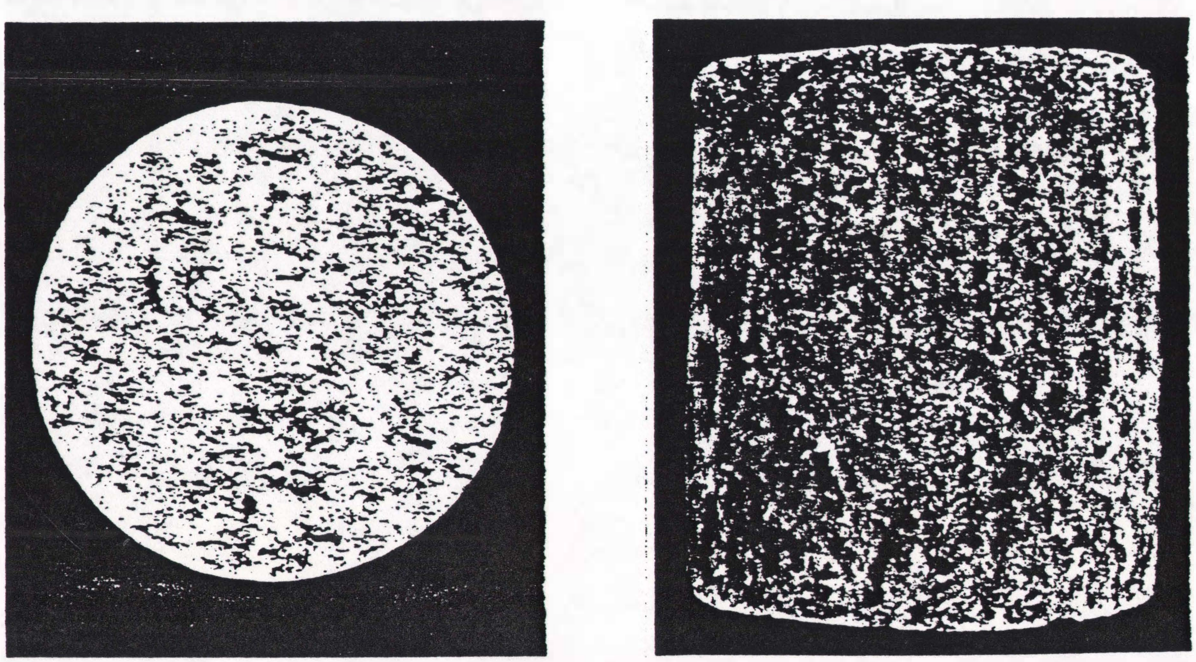
c) Stabilized Westchester Incineration Residue a)



b)



c)



Section 5

PHYSICAL CHARACTERIZATION OF THE STABILIZED RESIDUE

Porosity

Porosity of the optimum mixes was determined in accordance with ASTM C642-82 "Standard Test Method for Specific Gravity, Absorption and Voids in Hardened Concrete". Blocks were sectioned into three equal layers - top, middle, and bottom, with the middle layer reserved for the porosity study and the end sections used in the permeability investigation. Specific gravity, % absorption and % voids were calculated using the following equations:

Absorption after immersion, %	= [(B-A)/A] * 100
Absorption after immersion and boiling, %	= [(C-A)/A] * 100
Bulk specific gravity, dry	= A/(C-D)
Bulk specific gravity after immersion	= B/(C-D)
Bulk specific gravity after immersion and boiling	= C/(C-D)
Apparent specific gravity	= A/(A-D)
Volume of permeable pore space (voids), %	= [(C-A)/(C-D)] * 100

Where:

A = Weight (in air) of oven-dried sample; grams

B = Weight (in air) of sample after immersion; grams

C = Weight (in air) of sample after immersion and boiling; grams

D = Weight (in water) of sample after immersion and boiling; grams

Samples were oven-dried at 100 ± 5°C for 24 h, then removed and allowed to cool to a room temperature of 20°C in a desiccating chamber, then weighed. This procedure was repeated until check weights were obtained, i.e. a difference less than .5% of the lesser weight exists between the two measurements; approximately 48 h. Saturated weight was obtained by placing the blocks into water at room temperature for 24 h increments. Blocks were then removed from the water and towel-dried to eliminate any surface moisture and weighed. This procedure was repeated until check weights were obtained showing an increase no greater than .5% of the heavier weight; approximately 72 h. Next the block was boiled in tap water for 5 h and allowed to cool for 24 h to room temperature. Surface moisture was removed with a towel and the sample weighed. Finally, the block was suspended from a monofilament line and weighed in water.

Results from ASTM C642-82 test can be found in Table 5.1 and the results of the calculations for specific gravity, absorption and voids can be found in Table 5.2. The volume of permeable pore space ranged from 35.77% to 47.92%. City block samples had the highest amount of pore space averaging 47.5%. This value was approximately 7.7% greater than Huntington blocks and 10.8% greater than Westchester blocks.

The percent pore space in the optimum mix blocks provides an indication of the extent to which cementitious crystals have permeated the void space between ash particles. These results parallel the compressive strength values of the optimum mix blocks. Westchester ash blocks have the highest compressive strength and lowest percent pore space while the City ash blocks have the lowest strength and highest percent pore space.

Permeability

Permeability of the optimum mixes was determined by the Darcy falling-head method (Harder et al., 1981) shown in Figure 5.1. The proctors were cut into three equal sections approximately 1.5 inches in height with the top and bottom layers being used for the permeability study. The sections were ground with sand paper to reduce their diameter

Table 5.1. Measured values for ASTM C642-82: Test for specific gravity, % absorption and % voids of optimum mixes.

Proctor Number	Original Weight (g)	A Oven Dried Weight (g)	B Saturated Wt. After Immersion (g)	C Saturated Wt. After Boiling (g)	D Immersed Weight (g)
COE5	395.75	370.50	497.54	511.00	214.45
COC5	385.37	364.53	508.19	511.90	204.35
HA5	494.93	475.93	573.04	593.80	287.85
HC3	456.84	439.60	535.27	556.70	265.81
WAB5	527.55	502.97	591.97	615.04	301.70
WAD1	498.23	474.83	564.13	586.55	285.92

a. All proctors are middle portions.
b. Total number of hours dried for Oven Dried Weight equal 48.
c. Total number of hours soaked for Saturated Weight equal 72.
d. Total number of hours boiled equal 5.

Table 5.2. A summary of specific gravity, % absorption and % voids for optimum mixes: ASTM C642-82.

Proctor Number	Absorption after Immersion (%)	Absorption after Immersion and Boiling (%)	Bulk Specific Gravity, Dry	Bulk Specific Gravity after Immersion	Bulk sp. Gravity after Immersion and Boiling	Apparent Specific Gravity	Vol. of Permeable Pore Space (Voids) (%)
COE5	34	38	1.25	1.68	1.72	2.37	47.38
COC5	39	40	1.19	1.65	1.66	2.28	47.92
HA5	20	25	1.56	1.87	1.94	2.53	38.53
HC3	22	27	1.51	1.84	1.91	2.53	40.26
WAB5	18	22	1.61	1.89	1.96	2.50	35.77
WAD1	19	24	1.58	1.88	1.95	2.51	37.16

to fit inside of a 4 inch i.d. PVC pipe. Each section was dusted with compressed air to remove any adhering dust particles resulting from the sanding and cutting of the proctors. Each specimen was then epoxied into the base of a 1 foot high translucent PVC pipe with PC•7 epoxy. A PVC threaded male collar was cemented to the bottom of the column and a PVC end cap fitted with a nylon hose nipple was threaded onto the male collar. Elutriates from the permeability column passed through the nylon nipple, through a length of Tygon tubing, and into a covered plastic beaker for collection. To begin the test, .45μm filtered seawater was added to the columns. A plastic bag was attached to the open end of the columns to prevent evaporation. Starting time and height of the water column were recorded. Water column heights for each column were next recorded when a measurable difference in height could be discerned. The coefficients of permeability of the optimum mixes in seawater were determined by the following equation:

$$K = [(Q*L)/(H_o*A*T)] * \ell n(H_i/H_t)$$

where:

K = coefficient of permeability, cm/sec
Q = volume of elutriate, cm^3
L = height of proctors, cm
A = area of proctor, cm^2
T = test time between readings, sec
H_i = initial height of water column, cm
H_t = height of water column at time t, cm
$H_o = H_i - H_t$, cm

The permeability of the top and bottom layers of optimum mix proctors from Westchester, Huntington and NY City incineration ash was determined in duplicate. Results are presented in Table 5.3 and in Figures 5.2 - 5.4. All samples show a decrease in permeability with time with the top sections always less permeable than the bottom sections for each ash type. Also, all bottom sections show higher standard deviation values than the top sections, indicating poor reproducibility in the bottom

Figure 5.1 Darcy falling head permeability apparatus.

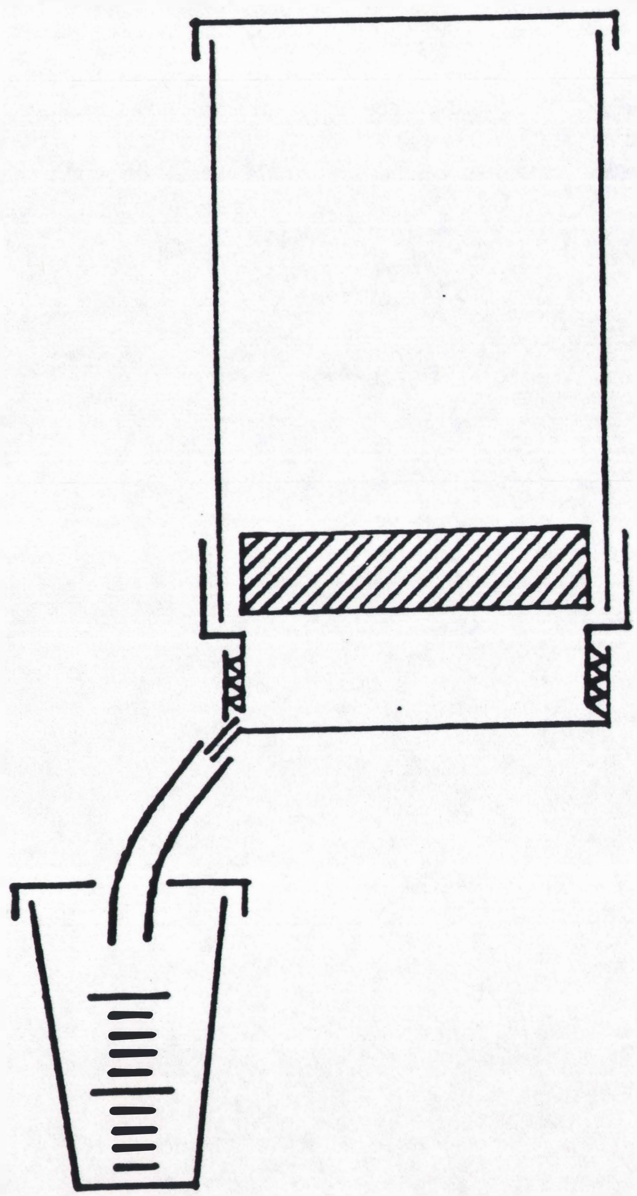
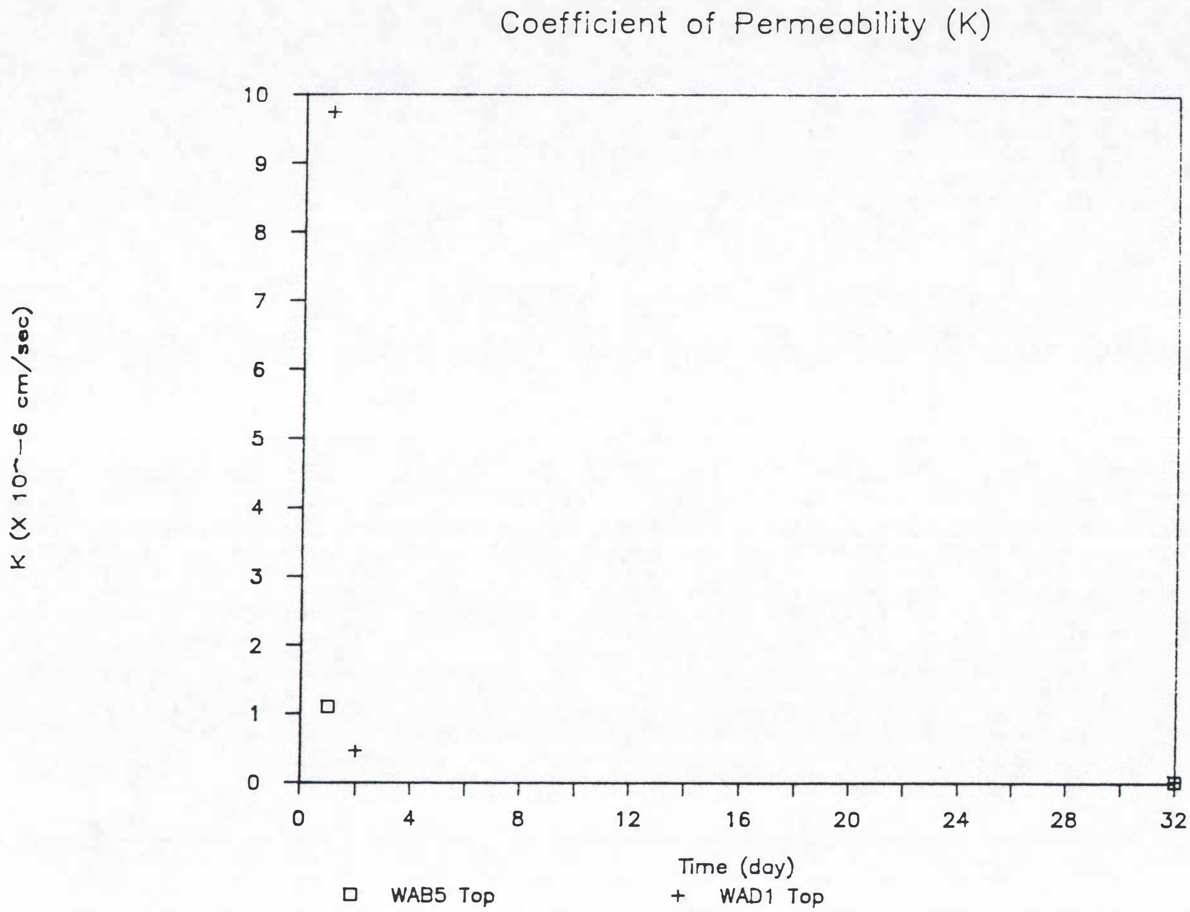


Table 5.3. Permeability coefficients[a] for proctor sections.

	TOP	BOTTOM
COC5	1.21×10^{-7}	1.35×10^{-5}
COE5	1.31×10^{-7}	7.65×10^{-6}
AVERAGE	$1.26(\pm.07) \times 10^{-7}$	$1.06(\pm.41) \times 10^{-5}$
HA5	5.96×10^{-8}	6.22×10^{-7}
HA3	1.51×10^{-7}	7.02×10^{-5}
AVERAGE	$1.05(\pm.65) \times 10^{-7}$	$3.54(\pm4.92) \times 10^{-5}$
WAB5	2.05×10^{-8}	1.50×10^{-8}
WAD1	2.29×10^{-8}	3.56×10^{-8}
AVERAGE	$2.17(\pm.17) \times 10^{-8}$	$2.53(\pm1.46) \times 10^{-8}$

a. Unit is cm/sec.
b. Numbers in parentheses denote standard deviations.

Figure 5.2 Permeability of Westchester optimum mix.


Coefficient of Permeability (K)
K (X 10^-6 cm/sec)
10
9
8
7
6
5
4
3
2
1
0
0
4
8
12
16
20
24
28
32
Time (day)
WAB5 Top
WAD1 Top

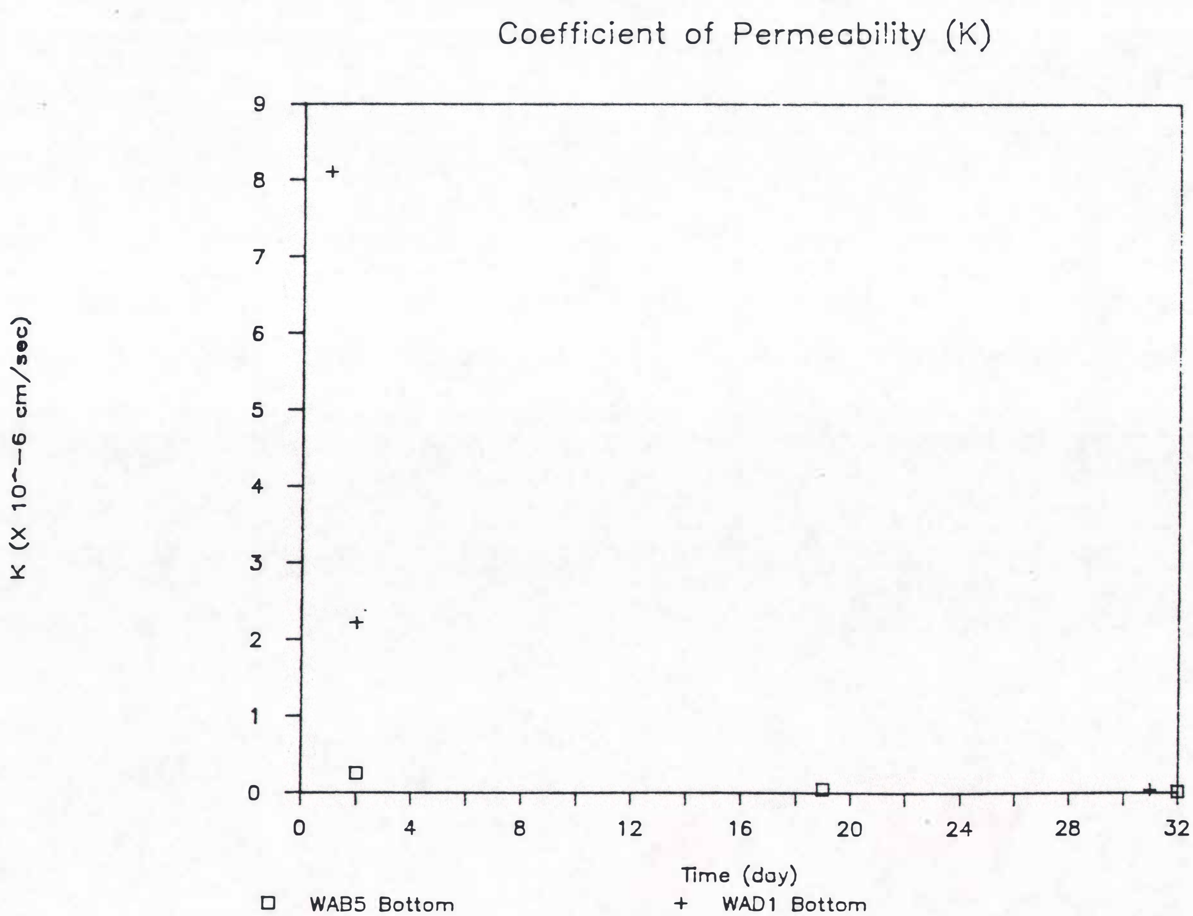
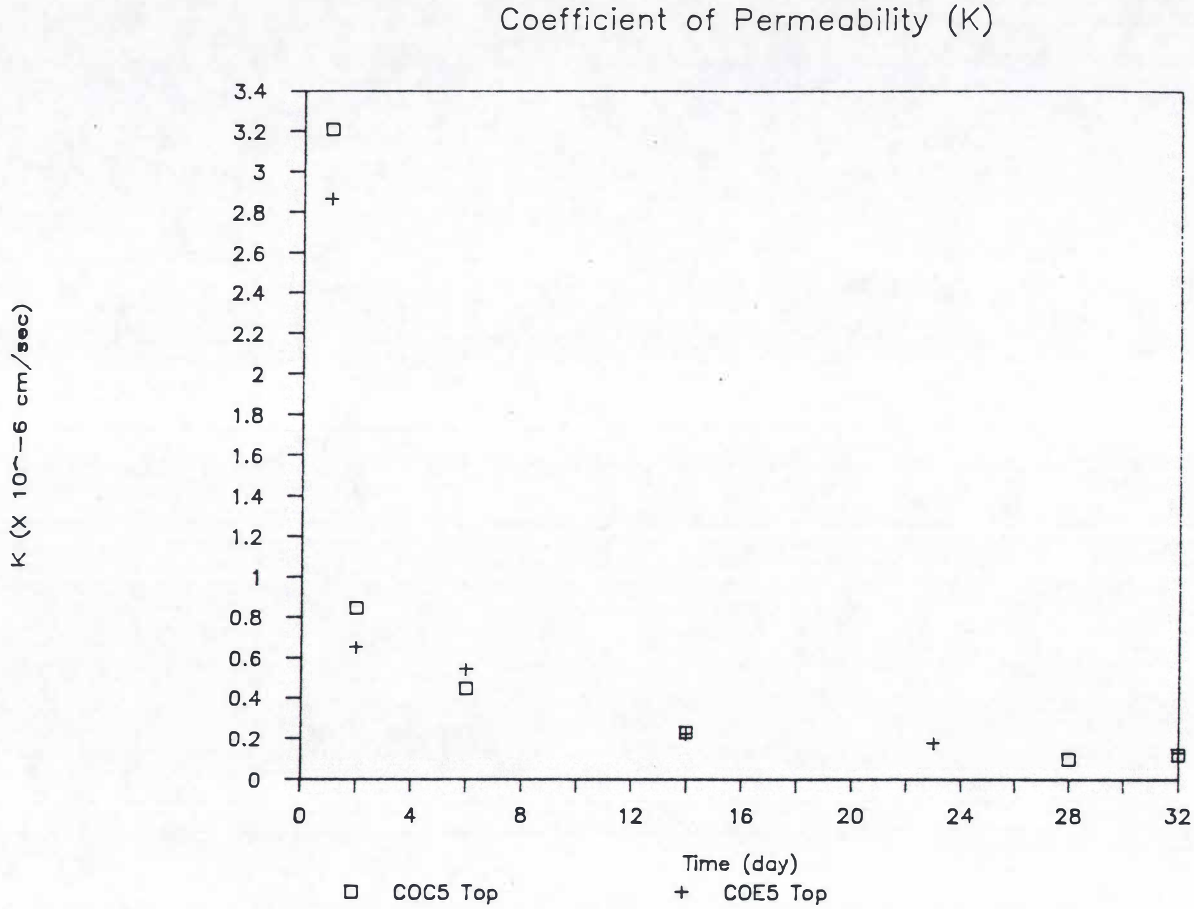
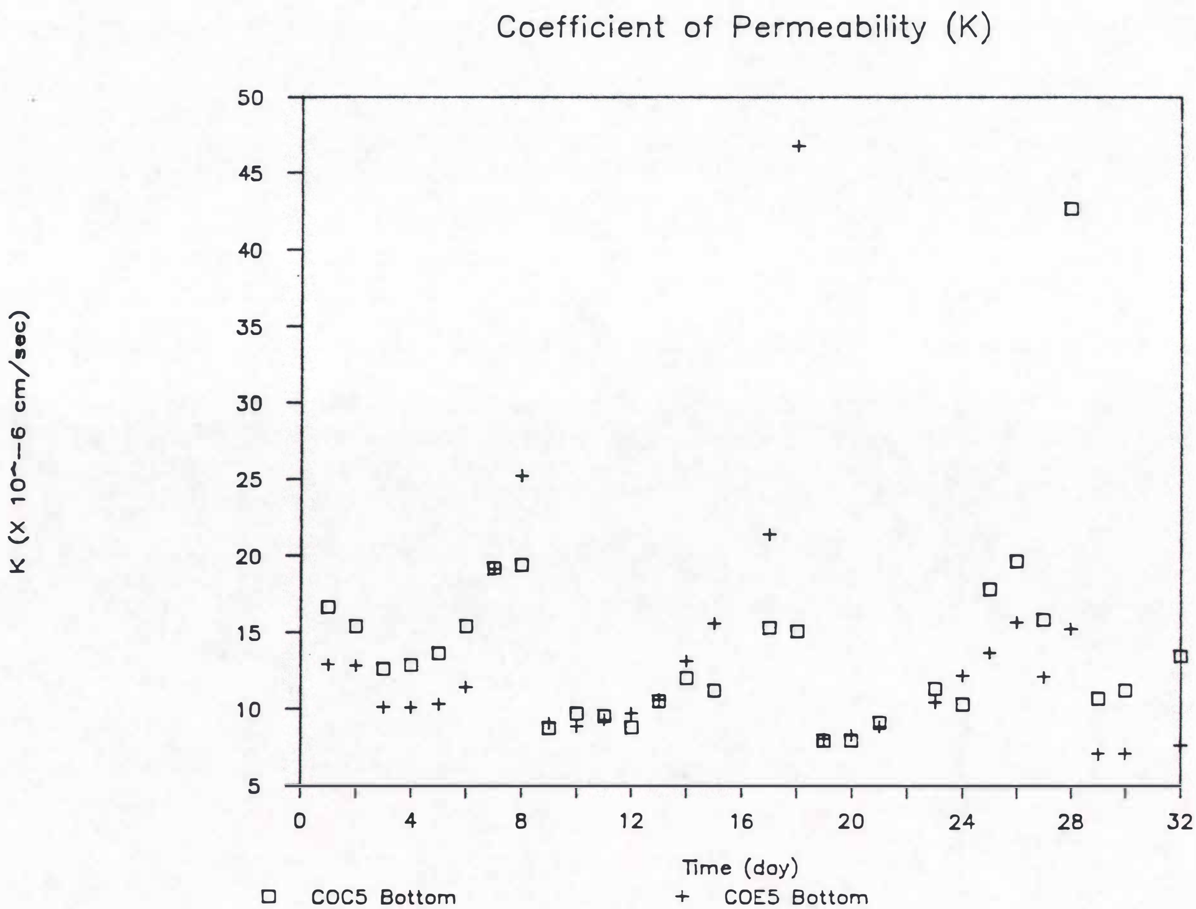

Coefficient of Permeability (K)
K (X 10^-6 cm/sec)
9
8
7
6
5
4
3
2
1
0
0
4
8
12
16
20
24
28
32
Time (day)
WAB5 Bottom
WAD1 Bottom

Figure 5.3 Permeability of New York City optimim mix.



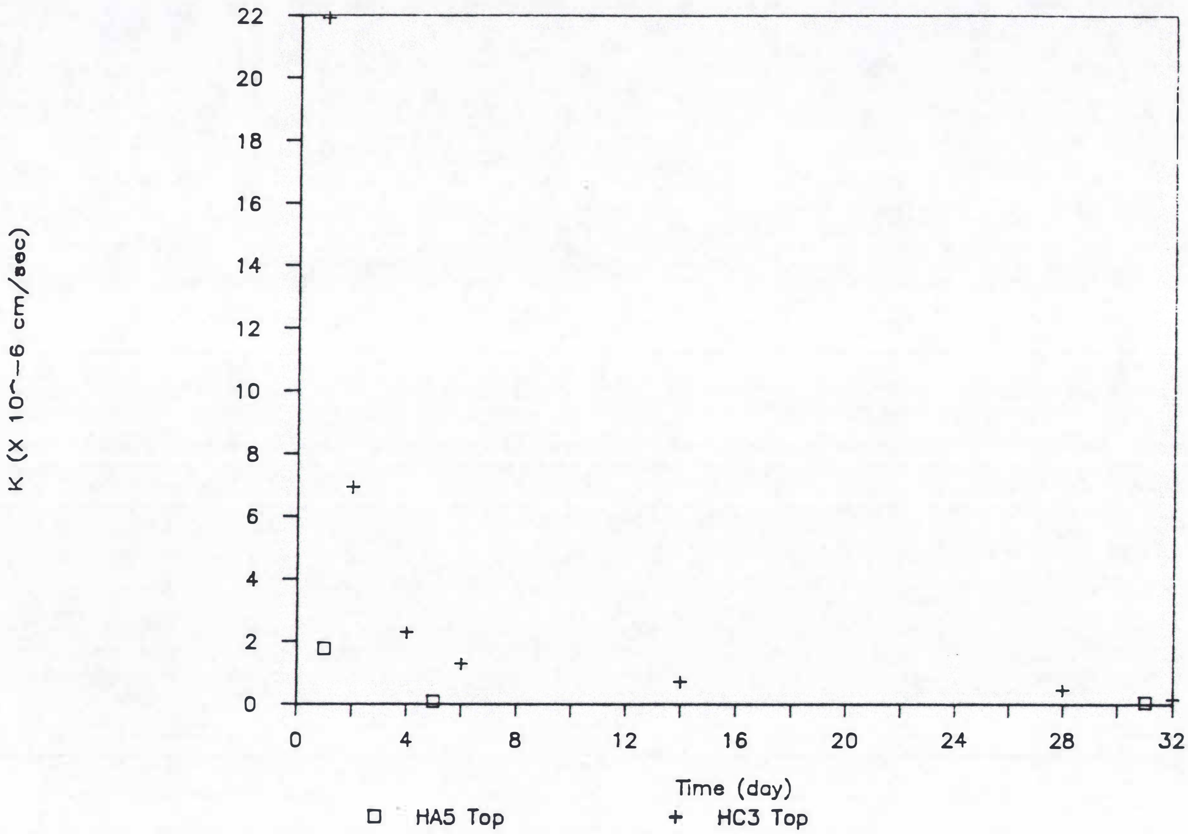
Coefficient of Permeability (K)
K (X 10^-6 cm/sec)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
4
8
12
16
20
24
28
32
Time (day)
COC5 Top
COE5 Top



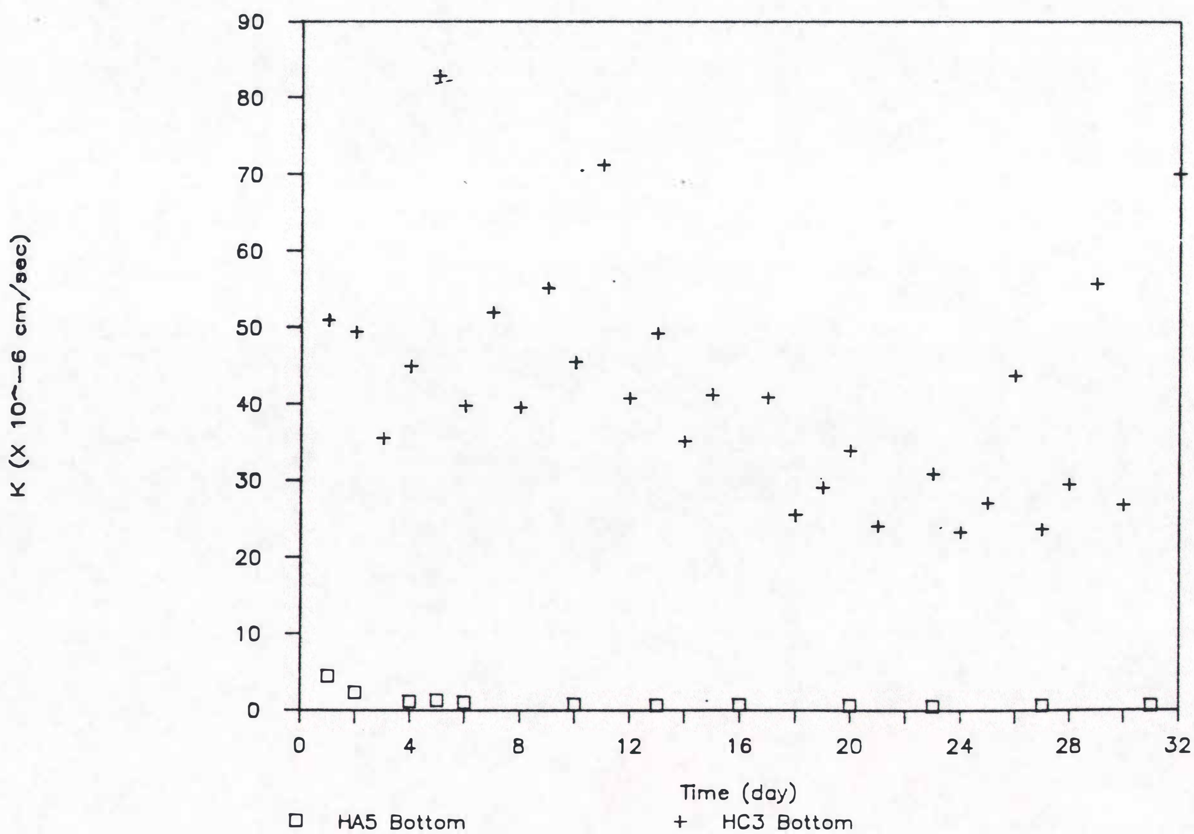
Coefficient of Permeability (K)
K (X 10^-6 cm/sec)
50
45
40
35
30
25
20
15
10
5
0
4
8
12
16
20
24
28
32
Time (day)
COC5 Bottom
COE5 Bottom

Figure 5.4 Permeability of Huntington optimum mix.

Coefficient of Permeability (K)



Coefficient of Permeability (K)



sections. The bottom sections of New York City and Huntington blocks have the highest average permeabilities of 1.06 X 10^{-5} and 3.45 X 10^{-5} cm/sec while the top sections of the Westchester blocks had the lowest average of 2.17 x10^{-8} cm/sec.

A rapid initial decrease in permeability occurs in all samples as seawater fills the pore space of the blocks. When the block is fully saturated, the surface tension between the internal block surfaces and the seawater in the pore space slows the flow of fluid to the asymptotic value of the permeability coefficient. Seligman (1978) argues that the reduction of permeability may be due to the precipitation of calcium alumina-silicate in the cementation processes. Since seawater, which provides Ca^{2+} for the reaction, was used over the period of the test, Seligman's argument can also account for the decreasing permeability coefficient found in the study. The absorption of calcium from seawater by proctor sections was directly observed in our calcium-flux study (refer to Table 6.14 and 6.15).

One unexpected result of the permeability experiment is that the bottom sections of all proctors tested are more permeable than the corresponding top sections. This is surprising because our proctor fabrication technique follows ASTM D698-78 which results in the bottom layer receiving a total of 75 compactions during production and the top layer only 25. This should reduce the percentage of pore space in the bottom section below values for the top sections. However, this result has also been observed by Harder et al. (1981) where more compactions produced a higher porosity and permeability. Because our porosity experiment used only the middle section from the proctor, no comparison between compactions and porosity was available.

The most probable cause for this anomaly is that some damage results to the bottom portion of the proctor during extrusion from the mold. This may be difficult to detect and fully cover with epoxy when the section is mounted into the bottom of the PVC column. This effect could result in water channelling through small cracks between the exterior of the proctor and the PVC pipe. This could also explain the high standard deviation in the bottom sections due to the unreproducible manner in which these cracks would occur.

Freeze-Thaw

To determine the behavior of the proctors to weathering, six blocks were exposed to a freeze-thaw regime following ASTM C666 protocol. Blocks were placed in a freezer at -5°C for 24 h, then removed and allowed to return to room temperature for 24 h and then returned to the freezer. This procedure, which was followed for forty-one (41) days, resulted in 20 freeze-thaw cycles after which the compressive strength of the blocks was tested following methods described earlier.

Results of the freeze-thaw procedure can be found in Table 5.4. No statistically significant change was observed in the average compressive strengths of New York City or Huntington blocks due to the procedure. This is observed from the overlap of the average values within the standard deviation of the averages. The Westchester blocks, however, exhibited a decrease of 16% in their strengths after the procedure.

Westchester blocks exhibited a 16% decrease in their strengths after the freeze-thaw procedure. They also showed the smallest percentage of pore space, the lowest permeability values and the smallest standard deviation in strength values. This indicates that the Westchester blocks are more uniform and more compact than the other two types of ash blocks. When the blocks are frozen, any moisture in the blocks will form ice crystals and, due to the lack of pore space, the formation of these crystals may disrupt the cementitious crystals of the block. This would result in lower compressive strength of the blocks. New York City blocks have the largest percentage of pore space and the greatest permeability thereby allowing ice crystals to form without causing much disruption of the cementitious bonds. In Table 5.4, it is observed that freeze-thaw cycled New York City block strengths fall within the standard deviation of the uncycled blocks indicating no major structural damage occurring during the weathering process. Huntington freeze-thaw blocks are slightly stronger than uncycled blocks. This could be explained by the variability of the blocks, as indicated by the large standard deviation values.

Table 5.4. Compressive strengths before and after freeze-thaw cycle.

			Compressive Strength (psi)
New York City			
	Before		228 (±73)
	After	COB5	199
		COD5	247
		Average	224 (±26)
Huntington			
	Before		455 (±63)
	After	HB2	557
		HD2	374
		Average	466 (±129)
Westchester			
	Before		1231 (±53.5)
	After	WAA3	1031
		WAB3	1027
		Average	1029 (±3)

a. Numbers in parentheses denote standard deviation.

EFFECTS OF SEAWATER EXPOSURE

Twelve proctor sized samples of the optimum mix for each ash were placed on a seatable at the Flax Pond facility. Filtered seawater was continuously circulated through the seatable to provide an indication of how the stabilized ash would behave in the sea. Two blocks were retrieved from the seatable at approximately 60 day intervals for compressive strength determinations. Results are shown in Table 5.5 and Figure 5.5. The results show that Westchester block average strength actually increases almost 19% above it's initial strength after the first 60 days of submersion then slowly decreases thereafter. The Huntington blocks initially lose less than 6% of their initial strength after 60 days of submersion then maintains a strength of approximately 385 psi which is still above our 300 psi minimum strength criteria after 185 days of submersion. The New York City blocks failed the submersion test. Total loss of structural integrity was observed after 122 days of submersion .

Fragments from the blocks broken after 60 days were then freeze-dried for 24 h, ground with mortar and pestle to pass through a 75μm opening sieve, and again freeze-dried. This sample was subsequently used for powder X-ray diffraction analysis (see Section 7).

HOLLOW UNIT MASONRY BLOCK MANUFACTURING

Using the facilities of Barrasso and Sons, Inc. at 160 Floral Park Road, Islip Terrace, New York, approximately 300 standard sized (8x8x16) hollow unit masonry blocks were fabricated substituting Westchester incineration residues sieved through a 3/4" flat mesh screen for aggregate. Three mix designs were examined:

Table 5.5. Effects of seawater submersion test on compressive strengh.

Unsubmerged Optimum Mix Proctor Characteristics

	Westchester	Huntington	New York City
Moisture (%)	17	18	23
Cement (%)	15	15	15
Curing Temp (C)	49	Air	49
Curing Time (h)	24	168	72
Avg. Strength (psi)	1231 ± 54	455 ± 63	228 ± 74

Submerged Optimum Mix Proctor Characteristics

Date 2/18/86 Total submersed time : 60 days

Proctor Code	WAB2	WAE2	HC4	HE1	COD7	COE7
Compressive Strength (psi)	1468	1456	458	402	72	95
Avg. Strength	1462 ± 6		430 ± 28		84 ± 12	
% Change	18.8		-5.5		-63.4	

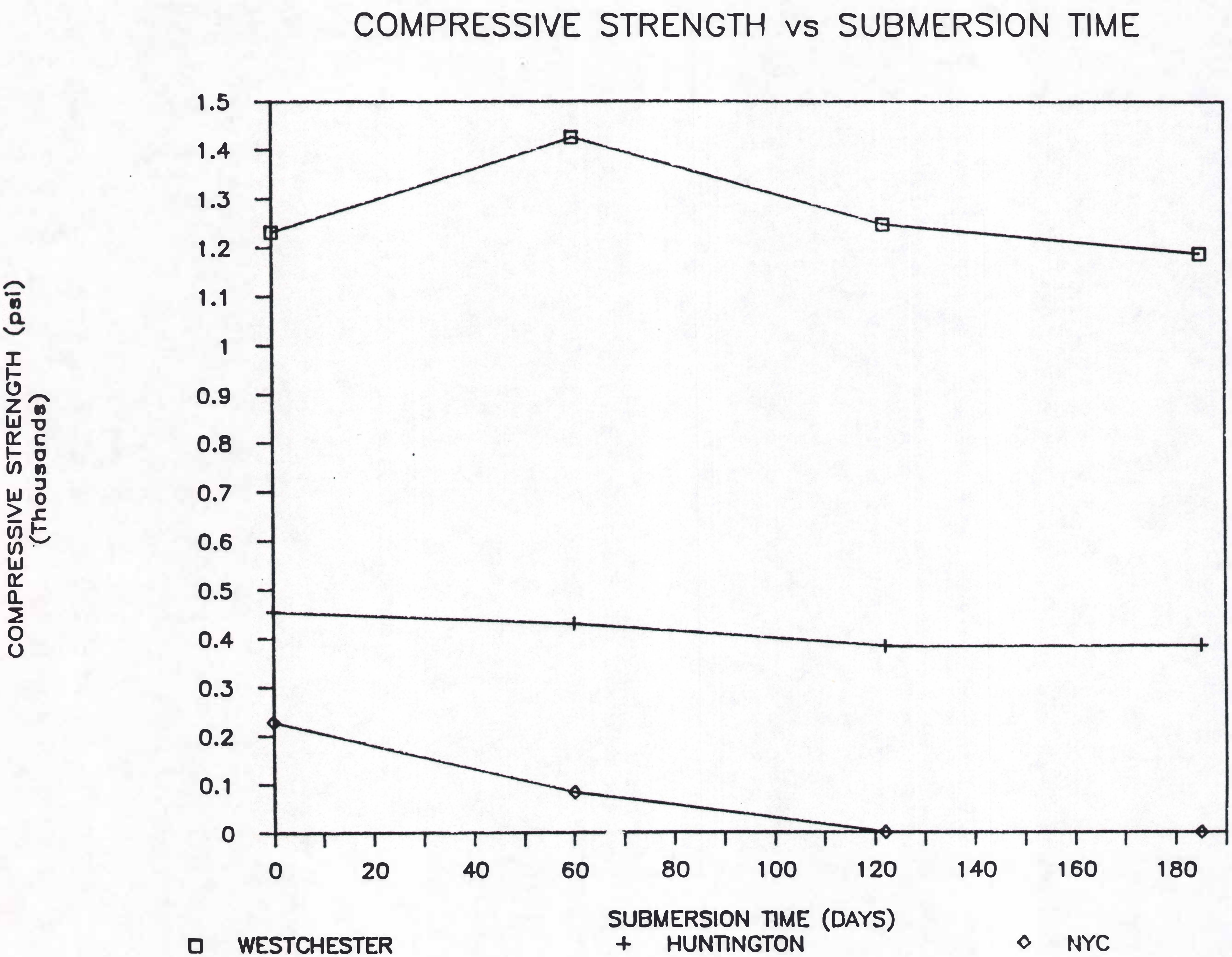
Date 4/21/86 Total submersed time : 122 days

Proctor Code	WAD2	WAE3	HA4	HE2	COA4	COC1
Compressive Strength (psi)	1110	1385	418	350	0	0
Avg. Strength	1248 ± 138		384 ± 34		0 ± 0	
% Change	1.3		-15.6		-100.0	

Date 6/23/86 Total submersed time : 185 days

Proctor Code	WAD3	WAE5	HC2	HE4	COA1	COD3
Compressive Strength (psi)	1170	1206	414	358	0	0
Avg. Strength	1188 ± 18		386 ± 28		0 ± 0	
% Change	-3.5		-15.2		-100.0	

Figure 5.5


COMPRESSIVE STRENGTH vs SUBMERSION TIME
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
20
40
60
80
100
120
140
160
180
SUBMERSION TIME (DAYS)
WESTCHESTER
HUNTINGTON
NYC

Mix Design	Materials	Volume (ft^3)	Weight (lbs)
1	cement		251
(Red)	sand	15	1368
	residue	10	624
2	cement		250
(yellow)	sand	10	900
	residue	15	900
3	cement		250
(natural)	sand	0	0
	residue	25	1500

Each mix design was colored as noted above and cured for 18 hours at 134^{o}F. One difficulty during the block manufacturing process was the inability to use the mixers moisture probe to determine the moisture content of the mix prior to compaction. This was due to the small sample size, and therefore only an estimate of the moisture content was established. Barrasso personnel were impressed by the ease of handling the incineration ash and moving the mix throughout the facility by conveyor belts prior to compaction. Overall it was their impression that this material behaved in a similar manner to the standard mixes they handle daily.

Following curing, the blocks were transported to MSRC where a number of blocks of each mix design were moistened and wrapped in plastic to determine whether additional moisture would result in a continuation of the curing process and therefore improve compressive strengths. Every seven days the structural integrity of the blocks was determined in replicate (n=3).

Table 5.6 indicates that the second mix design produced blocks possessing a mean compressive strength of approximately 90,000 lbs total load. The blocks manufactured using only incineration ash had a strength of 65,000 lbs. The data indicates that little, if any improvement in strength was accomplished by wetting the blocks and that compressive strength values fall short of the ASTM C-90 800 psi minimum strength.