TRANSPORTATION RESEARCH BOARD
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IDEA *Innovations Deserving Exploratory Analysis Project*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report of Investigation

IDEA

NCHRP

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NEW ADDITIVE FOR IMPROVED DURABILITY OF CONCRETE AND PREVENTION OF REINFORCING CORROSION

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS
MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

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EXECUTIVE SUMMARY

Portland Cement concrete is one of today's major construction materials. Pavements, bridge spans, high rise buildings, house basement walls, etc are made of this versatile material. It is used for literally 100 percent of structural foundations. The tendency for concrete to deteriorate under repeated freeze/thaw cycles has long been recognized as a major weakness of this material. In recent years, resistance to freeze/thaw deterioration has been provided by air entrainment, the deliberate inclusion of micro bubbles. For air entrainment to be successful, concrete must be placed carefully as over vibration while plastic can cause the bubbles to coalesce and float to the surface. An additive that can not separate out is needed.

Dipolar alkenyl dicarboxylic acid diammonium salt is a highly hydrophobic chemical. There is a natural attraction of the dipole molecules to concrete ingredients that make mechanical separation improbable. This study was planned to verify that the diammonium salt, as an admixture in concrete, would provide frost protection. Mixes with different levels of salt treatment were put through three hundred or more freeze/thaw cycles. The resulting dynamic modulus was determined for use as a measure of the resistance to damage.

The diammonium salt at several levels performed as well as air entrainment. The salt can be obtained as a water solution and can easily be introduced into the concrete mixer along with the mixing water. The levels used in this study lowered the compressive strength more than did the air entrainment treatment used for the control mixes. However, the strength was adequate for many common uses of concrete and the elimination of unprotected pockets of concrete which shorten masonry life should encourage use of the material. More work should be done to determine the treatment level for balance between compressive strength and frost protection.

The salts also have promise as a means of reducing environmental concerns about the potential level of heavy metal leachates from incinerater ash in concrete. With the increasing scarcity of natural aggregates and the growing problem of incinerater ash disposal, an environmentally safe mix is attractive. The diammonium salt reduced the leachate of nearly all metals. The possibility that the chelating and hydrophobic nature of the material can provide corrosion protection for rebar should also be investigated.

IDEA PRODUCT

A chemical additive for Portland Cement concrete which will be less sensitive to placing conditions than air entrainment but provide equivalent protection from frost damage has been laboratory tested. The material also reduces heavy metal leachate potentially making the use of incinerater ash, either bottom or fly ash, in concrete environmentally acceptable.

CONCEPT AND INNOVATION

Repeated freezing of concrete, with water in the voids, destroys the concrete. The increase in volume as the water changes into ice, causes tension stresses in the cement paste around the void . Fatigue after a number of cycles causes failure. Entrainment of fine bubbles which can not readily fill with water, provides relief for the expansion pressure. Care must be exercised when placing air entrained concrete as over vibration, while in the plastic phase, can float the bubbles from the mix eliminating the protection.

Dipolar alkenyl dicarboxylic acid diammonium salts are strongly hydrophobic. A small amount mixed into concrete should make the entire mix hydrophobic. If the cement paste around every small void were hydrophobic, the voids would not fill with water and freezing expansion would be reduced.

A secondary benefit could be the metal chelating property of the diammonium salt. Fly ash is frequently used as a workability additive to concrete. Chelating of heavy metals by the diammonium salt would reduce leaching and permit the use of local incinerater fly ash in place of more expensive power plant fly ash.

IDEA PRODUCT INVESTIGATION AND PROGRESS

The basic purpose of this study was the evaluation of the freeze/thaw performance of diammonium modified concrete. A concrete mix was selected based on 3/8 inch crushed trap rock, a local well graded natural sand and type I/II Portland cement. This mix with and without air entrainment (Darex as an additive) provided the standards for comparison of the modified mixes. The base mix was then modified by the addition of a dipolar alkenyl dicarboxylic acid diammonium salt. Two different salts were used. One was a 12 carbon molecule and the other an 18 carbon. The levels of salt added were small percentages by weight of the cement content. As the addition of the salt to the mixes required increased mixing water for workability which increased the W/C ratio and probably reduced the strength, additional mixes were made incorporating Polyheed as plasticizer

The labeling system for the mixes used three descriptors. The first was the level of diammonium salt expressed as percent of cement. The second was the type of diammonium salt, 12C for the 12 carbon material, 18C for the 18 carbon or N for none. The third was other additive present, AE for Darex II Air Entrainment, P for Polyheed, MA for Micro Air or N for none.

Entrained air content, compressive and indirect tensile strengths and freeze/thaw resistance tests were carried out on most mixes. Capillarity and permeability measurements were made on selected mixes.

A series of similar mixes with 15% of the cement replaced with incinerator fly ash was used for leaching tests. The added fly ash assured the presence of heavy metal that could leach when washed with water.

SPECIMEN PREPARATION

Ingredients were weighed to 0.01 kg. Mixing was in a small drum type concrete mixer. The 12 and the 18 carbon dipolar alkenyl dicarboxylic acid diammonium salts were obtained as 20% in water solutions. The 80% water in the salt solution was considered part of the mixing water. The consistency of the mixes was difficult to predict as each change in additive treatment also changed the slump. The target was 12.5 cm, however due to time constraints, some variation was accepted.

Cylinders, 101.6 mm (4 inch) for compression, indirect tension and capillarity and 76.2 mm (3 inch) for permeability, were molded in three rodded layers, ASTM C-192. 76.2 by 101.6 by 406.4 mm (3 by 4 by 16 inch) freeze/thaw beams were molded in two layers each rodded 32 times. All samples were moist cured. The freeze/thaw beams for 14 days and the cylinders 28 days. As the mixes for leachate testing were too small to tumble well in the drum mixer, they were mixed in a Hobart counter mixer. In order to secure maximum surface area for leaching, the mixes were spread without compaction 12.5 mm (1/2 inch) thick on plastic sheeting and moist cured 24 hours. The concrete was then crumbled up and moist curing continued to 7 days. For actual test, that portion of the mix that passed through a 6.4 mm (1/4 inch) and was retained on a 3.2 mm (1/8 inch) sieve was used.

TESTING

Slump, ASTM C-143, and air content, pressure method ASTM C-231, tests were made on the fresh concrete.

Compression tests, ASTM C-39, were performed after 28 days moist curing. Elastomeric caps were placed at both top and bottom of the cylinders. Loading was at a constant rate of 275 kPa (40 psi) per second.

Indirect tension tests, ASTM C-496 were also perforMed at 28 days. New plywood strips along the lines of loading were used for each specimen. Loading was at a constant rate of 69 kPa (10 psi) per second.

Freeze/thaw cycling was carried out in an automatic cabinet with the samples continuously wet, ASTM C-666. Cycling was set for 8 complete cycles per day with a temperature range of 0 to 40 F. The dynamic sonic testing was performed before cycling commenced and periodically thereafter with the beams thawed and at a temperature of 40 F. The relativedynamic modulus in percent is 100 times the ratio of the square of the fundamental transverse frequency at cycle n to the square of the fundamental transverse frequency at zero cycles.

The simple capillarity test used consisted of the determination of the amount of water drawn into a 101 mm (4 inch) diameter by 202 mm (8 inch) tall oven dry concrete cylinder when standing in 25.4 mm (1 inch) of water for 48 hours.

Permeability tests were carried out in a triaxial cell. The specimen were obtained by sawing slices out of the centers of 76 mm (3 inch) by 152 mm (6 inch) cylinders. The thickness ranged from 25 mm (1 inch) to 38 mm (1.5 inch). After the perimeter was covered with high vacuum silicon grease, the disk was inserted into a latex membrane and a 275 kPa (40 psi) confining pressure applied. Flow under a pressure differential of 69 kPa (10 psi) was determined. The permeability coefficient was calculated using the Darcey equation.

The University of Connecticut Environmental Research Institute carried out the leachate work. Ten grams of the 3.2 to 6.4 mm (1/8 to 1/4 inch) material was placed in 100 ml of deionized water and rotated for one hour. The sample was then washed with hot deionized water through an acid washed Millipore quartz fiber filter and volumetrically diluted to 250 ml. The diluted leachate was analyzed using Inductively Coupled Plasma (ICP) spectroscopy. Those showing small concentrations of lead, arsenic or selenium were rerun by Graphic Furnace Atomic Absorption (GFAA).

RESULTS

The freeze/thaw data indicates that the 12C did provide effective frost protection, Fig. 1. The basic mix failed at less than 100 cycles. At 300 cycles, the 1%-12C-N mix still had a relative dynamic modulus of 98%. The highest 300 cycle dynamic modulus was that of the Polyheed mix at 101.6%. The difference of 3.6% is not very significant. There is a weak trend for the 300 cycle modulus to vary inversely with the percentage of 12C indicating that lower levels should be tried. A much stronger trend exists for the 300 cycle modulus to vary directly with the slump.

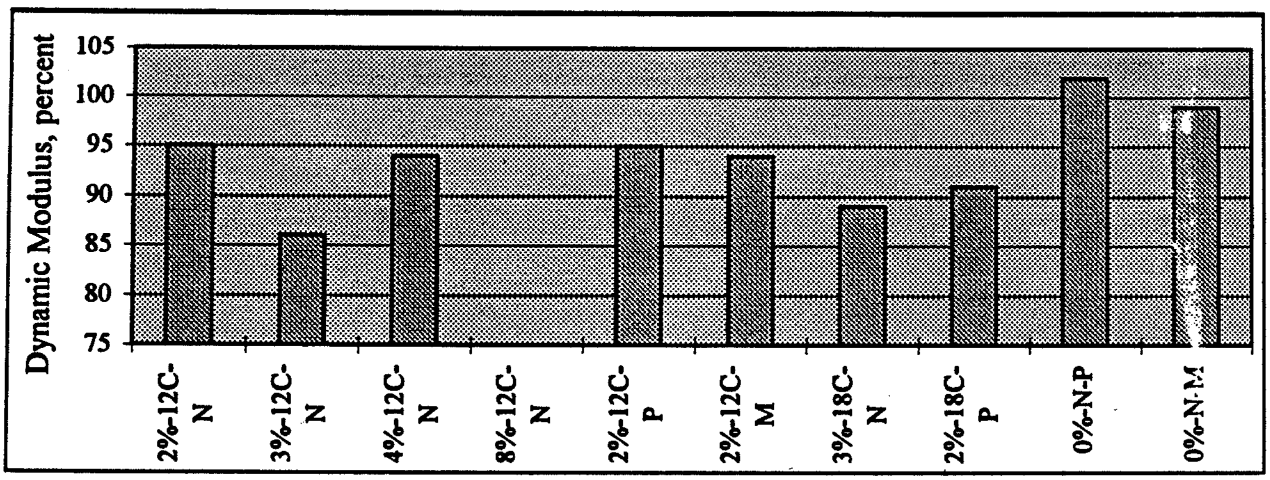

FIGURE 1. Dynamic Modulus after 300 Freeze/Thaw Cycles

The 12C additive at the 1% level reduced the compressive strength of the basic mix by 50%, Fig. 2. The strength of the basic mix was decreased only 25% by Darex II air entrainment. Increasing the 12C to 2, 3 and 4 % resulted in minor strength gains but further increase to 8 % destroyed the strength. The addition of Polyheed improved the compressive strength and frost resistance of both the basic mix and the 2%-12C mix. The tensile strength was consistently 10 to 15% of the compressive strength, Fig. 3.

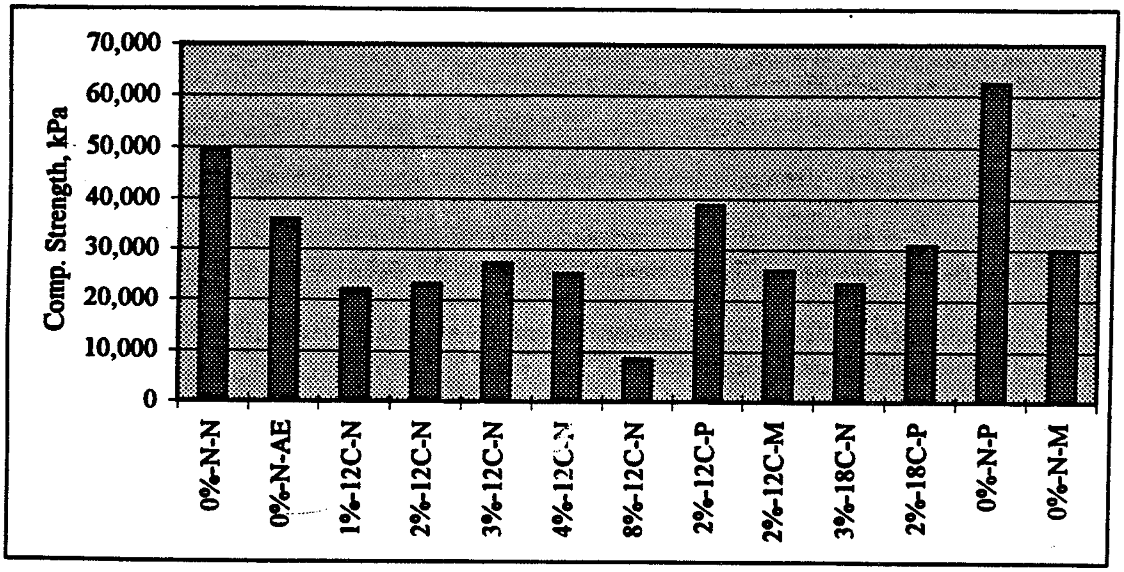

FIGURE 2. Compressive Strength, 28 Days

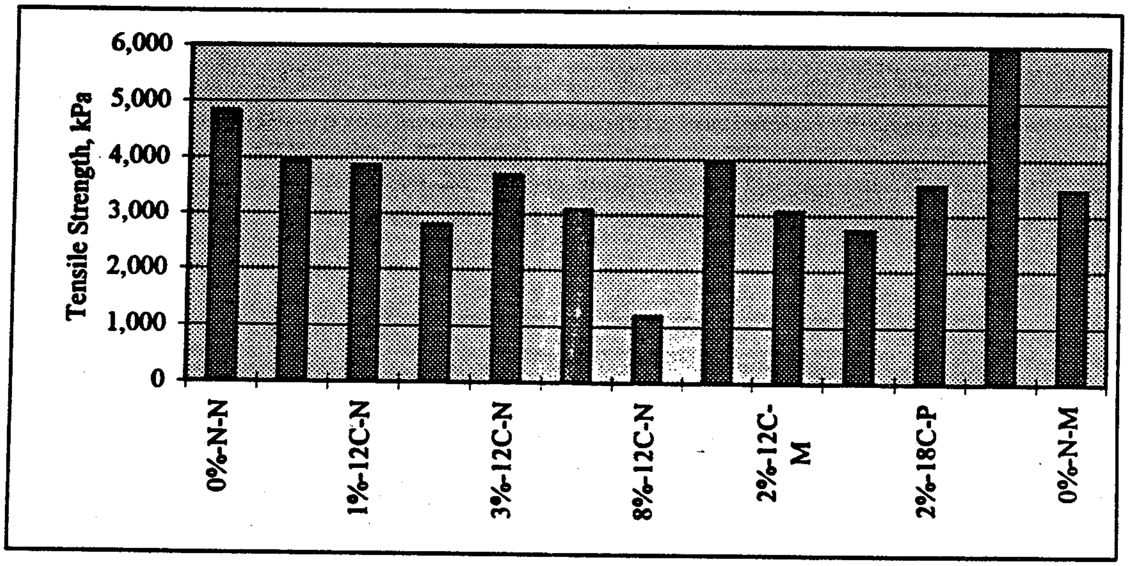

Figure 3. Tensile Strength, 28 Days

The entrained air varied greatly with the different treatments, Table 1. The 12 carbon at both 1 and 2% entrained more air than the air entraining additives. This may be a partial explanation for the strength reduction. The air in the voids carries no load but displaces load carrying concrete. There are no clear trends in the air entrainment data. For example, adding Polyheed to the plain mix more than doubled the air entrainment and increased sharply both the compressive strength and the resistance to frost damage. Adding Polyheed to the 2%-12C mix reduced the entrained air by 1/3 yet increased the compressive strength 50%.

Capillarity was measured for all mixes made, Table 1. Time restraints limited the number of permeability tests completed, last column of Table 1. Comparing the results of the two tests on the 2%-12C-N mix to those of the basic mix presents an interesting contrast. Addition of the 12C reduced the capillarity by three times but increased the permeability by three plus times. As the entrained air also increased by three times, the implications are that the micro voids increased permitting more water to be forced through the concrete under pressure. At the same time, the hydrophobic character of the 12C combats capillary motion.

TABLE 1 Water and Air Related Mix Properties

Mix	W/C	Air Entrain (percent)	Slump cm	Capillarity (percent)	Permeability (cm/sec)
0%-N-N	0.53	3.2	15.2	1.74	4.7 E-10
0%-N-AE	0.53	7.2	20.3	1.98	9.9 E-10
1%-12C-N	0.53	10	17.8	0.72	
2%-12C-N	0.53	9.8	12.7	0.57	1.2 E-9
3%-12C-N	0.5		2.5	0.55	
4%-12C-N	0.56		10.2	0.54	
8%-12C-N	0.65		17.8	0.61	
2%-12C-P	0.39	6.5	12.7	0.4	1.1 E-9
2%-12C-MA	0.47	6.2	8.9	0.42	
3%-18C-N	0.61		12.7	0.61	3.9 E-9
2%-18C-P	0.43		17.8	0.57	
0%-N-P	0.38	6.9	17.8	1.83	Impervious
0%-N-MA	0.48	8.6	6.4	1.54	

TABLE 2 Heavy Metal Concentration in Leachate from Intinerator Fly Ash Concrete

Test Parameter	Toxicity Level ug/L	Fly Ash No Cement ug/L	Fly Ash & 2%-12C No Cement ug/L	0%-N-N ug/L	Fly Ash & 0%-N-N ug/L	2%-12C-N ug/L
Silver	500	N D	N D	N D	N D	N D
Barium	100,000	2,225	1,668	638	676	423
Cadmium	1,000	43	64	5	5	5
Chromium	5,000	38	38	49	37	44
Arsenic,Total	5,000	10.1	10.7	N D	N D	N D
Selenium	1,000	4.6	3.6	N D	N D	N D
Lead	5,000	10,996	106.4	N D	6.7	N D

ND - Not Detected

TABLE 2 Continued

Test Parameter	Toxicity Level ug/L	Fly Ash & 2%-12C-N ug/L	Fly Ash & 0%-N-P ug/L	Fly Ash & 2%-12C-P ug/L	Fly Ash & 0%-N-MA ug/L	Fly Ash & 2%-12C-MA ug/L
Silver	500	N D	N D	N D	N D	N D
Barium	100,000	519	710	818	553	491
Cadmium	1,000	4	5	5	4	5
Chromium	5,000	36	36	34	32	33
Arsnic Total	5,000	N D	N D	N D	N D	N D
Selenium	1,000	N D	N D	N D	N D	N D
Lead	5,000	5.5	5.7	12.3	2.4	6.3

ND - Not Detected

The leachate tests were intended to evaluate the tendency for metals to wash out of the various concrete mixes. The third column of Table 2 lists the leachate levels from the untreated fly ash. All except lead were well below Federal Toxicity Limits. It should be recognized that, even when well mixed, incinerator fly ash has a variable composition and that minor differences may have little or no meaning. The fourth column represents the leachate from 12C treated fly ash that has not been in concrete. There was little change for four of the metals but barium was reduced by a quarter and lead by 100 times to a level well within the Toxicity limits. The addition of Portland Cement lowered most metals farther. The addition of Polyheed increased the quantity of barium and lead leached and the addition of Micro Air reduced both. The amount of chromium leachate was not affected by any of the the additives

PLANS FOR IMPLEMENTATION

The results justify trying Dipolar Alkenyl Dicarboxylic Acid Diammonium Salt modified concrete in exposed but non-strength critical work. An obvious place would be the Jersey barriers so widely used for traffic control during construction. At many sites, salt laden slush is thrown on the barriers by snow plows during winter storms creating severe freeze/thaw conditions. The barriers are moved frequently and any poor performers could be easily replaced.

There are several other characteristics that should be investigated for possible other uses. Unintentional removal of entrained air from concrete by vibration during placement often causes localized frost deterioration. The 12C as an additive did entrain substantial quantities of air. The tests, as performed in this study did not determine whether the frost protection was provided by the air entrained or by the hydrophobic character of the salt. If the latter, concrete using the salt as an additive would not be sensitive to placement vibration. Specimen should be made by rodding concrete containing the diammonium salt into molds and immediately vibrating until all entrained air is removed. If protection against frost damage persists, the problem of handling sensitivity would be solved.

The 12C salt has been used by the automobile industry to reduce corrosion. There have been serious corrosion problems with reinforcing bar. Galvanizing or epoxy coatings can reduce this problem but are susceptible to damage in shipping and placing. The degree to which the 12C salt, when added to concrete, chelates with the rebar surface should be investigated. As exposure of the bar to the diammonium salt in the concrete would occur after all bar handling was completed, there would be no further damage. This would be an extremely simple means of anti-corrosion treatment.

CONCLUSIONS

The Dipolar Alykenyl Dicarboxylic Acid Diammonium Salt has been proven to be as effective as conventional air entrainment for providing concrete with frost protection. There are many concrete uses where this material can now serve as an effective frost protection additive. Further studies are needed to evaluate other characteristics and to determine the best level of additive to balance strength and frost protection.

GLOSSARY

AE	Air Entrainment, deliberate inclusion of microscopic air bubbles
ASTM	American Society for Testing Materials
Darex	Commercially available air entrainment agent
GFAA	Graphite Furnace Atomic Absorption
ICP	Inductively Coupled Plasma Spectroscopy
Leachate	Water borne metal ions
Micro Air (MA) or (M)	Air entrainment agent marketed by Master Builders Co.
Polyheed (P)	Mid/high level plasticizer marketed by Master Builders Co.
W/C	Water to cement ratio
12C	12 Carbon molecule, Dipolar Alkenyl Dicarboxylic Diammonium Salt
18C	18 Carbon molecule, Dipolar Alkenyl Dicarboxylic Diammonium Salt

INVESTIGATORS PROFILES

JACK E. STEPHENS - Principle Investigator Professor Emeritus, Civil Engineering, University of Connecticut with a Masters and Doctorate from Perdue University with emphasis on construction materials. Taught the undergraduate and graduate lecture and laboratory courses in materials for the Civil Engineering Department at the University of Connecticut for 40 years. Carried out numerous researches on construction materials, both in the lab and in the field. Consultant to the construction industry and to state transportation departments.

James A. Mahoney - Research Assistant, Civil Engineering Department, University of Connecticut. C E Bachelors Degree from U. of Connecticut. Masters student and laboratory instructor.

James Humphrey - Consultant to Todd Chemical, Cheshire, CT. B S Chemistry, Bates College. Formerly applications chemist with Humphrey Chemical, North Hav_n, Connecticut. Worked with alkenyl succinic anhydrides. Chemical advisor to project.

John Zukel - Principle in Todd Chemical, Cheshire, Connecticut. B. S. Chemistry, University of Massachusetts, M. S. Biochemistry, University of Idaho, Ph.D. Biochemistry, Iowa State University. Formerly Senior Research Associate, Uniroyal Chemical Division, Naugatuck, Connecticut. Researched and developed products related to bioscience. Holds several patents in this area. Chemical advisor to project.

APPENDIX

TEST DATA

0%-N-N

	Mix Composition				
Cement	Sand	3/8" Trap	Water	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.68 kg	0.53	15.2 cm

Compression Strength		
Specimen	Reading	C. Strength
1	92,500 lb	50,700 kPa
2	89,000 lb	48,800 kPa
3	89,500 lb	49,100 kPa
	Average	49,500 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	36,400 lb	4,990 kPa
2	37,200 lb	5,100 kPa
3	31,900 lb	4,380 kPa
	Average	4,820 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.977	100%	7.999	100%	8.031	100%
36	7.980	62.7%	7.995	67.1%	8.018	67.8%
85	7.963	38.2%	7.999	42.7%	7.999	51.9%

0%-N-AE

	Mix Composition					
Cement	Sand	3/8" Trap	Water	AE Agent	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.68 kg	19.4 kg	0.53	20.3

Compression Strength		
Specimen	Reading	C. Strength
1	63,500 lb	34,800 kPa
2	67,500 lb	37,000 kPa
3	65,500 lb	35,900 kPa
	Average	35,900 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	28,400 lb	3,890 kpa
2	29,400 lb	4,030 kPa
3	28,000 lb	3,840 kPa
	Average	3,920 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.536	100%	7.559	100%	7.500	100%
36	7.532	98.7%	7.564	97.7%	7.496	98.1%
85	7.532	98.4%	7.582	98.2%	7.505	97.4%
126	7.545	99.3%	7.586	98.9%	7.514	98.9%
162	7.541	98.8%	7.586	99.3%	7.523	99.1%
201	7.545	99.2%	7.586	99.6%	7.527	98.8%
247	7.545	99.4%	7.591	99.8%	7.532	100.0%
297	7.550	100.1%	7.582	99.3%	7.527	99.7%
328	7.541	99.1%	7.577	98.3%	7.523	98.1%

1%-12C-N

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.67 kg	0.13 kg	0.53	17.8

Compression Strength		
Specimen	Reading	C. Strength
1	43,900 lb	24,100 kPa
2	39,600 lb	21,700 kPa
3	38,100 lb	20,900 kPa
	Average	22,200 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	19,200 lb	2,630 kPa
2	21,300 lb	2,920 kPa
3	22,000 lb	3,020 kPa
	Average	2,860 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.170	100%	7.184	100%	7.125	100%
48	7.206	97.8%	7.220	97.4%	7.147	96.2%
80	7.211	97.6%	7.238	97.3%	7.166	96.8%
131	7.229	98.1%	7.252	97.9%	7.179	97.6%
195	7.229	99.1%	7.243	98.4%	7.179	98.2%
238	7.211	98.7%	7.224	98.5%	7.156	98.6%
308	7.193	97.7%	7.193	98.0%	7.134	98.4%

2%-12C-N

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.69 kg	0.25 kg	0.53	12.7

Compression Strength		
Specimen	Reading	C. Strength
1	42,800 lb	23,500 kPa
2	42,600 lb	23,400 kPa
3	42,000 lb	23,000 kPa
	Average	23,300 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	22,300 lb	3,060 kPa
2	19,400 lb	2,660 kPa
3	19,800 lb	2,710 kPa
	Average	2,810 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.491	100%	7.323	100%	7.382	100%
31	7.523	96.3%	7.355	96.0%	7.418	95.8%
76	7.545	98.0%	7.373	98.5%	7.441	98.5%
117	7.541	99.1%	7.355	100.2%	7.427	99.2%
166	7.527	99.3%	7.337	99.5%	7.414	99.4%
200	7.527	99.5%	7.332	99.3%	7.396	99.4%
240	7.505	98.7%	7.323	98.3%	7.378	98.0%
286	7.491	98.1%	7.305	95.5%	7.364	97.2%
330	7.473	96.0%	7.296	93.9%	7.355	96.6%

3%-12C-N

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.30 kg	0.38 kg	0.5	2.5

Compression Strength		
Specimen	Reading	C. Strength
1	45,500 lb	24,700 kPa
2	53,000 lb	29,100 kPa
3	51,200 lb	28,000 kPa
	Average	27,300 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	27,500 lb	3,770 kPa
2	27,700 lb	3,800 kPa
3	25,900 lb	3,550 kPa
	Average	3,710 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.872	100%	7.954	100%	7.832	100%
41	7.913	96.9%	7.990	97.1%	7.872	96.8%
77	7.913	96.8%	7.986	97.0%	7.859	96.4%
116	7.904	95.9%	7.986	96.1%	7.859	94.5%
163	7.904	94.1%	7.977	95.6%	7.845	94.6%
213	7.900	90.0%	7.977	94.7%	7.845	94.0%
244	7.886	86.9%	7.968	91.6%	7.841	91.5%
289	7.877	87.1%	7.950	9.1%	7.827	90.4%
330	7.877	86.5%	7.950	88.0%	7.827	90.2%
379	7.854	82.4%	7.931	85.5%	7.809	88.1%

4%-12C-N

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	7.02 kg	0.50 kg	0.56	10.2

Compression Strength		
Specimen	Reading	C. Strength
1	46,300 lb	25,400 kPa
2	47,200 lb	25,900 kPa
3	45,100 lb	24,700 kPa
	Average	25,300 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	22,200 lb	3,050 kPa
2	23,500 lb	3,220 kPa
3	21,900 lb	3,000 kPa
	Average	3,090 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.441	100%	7.341	100%	7.382	100%
41	7.464	97.7%	7.373	97.6%	7.405	97.2%
90	7.450	97.3%	7.355	96.7%	7.396	97.2%
124	7.437	96.9%	7.332	96.8%	7.387	96.6%
164	7.409	96.1%	7.305	95.8%	7.359	95.2%
210	7.364	95.9%	7.273	94.7%	7.328	94.0%
254	7.359	94.0%	7.264	92.7%	7.314	92.6%
302	7.337	93.2%	7.232	92.6%	7.246	90.9%

8%-12C-N

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	8.25 kg	1.01 kg	0.65	17.8

Compression Strength		
Specimen	Reading	C. Strength
1	16,200 lb	8,890 kPa
2	15,400 lb	8,470 kPa
3	15,600 lb	8,540 kPa
	Average	8,630 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	8,700 lb	1,190 kPa
2	8,650 lb	1,180 kPa
3	8,900 lb	1,220 kPa
	Average	1,200 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.378	100%	7.505	100%	7.332	100%

Test Discontinued, Specimens Fell Apart

2%-12C-P

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	5.65 kg	0.25 kg	0.39	12.7
			Polyheed			
			197 ml			

Compression Strength		
Specimen	Reading	C. Strength
1	72,000 lb	39,500 kPa
2	70,000 lb	38,400 kPa
3	67,500 lb	38,100 kPa
	Average	38,700 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	30,700 lb	4,210 kPa
2	27,500 lb	3,770 kPa
3	28,100 lb	3,850 kPa
	Average	3,940 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.533	100%	7.533	100%	7.519	100%
42	7.565	96.4%	7.556	97.5%	7.560	96.9%
88	7.578	97.0%	7.569	98.2%	7.573	99.4%
130	7.583	95.8%	7.569	96.9%	7.573	97.5%
178	7.574	93.4%	7.569	96.3%	7.565	95.7%
221	7.560	92.8%	7.560	98.8%	7.556	93.8%
264	7.546	93.4%	7.551	98.2%	7.542	93.8%
304	7.565	93.4%	7.546	96.9%	7.528	94.5%

2%-12C-MA

	Mix Composition					
Cement	Sand	3/8" Trap	Water	12C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.62 kg	0.25 kg	0.47	8.9
			Micro Air			
			132 ml			

Compression Strength		
Specimen	Reading	C. Strength
1	48,800 lb	26,800 kPa
2	48,200 lb	26,400 kPa
3	45,500 lb	24,900 kPa
	Average	26,000 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	25,600 lb	3,510 kPa
2	19,300 lb	2,650 kPa
3	22,200 lb	3,040 kPa
	Average	3,070 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.401	100%	7.410	100%	7.546	100%
42	7.451	95.9%	7.465	95.9%	7.560	94.7%
88	7.433	97.3%	7.451	100.0%	7.583	96.7%
130	7.406	95.3%	7.442	97.3%	7.556	95.4%
178	7.374	97.3%	7.383	94.6%	7.528	93.4%
221	7.338	92.6%	7.333	92.6%	7.450	94.1%
264	7.333	91.9%	7.311	93.3%	7.490	94.1%
304	7.283	91.9%	7.280	91.9%	7.438	94.7%

3%-18C-N

Mix Composition						
Cement	Sand	3/8" Trap	Water	18C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	7.68 kg	0.39 kg	0.61	12.7

Compression Strength		
Specimen	Reading	C. Strength
1	44,200 lb	24,300 kPa
2	43,700 lb	24,000 kPa
3	39,800 lb	21,800 kPa
	Average	23,400 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	19,400 lb	2,660 kPa
2	20,400 lb	2,780 kPa
3	19,800 lb	2,710 kPa
	Average	2,720 kPa

Freeze Thaw Data

Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.241	100%	7.291	100%	7.282	100%
34	7.282	97.6%	7.323	97.9%	7.318	98.3%
74	7.264	97.5%	7.309	98.8%	7.300	98.6%
120	7.250	99.2%	7.309	98.7%	7.282	97.6%
164	7.223	96.9%	7.287	97.2%	7.246	95.0%
212	7.205	95.0%	7.259	96.9%	7.228	94.8%
244	7.180	91.4%	7.239	94.5%	7.203	92.1%
295	7.158	89.6%	7.212	91.8%	7.185	91.1%
359	7.126	87.80%	7.199	91.0%	7.126	90.1%

2%-18C-P

	Mix Composition					
Cement	Sand	3/8" Trap	Water	18C Additive	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.13 kg	0.25 kg	0.43	17.8
			Polyheed			
			197 ml			

Compression Strength		
Specimen	Reading	C. Strength
1	56,500 lb	31,000 kPa
2	58,000 lb	31,800 kPa
3	54,500 lb	29,900 kPa
	Average	30,900 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	25,800 lb	3,540 kPa
2	25,200 lb	3,450 kPa
3	26,300 lb	3,600 kPa
	Average	3,530 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.388	100%	7.347	100%	7.488	100%
42	7.406	95.6%	7.397	95.5%	7.533	93.8%
88	7.433	98.1%	7.406	95.5%	7.538	93.1%
130	7.424	94.9%	7.397	94.2%	7.528	91.3%
178	7.415	94.9%	7.392	94.2%	7.515	90.1%
221	7.397	92.5%	7.367	89.9%	7.450	89.4%
264	7.388	94.9%	7.361	90.5%	7.480	90.1%
304	7.370	93.1%	7.379	91.1%	7.460	89.5%

0%-N-P

Mix Composition						
Cement	Sand	3/8" Trap	Water	Polyheed	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	4.84 kg	197 ml	0.38	17.8

Compression Strength		
Specimen	Reading	C. Strength
1	114,000 lb	62,500 kPa
2	113,500 lb	62,200 kPa
3	115,000 lb	63,100 kPa
	Average	62,600 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	41,900 lb	5,740 kPa
2	43,200 lb	5,920 kPa
3	47,400 lb	6,500 kPa
	Average	6,050 kPa

Freeze Thaw Data						
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.542	100%	7.624	100%	7.506	100%
42	7.550	97.7%	7.628	98.8%	7.510	96.5%
88	7.550	99.4%	7.633	102.9%	7.510	100.0%
130	7.551	98.8%	7.633	102.3%	7.524	100.0%
178	7.551	98.8%	7.633	104.1%	7.524	100.0%
221	7.551	99.4%	7.633	103.5%	7.519	104.1%
304	7.551	100.6%	7.633	102.9%	7.524	101.2%

0%-N-MA

	Mix Composition					
Cement	Sand	3/8" Trap	Water	Micro Air	Water/Cement	Slump (cm)
12.61 kg	24.57 kg	22.02 kg	6.05 kg	132 ml	0.48	6.4

Compression Strength		
Specimen	Reading	C. Strength
1	48,800 lb	30,300 kPa
2	48,200 lb	29,900 kPa
3	45,500 lb	30,200 kPa
	Average	30,100 kPa

Indirect Tension Strength		
Specimen	Reading	T. Strength
1	25,600 lb	3,650 kPa
2	19,30(lb	3,320 kPa
3	22,200 lb	3,370 kPa
	Average	3,450 kPa

		Freeze Thaw Data				
Cycles	Weight (kg) Specimen 1	Rel.Dyn.Mod Specimen 1	Weight (kg) Specimen 2	Rel.Dyn.Mod. Specimen 2	Weight (kg) Specimen 3	Rel.Dyn.Mod. Specimen 3
0	7.424	100%	7.410	100%	7.415	100%
42	7.460	98.7%	7.442	96.2%	7.451	96.1%
88	7.460	99.4%	7.447	98.7%	7.465	100.0%
130	7.442	98.1%	7.429	97.4%	7.447	97.4%
178	7.424	98.1%	7.410	98.1%	7.430	98.7%
221	7.401	100.6%	7.392	98.7%	7.415	100.7%
304	7.374	99.4%	7.365	100.0%	7.390	98.7%