ESCSI
Expanded Shale Clay & Slate Institute

Information Sheet # 3384

FREEZING AND THAWING RESISTANCE OF SEGMENTAL RETAINING WALLS

This research report on the Freeze-Thaw performance of commercially available lightweight and normalweight segmental retaining wall (SRW) units was presented at the Seventh North American Masonry Conference - June 2-5, 1996, University of Notre Dame, South Bend, Indiana.

The report concludes that the density of the SRW unit has no significant effect on its durability. Consequently, properly designed SRW units containing expanded shale, clay and slate aggregate can be expected to perform comparably to normalweight aggregate units.

SRW units are frequently placed in harsh environments where moist conditions and a large number of freezing and thawing cycles can occur each year. Therefore, the concrete mixture must be designed to be durable in a freezing and thawing environment, regardless of the type of aggregate used in the SRW units. This study reinforced and expanded our knowledge of what is needed to provide freeze-thaw durability. The ESCS producer should be consulted about recommended mix designs.

TEST OF FREEZE-THAW RESISTANCE OF COMMERCIALLY AVAILABLE LIGHTWEIGHT AND NORMALWEIGHT CONCRETE MASONRY MIXES USED IN SEGMENTAL RETAINING WALL UNITS

Theodore W. Bremner[1] and John P. Ries[2]

ABSTRACT

The purpose of this test program was to analyze the freeze-thaw performance of commercially available lightweight and normalweight segmental retaining wall (SRW) units made at thirteen (13) different block manufacturing plants located in the United States. The block manufacturing plants made both lightweight and normalweight units on the same day using the same machine, cement, and curing regime. The thirteen normalweight control mixes (130 to 145 lbs/cf) (2080 to 2320 kg/m^3) were typically what the block company uses on a regular basis for SRW units, and were made with normalweight sand and gravel aggregate. The twenty mixes incorporating lightweight aggregate (90 to 118 lbs/cf) (1440 to 1890 kg/m^3) were developed using higher design criteria than regular concrete masonry units to accommodate the harsh environment often endured by SRWs. Net compressive strength of 4000 to 6000 psi (27.6 to 41.4 MPa), and absorption of less than 10 lbs/cf (160 kg/m^3) were targeted. Some of these lightweight mixes are also being used commercially on a regular basis. The lightweight aggregate used was predominately expanded shale, clay, and slate (ESCS) manufactured by the rotary kiln method.

Over 175 test coupons, from 33 lightweight and normalweight mixes, were tested according to ASTM C1262-94, Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units (1).

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[1] Professor of Civil Engineering, University of New Brunswick, Fredericton, NB E3B 5A3 Canada

[2] Executive Director, Expanded Shale, Clay, and Slate Institute, Salt Lake City, Utah, USA

The results of these tests indicated that no correlation existed between freeze-thaw durability and concrete density. The lighter units made by adding ESCS aggregate performed as well as the control normalweight units. As a secondary interest, the data were analyzed to determine if any correlation existed between the extent of deterioration and the absorption, cementitious content, strength, and admixture usage.

KEYWORDS

Concrete masonry, freeze-thaw durability, absorption, lightweight, normalweight, segmental retaining walls, expanded, aggregates.

INTRODUCTION

This project investigates the freeze-thaw durability of commercially available lightweight and normalweight block concretes used in the manufacture of segmental retaining wall (SRW) units. The mixtures were run at 13 different block manufacturing plants with all units made being 4 x 8 x 16 in. (102x204x406 mm) solid masonry units. Coupons (5 per mix) were cut from the end of the 4 x 8 x 16 in. (102x204x406 mm) solid units, and sent to the University of New Brunswick (UNB) to be tested according to the American Society for Testing and Materials (ASTM) C1262-94, Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units (1). Tests for strength, absorption, and density (unit weight) were completed at local laboratories on companion specimens. The results of these tests were analyzed to determine if lowering the weight of a SRW unit by adding ESCS lightweight aggregate would effect the freeze-thaw durability of the unit. As a secondary interest, the data were analyzed to determine if any correlation existed between the extent of deterioration and the absorption, cementitious content, strength, and admixture usage.

The reason for doing this work is two fold. First, to help set industry standards for durable concrete SRW units. Secondly, SRW units made with normalweight aggregate are very heavy, with some weighing more than 100 lbs.(45.5 kg) each. If the units weighed less, there would be many economical advantages. Labor productivity on commercial projects would greatly increase because less weight is being handled. The do-it-yourself market would increase because the SRW systems would be more user friendly and easier to handle. Other advantages would be fewer worker-compensation injuries, and more units can be transported on the same truck.

DETERIORATION DUE TO FREEZING AND THAWING

Segmental retaining wall units are frequently placed in harsh environments where a large number of freezing and thawing cycles can occur each year. Also, they are used in high moisture content applications where they can absorb water. Water expands by nine (9) percent when it freezes. Any voids in the hydrated cement paste or aggregate that are greater than 91 percent full will develop a hydraulic pressure when the water changes to ice, unless the water can be forced from the void during freezing (2). Masonry units, being of a porous texture, tend to lose water during the dry season of the year and so the chances of having voids fully saturated during the cold wet season are reduced. Although masonry units normally are not air entrained, they frequently have a chemical admixture added to the mix that would entrain some air in a regular concrete mixture. When expanded shale, clay, and slate aggregates are used to produce lightweight concrete masonry units the vesicules within these expanded aggregates can act as relief mechanisms, whereby the pores within the aggregates can provide relief from the hydraulic pressure developed during the freezing of the concrete. With normalweight aggregates that contain coarse internal channels that easily fill with water, the opposite can occur; in some instances, deterioration of concrete has been traced to the use of this type of aggregate (3).

MIX PROPORTIONS

Mix designs ranging from 93 lbs/cf to 143 lbs/cf (1490 to 2290 kg/m^3) were tested in this investigation. The variation of density is largely due to the amount of expanded shale, clay, or slate lightweight aggregate in the mix. The mixture proportions for the various concretes are given in Table 1A of the Appendix.

AGGREGATES

Most normalweight aggregates have relative densities (specific gravities) in the order of 2.4 to 2.9 with lightweight aggregates having relative densities from 0.5 to 2.0. The lower density for lightweight aggregates is due to the aggregates having a vesicular structure. Although lightweight aggregates are generally less strong than normalweight aggregates due to their less dense interior structure, they are still able to make concretes of acceptable and, in some cases, extremely high strength. Lightweight aggregates perform extremely well in concrete because, when combined with a cement mortar matrix, they form a homogeneous, elastically compatible material.

The lightweight aggregates used in this investigation were expanded shale, clay, or slate made by the rotary kiln process with the exception of one control mix that included a small amount of pumice, and another control mix that included a small amount of bottom ash.

MANUFACTURE OF MASONRY UNITS

Each block manufacturing plant made both lightweight aggregate mixes and normalweight aggregate mixes on the same day using the same machine, cement, and curing regime. Most of the normalweight control mixtures (130 to 142 lbs/cf) (2080 to 2270 kg/m^3) tested were standard commercially available SRW mixtures used by that block company. The lightweight aggregate SRW mixes ranging from 94 to 118 lbs/cf (10510 to 1890 kg/m^3) were developed jointly by the lightweight aggregate producer and the block plant using a higher design criteria with a net strength greater than 4000 psi (27.6 MPa) and 10 lbs/cf (160 kg/m^3) maximum absorption. Some of the lightweight aggregate mixtures are used extensively, and some needed to be modified slightly for commercial use.

TESTING PROCEDURE

Over 175 test coupons from lightweight and normalweight concrete masonry units were tested according to ASTM C1262-94 "Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units." As required by this standard, each specimen was completely submerged in water at a temperature of 60 to 80 degrees F (15.6 to 26.6°C) for 48 hours. Upon removal from the water, the visible surface water was removed with a damp cloth, and the specimen was weighed. The specimen weight was recorded as the saturated weight. The saturated specimens were then placed face down in the containers on the specimen supports (non saw-cut surface) and the water in the container was adjusted to 10 mm from the bottom of the concrete specimens. The containers were sealed to prevent evaporation.

The test begins with a freezing cycle for a period of 4.5 hours and a thaw cycle of 3.5 hours. One freeze thaw cycle is defined as a complete freeze cycle followed by a complete thaw cycle.

Three freezing and thawing cycles are completed each day, seven times a week for a total of twenty-one cycles per week. After 21 cycles the individual specimens are removed from the container and rinsed with water. All the rinse water is carefully collected in the container along with all loose particles from the specimen. The water is poured from the specimen container through previously weighed filter paper (Wf) to collect the residue from the test specimen. This is continued until all residue is collected. The specimen is then returned to the container and sealed, and the next freezing and thawing cycle can then begin. The filter paper is dried, then weighed (Wf+r), and the residue weight is calculated: Wr=Wf+r-Wf. The amount of deterioration can be calculated by dividing the weight of residue by the saturated weight of the specimen. The procedure was repeated until all the accumulated residue of a specimen exceeds 10% of the initial saturated weight, or until 500 freezing and thawing cycles have been completed. The cumulative % loss at 105, 315, and 500 cycles, as well as the cycles at which dilation occurred are listed in Table 1A of the Appendix.

Although ASTM 1262-94 specifies that percent deterioration should be calculated after every 8 to 12 freeze-thaw cycles, it was decided to calculate deterioration after every 21 cycles so as to fit in with a weekly cycle. This procedure will be submitted to ASTM Committee C-15 as a recommended change.

TEST RESULTS

Deterioration expressed as a percentage loss in mass is plotted against density, absorption, cementitious content, and strength in Figures 1 to 4.

Deterioration vs Density

The relationship between deterioration and density at 105 and 315 cycles of freezing and thawing is shown in Figure 1. No correlation between the density of the concrete and the concrete's ability to resist freezing and thawing is evident.

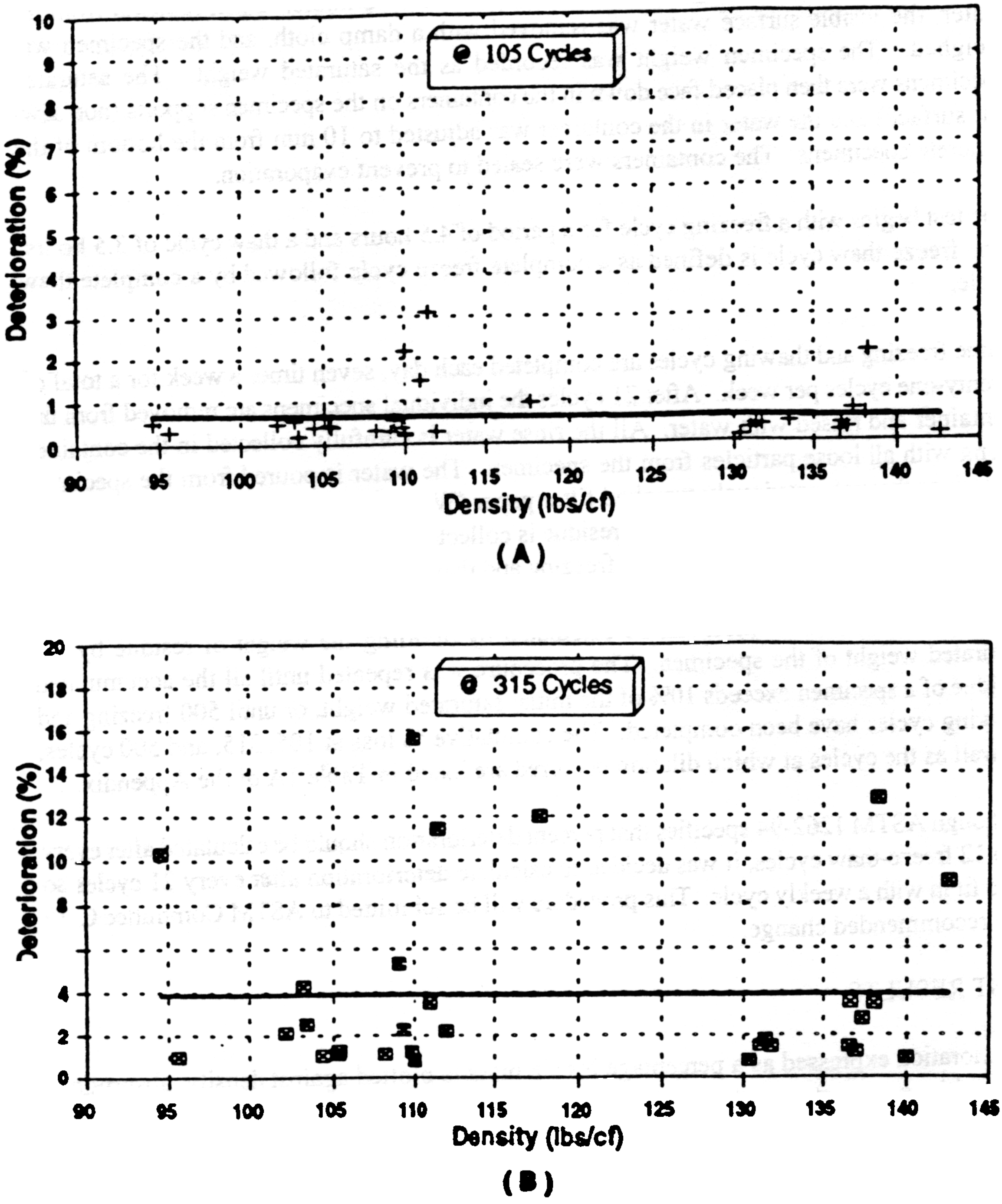

Figure 1. Relationship between deterioration and density at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

Deterioration vs Absorption

The relationship between deterioration and absorption at 105 and 315 cycles of freezing and thawing is shown in Figure 2. No correlation between the concrete's absorption and its resistance to freezing and thawing is evident at 105 cycles, but at 315 cycles a slight tendency for deterioration to increase with increasing absorption was observed.

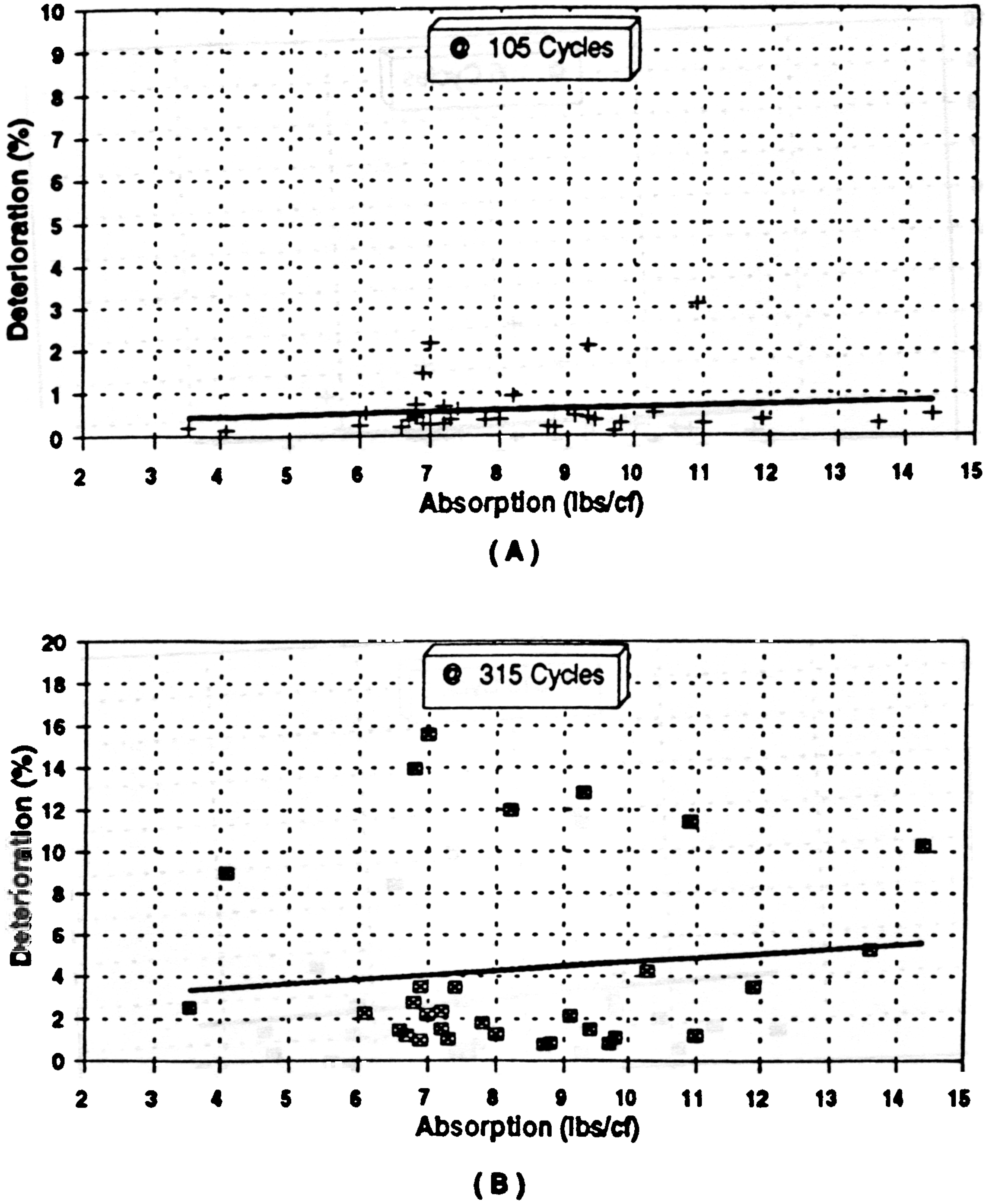

Figure 2. Relationship between deterioration and absorption at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

Deterioration vs Cementitious Content

The relationship between deterioration and cementitious content at 105 and 315 cycles is shown in Figure 3. The results show durability slightly improving with increasing cementitious content.

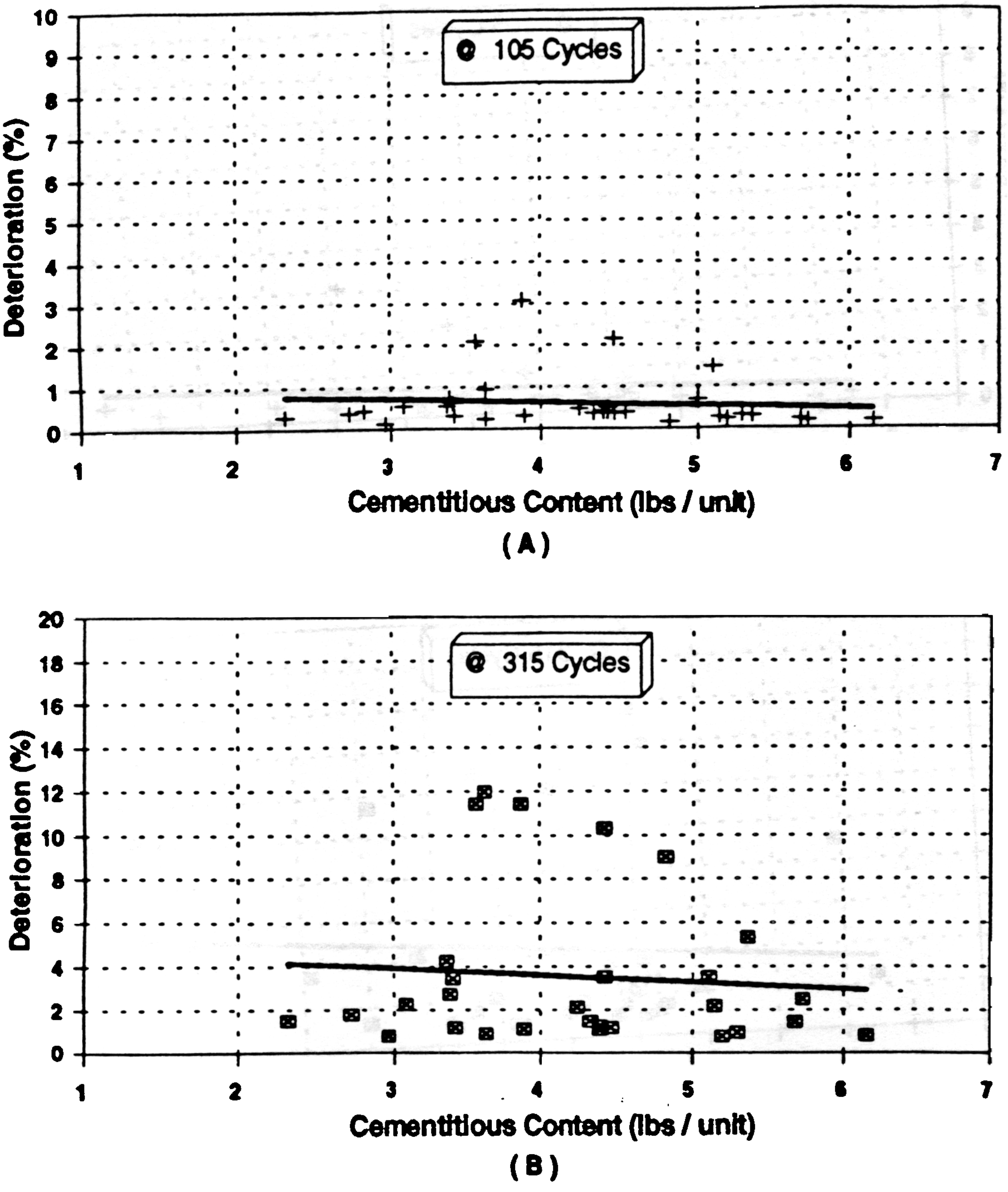

Figure 3. Relationship between deterioration and cementitious content at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

Deterioration vs Strength

The relationship between deterioration and strength at 105 and 315 cycles of freezing and thawing is shown in Figure 4. The graphs show a trend towards increased durability with increase in strength.

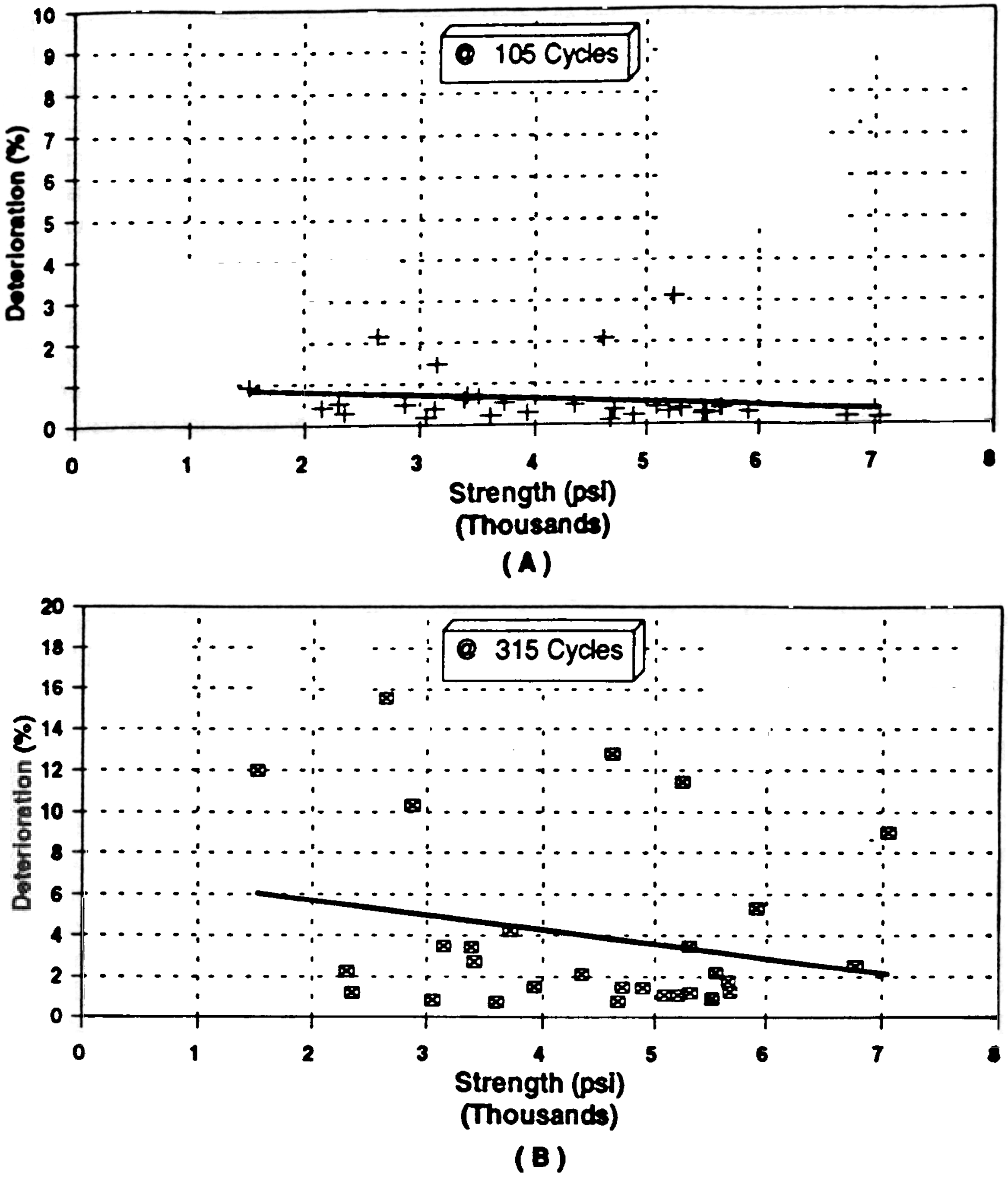

Figure 4 Relationship between deterioration and strength at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

DISCUSSION OF RESULTS

In Figures 1 to 4 the deterioration (% loss) is plotted against density, absorption, cementitious content, and strength respectively. There is no strong correlation with any of these variables. In Figures 1 and 2 all specimens of density less than 120 lbs/cf (1920 kg/m^3) contain varying amounts of expanded shale, clay, or slate lightweight aggregates. Specimens above 130 lbs/cf (2080 kg/m^3) contain essentially all normalweight aggregates. Figures 1 and 2 indicate that expanded shale, clay and slate aggregate produce as durable a concrete with respect to the ASTM C1262 test as does normalweight concrete. Wendt and Woodworth did a similar type of freezing and thawing testing, and for units with a compressive strength of approximately 1000 psi (6.9 MPa) gross, arrived at similar results (4). Shideler and Toennies (5) also obtained similar results on freeze-thaw tests on concrete masonry units at 1000 and 1500 psi (6.9 and 10.3 MPa) using low-pressure and high-pressure steam curing. A trend towards more durable masonry units with increasing strength can be inferred from Figures 4 which was confirmed by the two previously mentioned studies.

Considering the scatter of data in Figures 1 to 4 inclusive, it would appear that additional factors need to be considered. Based on a visual observation of the detritus, it would appear that aggregate gradation is a significant factor affecting the failure mechanism. Additional information has been requested from the producers of the masonry units, and this data, as well as the information in Table 1A of the Appendix, will be subjected to further statistical analysis. Also, samples of the units tested, as well as untested companion samples, will be subjected to petrographic analysis to attempt to further analyze these results.

Plasticizers and/or integral-waterproofing admixtures were used in 78% of the mixes. In general, the mixtures without admixtures performed as well as mixtures with admixtures. Two mixtures used air entrained cement, and both performed well. Further work will be done to explain the role admixtures play in the durability of these masonry units.

METHOD OF FAILURE

The results of the cumulative weight loss (% deterioration) vs number of cycles of freezing and thawing show two distinct patterns. Figure 1A in the Appendix shows a uniform low rate of mass loss, and is typical of eleven lightweight samples and six normalweight samples. Figure 2A in the Appendix also shows a uniform loss of mass but at a high rate, and is typical of one lightweight sample and one normalweight sample. Figure 3A and 4A show a different pattern: a slow rate of mass loss for several freeze-thaw cycles initially, then rapid rate of deterioration occured. It resulted in a dilation of the specimen with a rapid increase in the rate of deterioration per cycle, leading to complete collapse of all or part of the specimen in a few cycles. The dilation prior to collapse resulted in the thickness of some specimens increasing by about 10%. The failure was a granularization process with the individual granules in some instances being relatively strong. Figures 3A and 4A in the Appendix are typical of eight lightweight samples and six normalweight samples.

As can be seen in Figure 1A to 4A inclusive, the within test variation for the five cupons each cut from a separate masonry unit (and representing one mix) is small, and confirms the effectiveness of the testing procedure used.

CONCLUSION

Based on the results of these tests the density of the concrete masonry units appears to have no significant effect on the results of the ASTM C1262-94 Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units. Consequently, concrete masonry units containing expanded shale, clay, and slate can be expected to perform as well as normalweight aggregates where freezing and thawing is involved.

ACKNOWLEDGEMENTS

We would like to thank Michele A. Blanchard and Sina Zabihiyan at the University of New Brunswick for carrying out the tests, recording the data, preparing the tables, graphs, and preliminary report.

A special thanks to the block companies that made the SRW units, and helped in the development and testing of the mixes used: Adams Products, Akron Brick and Block, Anchor Concrete, Capitol Concrete Products, Charlotte Block Inc., Cinder and Concrete Block Corp., Clayton Block Company, Consumers Block Company, Dubois County Concrete, Johnson Concrete Co., Mooresville Block Company, Superior Plasticrete Corp., and TXI Concrete Products.

Lightweight aggregate manufacturers participating in the study were: Big River Industries, Buildex Inc., Carolina Stalite Co., Lehigh Portland Cement Co., Norlite Corp., Hydraulic Press Brick Co., Solite Corporation, and Texas Industries.

REFERENCES

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3 Concrete Manual, 8th Edition revised 1981. "A Water Resources Technical Publication." US Department of the Interior, Water and Power Resources Service.

4 Wendt, Kurt F. and Woodworth, Paul M. 1939. "Tests on Concrete Masonry Units Using Tamped and Vibrated Molding Methods." American Concrete Institute, Vol. 36, November: 121-163.

5. Shideler J. and Toennies, H. 1967. "Laboratory Freeze-Thaw Resistance of Concrete Masonry." Portland Cement Association, Research and Development Division, PCA R/D, Ser. 1294-1.

'abl Ml Proportions

Mix	Cement	Flyash	Cementitious	LWA	NWA	Admixture	Strength	Absorption	Density	Cum. % Loss at Cycles			Cycles to Dilation
#	lbs - type (kg)	lbs - class (kg)	material lbs / unit	lbs (kg)	lbs (kg)		psi (MPa)	lbs/cf (kg/m)	lbs/cf (kg/m)	105	315	500	
1	650 I 295		3.63	800 364	3800 1727	YES	1519 10	8.2 131.4	117.6 1884	0.94	F	F	168
2	500 III 227		2.96		5000 2273	NO	4687 32	9.7 155.4	130.4 2089	0.12	0.82	1.92	
3	530 III 240		2.31		7000 3182	YES	3931 27	7.2 115.3	131.1 2100	0.29	1.15	2.46	
4	600 I 273		4.26	2495 1134	500 227	YES	4360 30	9.1 145.8	102.1 1635	0.46	2.12	3.48	
5	800 I 364		5.19	2000 909	1425 648	YES	3610 25	8.7 139.4	110.0 1762	0.21	0.78	1.58	
6	575 I 261	90-C 41	5.68		3331 1514	YES	4893 34	6.6 105.7	136.6 2188	0.28	1.45	3.24	
7	800 I 364	192-F 87	6.16	2000 909	1425 648	YES	3054 21	8.8 141.0	110.0 1762	0.19	0.84	1.56	
8	775 352		3.88	1500 682	3300 1500	YES	5240 36	10.9 174.6	111.5 1786	3.06	F	F	42
9	680 III 309		2.81		7410 3368	NO	2155 15	6.8 108.9	133.4 2137	0.44	F	F	147
10	600 I 273		4.44	2400 1091	4000 1818	YES	5301 37	11.9 190.6	136.7 2190	0.38	3.49	F	273
11	1000 III 455		3.89	2400 1091	3537 1608	YES	5197 36	9.8 157.0	108.1 1732	0.31	1.09	2.38	
12	600 I 273		4.41	2495 1134	500 227	NO	5670 39	8.0 128.1	105.4 1688	0.40	1.26	2.06	
13	750 I 341		5.1	2100 955	1225 557	YES	3150 22	6.9 110.5	111.0 1778	1.46	3.49	5.37	
14	455 I 207	50-F 23	4.55	1500 682	900 409	YES	3127 22	7.3 116.9	104.4 1672	0.36	1.03	3.84	
15	650 I 295		4.48	2100 955	1225 557	YES	5313 37	6.7 107.3	109.8 1759	0.37	1.28	9.82	
16	783 III 356		4.83		5000 2273	YES	7050 49	4.1 65.7	142.6 2284	0.16	9.03	F	147
17	600 IA 273		4.44	1700 773	900 409	NO	2875 20	14.4 230.7	94.6 1515	0.50	F	F	189

Failed

on

Table 1A (Cont.) Mix Proportions

Mix #	Cement	Flyash	Cementitious material	LWA	NWA	Admixture	Strength	Absorption	Density	Cum. % Loss at Cycles			Cycles to Dilation
	lbs - type (kg)	lbs - class (kg)	lbs / unit	lbs (kg)	lbs (kg)		psi (MPa)	lbs/cf (kg/m)	lbs/cf (kg/m)	105	315	500	
18	525 I 239		3.39		4800 2182	YES	3420 24	6.8 108.9	137.4 2201	0.74	1.73	3.96	
19	750 I 341		5.14	2100 955	1225 557	YES	5535 38	7.0 112.1	112.0 1794	0.28	2.13	6.23	
20	500 IA 227		4.35		3300 1500	YES	4723 33	9.4 150.6	131.8 2111	0.37	1.47	3.64	
21	783 III 356		5.72	2505	253 115	YES	6754 47	3.5 56.1	103.4 1656	0.19	2.53	6.47	
22	720 III 327		3.09	2180	3880 1764	NO	2300 16	6.1 97.7	109.3 1751	0.54	2.34	F	336
23	500 I 227		3.42		4500 2045	YES	2350 16	11.0 176.2	137.0 2195	0.30	1.27	F	378
24	450 III 205		2.71		5000 2273	YES	4655 32	7.8 124.9	131.4 2105	0.37	1.80	3.64	
25	455 I 207	120-F 55	5	1400 636	1050 477	YES	3510 24	7.2 115.3	105.0 1682	0.73	2.47	3.51	
26	525 I 239		3.41		4800 2182	NO	3390 23	7.4 118.5	138.1 2212	0.62	3.46	9.30	378
27	660 300		3.57		5750 2614	YES	4630 32	9.3 149.0	138.3 2215	2.06	F	F	63
28	575 I 261	90-C 41	5.36	2420 1100	300 136	YES	5910 41	13.6 217.9	109.0 1746	0.28	5.25	F	273
29	450 III 205	130-F 59	3.37	2000 909	1850 841	NO	3725 26	10.3 165.0	103.2 1653	0.57	4.19	F	399
30	650 I 295		4.48	2100 955	1225 557	YES	2650 18	7.0 112.1	110.0 1762	2.16	F	F	168
31	783 III 356		5.29	2505 1139	253 115	YES	5510 38	6.9 110.5	95.6 1531	0.30	0.91	1.87	
33	340 I 155	135-C 61	3.63		4100 1864	YES	5500 38	6.0 96.1	140.0 2243	0.25	0.91	1.66	
34	580 I 264		4.14	1600 727	1500 682	YES	5082 35	9.3 149.0	105.3 1687	0.43	1.41	2.71	

Failed

Mix 32 lost in shipping

Revised on 996, 07,

Appendix

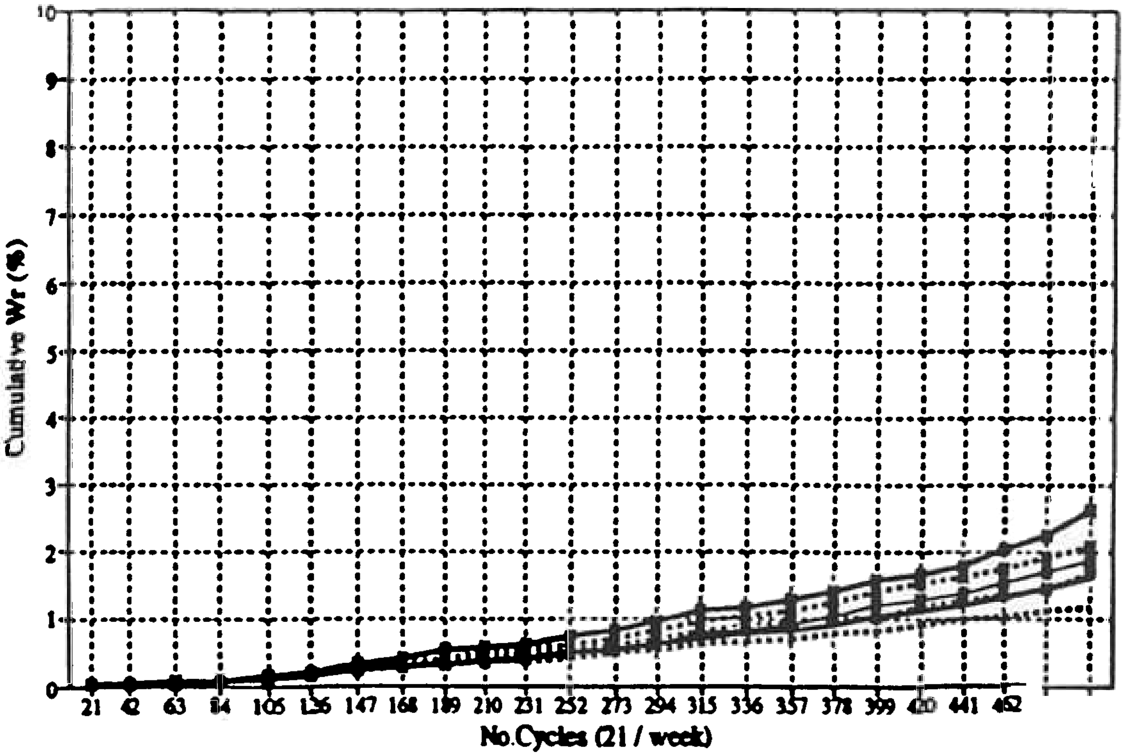

Figure 1A. Effect of freezing and thawing on coupons cut from masonry units showing good performance.

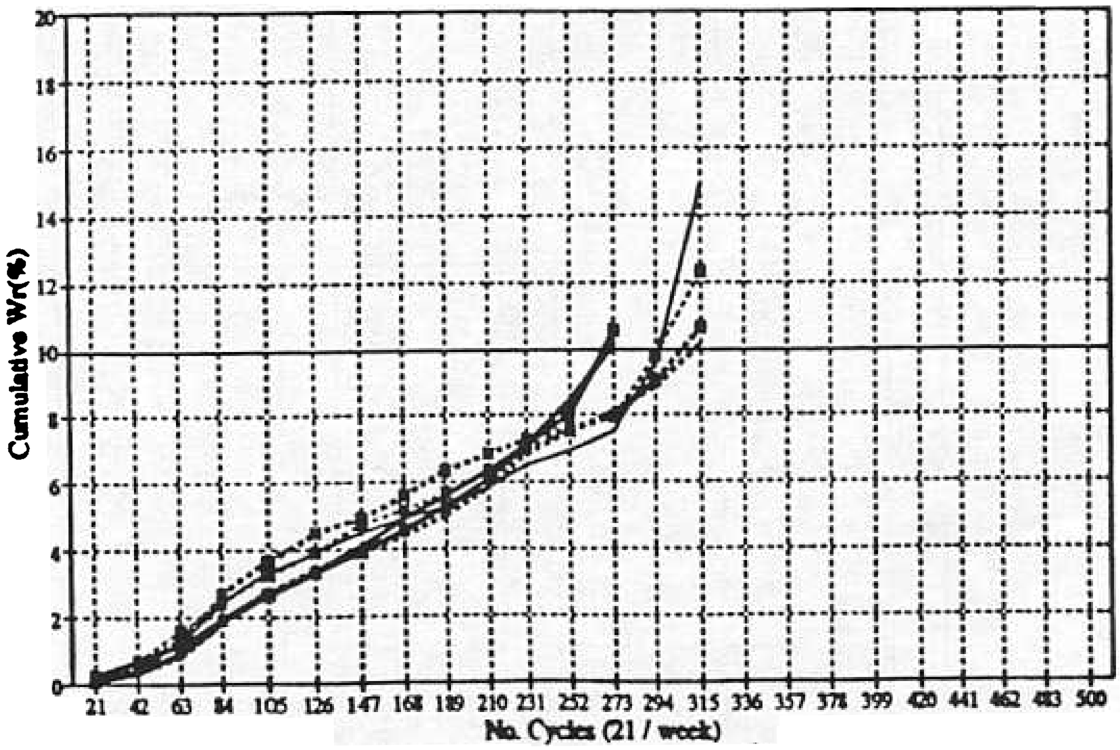

Figure 2A. Effect of freezing and thawing on coupons cut from masonry units showing a very high rate of loss.

Appendix

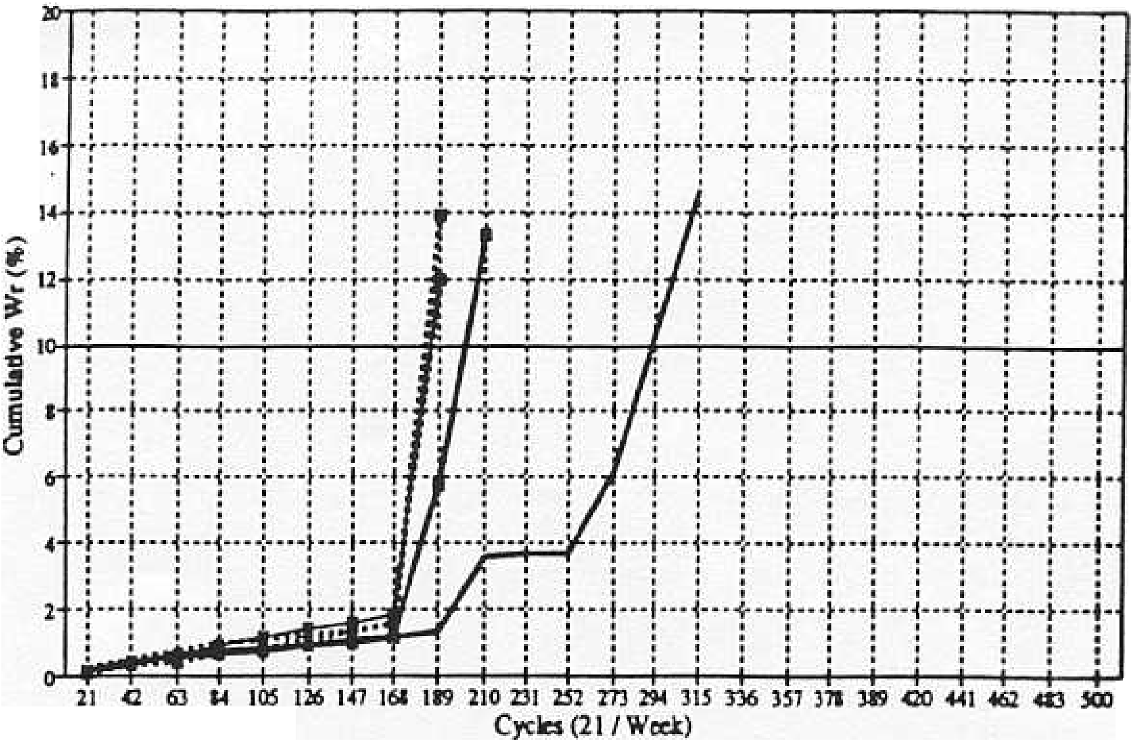

Figure 3A. Effect of freezing and thawing on coupons cut from units showing dilation after a few cycles of freeze and thaw.

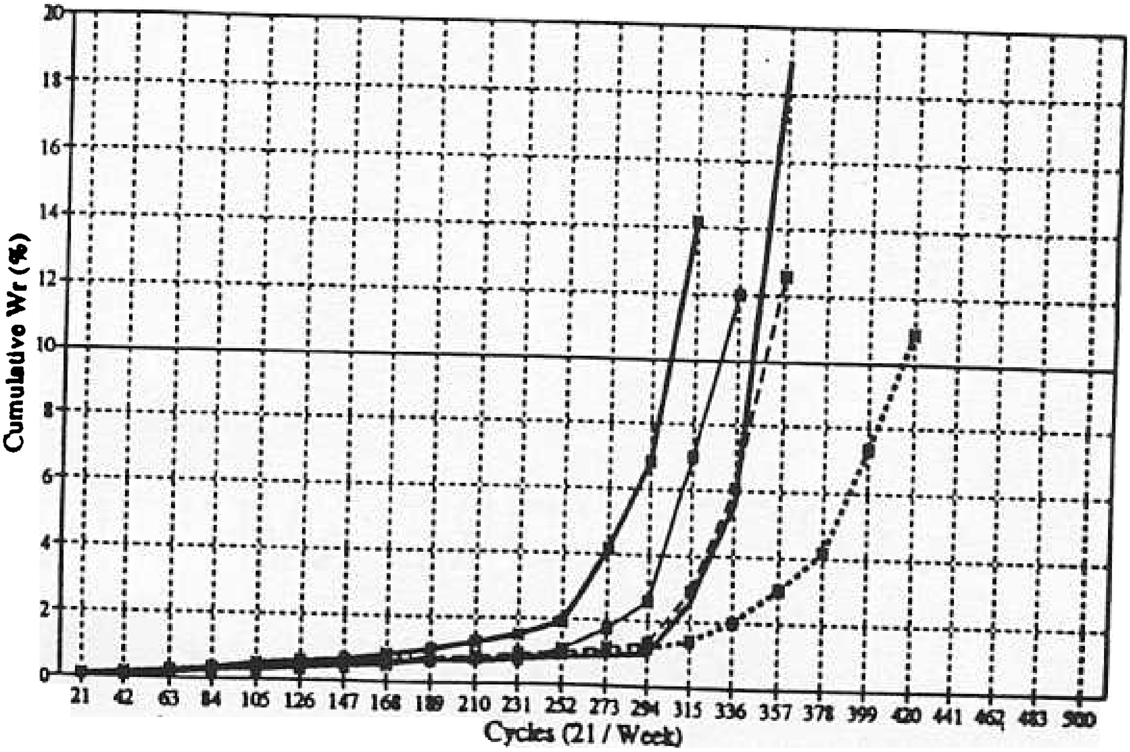

Figure 3A. Effect of freezing and thawing on coupons cut from masonry units showing dilation after a large number of freeze and thaw cycles.

Expanded Shale Clay and Slate Institute
Tel.: 801-272-7070
FAX: 801-272-3377
2225 East Murray-Holladay Road, Suite 102
Salt Lake City, Utah 84117

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What is ESCS? It is a unique, ceramic lightweight aggregate prepared by expanding select minerals in a rotary kiln at temperatures over 1000°C. The production and the raw materials selection processes are strictly controlled to insure a uniform, high quality product that is structurally strong, stable, durable and inert, yet also lightweight and insulative. ESCS gives designers greater flexibility in creating solutions to meet the challenges of dead load, terrain, seismic conditions, construction schedules and budgets in today's marketplace.