CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT

IR 71-36 May 27, 1971

FREEZE-THAW DURABILITY OF PRECAST PRODUCTS MADE WITH PREHEATED CONCRETE

by

N.G. Zoldners and G.G. Wallace

Mineral Processing Division

NOTE: This report relates essentially to the samples as received. The report and any correspondence connected therewith shall not be used in full or in part as publicity or advertising matter.

Industrial Confidential

Mines Branch Investigation Report IR 71-36

FREEZE-THAW DURABILITY OF PRECAST PRODUCTS MADE WITH PREHEATED CONCRETE

by

N.G. Zoldners* and G.G. Wallace**

- - -

SUMMARY OF RESULTS

Concrete of about 3500 psi compressive strength at 6-hr age may be produced by heat treatment. However, the later strength increase is limited and may reach at 28 days only 2/3 of that for standard moist-cured concrete.

No visible damage was sustained by the concrete test beams after exposure to 1000 cycles of freezing and thawing. Also, no indication of concrete deterioration was detected by non-destructive dynamic methods.

The results of destructive tests show that the loss in flexural strength after freeze-thaw exposure was insignificant and amounted to 5.5 and 3.1 per cent for pre-heated concrete in Series I and III, respectively, compared with an increase of 1.9 per cent for standard moist-cured Series II.

In summary, the results of this investigation indicate that, apart from the general loss in strength, the freeze-thaw durability of the preheated concrete under investigation is excellent.

*Head, and **Senior Technician, Construction Materials Section, Mineral Processing Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

INTRODUCTION

By a letter of June 26, 1969, Francon Limited, Montreal, P.Q., manufacturers of precast concrete structural members, requested the Mines Branch to conduct freeze-thaw durability tests on concrete specimens cured by different heat treatment methods.

The company submitted a number of specimens suitable for testing. Concrete in one series was pre-heated by the use of hot water, and in another by injection of live steam during mixing. In each case, hot concrete was placed in heated forms and cured at pre-determined temperature for several hours, then removed to a dry-storage room.

Strength development and freeze-thaw durability of the heat-treated test specimens were evaluated against those of companion series of concrete specimens cured under standard moist-curing conditions.

CONCRETE MIXES

Concrete mix proportions used in all three test series were the same and are shown in Table 1.

A high early-strength (Type III) cement was used in all concrete mixes. The coarse aggregate was minus 1/2-in. crushed limestone; the fine aggregate was natural sand.

All mixes were air-entrained. A Darex-type AEA (air-entraining agent) was used in amounts shown in Table 1.

TABLE 1

Concrete Mix Data

Mix Series No.	Date of Mix	Cement lb	Aggregates, lb		Water lb	Admixt Darex, oz	Air %	Slump in.
			Coarse	Fine				
I	1969 June 11	750	1580	1380	310	6	4.4	3
II	June 12	750	1580	1380	310	5	3.3	2 3/4
III	June 16	750	1580	1380	320	6	4.3	2 3/4

PREPARATION AND CURING OF TEST SPECIMENS

For each of the three series, 4 test beams (3 x 4 x 16-in.) were cast in heavy brass moulds. The number of cylinders (6 x 12-in.) cast in steel moulds was 7 in Series I and 6 in Series II and III. The temperature of fresh concrete and the curing conditions of test specimens were as follows:

Series I (Production line - 106/130°F)

A concrete mixture at 106°F, made with hot water, was placed in preheated moulds in which the temperature of the concrete was maintained at 130°F for 6 3/4 hr. When removed from the forms,the test specimens were placed in a dry-storage room at 40% RH and 70°F.

Series II (Reference series - standard curing)

An identical concrete mix was prepared under normal room conditions, unheated. The test specimens were removed from the moulds and stored under standard moist-curing conditions until tested.

Series III (Trial mix - 150°F heat treatment)

The concrete mixture was heated by steam injection to 150°F and the moulded test specimens were kept at this temperature for 6 hr. When removed from the forms the test specimens were placed in the dry-storage room.

STRENGTH DEVELOPMENT

The strength development of concrete in each series was determined by measuring the compressive strength of 6 x 12-in. cylinders after 7, 14, and 28 days.

Though practically identical concrete mixes were used in all three test series, the initial pre-heating and subsequent dry-curing of test specimens drastically reduced their strength. The test results submitted by the company are compiled in Table 2. Results indicate that the 28-day strength of concrete in Series I and III is 66 and 67 per cent, respectively, of the standard moist-cured concrete in Series II.

TABLE 2

Compressive Strength
(average of two test results)

Test Series	Thermal Conditions A/B*	Compressive Strength, psi			
		Accelerated Strength	Age		
			7 days	14 days	28 days
I	106/130	2260** (6 3/4 hr)	4450	4900	4730 (66%)
II	73/73	-	5730	6490	7190 (100%)
III	150/150	3500*** (6 hr)	4170	4590	4790 (67%)

*A - temp of fresh concrete, °F;
B - curing temperature in moulds °F.
**One test cylinder only.
***Test result from another, identical test series.

DURABILITY STUDIES

The main objective of this investigation was to study the freeze-thaw durability of heat-treated concrete specimens in comparison with the durability of standard-cured concrete.

For these studies the freeze-thaw test beams were exposed to repeated cycles of freezing in air and thawing in water according to the ASTM Standard Method C 666-70.

Four test beams from each of the three series were submitted to the Mines Branch at an age of 14 days after casting and preliminary curing at the company's laboratory in Montreal. On arrival, all beam specimens were placed in the moist-curing room for 7 days. Thus the beams were 21 days old when they were exposed to the freeze-thaw cycling. Before commencing testing, all beams were placed in the freeze-thaw cabinet at the thawing phase of the cycle for one hour in order to bring their temperatures down to a uniform $40 \pm 3^{o}F$. At this temperature, the initial and all following test measurements were taken.

FREEZING AND THAWING PROCEDURE

After the initial measurements were made, two beams (A & B) of each series were returned to the moist-curing room for use as reference specimens. The remaining two beams (C & D) in each series were then placed in the freeze-thaw cabinet and subjected to repeated cycles of freezing in air and thawing in water. The duration of one complete cycle, from $40 \pm 3^{o}F$ to $0 \pm 3^{o}F$ and back to $40 \pm 3^{o}F$, was about 3 hours, providing for approximately 8 cycles during each 24-hr period. Completion of 1000 cycles required 125 days.

Testing of Freeze-Thaw Specimens

The following measurements and tests were made at about 100-cycle intervals to evaluate the resistance of concrete test specimens to accelerated freezing and thawing:

1. Determination of weight changes
2. Measurements of ultrasonic pulse velocities

3. Measurements of longitudinal resonant frequencies
4. Visual examination of test specimens for evidence of deterioration or surface pop-outs

Length change determinations were not carried out because the reference studs at the ends of the beams were not of the type required for length measurements with the comparator in use at this laboratory.

Flexural strengths were determined at the end of the freeze-thaw test (1000 cycles).

Test Results

The weights of the test beams were determined at the beginning (0 cycles) and the end of freeze-thaw cycling (1000 cycles); the results are shown in Table 3. The table also gives weight changes of the standard moist-cured test beams during the same period of time (125 days).

The values of ultrasonic-pulse valocity "V" and longitudinal resonant frequency "n" measured on the freeze-thaw test beams at the beginning of cycling and after 1000 cycles are shown in Table 4. Also shown are the "V" and "n" values of the standard moist-cured test beams determined at the beginning (21-day age) and the end (146-day age) of the freeze-thaw cycling period.

The changes in these values are expressed as percentages of their initial values.

Flexural strengths of both the freeze-thaw and standard moist-cured beams after completion of the freeze-thaw cycling are shown in Table 5. Also shown is percentage strength change in each test series.

Visual examination of the freeze-thaw test specimens after 1000 cycles revealed no signs of deterioration or pop-outs.

TABLE 3

Weight Changes of Test Beams

Test Series	Standard Moist-Curing					Freezing and Thawing Cycling				
	Beam Nos.	Beam Weight lb		Weight Change		Beam Nos.	Beam Weight lb		Weight Change	
		21 days	146 days	%	av		0 Cycle	1000 Cycle	%	av
I Product. Line	1-A	16.500	16.765	+1.50	+1.7	1-C	16.442	16.675	+1.41	+1.3
	1-B	16.552	16.865	+1.88		1-D	16.550	16.750	+1.21	
II Reference Series	2-A	16.860	17.003	+0.85	+0.7	2-C	16.810	16.920	+0.65	+0.7
	2-B	16.910	17.008	+0.58		2-D	16.863	16.975	+0.66	
III 150°F Series	3-A	16.508	16.790	+1.70	+1.9	3-C	16.428	16.670	+1.47	+1.6
	3-B	16.512	16.870	+2.16		3-D	16.490	16.775	+1.72	

TABLE 4

Ultrasonic-Pulse Velocities and Longitudinal Frequencies of Beams

Test Series	Ultrasonic Pulse Velocity V, fps								Longitudinal Resonant Frequency n, cps							
	Standard Moist-Cured				Freezing - Thawing				Standard Moist-Cured				Freezing - Thawing			
	No.	V_{21}	V_{146}	% Change	No.	V_o	V_{1000}	% Change	No.	n_{21}	n_{146}	% Change	No.	n_o	n_{1000}	% Change
I Product. Line	1-A	15220	16140	+6.1	1-C	15290	15815	+3.4	1-A	4790	5110	+6.7	1-C	4780	4960	+3.8
	1-B	15050	16160	+7.4	1-D	15290	15780	+3.2	1-B	4770	5100	+6.9	1-D	4810	4980	+3.5
II Reference Series	2-A	16045	16835	+4.9	2-C	16120	16180	+0.4	2-A	5170	5280	+2.1	2-C	5180	5200	+0.4
	2-B	16105	16920	+5.14	2-D	16220	16160	-0.4	2-B	5140	5250	+2.1	2-D	5180	5220	+0.5
III 150°F Series	3-A	14650	15910	+8.6	3-C	14750	15610	+5.8	3-A	4690	5030	+7.2	3-C	4710	5000	+6.2
	3-B	14685	15910	+8.3	3-D	14915	15650	+4.9	3-B	4700	5070	+7.9	3-D	4710	5020	+6.6

TABLE 5

Flexural Strength Changes of Beam Specimens

Test Series	Beam No.	Standard (moist-cured) psi	Beam No.	Freeze-Thaw (after 1000 cycle) psi	Flexural Strength Loss %
I Product. Line	1-A 1-B	887 av 900 915 (85%)	1-C 1-D	840 av 850 860 (78%)	-5.5
II Reference Series	2-A 2-B	1070 av 1065 1060 (100%)	2-C 2-D	1035 av 1085 1135 (100%)	+1.9
III 150°F Series	3-A 3-B	875 av 805 735 (75%)	3-C 3-D	795 av 780 770 (72%)	-3.1

DISCUSSION

As shown in Table 1, the concrete mixes used in all three test series were identical with high cement content (750 lb/cu yd). Air entrainment and fairly low slump produced concrete of high resistance to freezing and thawing exposure. Though the entrained air content in concrete mixes was on the low side, i.e., 3.3 per cent for Series III, the high strength level reached at the time of commencing freeze-thaw cycling affected favourably the durability of all test specimens.

Strength

The strength data given in Table 2 indicate that the accelerated curing of concrete, with pre-heating of the mixture by hot water to 106°F followed by curing at 130°F, produced 2260 psi strength after 6 3/4 hours.

In a modified pre-heating procedure in Series III, live steam was injected, during the mixing, to raise temperature of this trial mixture to 150°F. Thereafter the curing temperature of moulded test beams was maintained at 150°F, producing concrete strength, after 6 hr, of about 3500 psi.

Though a high early strength of concrete was produced by the heat treatment, only a small increase in strength was achieved at later ages, reaching about two thirds of the standard moist-cured test cylinder strength.

Durability

No visible damage was sustained by the concrete test beams after exposure to 1000 cycles of freezing and thawing.

a) Weight Change. The measured weight changes of the test beams compiled in Table 3 indicate that after exposure to 1000 cycles of freezing and thawing the weight of the test beams increased for the heat-treated concrete in Series I and III by 1.31 and 1.60 per cent, respectively, whereas Series II of standard cured specimens showed only 0.65 per cent weight increase.

On the other hand, companion test beams from each series kept under standard moist-curing all the time until the end of freeze-thaw cycling showed weight increases in Series I and III of 1.69 and 1.93 per cent, respectively, whereas Series II showed only 0.71 per cent weight increase.

There was no reduction in weight due to breakdown of test specimens during freezing and thawing exposure. The weight increase of test specimens was apparently due to water absorption. This was less pronounced on freeze-thaw test specimens than on the companion specimens which were continuously moist cured. It is quite understandable that the moist-cured beams of Series II absorbed less water than the initially heat-treated and then dry-stored beams of Series I and III.

b) Non-Destructive Testing. The test results shown in Table 4 indicate that both the ultrasonic pulse velocity and the longitudinal resonant frequency increased during the standard moist-curing as well as during exposure to freeze-thaw cycling in all test series.

Gains in pulse velocity in heat-treated concrete for moist-cured specimens averaged 6.7% in Series I and 8.5% in Series III, or about double the gains obtained for corresponding freeze-thaw test specimens, which averaged 3.3% and 5.4%, respectively.

For the standard moist-cured reference Series II pulse velocity gains averaged 5.0% for the moist-cured and 0% for the freeze-thaw test specimens.

A similar trend was also observed in the resonant frequency measurements. The gains in both pulse velocity and resonant frequency were caused primarily by the weight increase of concrete due to differential absorption in each test series of both moist-cured and freeze-thaw specimens (see section (a) of this discussion and Table 3). Hence, the values obtained by dynamic test methods before and after freeze-thaw cycling may not reflect minor deteriorations of concrete, being overshadowed by gains in density or weight due to water absorption. In fact, the concrete had deteriorated to some extent, as shown in the results obtained on the flexural strength of beams after freeze-thaw exposure.

c) Flexural Strength. The results of flexural tests compiled in Table 5 show the same trend as those of compression tests - both heat-treated series produced lower strength than the standard moist-cured test series. However, the per cent loss in flexural strength was less than in compression. The average flexural strengths in Series I and II for moist-cured beams were 85 and 75 per cent and, for freeze-thaw beams, 78 and 72 per cent of the strengths of continuously moist-cured Series II beams.

The final results of destructive tests, for flexural strength in particular, confirm the trend shown in the results of the two non-destructive dynamic test methods (see Table 4). Also remarkable is the close correlation between the results obtained by the respective methods - ultrasonic pulse velocity and the longitudinal resonant frequency.

CONCLUSIONS

Initially heat-treated concrete produces high early strength, little strength increase with age, and of lower ultimate strength than has the same concrete cured under normal temperature conditions.

The samples of heat-treated concrete submitted for this investigation have shown excellent durability after exposure to 1000 cycles of freezing and thawing.

/mn