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STRENGTH AND DURABILITY OF CONCRETE MADE WITH MODIFIED TYPE II CEMENT

by

V. M. MALHOTRA & N. G. ZOLDNERS

MINERAL PROCESSING DIVISION

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Mines Branch Investigation Report IR 65-27

STRENGTH AND DURABILITY OF CONCRETE MADE WITH MODIFIED TYPE II CEMENT

by

V.M. Malhotra* and N.G. Zoldners**

SUMMARY OF RESULTS

Strength properties and durability of concretes made with a blended and three different brands of modified type II low-heat portland cement were studied in comparison with the normal type I cement.

The long-term compressive strength test results show that modified type II cement has satisfactory strength development characteristics; though slower in gaining strength at early ages, it attains strength equal to that of concrete made with normal type I portland cement at 90 days and is quite superior at one year's age.

The durability studies for all three brands of Type II cement show that both medium- and high-strength concrete beam specimens ($3\frac{1}{2}$x4x16 in.) performed well at the completion of about 800 cycles of freezing and thawing and that the test specimens of the low-strength series suffered considerable loss in flexural strength. The lowest residual flexural strength obtained after 781 cycles was 45.2 per cent of the standard-cured reference beam strength.

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Rapport d'investigation de la Direction des mines IR 65-27

RÉSISTANCE ET DURABILITÉ DU BÉTON FAIT DE CIMENT DE TYPE II MODIFIÉ

par

V.M. Malhotra* et N.G. Zoldners**

RÉSUMÉ

Les auteurs ont étudié, en comparaison du ciment de type I normal, les propriétés de résistance et de durabilité de bétons faits, séparément et mêlés, de trois différentes marques de ciment portland du type II modifié à faible chaleur de prise.

Les résultats de l'essai de résistance à la compression à long terme indiquent que le ciment de type II modifié présente des caractéristiques de résistance satisfaisantes. Quoiqu'il soit plus lent à acquérir de la résistance au début, cette résistance atteint celle du béton fait de ciment portland de type I normal en 90 jours et lui est supérieure après un an.

Les études sur la durabilité des trois marques de ciment de type II indiquent que les poutres de béton à moyenne et haute résistance (3 1/2 sur 4 sur 16 pouces) qui ont servi dans cette essai se comportaient bien à la fin d'environ 800 cycles de gel et de dégel, mais que les échantillons à moyenne résistance ont perdu beaucoup de leur résistance à la flexion. La plus basse résistance résiduelle à la flexion obtenue après 781 cycles a été de 45.2 p. 100 de la résistance d'une poutre de référence traitée normalement.

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CONTENTS

TABLES

FIGURES

INTRODUCTION

The Quebec Hydro-Electric Commission (Hydro-Quebec) started building in 1961 in northern Quebec a two billion dollar hydro-electric power complex known as the "Manicouagan-Outardes Project". The Manicouagan-2 power station of this huge complex is nearing completion, with the first turbine to be in operation by June 15, 1965.

In the construction of concrete dams Hydro-Quebec is using a modified type II cement. The principal feature of this cement is its low heat of hydration (60 to 63 cal/g in 7 days) as compared to the normal portland cement (70 to 76 cal/g). Canada Cement Company, Miron Company and St. Lawrence Cement Company, all from the province of Quebec, are manufacturing this type of cement to the specifications of Hydro-Quebec.

The Mineral Processing Division of the Mines Branch was asked by Hydro-Quebec in Montreal to carry out a long-term study on strength development and durability of concrete made with the modified type II cement. Results of earlier studies dealing with the durability of concrete made with the modified type II cement have been reported in Mines Branch investigation reports (1, 2).

This report gives the results obtained in the first two series of tests comprising a part of the long-term durability study.

SCOPE OF INVESTIGATION

In order to study the compressive strength and relative durability of the three brands of modified type II cement, the concrete mixes were divided into the following two series:

Series 1:

Two concrete mixes were made using normal type I cement and modified type II cement, blended from three brands. Nine 6x12 in. cylinders were cast from each mix to investigate the strength development at ages up to one year.

Series 2:

Three different strength levels were selected, and one mix for each of the three brands of modified type II cement was made at each strength level - a total of nine mixes. Six 6x12 in. cylinders and six 3½x4x16 in. beam specimens were cast from each mix for compressive strength and durability studies.

CONCRETE MIXES

The two series of concrete mixes were designed and prepared, and test specimens were cast in the Mines Branch laboratory at Ottawa between May 26 and June 8, 1964.

The details of the materials used, mix design data and the test results on fresh concrete are described below:

Materials Used

(1) Cement

Normal type I portland cement was supplied from Canada Cement Company's Montreal East plant.

The three brands of low-heat modified type II cement, four bags of each, were supplied by the Concrete Laboratory Inc., Montreal. The three brands of the cement were produced by the following cement companies:

Brand "A" - Miron Company Ltd.,
City of St. Michel, P.Q.

Brand "B" - Canada Cement Company, Limited,
Montreal East, P.Q.

Brand "C" - St. Lawrence Cement Co.,
Villeneuve, P.Q.

The chemical analyses and the calculated compound composition of each cement are given in Tables 1 and 2.

TABLE 1

Chemical Analysis of the Cements
(in per cent)

Chemical Constituents	Type I*	Type II**		
	Montreal East	Brand "A"	Brand "B"	Brand "C"
SiO_2	21.2	22.58	22.34	22.44
Al_2O_3	5.4	3.66	3.88	4.60
Fe_2O_3	2.5	3.72	4.36	4.22
CaO	63.3	59.76	59.76	58.89
MgO	3.0	3.30	3.21	3.24
Na_2O		0.24	0.33	0.33
K_2O		0.72	0.55	0.67
SO_3	2.6	2.22	1.45	2.19
Loss on Ignition	0.7	3.69	3.73	3.37
Insoluble Residue	0.3	0.04	0.09	0.030
Total	99.0	99.93	99.70	99.98

*Chemical analysis from Cement Test Report, February, 1964, supplied by Canada Cement Company, Montreal East plant.
**Chemical analysis from Mines Branch Internal Report MS-AC-65-605.

TABLE 2

Potential Compound Composition of the Cements
(in per cent)

Compound Compositions	Type I	Type II		
	Montreal East	Brand "A"	Brand "B"	Brand "C"
Tricalcium Silicate(C_3S)	49.3	35.2	38.0	26.7
Dicalcium Silicate(C_2S)	23.6	38.2	36.2	44.2
Tricalcium Aluminate(C_3A)	10.1	3.4	2.9	5.1
Tetracalcium Alumino-ferrite (C_4AF)	7.6	11.3	13.3	12.8
Total	90.6	88.1	90.4	88.8

To prepare a blended type II cement, two bags of each brand were placed in a Taylor tube mill and mixed dry for 30 minutes. The resultant blended cement was used in Series 1 concrete mixes.

(2) Aggregates

The coarse aggregate used was a coarse-grained pink granite from the bedrock near the Manic-2 dam site. The crushed 3/4 and 1½ in. nominal size aggregate was shipped by the Concrete Laboratory Inc. from Baie Comeau, P.Q., to the Mines Branch concrete laboratory in Ottawa.

As fine aggregate for concrete mixes in series 1, a blend of two types of natural sands, a coarse sand (A), and a fine sand (B) from the vicinity of Manic-2 dam site, was used. The coarse and fine sands were blended in the ratio of 60 to 40.

For concrete mixes in series 2, a locally obtained Ottawa Valley natural sand was used to provide uniform grading for each mix; the sand was first separated in size fractions and then re-blended to the specified normal grading.

The gradings and physical properties of both coarse and fine aggregates are given in Tables 3 and 4.

(3) Admixtures

No admixtures were used in the concrete mixes of series 1; however, an air-entraining agent, AEA-Darex, was used for mixes of series 2.

TABLE 3

Gradings of Coarse and Fine Aggregates

Sieve Size	Coarse Aggregate, Percentage Retained Nominal Sizes		Sieve Size	Fine Aggregate, Percentage Retained		
				Manic-2 Sand		Local Sand
	1½ in.	3/4 in.		Coarse	Fine	
1½ in.	1.3		No. 4	5.8	-	-
1 in.	36.9		No. 8	12.0	-	10
3/4 in.	83.4	7.2	No. 16	26.4	0.1	32.5
½ in.	98.4	63.5	No. 30	56.6	1.8	57.5
3/8 in.	99.6	89.8	No. 50	88.6	30.2	80.0
Pan	100.0	100.0	No. 100	99.2	84.6	94.0
			Pan	100.0	100.0	100.0

TABLE 4

Physical Properties of Coarse and Fine Aggregates

Physical Properties	Coarse Aggregate	Fine Aggregate	
		Manic-2 Sand	Local Sand
Specific Gravity, bulk, SSD*	2.64	2.68	2.70
Absorption, per cent (by weight)	0.20	0.40	0.70

*SSD = Saturated Surface-Dry.

Mix Design Data

Detailed mix design data for concrete test mixes of series 1 and 2 are given in Table 5.

In series 2, mixes with three different cement contents were prepared to produce concrete in (a) low, (b) medium, and (c) high strength ranges.

TABLE 5

Concrete Mix Design Data

Series No.	Mix Proportions, per cu.yd.				Water-Cement Ratio (by weight)
	Cement, lb.	Water, lb.	Aggregates, lb.		
			Coarse	Fine	
1	420 ± 3	274 ± 2	1,899	1,437	0.63
2-a	320 ± 1	250 ± 1	1,766	1,526	0.74
-b	409 ± 3	245 ± 1	1,847	1,398	0.56
-c	503 ± 3	244 ± 2	1,927	1,267	0.46

Properties of Fresh Concrete

The properties of fresh concrete, i.e., temperature, slump, unit weight and air content, for mixes of series 1 and 2 are given in Table 6.

TABLE 6

Properties of Fresh Concrete

Series No.	Cement Type and Brand	Properties					
		Water-Cement Ratio	Cement Content, lb./cu.yd.	Temperature, °F.	Slump, in.	Unit Weight, lb./cu.ft.	Air Content*, per cent
1	I-Montreal East	0.63	422	76	1	149.8	2.6
	II-Blend of A,B, C	0.63	417	77	2	148.4	2.4
2-a	II-A	0.74	321	75	1-3/4	143.4	4.1
	II-B	0.74	321	75	1-3/4	143.2	5.5
	II-C	0.74	319	75	1-3/4	142.6	5.4
-b	II-A	0.56	407	72	2-1/2	144.0	5.1
	II-B	0.56	406	72	2-3/4	143.2	5.6
	II-C	0.56	412	72	2-1/4	145.6	4.9
-c	II-A	0.46	506	75	1	147.0	4.6
	II-B	0.46	500	73	1-1/4	145.4	5.2
	II-C	0.46	501	72	1	145.8	4.6

*No air-entraining agent (A.E.A.) was used in mixes of series 1, but Darex A.E.A. was used for mixes of series 2.

PREPARATION OF TEST SPECIMENS

For each mix of series 1 and 2, ten and six 6x12 in. test cylinders, respectively, were moulded for compression test studies. In addition, from each mix of series 2, six 3½x4x16 in. beams were prepared for durability studies.

The test cylinders were prepared by filling 6x12 in. steel moulds in two approximately equal layers. Each layer was compacted with a 1-1/8 in. diameter internal vibrator by a single insertion for approximately 4 to 6 seconds.

The test beams were cast in heavy brass moulds with 3/8 in. side plates and ½ in. end plates. Stainless steel reference plugs were cast at each end of the beam specimen for length measurements. The beams were moulded by placing concrete in the moulds in two layers and vibrating these on a vibrating table for 10 and 20 seconds for each layer.

The moulded test specimens, covered with glass plates and water-saturated burlap, were left in the casting room for 24 hr.

At the end of this period the test specimens were removed from the moulds and transferred immediately to a moist-curing room under standard conditions.

From each batch one pair of test cylinders was set aside for accelerated strength testing using the boiling water method (3). The moulds of these test cylinders were tightly closed by a machined steel cover plate. After an initial 24-hr. period of standard moist-curing, these test specimens were placed complete with their moulds in boiling water for 3½ hr. Then the cylinders were removed, stripped of moulds, capped, allowed to cool and tested for compression at the age of 28½ hr.

COMPRESSION AND FLEXURE TESTS

Concrete test cylinders were tested for compressive strength in accordance with the ASTM Standard Method of Test C39-64.

Concrete test beams were tested for flexural strength in accordance with the ASTM Standard Method of Test C78-64.

Test Results

Compressive strength results obtained in the accelerated test, as well as those obtained on the standard cured cylinders at 7, 28, 90 days and one year age, are shown in Table 7. Also shown are the results of flexural tests on standard cured concrete at 14 and 150 days' age.

The densities of hardened concrete were obtained on 7-day moist cured test cylinders in saturated surface-dry condition (SSD), and are also shown in Table 7.

TABLE 7

Properties of Hardened Concrete

Series No.	Cement Type and Brand	Water-Cement Ratio	Cement Content, lb/cu.yd.	Density, (SSD) lb/cu.ft.	Properties of Hardened Concrete: Compressive Strength, psi* (6x12 in. cylinders)					Flexural Strength, psi ($3\frac{1}{2}$x4x16 in. beams)	
					$28\frac{1}{2}$-hr. Accelerated	7-days	28-days	90-days	1-year	14 days	150 ± 4 days
1	I-Montreal East	0.63	422	149.3	1,745	2,960	4,150	4,500	4,775	-	-
	II-Blend of A,B,C.	0.63	417	149.3	935	1,540	3,225	4,675	5,270	-	-
2-a	II-A	0.74	321	148.1	550	-	2,125	3,265	-	285	555
	II-B	0.74	321	146.9	510	-	1,905	2,835	-	275	605
	II-C	0.74	319	145.3	400	-	1,565	2,395	-	260	530
-b	II-A	0.56	407	148.2	1,070	-	2,960	4,115	-	420	635
	II-B	0.56	406	146.0	835	-	2,970	3,995	-	410	590
	II-C	0.56	412	147.8	755	-	2,825	3,775	-	370	640
-c	II-A	0.46	506	149.2	1,735	-	4,835	5,980	-	595	760
	II-B	0.46	500	147.8	1,570	-	4,225	5,280	-	540	700
	II-C	0.46	501	148.3	1,240	-	3,825	5,100	-	485	790

*Each result is a mean of two cylinders, except for 7-day results, for which only one cylinder was tested.

CONCRETE DURABILITY STUDIES

Although durability of concrete cannot be measured directly, prolonged exposure of concrete to accelerated cycles of freezing and thawing produces measurable changes in the test specimens, and these changes can be used for evaluating the relative frost resistance or durability of the concrete.

Two test beams from each mix of serie 2 were subjected to the freezing and thawing tests. The four companion test beams from each mix were kept in moist-curing: two for the 14-day flexural strength and two, as reference, until end of the freeze-thaw cycling.

Freezing and Thawing Procedure

After 14 days of initial moist curing, the freeze-thaw test specimens were exposed to repeated cycles of freezing in air and thawing in water according to ASTM Test Method C291-61T.

The automatic freeze-thaw unit* used performs 8 cycles per day. One complete cycle, from 40 ± 3° F. to 0 ± 3° F. and back to 40 ± 3° F., requires about three hr.

Before the freezing and thawing test was commenced, the temperatures of all six test beams from each test mix was reduced to a uniform 40 ± 3° F. by holding the test specimens in the freeze-thaw cabinet at the thawing phase of the cycle for one hr. The initial and all subsequent measurements on the freeze-thaw and the reference specimens were made at this temperature.

After the initial measurements had been taken, two beams were placed back in the freeze-thaw cabinet and the four companion beams were placed in the moist-curing room. The freezing and thawing cycling was started on June 17, 1964, and was terminated on November 5, 1964, at the completion of a maximum of 799 cycles.

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*Manufactured by the Canadian Ice Machine Company Ltd., Toronto, Ontario.

Test Methods

The following tests were made to evaluate the resistance of concrete test beams to accelerated cycles of freezing and thawing:

1. Weight determinations.
2. Length determinations.
3. Flexural strength determinations of
   a) test beams after freeze-thaw cycling;
   b) reference beams after standard curing.
4. Visual examination of test specimens.

The freeze-thaw test specimens were weighed and measured at the end of approximately 100, 300 and 800 cycles. At completion of the test, both freeze-thaw and reference beams were broken for flexural strength.

Test specimens were weighed with a probable accuracy of ± 0.005 lb.

Length measurements were made on an Ames comparator, having a dial reading of 0.0001 in.

Flexural strength tests were made, as mentioned earlier, in accordance with the ASTM Standard Method C78-64, using simple beam with third-point loading.

Test Results

Table 8 shows weight and length values as determined at the start of the test and at the completion of various freeze-thaw periods. Also included in these tables are the flexural strengths and the description of visual observations of the freeze-thaw prisms at the end of cycling.

The weight loss and length changes in per cent are shown in Table 9. A gauge length of 13.6 in. has been used for calculations of the length changes.

The flexural strength test results for the reference as well as the freeze-thaw test beams are summarized in Table 10. Also included in the table are the residual strength

TABLE 8

Test Results on Beams Subjected to Freezing and Thawing

Mix Series and Cement Brands	Water-Cement Ratio	Number of Freeze-Thaw Cycles	Test Results: Weight, lb.	Length,* in.	Flexural Strength, psi	Description of Test Beams at the End of Freeze-Thaw Cycling
2-a A	0.736	0	18.552	0.051		A few pop-outs, slight deterioration along the edges.
		305	18.550	0.047		
		781	18.541	0.048	370	
B	0.736	0	18.659	0.050		Slight deterioration along the edges.
		305	18.666	0.050		
		781	18.671	0.051	365	
C	0.736	0	18.696	0.062		Slight deterioration along the edges.
		305	18.701	0.062		
		781	18.704	0.064	240	
2-b A	0.565	0	18.889	0.056		Both beams in relatively good condition.
		319	18.885	0.056		
		781	18.876	0.059	485	
B	0.565	0	18.202	0.015		Both beams in relatively good condition.
		319	18.193	0.016		
		773	18.876	0.016	490	
C	0.565	0	18.730	0.055		Both beams in relatively good condition.
		319	18.720	0.055		
		773	18.710	0.056	465	
2-c A	0.459	0	18.930	0.073		Both beams in excellent condition.
		312	18.884	0.073		
		799	18.879	0.075	790	
B	0.459	0	18.867	0.027		Both beams in excellent condition.
		312	18.824	0.030		
		799	18.812	0.030	740	
C	0.458	0	18.693	0.044		Both beams in excellent condition.
		312	18.661	0.044		
		799	18.652	0.045	600	

*Gauge length = 13.6.

TABLE 9

Weight and Length Changes of Test Beams*

Mix Series and Cement Brands	Weight of Beams, lb.						Length of Beams**, in.					
	Reference			Freeze-Thaw			Reference			Freeze-Thaw		
	(a) W_{14}	(b) W_x	Per Cent Change	(c) W_o	(d) W_x	Per Cent Change	(a) L_{14}	(b) L_x	Per Cent Change	(c) L_o	(d) L_x	Per Cent Change
2-a												
A	18.859	18.801	-0.307	18.552	18.541	-0.059	0.0515	0.0507	-0.00588	0.0510	0.0479	-0.023
B	18.666	18.635	-0.166	18,659	18.671	+0.064	0.0410	0.0393	-0.01250	0.0500	0.0512	+0.009
C	18.617	18.604	-0.070	18.696	18.704	+0.043	0.0398	0.0394	-0.00294	0.0622	0.0636	+0.010
2-b												
A	18.814	18.833	+0.101	18.889	18.876	-0.069	0.0593	0.0608	+0.01103	0.0560	0.0589	+0.0210
B	18.065	18.094	+0.161	18.202	18.180	-0.121	0.0698	0.0706	+0.00588	0.0152	0.0160	+0.006
C	18.647	18,685	+0.204	18.730	18.710	-0.107	0.0529	0.0539	+0.00735	0.0552	0.0557	+0.004
2-c												
A	18.891	18.909	+0.095	18.930	-18.879	-0.269	0.0397	0.0394	-0.00221	0.0735	0.0749	+0.010
B	18.631	18.654	+0.123	18.867	-18.812	-0.292	0.0316	0.0312	-0.00294	0.0272	0.0299	+0.020
C	18.960	18.969	+0.047	18.693	-18.652	-0.219	0.0228	0.0221	-0.00515	0.0444	0.0446	+0.001

* Each result is a mean of two beams.
** Gauge length, 13.6 in.

(a) Weight and length of beams at the end of 14 days.
(b) Weight and length of beams at the end of 150, 146 and 152 days for low, medium and high strength mixes.
(c) Weight and length of beams at zero cycles of freezing and thawing.
(d) Weight and length of beams at the end of 781, 773 and 799 cycles of freezing and thawing for low, medium and high strength mixes.

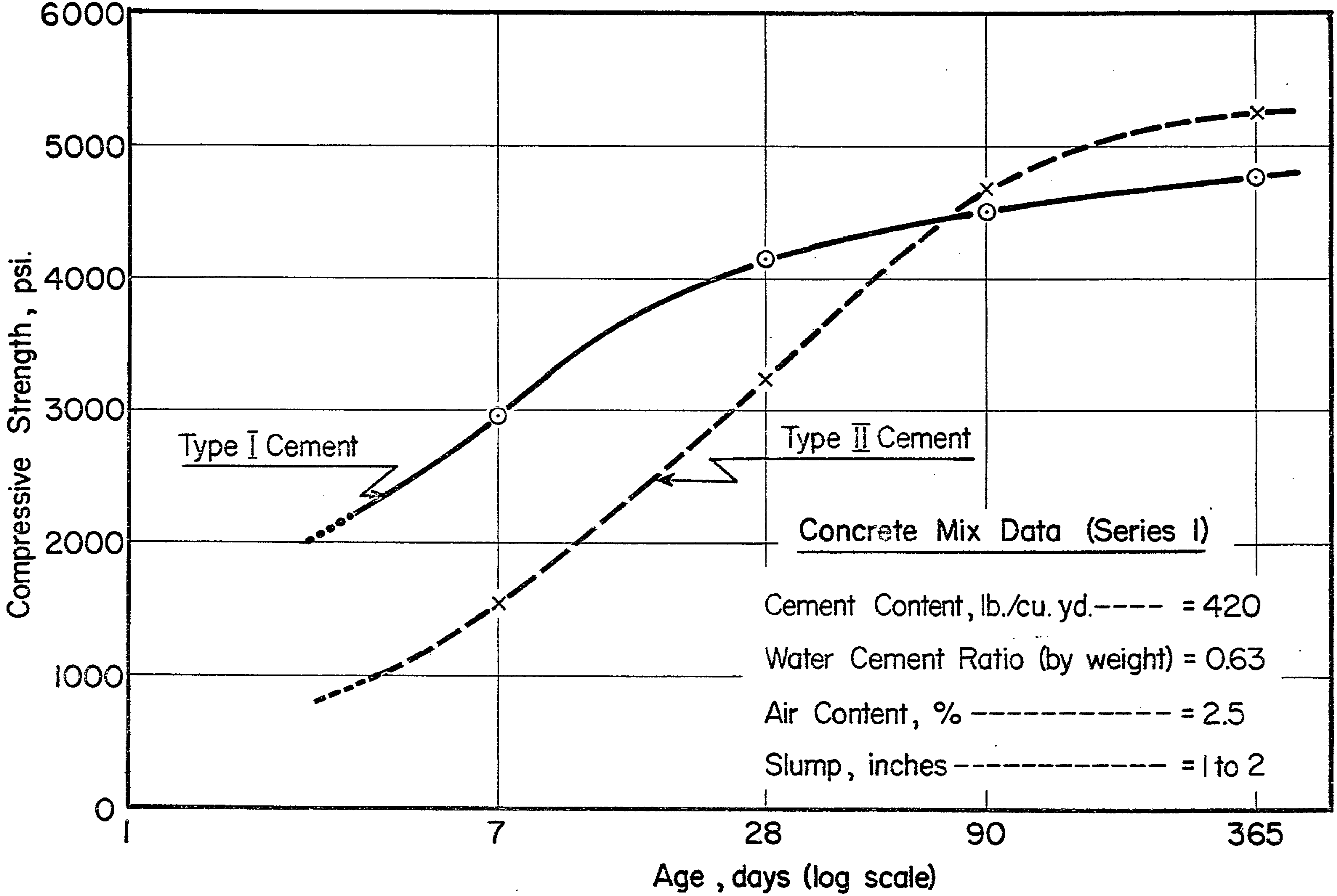

FIG. 1. CONCRETE STRENGTH DEVELOPMENT

Standard Type I and Modified Type II Cements values of freeze-thaw beams expressed as percentage of the strength of the standard cured reference beams.

DISCUSSION OF TEST RESULTS

Strength Development

Compressive strength values of concrete mixes in series 1 at different ages are given in Table 7 and are plotted in Figure 1. The concrete made with the blended type II cement, though slower to gain strength at early ages, reaches a compressive strength equal to that of type I cement at 90 days, and has attained a much higher strength at one year's age.

Compressive and flexural strength values of concrete mixes prepared for the three strength levels A, B and C are shown in Table 7 for the three brands A, B and C of the modified type II cement. The results show that concrete made with brand "A" cement performed the best, followed by that made with brand "B" and brand "C" cements.

Durability Studies

For all three brands of the modified type II cement the weight loss was less than 0.5 per cent at the end of about 800 cycles of freezing and thawing. This was true for concretes at all strength levels.

The expansion of the test prisms at the end of 800 cycles of freezing and thawing was generally low. The maximum expansion of 0.0210 per cent was for beams of Brand "A" cement in medium strength range. Shrinkage of 0.023 per cent for beam specimens of Brand "A" in low strength range is not explained.

The flexural strength of both low and medium strength concrete test beams showed considerable loss at the completion of about 800 cycles of freezing and thawing.

TABLE 10

Summary of Flexural Strength Test Results*

Mix Series	Type II Cement Brands	W/C Ratio (by weight)	Standard - Cured		Freeze-Thaw Beams		
			Age, days	Reference, psi	Number of Cycles	Strength, psi	Residual Strength, per cent
2-a	A	0.736	150	555	781	370	66.5
	B	0.736		605	781	365	60.2
	C	0.738		525	781	240	45.2
2-b	A	0.565	146	635	773	485	76.5
	B	0.565		590	773	490	83.0
	C	0.565		640	773	465	72.5
2-c	A	0.459	152	760	799	790	103.8
	B	0.459		700	799	739	105.5
	C	0.459		790	799	600	76.1

*Each result is a mean of tests on two beams.

The maximum loss was suffered by low strength concrete beams (W/c = 0.736) made with Brand "C" cement. This concrete had a residual strength of only 45.2 per cent. The high strength concrete test beams (W/c = 0.459) made with Brands "A" and "B" cements performed excellently at the completion of freeze-thaw test; however, the residual strength of concrete test beams of the same mix series made with Brand "C" cement was only 76.1 per cent.

CONCLUSIONS

1. The strength development characteristics of concrete made with blended and the individual brands of modified type II (low heat) cement appear to be satisfactory.

2. The durability studies show that at the completion of 800 cycles of freezing and thawing at medium and high strength levels, concretes made with the three brands of type II cement performed well. At these strength levels there was little to choose between Brands "A" and "B" cements; however, the performance of concrete made with these cements was superior to that made with Brand "C" cement.

3. At low strength levels, concrete beams made with all brands of type II cement showed considerable loss in flexural strength, with beams made with Brand "C" cement having a residual strength of only 45.2 per cent.

It must be noted that the above conclusions refer to the test results obtained from concretes made with the samples of cement supplied to the Mines Branch by the Concrete Laboratory Inc., Montreal. On the basis of this limited investigation, no final conclusions can be drawn with regard to the relative performance of various brands of cement.

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