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Performance of Superplasticized Concretes That Have High Water-to-Cement Ratios

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This study presents results of laboratory investigations into superplasticized concretes that have high water-to-cement (w/c) ratios. Two series of concrete mixes totaling 18 were made at a w/c ratio of 0.65 and a slump of 50 mm (2 in). Various dosages of different superplasticizers were added to the mixes after completion of the initial mixing and then mixed for 2 min. Initial setting times, increases in slump, and subsequent slump loss with time were recorded. A number of test specimens were cast to determine mechanical strength and freeze-thaw durability. The incorporation of superplasticizers in concrete did not significantly affect initial setting time. The large increases in the slump of superplasticized concrete and its loss with time were found to be functions of the dosage rate of the superplasticizer used. At the recommended dosage rates, the 28-day compressive strengths of the test specimens cast with and without vibration were comparable to or greater than those of the control specimens. In the superplasticized concretes, the bubble-spacing factor ranged from 0.254 to 0.432 mm (0.01 to 0.017 in), compared to 0.254 mm for the control. In spite of the increased bubble spacing, the freeze-thaw durability of test prisms cast from the air-entrained superplasticized concretes at the end of 300 freeze-thaw cycles compared favorably with those cast from the air-entrained control mix.

Superplasticizers, although relatively new, are finding increasing acceptance in the concrete industry in North America and offer considerable potential for energy saving in the precast-concrete industry and for the use of marginal aggregates in construction (1,2).

In 1976, the Canada Centre for Mineral and Energy Technology (CanMET) initiated laboratory investigations to determine the effect of superplasticizers on the mechanical properties and freeze-thaw durability of concrete. Earlier reports had discussed the use of superplasticizers in high-strength concrete with a water-to-cement (w/c) ratio of 0.42 and the effect of repeated dosages of superplasticizers on the workability, strength, and durability of concrete (3-5). This study deals with performance of superplasticizers in concretes having a w/c ratio of 0.65.

SCOPE OF INVESTIGATION

In this study, two series of concrete mixes were made with a w/c ratio of 0.65 and a cement content of 246 kg/m^3 (415 lb/yd^3). Four commonly available superplasticizers were incorporated into the mixes at dosages varying from 0.5 to 3.0 percent by weight of cement. The properties of the fresh concrete were determined. For mixes of series A, a number of 100x200-mm (4x8-in) cylinders were cast with and without vibration for compression testing at 28 days. Test prisms were also cast for determining flexural strength and resistance to freeze-thaw cycles. Air-void parameters of the hardened concrete were determined. For mixes of series B a large number of 200x300-mm (6x12-in) cylinders were cast to establish strength-versus-age relationships.

CONCRETE MIXES

The mixes were made in the CanMET laboratory during April and May 1977. Initial mixing time for each batch was 6 min. The properties of the fresh concretes were determined immediately following mixing, after which the required dosage of the superplasticizer was added and the concrete was mixed for 2 min.

Normal portland cement ASTM type I was used. It had a fineness of 373 m^2/kg, sulfate content of 3.24 percent, and C_3A content of 8.27 percent. Minus 19-mm (0.75-in) crushed limestone was used as the coarse aggregate and local sand as the fine aggregate. To keep the grading uniform for each mix, the sand was separated into different size fractions that were combined to a specified grading. A sulfonated-hydrocarbon air-entraining agent was used in all the concrete mixes except the non-air-entrained control mix.

Superplasticizers

The following three types of superplasticizers were used in the concrete mixes:

1. Sulfonated naphthalene formaldehyde condensates: Superplasticizers A and C fall in this category. Superplasticizer A is of U.S. origin. It is usually available as a soluble powder or as a 34 percent aqueous solution with a density of 1200 kg/m^3 (74.9 lb/ft^3) and is dark brown. The chloride content is negligible. Superplasticizer C is of Japanese origin. It is usually available as a 42 percent aqueous solution that also has a density of

1200 kg/m^3 and is dark brown. The chloride content is also negligible.

2. Sulfonated melamine formaldehyde condensates: Superplasticizer B belongs to this category and is of German origin. It is usually available as a 20 percent aqueous solution with a density of 1000 kg/m^3 (62.4 lb/ft^3) and is limpid (clear) to slightly turbid (milky) in appearance. The chloride content is 0.005 percent.

3. Modified lignosulfonates: Superplasticizer D falls in this category. It is of French origin but is now being manufactured in Montreal. It is usually available as a 20 percent aqueous solution, has a density of 1100 kg/m^3 (68.6 lb/ft^3), and is light brown in appearance. It contains no chlorides.

Mix Proportioning

The graded coarse and fine aggregates were weighed in the room-dry condition. The coarse aggregate was then immersed in water for 24 h. The excess water was decanted and the water retained by the aggregate was determined by weight difference. A predetermined amount of water was added to the fine aggregate, which was then allowed to stand for 24 h.

A standard mix with a w/c ratio of 0.65, aggregate-to-cement (a/c) ratio of 7.76, and cement content of 246 kg/m^3 (15 lb/ft^3) was used. The dosage of the air-entraining agent was kept constant, but the type and dosage of superplasticizers were varied.

Properties of Fresh Concrete

The properties of the fresh concrete—temperature, slump, unit weight, and air content—were determined after the initial mixing time of 6 min and again after addition of the superplasticizers and further mixing for 2 min (Table 1). Also, measurements were taken frequently to determine the rate of slump loss.

Initial Time of Set of Fresh Concrete

To determine whether the superplasticizers retarded the set of the concrete, initial times of set were determined in accordance with ASTM standard C403-70 (1976) for the time of setting of concrete mixtures by penetration resistance.

PREPARATION AND CASTING OF TEST SPECIMENS

Series A: Concrete Mixes 1-14

Nine 100x200-mm (4x8-in) cylinders and six 90x100x400-mm (3.5x4x16-in) prisms were cast from each mix. The only exception was the non-air-entrained control mix, for which only three cylinders and five prisms were cast. All test specimens except the control mixes 1 and 2 were cast after adding superplasticizers. Three cylinders were compacted by using a vibrating table; three cylinders were not subjected to any vibration; and the remaining three cylinders were cast (compacted on a vibrating table) after the slump had turned to its original value. The prisms were cast by filling brass molds and compacting them on a vibrating table. After casting, all the molded specimens were covered with water-saturated burlap and left in the casting room at 24 ± 1°C (75 ± 2°F) and 50 percent relative humidity for 24 h. They were then unmolded and transferred to the moist-curing room until they were required for testing.

Series B: Concrete Mixes 15-18

Ten 200x300-mm (6x12-in) cylinders were cast from each of the four mixes. All cylinders except that for control mix 15 were cast after superplasticizers were added. The cylinders were compacted by using an internal vibrator. After casting, all the molded specimens were covered with water-saturated burlap and left in the casting room at 24 ±1°C and 50 percent relative humidity for 24 h. They were then unmolded and transferred to the moist-curing room until required for testing.

TESTING OF SPECIMENS

Series A: Concrete Mixes 1-14

The test cylinders from control mix 1 were tested at 28 days only, whereas the cylinders from control mix 2 were tested at both 7 and 28 days. All cylinders of mixes

Table 1. Properties of fresh concrete.

	Superplasticizer		After Initial 6-Min Mixing				After Addition of Superplasticizer and 2-Min Mixing		
Mix No.	Type	Dosage (%)	Temperature (°C)	Slump[a] (mm)	Unit Weight (kg/m^3)	Air Content (%)	Slump[a] (mm)	Weight (kg/m^3)	Air Content (%)
1	Control without AEA		23	50	2371	2.8	-	-	-
2	Control with AEA		21	50	2333	5.0	-	-	-
3	A	1.0	20	80	2290	5.7	220	2345	3.6
4		1.5	17	80	2270	6.7	210	4360	3.0
5		2.0	19	100	2270	7.2	230	2430	1.5
6	B	1.0	21	50	2340	5.0	90	2345	4.5
7		2.0	21	50	2310	5.0	210	2380	3.5
8		3.0	21	70	2340	4.6	250	2365	3.5
9	C	0.5	25	50	2320	5.4	100	2350	3.9
10		1.0	23	50	2320	5.8	210	2380	3.4
11		1.5	24	50	2310	5.8	250	2390	2.6
12	D	1.0	23	50	2330	5.0	80	2310	5.8
13		2.0	23	50	2330	5.0	200	2330	4.8
14		3.0	23	50	2330	5.0	250	2345	4.6
15	Control with AEA		24	70	2310	6.4	-	-	-
16	B	2.0	22	50	2330	5.0	210	2360	4.2
17	C	1.0	22	50	2320	5.5	210	2370	3.4
18	D	2.0	23	50	2320	6.0	200	2325	5.2

Notes: AEA = air-entraining agent; t°C = (t°F - 32)/1.8; 1 mm = 0.039 in; 1 kg/m^3 = 0.06 lb/ft^3.

[a] Slumps were read nearest to 10 mm for cases when slump was below 150 mm; they were read to nearest 20 mm when they were greater than 150 mm.

3-14 were tested at 28 days only. Before testing, the cylinders were removed from the moist-curing room and capped with a sulfur and flint mixture. A 272 160-kg (600 000-lb) capacity machine was used for compression testing.

Two test prisms from each of the 14 mixes were removed from the moist-curing room after 14 days and tested in flexure according to ASTM standard C78-75 by using a third-point loading.

Series B: Concrete Mixes 15-18

The test cylinders from each mix of series B were tested at 1, 7, 28, and 91 days. As in series A, the cylinders were removed from the moist-curing room immediately before testing and were capped with a sulfur and flint mixture before testing.

DURABILITY STUDIES

In this investigation, test prisms were exposed to repeated cycles of freezing in air and thawing in water according to ASTM standard C666-75. During this investigation the freeze-thaw unit did not fully meet the temperature requirements of the ASTM standard and fluctuated between -15 and -11.7°C (5 and 11°F) during freeze cycles.

The freeze-thaw test specimens were visually ex-

Figure 1. Loss of slump with time for superplasticizer A.

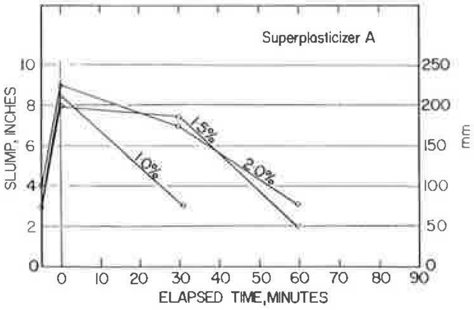


Figure 2. Loss of slump with time for superplasticizer B.

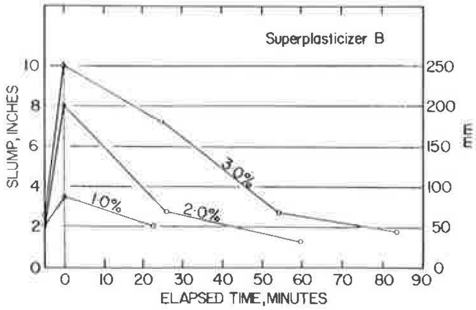


Figure 3. Loss of slump with time for superplasticizer C.

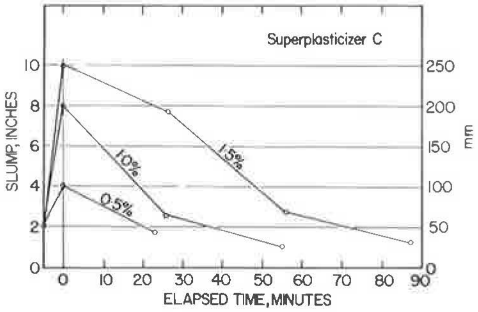


Figure 4. Loss of slump with time for superplasticizer D.

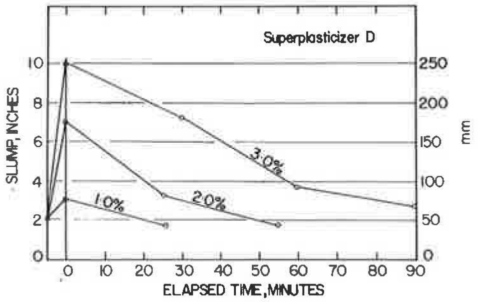


Table 2. Summary of compressive strengths after 7 and 28 days.

			Compressive Strength of 100x200-mm Cylinders[a]			
	Superplasticizer		After 7 Days,	After 28 Days		
Mix No.	Type	Dosage (%)	Vibrated (MPa)	Not Vibrated (MPa)	Vibrated (MPa)	Vibrated[b] (MPa)
1	Control without AEA		-	-	26.6	-
2	Control with AEA		19.2	-	24.4	-
3	A	1.0	-	24.8	23.6	25.8
4		1.5	-	18.8	20.3	25.9
5		2.0	-	11.7	12.1	27.4
6	B	1.0	-	25.4	26.9	26.8
7		2.0	-	25.5	27.9	27.2
8		3.0	-	25.5	23.8	27.1
9	C	0.5	-	24.1	26.5	24.9
10		1.0	-	24.2	27.1	25.3
11		1.5	-	24.0	27.0	27.2
12	D	1.0	-	23.8	25.0	26.5
13		2.0	-	24.0	23.0	24.5
14		3.0	-	24.4	23.9	24.6

Notes: 1 mm = 0.039 in; 1 MPa = 145 lbf/in².

[a] Compressive strength of control mix with AEA at 28 days is the average of six test results; the remainder are averages of three test results.

[b] These cylinders were cast after the slump had reverted to the original value.

Table 3. Summary of compressive strengths after 1, 7, 28, and 91 days.

Mix No.	Superplasticizer Type	Superplasticizer Dosage (%)	Compressive Strength of 100x200-mm Cylinders[a] After 1 Day (MPa)	After 7 Days (MPa)	After 28 Days (MPa)	After 91 Days (MPa)
15	Control with AEA		8.8	18.8	22.5	24.6
16	B	2	8.9	18.3	23.4	25.4
17	C	1	8.3	-	21.2	24.1
18	D	2	7.8	16.6	20.3	22.0

Notes: 1 mm = 0.039 in; 1 MPa = 145 lbf/in^2.

[a] Compressive strength of test specimens of control mix with AEA is the average of three test results. Compressive strengths of test specimens of the other mixes at 1, 7, 28, and 91 days are the averages of three, two, three, and two results, respectively.

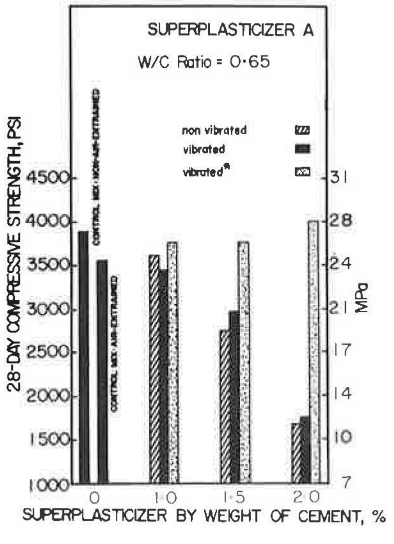
Table 4. Summary of flexural strength test results.

Mix No.	Superplasticizer Type	Superplasticizer Dosage (%)	Strength of Moist-Cured Prisms After 14 Days[a] (MPa)
1	Control without AEA		5.8
2	Control with AEA		5.2
3	A	1.0	5.4
4		1.5	4.3
5		2.0	3.3
6	B	1.0	5.1
7		2.0	4.9
8		3.0	4.9
9	C	0.5	5.4
10		1.0	5.1
11		1.5	4.8
12	D	1.0	5.1
13		2.0	5.1
14		3.0	5.2

Note: 1 MPa = 145 lbf/in^2.

[a] Each result is a mean of tests on two prisms; testing was done at third-point loading.

Figure 5. Compressive strength of test cylinders at 28 days for superplasticizer A.



amined at the end of every 50-cycle interval. At approximately every 100-cycle interval, their lengths were measured and they were weighed and tested by resonant frequency and by the ultrasonic pulse method. The freeze-thaw tests should be continued until the end of 1000 cycles if possible, so both freeze-thaw and reference prisms will be tested in flexure.

Another useful index for determining the durability of concrete exposed to freeze-thaw cycling is the bubble-spacing factor, an index related to the maximum distance in millimeters of any point in the cement paste from the periphery of an air void. The spacing factor for concrete under investigation was determined in accordance with ASTM standard C457-71 by using the modified point-count method.

TEST RESULTS AND ANALYSIS

Altogether 169 cylinders and 83 prisms were tested in this investigation. The loss of slump with time is shown in Figures 1-4. A summary of the compressive and flexural strength is given in Tables 2-4 and the data are illustrated in Figures 5-9. Changes in weight, length, pulse velocity, and resonant frequencies of reference prisms and prisms subjected to freeze-thaw cycles are shown in Table 5. The results of the air-void analyses of the hardened concrete test specimens are given in Table 6.

DISCUSSION OF RESULTS

Initial Time of Set of Concrete

Studies were performed only for superplasticizers B, C, and D, and in each case there was some retarding effect on the time of set. However, this was not significant from a practical point of view because maximum retardation was only 42 min (superplasticizer D). These results are similar to the data for concretes with a w/c ratio of 0.42 reported in 1977 (3).

Segregation of Superplasticized Concrete

When examined visually, the superplasticized concretes did show segregation that ranged from insignificant for concrete incorporating superplasticizer C to considerable for concrete incorporating superplasticizer A. In the latter case there was almost complete separation of the mortar fraction. This degree of segregation is unacceptable for field application.

The excessive segregation problem may be overcome by increasing the amount of fines in the mix, such as fly ash or the amount of 50- to 100-mesh fraction of the fine aggregate.

Slump Increases and Losses with Time

Superplasticized concretes exhibited large increases in slump at the recommended dosages. The slumps reached 175 mm (7 in) or more within minutes of adding the superplasticizers, and 50- to 75-mm (2- to 3-in) slump concretes became flowing concretes. And, except for concrete made with superplasticizer A, even at these high slumps there was no significant segregation. The concretes maintained the initial slump for about 5 min, after which there was rapid slump loss. Concrete incorporating superplasticizer A lost slump more rapidly than the other concretes.

Figure 6. Compressive strength of test cylinders at 28 days for superplasticizer B.

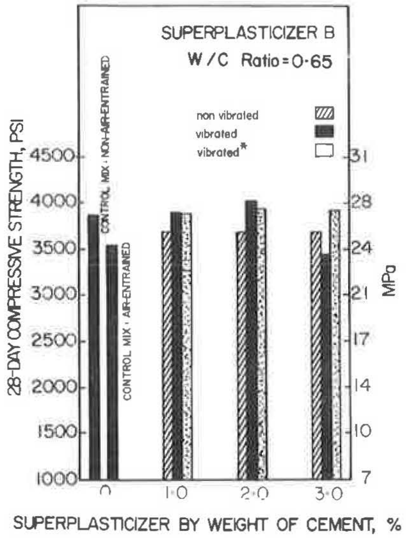
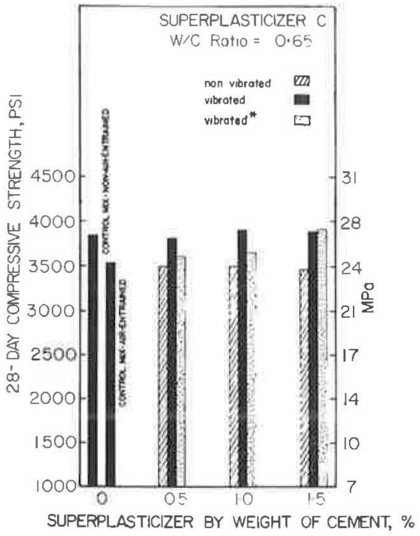


Figure 7. Compressive strength of test cylinders at 28 days for superplasticizer C.



Generally the concretes had reverted to about 50-mm (2-in) slumps in 40 ± 10 min, under laboratory temperature and humidity conditions. At maximum recommended dosages of superplasticizer A = 2.0 percent, superplasticizer B = 3.0 percent, superplasticizer C = 1.5 percent, and superplasticizer D = 3.0 percent, the superplasticized concrete lost slump at a slower rate. At the elapsed time of about 70 min, concretes incorporating superplasticizers A, B, and C had residual slumps of 50 mm (2 in). The corresponding value for

Figure 8. Compressive strength of test cylinders at 91 days for superplasticizer D.

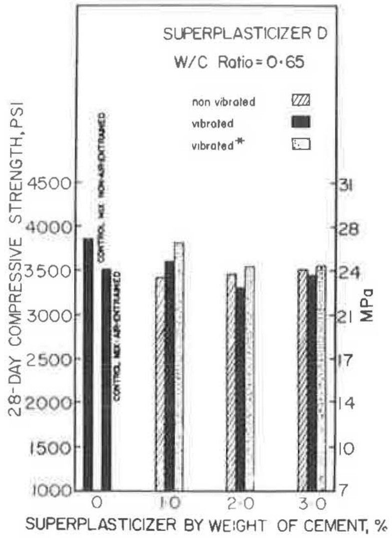


Figure 9. Compressive strength versus age relationship for control and superplasticized concretes.

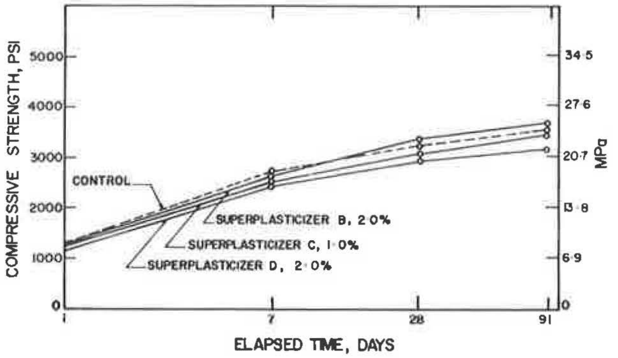


Table 5. Summary of freeze-thaw test results.

		Summary of Freeze-Thaw Test Results							
Superplasticizer		At 0 Cycles				At Completion of 300 Cycles			
Type	Dosage (%)	Weight (kg)	Length[a] (mm)	Longitudinal Resonant Frequency (Hz)	Pulse Velocity (m/s)	Weight (kg)	Length (mm)	Longitudinal Resonant Frequency (Hz)	Pulse Velocity (m/s)
Control without AEA		8.75	3.48	4950	4661	Prisms completely disintegrated at 45 cycles			
Control with AEA		8.46	3.06	4960	4520	8.48	3.49	4880	4467
A	1	8.16	3.65	4990	4611	8.63	3.28	4770	4402
B	2	8.63	3.67	5030	4530	8.66	2.53	4990	4488
C	1	8.71	3.93	5040	4617	8.74	3.27	4960	4541
D	2	8.58	2.71	5000	4557	8.54	3.26	4930	4472

Notes: 1 kg = 2.2 lb; 1 mm = 0.039 in; 1 m/s = 3.28 ft/s.

[a] Gauge length = 345 mm.

Table 6. Summary of air-void determination in hardened concrete.

Superplasticizer				
Type	Dosage (%)	Paste Content[a] (%)	Voids in Concrete (%)	Void-Spacing Factor (mm)
Control without AEA		27.9	2.2	1.27
Control with AEA		24.0	6.5	0.25
B	1.0	24.0	5.2	0.25
	2.0	24.0	4.9	0.36
	3.0	24.0	3.6	0.43
C	0.5	24.0	4.8	0.33
	1.0	24.0	3.0	0.41
	1.5	24.0	3.3	0.33
D	1.0	24.0	5.6	0.31
	2.0	24.0	4.8	0.28
	3.0	24.0	5.0	0.31

Note: 1 mm = 0.039 in.

[a] Calculated from mix proportions.

concrete incorporating superplasticizer D was 85 mm (3.5 in).

It appears that concretes having high w/c ratios can be superplasticized, which offers opportunities for placing flowing concretes in basement walls and other similar structures. The principal advantage of the superplasticizers under these conditions would be the savings from reduced labor needs for handling, placing, and compacting of concrete.

Compressive Strength Development

Compressive Strength at 28 Days

The compressive strength results are shown in Table 2 and in Figures 5-8. The following general observations can be made.

1. At the recommended dosage rates
    - a. The compressive strength of cylinders cast by vibration was between 2 and 10 percent higher than the strength of cylinders cast from the air-entrained control mix (the only exception was concrete incorporating superplasticizer A, where there was a very slight decrease in the strength that is of little practical significance);
    - b. The compressive strength of cylinders cast without vibration was comparable to that of the cylinders cast from the air-entrained control mix; and
    - c. The compressive strength of cylinders cast with vibration from concrete after it had reverted to the original slump was between 2 and 10 percent higher than the strength of cylinders cast from the air-entrained control mix. This is even true for concrete incorporating superplasticizer A.
2. At the maximum recommended dosage rates
    - a. The compressive strengths of superplasticized cylinders, cast with and without vibration, were comparable to strengths of cylinders cast from the air-entrained control mix, although there were exceptions: The cylinders cast from concrete incorporating superplasticizer A showed about 50 percent loss in strength compared to the control cylinders, which was probably due to the excessive segregation of the mix, while the strength of cylinders cast from concrete incorporating superplasticizer C was about 11 percent higher than the strength of the control cylinders;
    - b. The strengths of the superplasticized cylinders cast from concretes after the slump had returned to the original value of about 50 mm (2 in) were comparable to or about 11 percent higher than the strength of the control cylinders. This is probably due to the loss of moisture from the fresh concrete.

Compressive Strength Versus Age

The compressive-strength-versus-age test results are shown in Table 3 and Figure 9.

It will be seen from the data that, at the recommended dosage rates, the compressive strengths of cylinders cast from concrete incorporating superplasticizers B and C were comparable to the strength of the control cylinders at all ages. However, the compressive strength of cylinders cast from concrete incorporating superplasticizer D was consistently lower than the strength of the control cylinders at all ages. At 91 days the difference was about 9 percent. The lower strengths were probably due to the high amounts of entrained air retained by the concrete after the superplasticizer had been added. These results agree with data reported earlier for low w/c ratio concrete (3).

Flexural Strength

In general, the 14-day flexural strengths of test prisms (Table 4) cast from the concretes superplasticized at the recommended dosage rates showed no significant change from the strengths of the control prisms. The strength values were of the order of 5 MPa (725 lbf/in^2). However, the prisms cast from concrete incorporating superplasticizers A, B, and C showed a steady drop in strength with increased dosage rate. For example, at the maximum recommended dosage rates the 14-day strength values were 3.27, 4.92, and 4.76 MPa (475, 715, and 690 lbf/in^2), respectively. The prisms cast from concrete incorporating superplasticizer D, to the contrary, showed a very slight increase in strength with increased dosage rates; at the maximum recommended dosage rate, the 14-day strengths reached a value of 5.24 MPa (760 lbf/in^2).

DURABILITY OF CONCRETE PRISMS EXPOSED TO REPEATED FREEZE-THAW CYCLES

Durability of concrete prisms exposed to repeated cycles of freezing and thawing was determined by measuring weight, length, resonant frequency, and pulse velocity of test prisms before and after exposure to freeze-thaw cycles and then comparing these with corresponding values of the reference prisms. The test prisms had been cured for 13 days in a moist-curing room before being subjected to freezing and thawing.

The non-air-entrained control prisms had shown considerable distress after about 30 freeze-thaw cycles. The tests were discontinued after 45 freeze-thaw cycles, at the end of which the residual flexural strength of the prisms was only 3.8 percent.

In general, there were no significant changes in the test prisms cast from air-entrained superplasticized concrete at the end of 300 cycles (Table 5). Tests are being continued and the performance of the prisms up to the end of 1000 cycles will be reported at a later date.

Test results have indicated that all prisms performed just about equally well, at least up to 300 cycles. This was also confirmed by the results of flexural strength tests of the prisms. However, there are indications that test prisms incorporating superplasticizer A may not last much beyond 400 freeze-thaw cycles.

The freeze-thaw tests were performed using ASTM standard C666-76 and employing procedure B, rapid freezing in air and thawing in water. ASTM standard C494-71, chemical admixtures, specifies the use of procedure A, rapid freezing and thawing in water, for evaluating concrete that incorporates chemical admixtures. Nevertheless, the reported freeze-thaw data are still considered valid because the freeze-thaw is a comparative test carried out with the specimens cast from the control mixes. For this investigation, the test prisms cast from the non-air-entrained control mix had disintegrated at less than 45 freeze-thaw cycles. Data published by others (7) indicate that superplasticized concrete prisms perform satisfactorily when exposed to rapid freezing and thawing in water in accordance with procedure A.

AIR-VOID DETERMINATION OF HARDENED CONCRETE

The microscopic determination of air-void content and parameters of the air-void system in hardened concrete was made according to ASTM standard C457-71. It has been found that for satisfactory durability the cement paste should be protected with air bubbles (4). Adequate protection required that the spacing factor, an index related to the maximum distance of any point in the cement paste from the periphery of an air void, not exceed 0.20 mm (0.008 in).

In this investigation the air-entrained concrete had a void-spacing factor of 0.254 mm (0.01 in) but performed satisfactorily in freeze-thaw cycling (Table 6). The superplasticized concretes investigated for air-void determination had bubble-spacing factors that ranged from 0.254 to 0.432 mm (0.01 to 0.017 in). In spite of the increased bubble spacing, the durability of concretes incorporating superplasticizers B and D was not impaired. It appears that bubble-spacing factor limitations stipulated for air-entrained concrete may not be valid for concretes incorporating superplasticizers. Further research is needed on how these parameters can be correlated with the performance of concrete under freeze-thaw cycles.

CONCLUSIONS

At the recommended dosage rates there was no significant segregation of concrete except for the mix incorporating one of the naphthalene-based superplasticizers. High dosages of superplasticizers are not recommended because of the tendency of the concrete to segregate. This is particularly true of superplasticizer A.

All superplasticizers investigated had only insignificant retarding effects on the time of initial set of concrete.

When superplasticizers are added to concrete at the manufacturers' recommended dosage rates, the 28-day compressive strengths of test cylinders cast from superplasticized concrete are comparable to or greater than the corresponding strengths of cylinders cast from the reference mix. The strengths are comparable when the cylinders from the superplasticized concrete are cast without compaction by vibration and greater when cast with compaction by vibration.

For recommended dosage rates, the freeze-thaw durability of the test prisms cast from the air-entrained superplasticized concretes compared favorably with those cast from the air-entrained control mix at the end of 300 freeze-thaw cycles. The nature of the relationship between the durability of superplasticized concrete and the value of its bubble-spacing factor needs further research.

Superplasticizers are more expensive than ordinary water-reducing admixtures and therefore may or may not be economical for use in concrete of a high w/c ratio. This aspect will have to be considered for each job situation.

The results reported here were obtained with concrete of a w/c ratio of 0.65 and made with ASTM type I cement. The superplasticizers may or may not perform as reported in concrete made with other w/c ratios and with different types of cements and aggregates.

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