USE OF ADMIXTURES IN CONCRETE PLACED AT HIGH TEMPERATURES

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The difficulty posed by the high temperatures of concrete batches in areas such as the southwest United States limits the use of concrete. High temperatures and subsequent hot materials are present in the concrete mixers and the concrete poured. This high-temperature condition shortens the setting time and workability time of the concrete. Ice, which can be added to the mixer to reduce the temperature, is costly and sometimes not readily available at the job site. It is possible to lengthen the setting time and workability time by the addition of water-reducing, set-retarding chemical admixtures. This study attempts to determine by cement paste and concrete studies the best commercial and laboratory type of admixtures available for white and gray cement concretes. Thirty admixtures at normal and above-normal concentrations were tried in the paste systems, and the best retarders were tested subsequently in concrete batches. The temperature range used in this study varied from 70 to 110 F (21.1 to 43.3 C).

•THE placement of high-strength structural white concrete at ambient temperatures greater than 90 F (32.2 C) is a major problem in the Southwest and possibly other regions of the United States. The additional water required, sometimes in the form of high-cost ice, for maintaining slump during the 90 min necessary for placement (ASTM C94) results in losses in concrete compressive strengths [16 and 26 percent at 28 and 90 days respectively in our control batch at 90 F (32.2 C)].

The hot-weather concreting practice (ACI 605-59) did not meet the needs of and was not practical for concrete mixing operations in the Southwest. The maximum placement temperature of 85 F (29.4 C) at the completion of the 90-min mixing time during the summer months is lower than the actual temperatures experienced. The normal high temperature of the day during the summer months is 110 F (43.3 C). Random afternoon field inspection of summer concreting operations indicates placement temperatures between 90 and 100 F (32.2 and 37.8 C).

This project was initiated because it was believed that the use of a retarding admixture that would be effective at high ambient temperatures would solve the problems of adequate workability and strength development of white structural concrete. It was also found that the results of this study were applicable to types 2 and 3 gray cement concretes.

PROJECT SCOPE

Testing White Concrete

Thirteen laboratory concrete batches proportioned to have 7 sacks or 658 lb/yd^3 (390.4 kg/m^3) of white cement were used in the test program. The following cylinders, shrinkage bars, and flexure beams were cast (1 in. = 2.54 cm):

Item	Number	Measurement (in.)
Cylinders	560	4 × 8
Shrinkage bars	80	4 × 4 × 12
Flexure beams	100	2 × 2 × 12

The mix sequence involved 5 min at the start, at 45 min, and at 85 min of batch life or a total of 15 min of actual mixing during the 90-min period. The concrete between mixes remained at rest in the Essiz 9-ft^3 (0.26-m^3) mixing drum. ASTM tests of slump, unit weight, Proctor penetration resistance, setting time, and air content of freshly mixed concrete by the pressure method were conducted on each batch. Temperatures were also measured. Tests for compressive strength, flexural strength, and volume change were performed on cured specimens at intervals from 1 day to 1 year.

Admixture Testing

This program included tests on white cement pastes, mortars, and concretes at 70 F and at 90 to 110 F (21.1 C and 32.2 to 43.3 C) and involved 30 admixtures (Table 1). Thirteen commercially available admixtures from five companies were chosen as retarders. These have been documented as approved set-retarding or water-reducing admixtures at normal temperatures. The other 17 admixtures, designated as laboratory admixtures, were selected by us from previous studies that indicated particularly good retardation at high temperatures with white cement.

The categories of retarders include liquids and powders that range from high to low solubility in water and from white powders to dark-brown solutions. Liquids were added to the mixing water, and powders were blended into the white cement before water was added. The 13 commercial admixtures tested included lignosulfonates, salts of lignosulfonates and their derivatives, hydroxycarboxylic acids and their derivatives, and hydroxylated polymers. The 17 laboratory admixtures included sugars, heavy metal oxides, salts, and alkaline-alkaline earth hexafluorosilicates. This paper discusses the findings from both the laboratory and commercial admixtures.

PROCEDURES FOR EVALUATION OF ADMIXTURES IN WHITE CEMENT PASTES

A Japanese automatic vicat setting time recorder was used to determine the initial and final setting times of the white cement pastes with and without admixtures at normal temperatures of 75 F (23.9 C) and 50 percent relative humidity and at 110 F (43.3 C) and 20 percent relative humidity. The high temperatures are characteristic of the hot, dry summertime conditions in the southwest United States.

It was not necessary to test all admixtures at 75 F (23.9 C) to determine whether they retarded white cement. Those not tested were documented by manufacturers and were indicated by a literature search to retard portland cement systems at normal temperatures [75 F (23.9 C)]. The admixtures were added in an attempt to cause more than 60-min retardation of the initial setting time of the cements, as required in ASTM C494-68, at the high temperature of 110 F (43.3 C).

All admixtures were tested in cement pastes of normal consistency (ASTM C187) at 110 F (43.3 C) in a temperature-controlled cabinet. Random afternoon field inspection of summer concreting operations indicated placement temperatures between 90 and 100 F (32.2 and 37.8 C). The specified 0.39 ± 0.039-in. (10 ± 1-mm) plunger penetration was broadened to 0.39 ± 0.078 in. (10 ± 2 mm) for the extraordinary high temperatures of the test.

In the initial tests at 110 F (43.3 C) mixes were prepared at 75 F (23.9 C) and then immediately transferred to the 110 F (43.3 C) chamber for setting-time testing. These tests showed significantly different behavior compared to that of mixes prepared at

110 F (43.3 C). Consequently all 110 F (43.3 C) tests were mixed at 110 F (43.3 C) so that the most severe conditions likely to be encountered in high temperature concreting could be simulated.

The study of cement paste time of setting at 110 F (43.3 C) showed only four of the tested admixtures retarded without noticeable discoloration of the white cement pastes.

Admixture dosages from 0.1 to 4.0 percent by weight of cement were used in the admixture trials. Commercial admixture dosages varied from normal manufacturer's recommended dosages to seven times normal.

The admixtures and concentration levels that proved most successful in white cement pastes were

1. Two commercial admixtures of the hydroxycarboxylic acid type (admixtures A and B in Table 2) with a dosage varying from four to seven times normal dosage;
2. By weight, 1.0 percent of cement for the lead monoxide admixture (admixture C in Table 2); and
3. By weight, 0.7 to 1.0 percent of cement for the boron trioxide admixture (admixture D in Table 2).

When the study with cement pastes was completed, the four chosen admixtures as well as Borax (admixture E) and another commercial hydroxycarboxylic acid type of admixture (admixture F) were tested in concrete (Table 2). The first four admixtures (A, B, C, and D) were tested in concrete mixes at temperatures in the 70 F (21.1 C) range, and all six admixtures were tested in the temperature range higher than 90 F (32.2 C).

Because of space limitations, it is impossible to include the data obtained during the course of this study; however, Tables 3 and 4 give examples of the types of data obtained.

PROCEDURES FOR EVALUATION OF ADMIXTURES IN WHITE CEMENT CONCRETES

Modifications were made in the quantity of admixtures added to the concrete as compared with the quantity of admixtures added to the cement pastes. Normal concentrations of the commercial admixtures A and B were used in the 70 F (21.2 C) range. One-third of 1 percent by weight of cement was used for admixtures C and D in the 70 F (21.1 C) range.

High concentrations of admixtures (above normal dosages) were used in concrete in the greater than 90 F (32.2 C) range. This included a dosage of 8 to 12 oz (236.6 to 354.9 ml) per sack for the commercial admixtures A, B, and F and 0.4 to 1.5 percent by weight of cement for laboratory admixtures C, D, and E.

Control concrete mixes without admixtures were made at 70 F (21.1 C) and 90 F (32.2 C) at 7 sacks/yd^3 (390.4 kg/m^3) with a 4-in. (10.16-cm) slump target. A cement content of 7 sacks/yd^3 (390.4 kg/m^3) was selected because most field problems have occurred in mixes designed for high strength at 28 days. This is considered as the average cement content necessary to produce these high strengths. The mix water was reduced by 10 percent from that of the control when an admixture was used.

Concrete temperatures between 67 and 74 F (19.4 and 23.3 C) were maintained at laboratory conditions. Concrete temperatures higher than 90 F (32.2 C) were attained by preconditioning all components and the mixing drum to 100 F (37.8 C) before mixing. The temperature of the mixing drum was maintained by running hot water [140 F (60 C)] over the drum as needed during the mixing period.

Three times for measuring properties of the concrete were chosen: 5, 45, and 90 min. Slump, unit weight, air content, and temperature were determined after 5 min of mixing at 1, 40, and 85 min; however, specimens were cast only at the 5 and 90-min intervals.

The short time of 5 min was chosen for casting to simulate the conditions of on-site mixing. In some of these trials, the use of an admixture did not prove to be beneficial.

Table 1. Admixtures tested in concrete placed at high temperatures.

Commercial	Laboratory	Commercial	Laboratory
Daratard H.C.	Borax	Pozzolith MB-HC	Sodium borate concentrates
Daratard Lignin	Boric acid	Sonotard	Sodium hexafluorosilicate
Orzan Al-50	Boron trioxide	Sonotard 6050	Sodium hexametaphosphate
Orzan S	Calcium chloride	Zeecon R	Sodium tetraborate · water
PDA 25-R	Calcium hexafluorosilicate		Sorbitol
Plastiment	Iron sulfate		Sucrose
Pozzolith 8	Lead monoxide		Zinc hexafluorosilicate
Pozzolith 100R	Mannitol		Zinc oxide
Pozzolith 100XR	Potassium hexafluorosilicate		

Table 2. Admixtures used in concrete studies.

Admixture	Source	Type	Level of Addition At 70 F	Level of Addition At 90 F
A	Commercial	Hydroxycarboxylic acid	2 to 4[a]	6 to 12[a]
B	Commercial	Hydroxycarboxylic acid	2 to 4[a]	6 to 12[a]
C	Laboratory	Lead monoxide	0.33[b]	0.4 to 1.5[b]
D	Laboratory	Boron trioxide	0.33[b]	0.4 to 1.5[b]
E	Laboratory	Borax	—	0.4 to 1.5[b]
F	Commercial	Hydroxycarboxylic acid	—	6 to 12[a]

Note: 1 F = 1.8 (C) + 32. 1 oz = 29.6 ml.

[a]In ounces (milliliters) per sack. [b]In percent by weight of cement.

Table 3. Properties of fresh white cement concrete prepared with commercial admixtures.

Mix Type	Mix No.	Dosage per Sack (oz)	Mix Temper-ture (F)	Time of Test[a] (min)	Slump (in.)	Unit Weight (lb/ft^3)	Air Content (percent)	Cement Content (lb/yd^3)	Water-Cement Ratio
Control	1		70	1	4	148	2.0	650	0.44
	2		70	40	2	146	2.0	646	0.45
	3		70	85	1	146	2.0	646	0.45
	4		>90	1	2	146	4.0	640	0.51
	5		>90	40	1	144	3.5	640	0.50
	6		>90	85	1	143	3.5	640	0.53
With admix-ture A	1	4	70	1	4	153	1.2	678	0.41
	2	4	70	40	4	151	0.9	662	0.47
	3	4	70	85	4	148	1.2	639	0.56
	4	12	>90	1	4	152	1.4	665	0.44
	5	12	>90	40	4	150	1.4	648	0.52
	6	12	>90	85	4	149	1.4	639	0.55
With admix-ture B	1	3	70	1	6	152	1.2	667	0.43
	2	3	70	40	4	153	1.4	674	0.43
	3	3	70	85	4	152	1.2	664	0.46
	4	9	>90	1	5	153	1.6	679	0.38
	5	9	>90	40	5	151	1.2	665	0.43
	6	9	>90	85	5	151	1.2	660	0.46
With admix-ture F	1	8	70	1	5	152	1.5	660	0.49
	2	8	70	40	4	150	1.5	641	0.54
	3	8	70	85	4	150	1.4	641	0.56

Note: 1 oz = 29.6 ml. 1 F = 1.8 (C) + 32. 1 in. = 2.54 cm. 1 lb/ft^3 = 16.02 kg/m^3. 1 lb/yd^3 = 0.59 kg/m^3.

[a]After initial 5-min mixing.

Table 4. Strength of 4-in. (10.1-cm) slump white cement concrete made with various commercial admixtures mixed at 70 and 90 F (21.1 and 32.2 C) for various times.

Mix Type	Mix No.	Dosage per Sack (oz)	Mix Temper-ature (F)	Casting Time (min)	Compressive Strength (psi) 1 Day[a]	3 Day[b]	7 Day[b]	28 Day[b]	90 Day[c]	365 Day[c]	Flexural Strength (psi) 3 Day	7 Day	28 Day	90 Day
Control	1		70	5	2,400	3,280	3,790	4,690	5,790	5,800	480	460	560	600
	2		70	90	2,140	2,840	3,460	4,320	5,730	5,780	440	460	540	580
	3		>90	5	3,210	3,280	3,730	4,900	6,600	6,800				
	4		>90	90	1,910	2,230	2,610	4,110	4,880	5,000				
With admix-ture A	1	4	70	5	3,600	4,210	4,920	6,410	7,980	8,020				
	2	4	70	90	2,230	2,770	2,960	4,430	5,500	5,600				
	3	12	>90	5	1,140	3,780	4,310	5,220	6,070	6,200				
	4	12	>90	90	2,590	3,460	3,560	4,280	4,340	4,700				
With admix-ture B	1	3	70	5	2,870	4,140	4,450	6,060	7,520	7,600	540	620	680	970
	2	3	70	90	2,750	3,590	3,710	5,250	6,670	6,700	550	620	640	760
	3	9	>90	5	1,050	1,880	2,370	2,800	3,630	3,800				
	4	9	>90	90	2,080	2,340	2,620	4,970	5,260	5,300				
With admix-ture F	1	8	>90	5	3,590	3,540	4,480	5,350	6,250	6,300	610	610	850	880
	2	8	>90	90	2,930	2,940	3,330	4,010	5,580	5,900				

Note: 1 oz = 29.6 ml. 1 F = 1.8 (C) + 32. 1 psi = 6.9 kPa.

[a]Cured 1 day at mix temperature at 100 percent relative humidity.

[b]Cured 1 day at mix temperature at 100 percent relative humidity, then at 72 F (22.2 C) at 100 percent relative humidity until test.

[c]Cured 1 day at mix temperature at 100 percent relative humidity, then at 72 F (22.2 C) for 27 days at 100 percent relative humidity, then at 72 F (22.2 C) at 50 percent relative humidity until test.

The time of 90 min was chosen for casting to simulate the conditions of a transit-mix operation conforming to ASTM and AASHTO specifications for ready-mix concrete. At the 40 and 65-min time intervals, the concrete was remixed at 5 min, and water as needed was added to maintain a slump of approximately 4 in. (10.2 cm).

Initially, after all the ingredients were in the mixer, the concrete was mixed for 5 min in a 9-ft^3 (0.26-m^3) rotary drum mixer. After this 5-min period, the temperature, slump, unit weight, and air content were measured. Then, 4 by 8-in. (10.2 by 20.3-cm) cylinders, 4 by 4 by 11¼-in. (10.2 by 10.2 by 28.6-cm) bars, and 2 by 2 by 11¼-in. (5.1 by 5.1 by 28.6-cm) flexure beams were cast. Mortar was also separated from the concrete for initial and final setting time measurements by Proctor needle penetration.

At 90 min, all tests performed at 5 min were duplicated. It was found that the time of setting as measured by the Proctor needle showed no significant differences for samples taken from the mixer at 5 and at 90 min.

One test difference at 70 F (21.1 C) was ±9 min at 6¾ hours of initial setting and ±17 min at 7¾ hours of final setting.

At each time interval, the weight of concrete deducted from the batch of 7 sacks/yd^3 (390.4 kg/m^3) was determined, and corrected $yard^3$ ($meter^3$) weights were calculated. The water-cement ratios were then recomputed, and cement content in sacks per $yard^3$ (kilograms per $meter^3$) was calculated.

The cast specimens were cured for 24 hours at the mix temperature to simulate job storage conditions before specimens were taken to the testing storage facility.

The cylinders and beams were then cured up to 28 days at 72 F (22.2 C) and 100 percent relative humidity and then at 72 F (22.2 C) and 50 percent relative humidity until tested. The shrinkage specimens were at 72 F (22.2 C) and 100 percent relative humidity up to 7 days only. Test times chosen for the cylinder breaks were 1, 3, 7, 28, 90, and 365 days.

The shrinkage bars were measured at 1, 3, 7, 14, 21, 28, 35, 100, and 365 days to determine a correlation between short- and long-term shrinkage at the two temperature levels.

Flexural beams were not made from all batches; they were tested in flexure with third-point loading at 3, 7, 28, and 90 days. The 4 by 4 by 11¼-in. (10.2 by 10.2 by 28.6-cm) shrinkage bars were tested in flexure, center-point loading at 100 days for all mixes.

Some work was completed at a 2-in. (5.1-cm) slump at the 5-min mix time. In this work 200-lb (90.7-kg) batches mixed in a flat-bottomed Lancaster mixer were used, and 3 by 6-in. (7.6 by 15.2-cm) cylinders were cast and cured in the same manner as the larger batches for 1, 7, and 28-day tests.

Shrinkage bars of 3 by 3 by 11 in. (7.6 by 7.6 by 27.9 cm) and 4 by 4 by 11¼ in. (10.2 by 10.2 by 28.6 cm) were also cast and measured up to 100 days and then were tested in flexure. Beams of 2 by 2 by 11¼ in. (5.1 by 5.1 by 28.6 cm) were also cast and tested at 7 and 28 days.

Properties of White Concrete 1

White concrete 1 was mixed for 90 min and cured at 70 F (21.1 C) at a 4-in. (10.2-cm) slump, through 100 days. The properties of white concrete 1 were as follows:

1. At 70 F (21.1 C), admixture D and the commercial admixtures A and B [4 oz (118.3 ml) per sack] were found to be water-reducing, setting-time retarders.
2. The four admixtures tested (A, B, C, and D) did not entrain air.
3. The compressive strengths of concretes with admixture D, admixture C, and the commercial admixtures A and B were higher than those for the control for both 5 and 90-min mixing times.
4. The 100-day shrinkage bars indicated no additional shrinkage caused by admixture D, admixture C, or the commercial admixtures A and B [4 oz (118.3 ml) per sack].
5. Flexural strength tests indicated that all of the admixtures increased the strengths at both 5 and 90-min mixing times.

Properties of White Concrete 2

White concrete 2 was mixed for 5 min at 90 F (32.2 C) and cured at 90 F (32.2 C) for 24 hours, through 28 days at 70 F (21.1 C) at a 2-in. (5.1-cm) slump. The properties of white concrete 2 were as follows:

1. Admixture D (0.5 percent by weight of cement), admixture B [6 oz (177.4 ml) per sack], and admixture E (1.5 percent by weight of cement) were successful initial setting-time retarders.
2. Admixture D (0.5 percent by weight of cement) reduced the amount of water required for a 2-in. (5.1-cm) slump by 8.1 percent, but admixture B [6 oz (177.4 ml) per sack] and admixture E (1.5 percent by weight of cement) increased the water demand by 6.1 and 10 percent respectively in comparison to that of the control.
3. Admixture D (0.33 percent by weight of cement) and admixture B [6 oz (177.4 ml) per sack] produced cements with 7.6 and 3.7 percent respectively greater compressive strengths than the control, but cement with admixture E (1.5 percent by weight of cement) had a 47 percent lower strength than the control.
4. Admixture D (0.33 percent by weight of cement), admixture B [6 oz (177.4 ml) per sack], and admixture E (1.5 percent by weight of cement) increased the flexural strength of 2 by 2 by 11¼-in. (5.1 by 5.1 by 28.6-cm) beams by 19, 26, and 10 percent respectively.
5. Cement with admixture D (0.33 percent by weight of cement), admixture D (0.5 percent by weight of cement), admixture B [6 oz (177.4 ml) per sack], and admixture E (1.5 percent by weight of cement) had less shrinkage than the control at 100 days.
6. Admixtures B, D, and E did not entrain air.

Properties of White Concrete 3

White concrete 3 was mixed for 90 min at 90 F (32.2 C) and cured at 90 F (32.2 C) for 24 hours at a 4-in. (10.2-cm) slump, through 100 days at 70 F (21.1 C). The properties of white concrete 3 were as follows:

1. The setting times clearly indicated that admixture D (0.4 percent by weight of cement), admixture D (1.0 percent by weight of cement), admixture C (1.0 percent by weight of cement), admixture A [12 oz (354.9 ml) per sack], admixture E (1.2 percent by weight of cement), and admixture B [9 oz (266.2 ml) per sack] are effective for retarding the setting time of and reducing water in the concrete.
2. Admixture D (1.0 percent by weight of cement) and admixture B [9 oz (266.2 ml) per sack] were excessive dosages causing excessive retardation.
3. Some of the commercial admixtures discolored the white concrete.
4. The compressive strengths at 90 days of cements with admixture D (1.0 percent by weight of cement), admixture C (1.0 percent by weight of cement), and admixture B [9 oz (266.2 ml) per sack] were 32, 15, and 8 percent respectively greater than those of the control at 90-min mixing but were 63, 30, and 40 percent smaller than those of the control at 5 min of mixing. The low strength at 5 min of mixing resulted because the dosage levels were excessive for short mix cycles, but greater strengths were achieved at 90 min mixing through additional mixing time.
5. The compressive strengths at 90 days of cements with admixture D (0.4 percent by weight of cement) and admixture E (1.2 percent by weight of cement) were 39 and 28 percent greater than those of the control at 90-min mixing, but the compressive strengths at 5 min of mixing are 5 percent less for cements with admixture D (0.4 percent by weight of cement) and 7 percent greater for those with admixture E (1.2 percent by weight of cement).
6. Admixture A [12 oz (354.9 ml) per sack] resulted in 8 and 11 percent reductions in compressive strengths at 5 and 90 min of mixing.
7. The 100-day shrinkage bar tests indicated that at 90 min of mixing only admixture A [12 oz (354.9 ml) per sack] had a greater amount of shrinkage than the control.
8. Admixtures A, B, C, D, and E did not entrain air.

Recommendations for White Cement Concrete

The recommendations for white cement concrete mixed at 90 F (32.2 C) at a 4-in. (10.2-cm) slump are as follows:

1. The use of admixture B as an effective retarder for white cement concrete at elevated temperatures is not recommended because of the resulting discoloration at dosages of 6 to 9 oz (177.4 to 266.2 ml) per sack found necessary for 60 min of initial setting retardation.
2. Admixture A can be used at three times the normal dosage [9 to 12 oz (266.2 to 354.9 ml) per sack] at 90 F (32.2 C) and above.
3. The use of admixture C (1.0 percent by weight of cement) is not recommended because of toxicological properties, although it is an excellent retarder.
4. The use of admixture D (0.4 ± 0.1 percent by weight of cement) is recommended.
5. The use of dark-colored admixture solutions at two times the normal dosage is not recommended.
6. None of the admixtures tested entrained air.
7. The use of admixture E (1.0 ± 0.1 percent by weight of cement) is potentially useful.

Many other similar practical questions could be answered in a comprehensive study of the interactions of cement concrete and admixtures. This study would be of tremendous benefit in research and development, technical service work, and promotional activities. It is hoped that such a study might be initiated in the near future.

No work was performed on white structural concrete that contained entrained air. In climates where freezing and thawing are a problem, it would seem desirable to determine the effect of mixing time on air-entraining addition rates, freeze-thaw resistance, and strength, on high-strength, air-entrained white structural concrete. White structural concrete has been used by the Arizona Department of Transportation along I-66 in freeze-thaw areas, and, therefore, some investigation of the white air-entrained concrete, even in the Southwest, would seem appropriate.

Summary and Conclusions

1. The tests of cement pastes and admixtures indicated that an optimum amount of admixture was necessary to secure maximum retardation.
2. False set characteristics, as defined in ASTM C 451, were not improved by the addition of set-retarding, water-reducing admixtures A, D, and E.
3. The optimum percentage of admixtures required for retardation in the concrete was approximately half of that required in the pastes.
4. Substantial reductions in compressive strengths were obtained in 5 to 90-min mix life intervals at 70 (21.1 C) and 90 F (32.2 C). This is related to the additional water required for maintaining a constant slump.
5. Concretes with admixtures causing excessive retardation generally develop strengths approximately equal to those of concrete without admixtures at 28 days. This occurs even when the earlier strengths were drastically low.
6. Length change was affected by mixing time, admixture type, and admixture dosage level.
7. None of the admixtures tested entrained additional air.
8. Delayed addition of admixtures was not included in this series because this procedure is impractical for ready-mix operations. Field control is difficult, and the additional entrained air would be detrimental to concrete performance, particularly strength.
9. The use of dark-colored admixture solutions is not recommended with white cement unless color slab tests are made that result in satisfying job requirements.
10. Admixture D (0.4 ± 0.1 percent by weight of cement) is suggested for white cement concrete admixture use at 90 F (32.2 C). This admixture should be dissolved in the mix water first.

11. Admixture A can be used at two to three times the manufacturer's recommended dosage rate at 90 F (32.2 C) to effectively retard the initial setting time of concrete within ASTM C494-68 specifications.

12. The use of Admixture B (a dark-colored solution) is not suggested because of the discoloration resulting from the multiple dosage level required for initial setting-time retardation.

13. Concrete temperature above 90 F (32.2 C) and a mixing time of 90 min usually result in a loss of strength. It is important that this be considered in the mix design.

14. Although an admixture satisfies the requirements set forth in ASTM C494-68 at normal temperatures, it does not necessarily satisfy the requirements for mixing times and placing temperatures permitted by ASTM C94-67 (ready-mixed concrete) or ACI.

15. Mixing time, concrete temperature range, and admixture dosage rate should be included when concrete mixes are designed.

16. ASTM C494-68 for chemical admixtures for concrete does not provide adequate information for selection of an admixture for hot-weather concreting. This specification requires only 6 min of mixing time at a room temperature that is unrealistic for field use. Field problems are usually not encountered at 70 F (21.1 C); therefore, the implicit assumption that an admixture that retards at 70 F (21.1 C) will also do so at 90 F (32.2 C) is not valid. Our tests indicate that commonly accepted retarders, such as sugar, retard at 70 F (21.1 C), but act as accelerators at 90 F (32.2 C). Mixing times of 90 min and temperatures above the normal 75 F (23.9 C) should be used in evaluating the efficiency of a retarder for high-temperature concreting.

17. White structural concrete generally requires from two to three times the normal addition rate of a retarder, conforming to the requirements of C494-68, to permit sufficient mixing time without a significant addition of water and subsequent reduction in strength. These greater than normal additions may discolor the concrete and should be selected after field trials indicate that staining will not be a problem.

PROJECT SCOPE FOR TESTING TYPES 2 AND 3 GRAY CEMENT CONCRETE

This section discusses the use of chemical admixtures as retarders in types 2 and 3 gray cement concrete at 70 F (21.1 C) and 90 F (32.2 C).

All commercial and laboratory admixture selections from the previous discussion were first tested in gray cement pastes at 110 F (43.3 C). Automatic vicat cement setting times of normal consistency pastes (ASTM C187) were recorded at this temperature with and without admixtures. Concentrations of these admixtures were varied from 3 to 4 times normal recommended dosage to retard the initial set of the pastes by 1 hour (ASTM C494-68). A delay in setting time in the paste does not correlate directly with a delay in setting time in the concrete. Therefore, adjustments were made in additional levels when the admixtures that proved successful in pastes were used in concretes.

The color of the admixtures used was not a problem in these gray cements, although an overdose of admixture can cause discoloration in a buff-colored cement.

RESULTS OF TESTS

Admixtures in Gray Cement Concrete Pastes

Admixtures A, B, D, and E (Table 2) were effective for retarding the setting time of and reducing the water in the paste tests.

These admixtures were used in type 2 gray cement concrete mixes at 70 F (21.1 C) and 90 F (32.2 C) in varying concentrations so that an optimum level at each condition could be found.

Admixtures C and D (Table 2) were tried in type 3 gray cement concrete mixes at

70 F (21.1 C) and 90 F (32.2 C) at one concentration level. Further work with other admixtures and concentration should be conducted in the type 3 cement concrete.

Type 2 Gray Cement Concrete at >70 F (21.1 C) and >90 F (32.2 C)

The concrete mix design and mixing procedure in the gray cement project were as follows: a 7-sack/yd^3 (390.4-kg/m^3) mix; a 4-in. (10.2-cm) slump target maintained over the 90 min of batch life; two mix temperature ranges of 66 to 80 F (18.9 to 26.7 C) and 90 to 104 F (32.2 to 40.0 C); ASTM plastic concrete tests at 5, 50, and 90 min of batch life; and casting of specimens at 5 and 90 min of batch life. The mix sequence involves 5 min of mixing at 0, 40, and 85 min of elapsed batch life time for a total of 15 min of actual mixing. The concrete between mixes remained at rest in the mixing drum. Twenty-five 750-lb (340.2-kg) concrete batches were mixed from 3,060 lb (1388 kg) of cement and 13,000 lb (5897 kg) of aggregate. The following cylinders, shrinkage bars, and flexure beams were cast (1 in. = 2.54 cm):

Item	Number	Measurement (in.)
Cylinders	525	4 × 8
Shrinkage bars	126	4 × 4 × 11¼
Flexure beams	168	2 × 2 × 11¼

Tests were performed on cured specimens at 1, 3, 7, 28, 90, 100, and 180 days.

Concrete mixes at between 70 and 80 F (21.1 and 26.7 C) were performed in laboratory conditions, and materials stored under the same conditions were used. Curing of the cast specimens was performed in a moist room at 70 F (21.1 C) and 100 percent relative humidity and in another room at 70 F (21.1 C) and 50 percent relative humidity.

Concrete mixes at 90 F (32.2 C) were performed in the laboratory, and the materials and the mixer were preconditioned to 100 F (37.8 C). The temperature in the concrete was maintained by the use of hot running water [140 F (60 C)] on the 9-ft^3 (0.26-m^3) rotary drum when needed.

The ASTM tests performed on the plastic concrete mixes measured slump, temperature, unit weight, air content, and setting time of mortar separated from the concrete.

Type 2 Gray Cement Concrete at >70 F (21.1 C) and 180 Days

The findings for type 2 gray cement concrete at >70 F (21.1 C) and 180 days were as follows:

1. Type 2 gray cement concrete responds well to the manufacturer's normal recommended dosage rate of 2 to 3 oz (59.1 to 88.7 ml per sack) at 70 F (21.1 C).
2. Types 2 and 3 gray cement without admixtures have the same concrete setting times at 70 F (21.1 C) as determined by the Proctor penetration resistance setting time test (ASTM C 403-68).
3. None of the admixtures tested entrained air.
4. None of the admixtures tested reduced the water content requirements.
5. All of the admixtures tested retarded the initial and final setting times of the concrete.
6. Admixture B [3 oz (88.7 ml) per sack] and admixture D (0.15 percent by weight of cement) developed concretes with the best compressive (25 and 6 percent greater respectively) and flexural strengths at 70 F (21.1 C).
7. All admixtures tested produced increased shrinkage (from 6 to 35 percent) compared to the control specimens at 100 days. The amount of shrinkage in the admixture B specimens [3 oz (88.7 ml) per sack] exceeds the limits specified in ASTM C 494-68 in both 5 and 90-min mixes.

Type 2 Gray Cement Concrete at >90 F (32.2 C) and 180 Days

The findings for type 2 gray cement concrete at >90 F (32.2 C) and 180 days were as follows:

1. The type 2 gray cement concrete requires higher admixture additions [3 to 4 oz (88.7 to 118.3 ml) per sack] than the manufacturer's recommended dosage at 90 F (32.2 C).
2. Types 2 and 3 gray cement concretes have the same setting times in concrete at 90 F (32.2 C) without admixtures.
3. None of the admixtures tested entrained air.
4. All of the admixtures tested acted to reduce water in and retard the setting time of concrete.
5. Admixture D (0.30 percent by weight), admixture A [5 oz (147.9 ml) per sack], and admixture D (0.4 percent by weight) have developed concretes with the best compressive (36, 25, and 34 percent respectively) and flexural strengths at 90 F (32.2 C).
6. All of the admixtures tested reduced the shrinkage (from 7 to 48 percent in comparison to the control bars) at both 5 and 90-min mixing times.
7. Admixture A [12 oz (354.9 ml) per sack] was an overdose.

Type 3 Gray Cement Concrete at >70 F (21.1 C) at 180 Days

Findings for type 3 gray cement concrete at >70 F (21.1 C) at 180 days were as follows:

1. Type 3 gray cement concrete does not require any more than the manufacturer's normal recommended dosages at 70 F (21.1 C) [2 to 4 oz (59.1 to 118.3 ml) per sack].
2. None of the admixtures increased the air content.
3. All of the admixtures used in the concrete increased the drying shrinkage (from 14 to 35 percent) at 100 days in both 5 and 90-min mixing times.
4. Admixture A [4 oz (118.3 ml) per sack] and admixture B [3 oz (88.7 ml) per sack] retarded the setting times and increased the compressive (5 and 34 percent greater respectively) and flexural strengths.
5. Admixture A [4 oz (118.3 ml) per sack] reduced the water demand by 6 percent compared with that for the control.

Type 3 Gray Cement Concrete at >90 F (32.2 C) and 180 Days

Fingings for type 3 gray cement concrete at >90 F (32.2 C) and 180 days were as follows:

1. Type 3 gray cement concrete does not require any more than manufacturer's recommended dosages [2 to 3 oz (59.1 to 88.7 ml) per sack] at 90 F (32.2 C).
2. None of the admixtures used produced more shrinkage than the control batch bars at 100 days in mixing times of 5 and 90 min.
3. Admixture A [6 oz (177.4 ml) per sack] and admixture B [4 oz (118.3 ml) per sack] acted to reduce water in and retard setting of the concrete at 90 F (32.2 C).
4. Admixture B [4 oz (118.3 ml) per sack] developed a 40 percent greater flexural strength than the control.
5. Admixture A [6 oz (177.4 ml) per sack] resulted in an undesirably long setting time.

Summary and Conclusions

The conclusions about the use of chemical retarding admixtures in types 2 and 3 gray

Table 5. Use of admixtures at acceptable dosages in gray cement concrete.

Gray Cement Concrete	Admixture	Dosage Rate At >70 F	At >90 F
Type 2	A	2 to 3[a]	4 to 5[a]
	B	2 to 3[a]	4 to 5[a]
	D	0.10 to 0.20[b]	0.30 to 0.40[b]
	E	0.35 to 0.45[b]	0.80 to 0.90[b]
Type 3	A	2 to 3[a]	2 to 3[a]
	B	2 to 3[a]	2 to 3[a]

Note: 1 F = 1.8 (C) + 32. 1 oz = 29.6 ml.
[a]In ounces (milliliters) per 94 lb (42.6 kg) sack of cement.
[b]In percent by weight of cement.

cement concrete at >70 F (21.1 C) and >90 F (32.2 C) and 180 days are as follows:

1. The use of chemical admixtures A, B, D, and E at the dosage levels proved acceptable by this paper is given in Table 5.
2. All admixtures should be added to the mix water first.
3. Increments of 1 oz (29.6 ml) per sack of cement greater than recommended are very detrimental and should be avoided.
4. Specifications are needed about the use of chemical admixtures in concrete where other than normal type cements, at 5½ sacks or 517 lb/yd^3 (306.7 kg/m^3), and other than normal temperature conditions exist. ASTM C 494-68 is inadequate in this area and should be revised to contain standards for the above-mentioned conditions.

FUTURE STUDIES

A chemical investigation of admixture-concrete systems during mixing and subsequent hardening could provide valuable information for understanding why admixtures under various conditions act as they do. This information could then be correlated with data from physical test results. Many questions such as the following that concern admixture-concrete interactions could then be answered:

1. Why do some set-retarding admixtures produce lower compressive strengths with longer mixing time than others?
2. How do admixtures change with age?
3. Can one determine quantitatively the admixture contained in a 1-year-old specimen of concrete?
4. Why does a particular admixture react differently with the same type of cement from different sources?

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