Hot Cement and Hot Weather Concrete Tests

By William Lerch

Formerly Head, Performance Tests Group,
Research and Development Laboratories
Portland Cement Association

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PORTLAND CEMENT ASSOCIATION
5420 Old Orchard Road, Skokie, Illinois 60077

Introduction

The question of whether the temperature of the cement at the time of use affects the properties of the resulting concrete has been raised on some occasions. Strengths lower than anticipated are sometimes obtained from control specimens on construction projects during hot weather concreting. The use of hot cement is often blamed for these low strengths. Several state highway departments and the U.S. Corps of Engineers specifications have placed a maximum limit on the temperature of the cement at the time of use in the expectation that such a limit would improve the quality of the concrete. Extensive laboratory and field tests have shown that the temperature of the cement at the time of use will have only a slight effect on the properties of the concrete. However, similar tests have shown that the temperature of the freshly mixed concrete does have a significant effect on both the slump and the strength of the concrete. The temperature of the cement, because of its low specific heat and its relatively small quantity in the mix, is only a minor factor in affecting the temperature of the freshly mixed concrete. The temperatures of the aggregate and mixing water have a much larger effect on the temperature of the concrete. The results of these tests indicate that it would be desirable to specify a maximum limit for the temperature of the freshly mixed concrete rather than placing a limit on the temperature of the ingredients.

This report reviews the data available on hot cement and hot weather concrete tests and describes procedures for controlling the temperature of the freshly mixed concrete during hot weather.

Report by ASTM Committee C-1

A Working Committee of ASTM Committee C-1 on Cement prepared a digest of the information then available on Effect of Temperature of Cement at Time of Use. The Working Committee's report was published in the American Society for Testing Materials *Proceedings*, Vol. 32, Part I, page 298 (1932). The report includes data obtained from both laboratory tests and concrete construction projects. These data indicate that it is the temperature of the freshly mixed concrete rather than the temperature of any single ingredient that influences the properties of the concrete. On the concrete pavement projects it was found that the use of hot cement, with temperatures as high as 167°F. at the mixer, had no significant effect on workability, finishing operations, compressive or flexural strengths, volume change, checking and cracking. The report states that the data studied seem to warrant the following conclusions:

"1. The temperature of freshly mixed concrete rather than the temperatures of the separate ingredients appears to be the factor which influences the properties of the concrete.

"2. The temperature of freshly mixed concrete depends upon the temperatures, specific heats and weights of all of the materials entering into the concrete.

"3. Increasing the temperature of freshly mixed concrete decreases the slump and flow.

"4. Increasing the temperature of cement paste accelerates its rate of setting.

"5. There appears to be little effect on strength until the temperature of the freshly mixed concrete is well above 100°F. At 130 and 165°F. the one-day strength was increased, but at later periods the strength was decreased; the compressive strength was more affected than the modulus of rupture. The decrease in strength at the higher temperatures appears to be due in part to the additional water required to maintain a given consistency.

"6. On account of the low specific heat of portland cement and of its relatively small quantity in the usual mix, the temperature at the time of use of portland cement of normal properties appears to be a minor factor in producing high temperatures of freshly mixed concrete under usual job conditions.

"7. Temperature at time of use of portland cement of normal properties was unimportant under job conditions covered by this report."

More recent tests made in the laboratories of the U.S. Bureau of Reclamation and the Portland Cement Association also show that it is the temperature of the freshly mixed concrete and not the temperature of the separate ingredients that affects the properties of the concrete. The results of these tests are shown in Figs. 1 and 2 and in Tables 1 and 2.

Effect of the Temperature of Freshly Mixed Concrete on Slump

Fig. 1 shows that the water requirement of a concrete mix increases as the temperature of the freshly mixed concrete increases. When the temperature of the freshly mixed concrete is increased from 50°F. to 100°F., the quantity of mixing water must be increased 32 lb. per cu.yd. to maintain the same slump. The additional mixing water would be equivalent to approximately 0.7 of a gallon per sack of cement in a mix containing 5.5 sacks of cement per cu.yd. This increase in the water-cement ratio, of itself, would reduce the 28-day compressive strength by about 600 lb. per sq.in. and it would reduce the 28-day flexural strength by about 50 lb. per sq.in.

Effect of the Temperature of Freshly Mixed Concrete on Compressive and Flexural Strengths

Fig. 2 shows the effect of the temperature of the freshly mixed concrete on the compressive strengths at ages up to 6 months when the water-cement ratio was maintained constant at 0.50 by weight of the cement. This figure is taken from a paper by Walter H. Price, "Factors Influencing Concrete Strength," American Concrete Institute *Proceedings*, Vol. 47, page 417 (1951). The concretes were mixed at six different temperatures covering a range from 40°F. to 115°F. The specimens were cast and maintained at the mixing temperature for 2 hours and then stored at 70°F. until the age of test. The various curves in Fig. 2 show that the compressive strength decreases as the temperature of the freshly mixed concrete increases. The concretes mixed and placed at 40°F. had a 28-day compressive strength of 5,200 lb. per sq.in., while the same concrete when mixed and placed at 115°F. had a 28-day compressive strength of 4,300 lb. per sq.in. If the water-cement ratio had been adjusted in these tests to maintain the same slump, as shown in Fig. 1, the reduction in strength would have been even greater than that shown in Fig. 2.

Table 1 shows additional data on the effect of the initial temperature of the concrete on the slump and on the compressive and flexural strengths. These tests were made in the laboratories of the Portland Cement Association and they are for air-entrained concretes made with cements of Types I, II and III. The air-entraining agent was added at the mixer to maintain the same air content for the concretes mixed at different temperatures. The concretes were mixed and the specimens were fabricated at temperatures of 73, 90, 105 and 120°F. The specimens fabricated at 73°F. were cured continuously moist at 73°F.; those fabricated at higher temperatures were moist-cured 7 days at the higher temperature and then moist-cured at 73°F. until the age of test. These tests using concretes of the same water-cement ratio show the following results:

1. The slump decreases as the temperature of the freshly mixed concrete increases, and
2. The compressive and flexural strengths decrease, particularly at ages of

28 days and 3 months, as the initial temperature of the concrete increases even though the concretes mixed at the higher temperatures had the benefit of 7 days' curing at the higher temperature. This reduction in strength, like that in Fig. 2, would have been even greater if the water-cement ratio had been increased to maintain the same slump.

Effect of Hot Cement on the Properties of Concrete

Table 2 shows the effect of hot cement on the properties of the concrete. For these tests the cement was used at temperatures of approximately 74, 150 and 175°F. The cements were used in concretes mixed at temperatures of 76 and 105°F. The temperature of the mixing water was adjusted to compensate for the hot cement to obtain the desired temperature of the concrete. The results of these tests show that hot cement has no significant effect on the slump or the compressive and flexural strength when the temperature of the freshly mixed concrete is maintained constant. A comparison of the results obtained for concretes mixed at temperatures of 76 and 105°F. again shows that increasing the temperature of the freshly mixed concrete reduces the slump and decreases the 28-day compressive and flexural strengths. These results are in agreement with the conclusions in the 1932 report of ASTM Committee C-1.

Control of Temperature of Freshly Mixed Concrete During Hot Weather

Table 3 shows the influence of temperature of materials on the temperature of the concrete. These data were calculated for a concrete mixture containing 6.0 sacks of cement per cu.yd. with a water-cement ratio of 0.50 by weight. Similar calculations can be made readily for other mixes. These results show that the temperature of the aggregate and the mixing water have a much greater effect on the temperature of the freshly mixed concrete than does the temperature of the cement. It requires only 1.6°F. of aggregate temperature or 3.6°F. of the mixing water temperature, while it requires 9.0°F. of cement temperature to change the temperature of the concrete 1.0°F. Thus it becomes apparent that a control of the temperature of the aggregate and the mixing water is far more important than a control of the temperature of the cement in obtaining the required temperature of the freshly mixed concrete. Field experience has shown that practical procedures can be applied to control the temperature of the water and aggregates during hot weather. Every precaution should be used to maintain the temperature of the water as low as reasonably possible. It should not be stored in tanks exposed to the direct rays of sun unless the tanks are insulated. The aggregate piles should be sprinkled and kept moist at all times. Evaporation is a cooling process. It has been found that this is a very effective means of cooling the aggregates.

Concluding Remarks

Extensive laboratory tests and field observations have shown that the temperature of the cement at the time of use has no significant effect on the properties of the concrete, except insofar as it affects the temperature of the freshly mixed concrete. The temperature of the freshly mixed concrete does have a significant effect on the slump and on the compressive and flexural strengths. As the temperature of the freshly mixed concrete increases the slump is reduced, or more mixing water is required to maintain the same slump, and the compressive and flexural strengths are decreased. The temperature of the cement has much less effect on the temperature of the freshly mixed concrete than does the temperature of the aggregate and the mixing water. During hot weather, sprinkling the aggregate piles provides an effective means of cooling the aggregates and every precaution should be applied to maintain the temperature of the mixing water as low as possible.

The data now available show that it would be desirable to place a maximum limit on the temperature of the freshly mixed concrete rather than placing a limit on the temperature of the ingredients. A maximum temperature of 80°F. for the freshly mixed concrete would be satisfactory for most construction projects. A lower temperature would be desirable for mass concrete.

ADDENDUM

Freshly Ground Hot Cement

Shortly after this paper was prepared another paper entitled "The Use of Warm Cement on Concreting Jobs," by K. Seidel, was published in *Zement-Kalk-Gips*, Vol. 8, No. 1, page 1, January 1955. The results reported by Seidel are in good agreement with those cited above. Furthermore, Seidel's paper included tests of freshly ground hot cement and the same cement after storage for 21 days at 185°F. and at room temperature. The results of these tests, Table 4, show that the freshly ground hot cement and the cement stored for 21 days at 185°F. gave compressive and flexural strengths as high or slightly higher than those obtained with the same cement stored and tested at room temperature.

TABLE 1. Effect of Initial Temperature of Concrete on Compressive and Flexural Strengths

Cement content: 5½ sacks per cu.yd.

Air-entraining agent added to maintain an air content of 4½ ± ½ per cent.

Curing: Specimens fabricated at 73°F. were cured continuously moist at 73°F. Those fabricated at higher temperatures were moist-cured 7 days at the higher temperature and then moist-cured at 73°F. until age of test.

Init. Temp. Concrete, °F.	Slump, in.	Strength at age indicated, psi					
		Compressive strength			Flexural strength		
		7d.	28d.	3m.	7d.	28d.	3m.
TYPE I portland cement — W/C = 5.1 gal. per sack							
73	3.4	4,060(100)	*5,440(100)	6,000(100)	530(100)	675(100)	780(100)
90	3.1	4,160(103)	4,820(88)	5,460(91)	520(98)	610(90)	705(90)
105	1.9	3,850(95)	4,200(77)	4,920(82)	505(95)	600(89)	640(82)
120	1.3	3,440(84)	4,080(75)	4,320(72)	450(85)	550(82)	570(73)
TYPE II portland cement — W/C = 4.9 gal. per sack							
73	3.6	3,680(100)	5,230(100)	6,570(100)	490(100)	635(100)	740(100)
90	3.2	3,900(106)	5,190(99)	6,090(93)	540(110)	645(102)	740(100)
105	2.3	4,420(120)	4,990(95)	5,760(88)	515(105)	650(102)	720(97)
120	1.2	3,930(107)	4,720(90)	5,300(81)	480(98)	605(95)	610(82)
TYPE III portland cement — W/C = 5.6 gal. per sack							
73	3.2	4,610(100)	5,460(100)	5,970(100)	515(100)	600(100)	725(100)
90	3.2	5,010(109)	5,610(103)	5,940(100)	545(106)	660(110)	660(91)
105	3.1	4,580(99)	5,210(96)	5,300(89)	465(90)	575(96)	610(84)
120	2.2	4,160(90)	4,490(82)	5,000(84)	485(94)	575(96)	610(84)

*Values in parentheses are percentages of strengths of concretes mixed and cured continuously at 73°F.

TABLE 2. Effect of Hot Cement on Properties of Concrete

Type I portland cement.

Cement content: 5½ sacks per cu.yd.

Net W/C = 4.85 gal. per sack of cement.

Air-entraining agent added to maintain an air content of 4½ ± ½ per cent.

Curing: Specimens fabricated at 73°F. were cured continuously moist at 73°F. Those fabricated at 105°F. were moist-cured 7 days at 105°F., followed by 21 days moist-curing at 73°F.

Mix No.	Temp. of materials, °F.			Temp. of concrete, °F.	Slump, in.	Strength of concrete, psi			
	Cement	Water	Aggregate			Flexural		Compressive	
						7d.	28d.	7d.	28d.
1	74	73	74	76	3.5	550	685	4,730	6,230
2	148	44	74	76	3.2	545	650	4,560	5,950
3	179	33	74	76	2.7	550	655	4,650	5,960
4	74	124	101	108	0.6	555	610	4,500	5,060
5	149	60	104	102	0.7	535	635	4,600	5,190
6	174	50	104	102	1.0	535	640	4,540	5,090

TABLE 3. Influence of Temperature of Materials on Temperature of Concrete

Heat capacity of the ingredients of the mix:

Cement — 6 sacks per cu.yd. = 564 lb. X 0.20 (specific heat)	=	113 BTU per °F.
Water — W/C = 0.50 — 282 lb. X 1.00 (specific heat)	=	282 BTU per °F.
Total aggregate = 3,100 lb. X 0.20 (specific heat)	=	620 BTU per °F.
Total heat capacity of the concrete	=	**1,015 BTU per °F.**

Contribution of the temperature of the ingredients to the temperature of the concrete mixture:

9.0°F. $\left(\frac{1{,}015}{113}\right)$ cement temperature changes concrete temperature 1.0°F.

3.6°F. $\left(\frac{1{,}015}{282}\right)$ water temperature changes concrete temperature 1.0°F.

1.6°F. $\left(\frac{1{,}015}{620}\right)$ aggregate temperature changes concrete temperature 1.0°F.

TABLE 4. Flexural and Compressive Strengths of Mortars Made with Freshly Ground Hot Cement and with the Same Cement After Storage at Different Temperatures

(Data from paper by K. Seidel, *Zement-Kalk-Gips*, Vol. 8, No. 1, page 1, January 1955)

Tests carried out in the Structural Laboratory of the Münster Waterways Administration, Münster, Germany.

Cement tests made according to German Specification DIN 1164.

Condition of cement storage prior to test	Temp. of cement at time of test	Time of set of neat cement pastes		Flexural strength, psi		Compressive strength, psi	
		Init. h.m.	Final h.m.	7d.	28d.	7d.	28d.
Tested on day of grinding immediately upon delivery	185°F.	3:25	4:30	930	1,200	3,740	6,280
Cooled to room temp. on day of grinding	69°F.	4:30	5:10	960	1,190	3,840	6,170
In drying cabinet 3 days at 185°F.	185°F.	4:00	4:40	940	1,180	3,810	6,380
In lab. 3 days at 65% R.H., and 66°F.	66°F.	4:10	5:05	1,010	1,190	4,110	6,340
In drying cabinet 21 days at 185°F.	185°F.	4:45	5:20	910	1,210	3,980	6,380
In lab. 21 days at 65% R.H., and 66°F.	66°F.	8:15	9:30	680	1,070	2,900	4,140

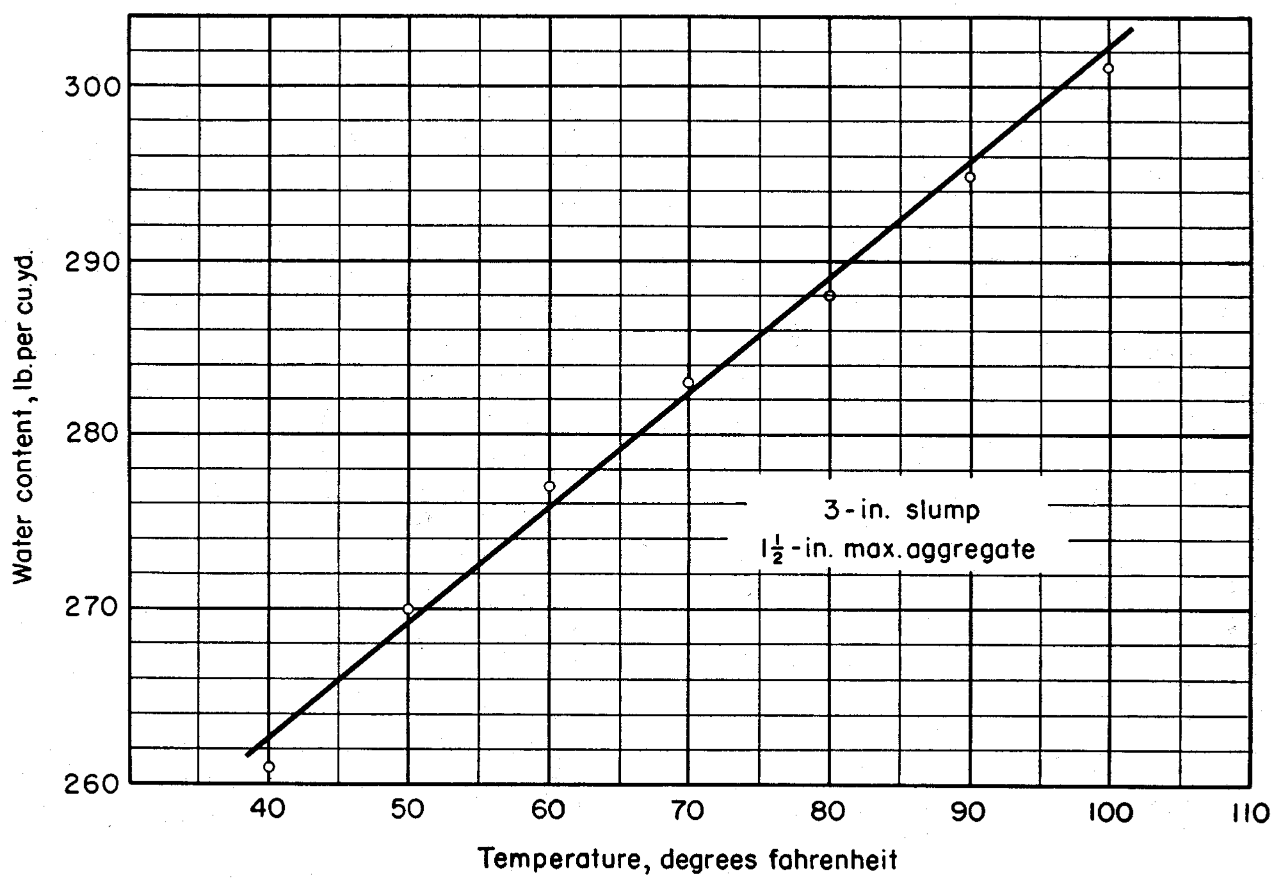

Fig. 1. The water requirement of a concrete mix increases with an increase in temperature.

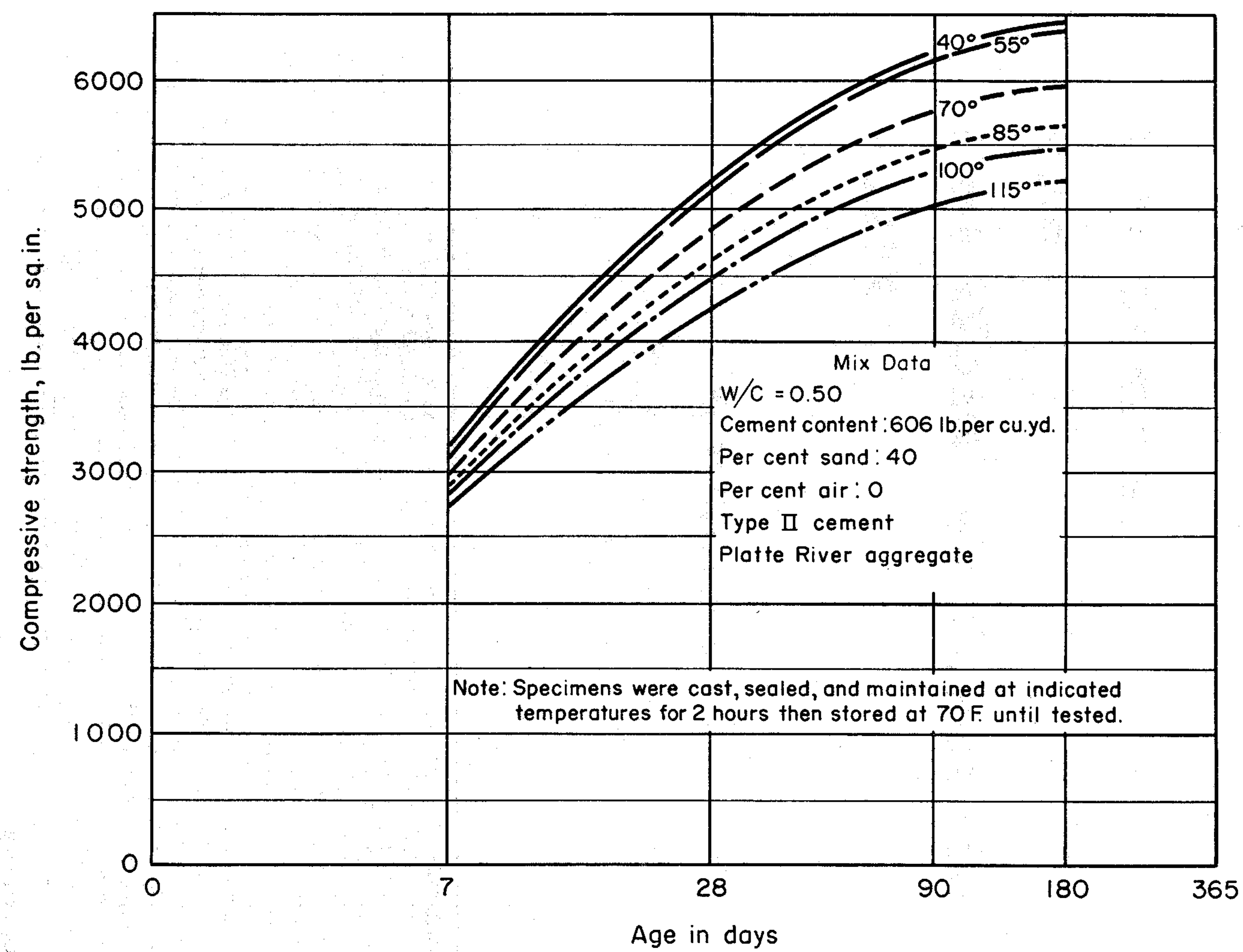

Fig. 2. Effect of initial temperature on the compressive strength of concrete.

CAUTION: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS, or SERIOUS EYE DAMAGE. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

Portland Cement Association *5420 Old Orchard Road, Skokie, Illinois 60077-1083*

An organization of cement manufacturers to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

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