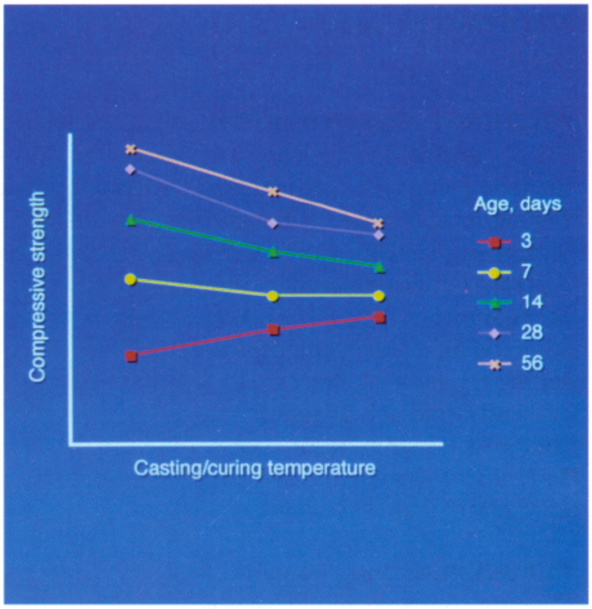
Portland Cement Association



Research and Development Bulletin RD113T

The Influence of Casting and Curing Temperature on the Properties of Fresh and Hardened Concrete

by Ronald G. Burg

KEYWORDS: Casting temperatures, curing temperatures, compressive strength, final set, initial set, slump, temperature effects.

ABSTRACT: Concretes, made with two different cements, were cast in the laboratory at temperatures of 10, 23 and 32°C (50, 73, and 90°F). The concrete mix design was held constant for each cement used in the study. Fresh properties, including slump, air content, and time of initial and final set, were measured. These concretes were moist cured at their casting temperature. In the case of the concrete cast at 23°C (73°F), an additional set of specimens was cured at a temperature of 10°C (50°F). Compressive strength was determined at ages between three and 56 days. Test results show workability, as measured by slump, is greatly affected by casting temperature. Slump at 10°C (50°F) was as much as 214% of the slump at 23°C (73°F), while slump at 32°C (90°F) was as little as 80% of the slump at 23°C (73°F). Time of set was similarly affected. Low temperature setting time was as much as 195% of setting time at 23°C (73°F). High temperature setting time was as short as 68% of setting time at 23°C (73°F). As expected, early age compressive strength of concrete cast and cured at high temperature was greater than concrete cast and cured at 23°C (73°F). However, after seven days, compressive strength of concrete cast and cured at high temperature was lower than concrete cast and cured at 23°C (73°F). Concrete cast and cured at low temperature had initial strength lower than concrete cast and cured at 23°C (73°F). However, later age strength either equaled or exceeded that of concrete cast at 23°C (73°F).

REFERENCE: Burg, Ronald G., *The Influence of Casting and Curing Temperature on the Properties of Fresh and Hardened Concrete*, Research and Development Bulletin RD113, Portland Cement Association, Skokie, Illlinois, U.S.A., 1996.

PALABRAS CLAVE: colado, curado, resistencia a la compresión, fraguado final, fraguado inicial, colocación, concreto de cemento portland, revenimiento, efecto de temperatura, manejabilidad.

SINOPSIS: Varios concretos fueron colados en el laboratorio a temperaturas de 10, 23 y 32° C (50, 73, y 90° F). Se midieron las propiedades del concreto fresco incluyendo su revenimiento, contenido de aire, y los tiempos de fraguado inicial y final. Se determinó la resistencia a la compresión a edades de entre 3 a 56 días. Los resultados de los ensayes demostraron que la manejabilidad de los concretos, medida por su revenimiento, fue bastante afectada por la temperatura durante el colado. El revenimiento a 10° C (50° F) fue tanto como 214% del revenimiento a 23° C (73° F), mientras que el revenimiento a 32° C (90° F) fué tan pequeño como 80% del revenimiento a 23° C (73° F). El tiempo de fraguado se vió afectado en manera similar. El tiempo de fraguado a baja temperatura fué tanto como 195% del tiempo de fraguado a 23° C (73° F). El tiempo de fraguado a alta temperatura fué tan pequeño como 68% del tiempo de fraguado a 23° C (73° F). Como esperado, a edad temprana resistencia, a la compresión del concreto colado y curado a alta temperatura fué mayor que la del concreto colado y curado a 23° C (73° F). Sin embargo, después de siete días, la resistencia a la compresión del concreto colado y curado a altas temperaturas fué menor que la del concreto colado y curado a 23° C (73° F). El concreto colado y curado a baja temperatura tuvo una resistencia inicial menor que la del concreto curado y colado a 23° C (73° F). Sin embargo, su resistencia a mayor edad igualó o excedió a la del concreto colado a 23° C (73° F).

REFERENCIA: Burg, Ronald G., *The Influence of Casting and Curing Temperature on the Properties of Fresh and Hardened Concrete*, Research and Development Bulletin RD113, Portland Cement Association, [Influencia de la temperatura durante el colado y el curado en las propiedades de concreto fresco y endurecido, Boletín de Investigación y Desarrollo RD113, Asociación de Cemento Portland], Skokie, Illlinois, U.S.A., 1996.

On the cover: Illustrations on the cover (clockwise from right) are: (1) chart showing the effect of casting and curing temperature on concrete compressive strength; (2) concrete protected by heated enclosure for placement and curing during cold weather (# XII 19); and (3) ice being used to cool concrete for production and placement during hot weather (# XI 12).

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The Influence of Casting and Curing Temperature on the Properties of Fresh and Hardened Concrete

by Ronald G. Burg

ISBN 0-89312-143-6

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by Ronald G. Burg*

INTRODUCTION

By its nature concrete is placed under many differing environmental conditions. In winter, concrete is often placed at cool temperatures and cured at even lower temperatures. In summer, concrete is often placed at warm temperatures and cured at even higher temperatures due to either heat of hydration effects or ambient temperature conditions. Considering the volume of research done on concrete, surprisingly little has been done on the effects of placing and curing temperatures on fresh and hardened concrete. By far, most research on concrete has been done under controlled laboratory conditions where casting and curing temperature are always at or near 23°C (73°F).

This work was undertaken recognizing the importance of producing data that would help predict the performance of concrete at temperatures often encountered in normal construction practice. To isolate the effects of temperature, no adjustments were made to the concrete mixes to offset the change in workability due to temperature effects. In actual construction adjustments are often made to a concrete mix to maintain its workability at the anticipated casting temperature. Typical adjustments may include change in water content, use of a chemical admixture(s), and/or change in cement content.

SIGNIFICANCE AND USE

Data in this report are useful for judging the relative changes in fresh and hardened concrete that are solely due to temperature effects and should be useful in making judgments as to the most appropriate adjustments in mix design to account for casting and curing temperatures.

MATERIALS

Cement

Two portland cements were used in this program. Each was obtained from a companion research project[1] on optimization of cement sulfate content in concrete. Both cements complied with ASTM C 150; one cement met the requirements for Type I, while the other met the requirements for Type I and II. The cement complying with Type I requirements will be referred to as Cement A in this report; the cement complying with Type I and II requirements will be referred to as Cement B.

Sulfate level was optimized for concrete compressive strength for each cement. To ensure the cement was not over-sulfated, expansion was measured following the procedures outlined in ASTM C 1038. Neither cement had measured autoclave expansion greater than the 0.020% maximum permitted by ASTM C 150. Chemical analyses of each cement, calculated Bogue compounds, and mortar cube strengths for each cement are given in Table 1. The primary difference between the two cements were alkali, sulfate and C_3A level. Cement B would be classified as a low-alkali cement with an equivalent alkali level of 0.58% as Na_2O, whereas Cement A has an equivalent alkali level of 0.91%. Sulfate content in Cement A was 4.51%. Sulfate content in Cement B was 3.02%. Other than somewhat higher than typical sulfate levels, the two cements are fairly representative of the range of compositional characteristics typically seen in commercial Type I or Type II cements.

Aggregate

Sand and gravel from Eau Claire, Wisconsin, were used in all mixes. The gravel was a 50:50 mixture of 19 to 13 mm (3/4 to 1/2 in.) and 10 to 5 mm (3/8 to 3/16 in.) size fractions. The sand had a fineness modulus of 2.97. Both aggregates are primarily siliceous in nature and meet the requirements of ASTM C 33.

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Table 1. Chemical Analysis and Physical Tests of Cement

Parameter, %	Cement A	Cement B
SiO_2	19.43	21.55
$Al2O_3$	4.73	3.58
Fe_2O_3	2.97	3.23
CaO	61.32	63.66
MgO	3.74	2.79
SO_3	4.51	3.02
Na_2O	0.40	0.35
K_2O	0.78	0.35
TiO_2	0.23	0.18
P_2O_5	0.11	0.07
Mn_2O_3	0.08	0.05
SrO	0.05	0.07
Loss on ignition	1.22	1.50
Equivalent alkalies as Na_2O	0.91	0.58
C_3S	51	57
C_2S	17	19
C_3A	8	5
C_4AF	9	10
Fineness, m^2/kg	385	371
ASTM C 109 mortar cube strength, MPa (psi)		
1 day	14.8 (2150)	11.4 (1650)
3 days	26.1 (3780)	27.0 (3920)
7 days	34.6 (4610)	33.3 (4830)
14 days	43.6 (5050)	39.4 (5710)
28 days	45.6 (5700)	41.4 (6010)
56 days	45.4 (6120)	45.3 (6570)
Time of set, Vicat, min		
Initial	93	214
Final	195	360

CONCRETE MIX DESIGN

A cement content of 356 kg/m^3 (600 pcy) was used for the concrete made with Cement A. Water was adjusted to yield a slump of approximately 75 mm (3 in.) at 23°C (73°F). This resulted in a water-to-cement ratio of 0.45. The mix design for the concrete made with Cement B cement was formulated to, as nearly practical, have the same slump, water-to-cement ratio, and cement content as the concrete made with Cement A. This resulted in a mix with a cement content of 335 kg/m^3 (564 pcy) and a water-to-cement ratio of 0.46. Complete information for both mix designs is given in Table 2. These mix designs were held constant throughout the program. No adjustment was made for mixes cast at either higher or lower temperatures; thus, workability changed for mixes cast at either high or low temperature. As previously pointed out, this approach was taken to isolate the effects of temperature and cement composition.

MIXING, FABRICATION, AND CURING OF SPECIMENS

All materials used in producing concrete were stored in controlled laboratories at the desired temperature of 10, 23 or 32°C (50, 73, or 90°F) for at least 24 hours prior to mixing of concrete to ensure the fresh concrete was at the correct temperature. Prior to temperature conditioning, the aggregates were oven-dried and the needed quantity weighed. Dried aggregates were then inundated with a known amount of water. Excess water was drawn off and weighed just prior to mixing.

A horizontal open pan mixer was used to produce 0.50 m^3 (1.75 ft^3) of concrete for each batch. All mixing was conducted in laboratories maintained at the desired temperatures. A 3-minute mix, 3-minute rest, 2-minute mix cycle was used for all mixes. At the completion of mixing, slump, unit weight, air content by the pressure method, and concrete temperature were determined. Fifteen 102x203-mm (4x8-in.) cylinders were then cast in single-use plastic molds.

Table 2. Concrete Mix Design

SI Units

Parameter	Cement A	Cement B
Cement, kg/m^3	356	335
Coarse aggregate, kg/m^3	1038	1038
Fine aggregate, kg/m^3	840	875
Water, kg/m^3	160	154
Water-to-cement ratio	0.45	0.46

USC Units

Parameter	Cement A	Cement B
Cement, pcy	600	564
Coarse aggregate, pcy	1750	1750
Fine aggregate, pcy	1415	1475
Water, pcy	270	259
Water-to-cement ratio	0.45	0.46

Concurrent with casting cylinders, a sample was obtained for the determination of initial and final set times by the method presented in ASTM C 403. Setting time samples were kept in the temperature controlled laboratories as long as measurements were taken.

Compressive strength specimens were kept in the molds in the temperature controlled laboratories for 24 hours. At that time they were removed from the molds and cured under water at the desired temperature until time of test. A total of four test conditions were included; (1) specimens cast at 23°C (73°F) and cured at 23°C (73°F), (2) specimens cast at 32°C (90°F) and cured at 32°C (90°F), (3) specimens cast at 10°C (50°F) and cured at 10°C (50°F), and (4) specimens cast at 23°C (73°F) and cured at 10°C (50°F). For the last test condition the specimens were held at 23°C (73°F) for 24 hours after which the molds were removed and the specimens cured under water at 10°C (50°F) until time of test. Compressive strength tests were performed at normal laboratory temperatures of 23°C (73°F) after test samples had come to thermal equilibrium.

DISCUSSION OF TEST RESULTS

Slump

As would be expected, when concrete water content is held constant, slump is significantly affected by concrete temperature. Figure 1 shows slump as a function of concrete temperature both as an absolute measurement and as a percentage of slump at 23°C (73°). The concrete made with Cement B cement showed a greater sensitivity to temperature than the concrete made with Cement A. Concrete made with Cement A had a nearly linear response to temperature. Slump decreased approximately 20 mm for each 10°C increase in temperature (0.8 in. slump decrease for each 20°F temperature increase). This is similar to the results reported by Klieger[2] of a 25 mm slump decrease for each 11°C temperature increase (1 in. slump decrease for each 20°F temperature increase). Concrete made with Cement B showed a nonlinear slump response to temperature. Decreasing concrete temperature had a more significant effect on slump in this case. When the concrete temperature was decreased from 23°C (73°F) to 10°C (50°F), the concrete slump increased by over 100%. This may be due in part to the increase in air content from 2.0% at 23°C (73°F) to 2.8% at 10°C (50°F). The decrease in slump between 23°C (73°F) and 32°C (90°F)

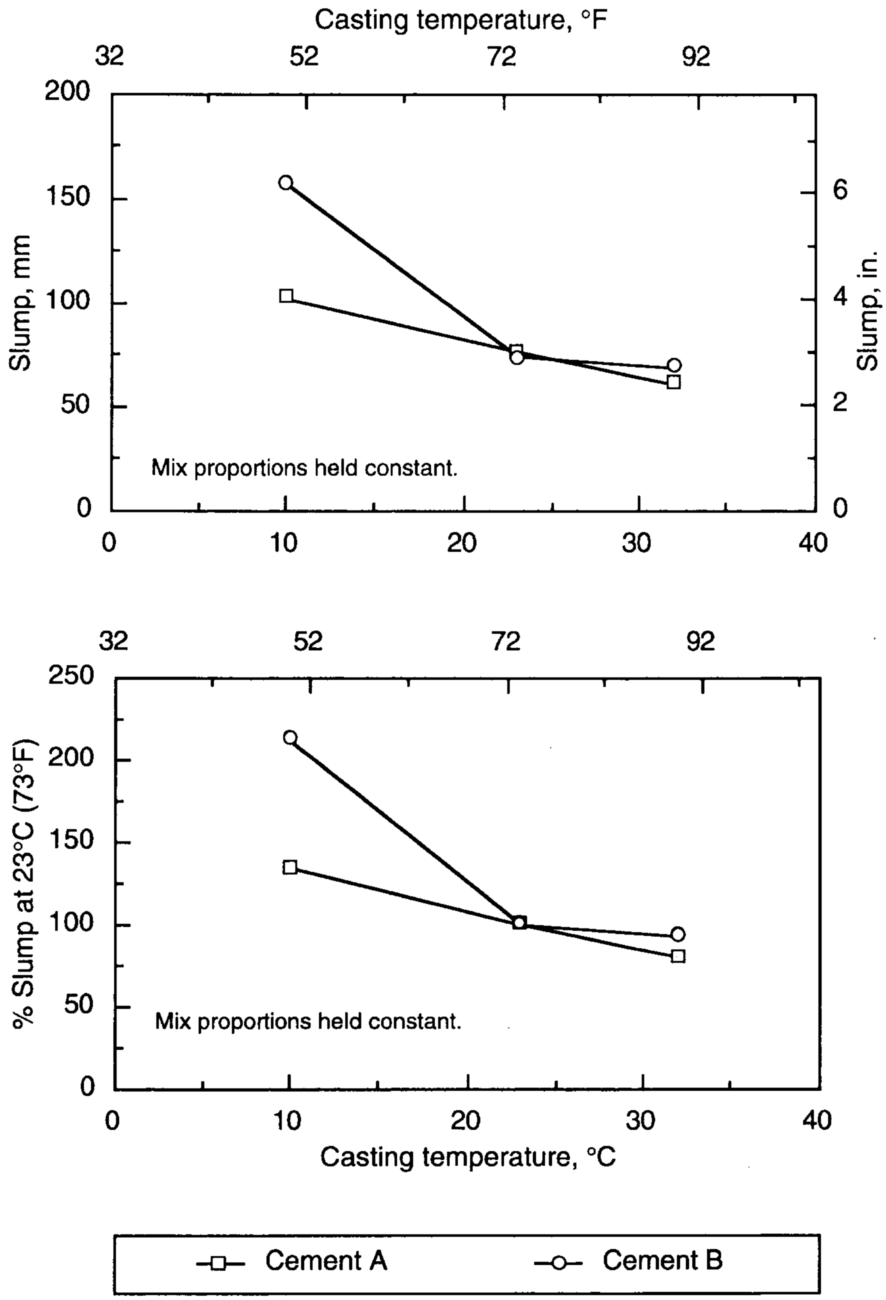

Fig. 1. Slump characteristics as a function of casting temperature.

for the concrete made with Cement B was similar to that of the concrete made with Cement A.

Setting Time

Concrete set time, both initial and final measured in accordance with ASTM C 403, along with other fresh concrete properties are given in Tables 3 and 4. Figures 2 and 3 present initial and final set time data both as absolute values and as percentage of set times at 23°C (73°) for both concretes.

Although there was significant difference in the absolute set time characteristics between concretes made with Cement A and Cement B, the impact of temperature on the relative change in setting characteristics was similar for both cements. At 10°C (50°F) initial set was 170% of initial set at 23°C (73°F) for the Cement A and 177% for the Cement B. This agrees well with data from Sprouse and Peppler[3] where they find initial setting times at 10°C (50°F) to be 190% of setting time at 23°C (73°F). Similar effects were noted with respect to effect of low temperature on final set time. At 10°C (50°F) Cement A had a final set time of 173% of its set time at 23°C (73°F). Cement B had a final set of 195% of its set time at 23°C (73°F). Sprouse and Peppler reported final set time at 10°C (50°F) to be 200% of setting time at 23°C (73°F).

The relative change in setting times was also similar for both cements at elevated temperatures. When temperature was increased from 23°C (73°) to 32°C (90°F), initial set time decreased by 19% for concrete made with Cement A and 32% for concrete made with Cement B. Final set time was decreased by 18% for concrete made with Cement A and 33% for concrete made with Cement B. Under similar temperature change conditions, Sprouse and Peppler reported a 30% decrease in initial set time and a 24% decrease in final set time.

The data developed in this program, along with the referenced data, suggest the influence of temperature on initial and final set time is nearly identical. That is, whatever relative change occurs in initial set time due to temperature, a nearly identical change in relative set time can be anticipated for final set. Furthermore, as a first order approximation, setting time can be anticipated to change approximately 50% for each 10°C change (30% for each 10°F change) in temperature from a base temperature of 23°C (73°). Lower temperatures increase set time; higher temperatures decrease set time. Two precautions should be kept in mind when applying this guideline to field situations. At temperatures above 32°C (90°F) some cements, and thus concrete, may show increased, not

Table 3. Fresh Mix Properties for Concrete Made With Cement A

SI Units

Casting temp, °C	Slump, mm	Fresh unit weight, kg/m³	Air content, %	Initial set, hr:mm	Final set, hr:mm
	Fresh concrete properties				
10	102	2437	3.1	5:10	6:49
23	76	2417	3.6	3:03	3:56
32	64	2424	3.2	2:29	3:14

USC Units

Casting temp, °F	Slump, in.	Fresh unit weight, pcf	Air content, %	Initial set, hr:mm	Final set, hr:mm
	Fresh concrete properties				
50	4	152.1	3.1	5:10	6:49
73	3	150.9	3.6	3:03	3:56
90	2-1/2	151.3	3.2	2:29	3:14

Table 4. Fresh Mix Properties for Concrete Made With Cement B

SI Units

Casting temp, °C	Slump, mm	Fresh unit weight, kg/m³	Air content, %	Initial set, hr:mm	Final set, hr:mm
	Fresh concrete properties				
10	159	2374	2.8	9:22	14:02
23	76	2435	2.0	5:17	7:12
32	70	2381	2.4	3:35	4:48

USC Units

Casting temp, °F	Slump, in.	Fresh unit weight, pcf	Air content, %	Initial set, hr:mm	Final set, hr:mm
	Fresh concrete properties				
50	6-1/4	148.2	2.8	9:22	14:02
73	3	152.0	2.0	5:17	7:12
90	2-3/4	148.6	2.4	3:35	4:48

decreased, set times.[4,5] It should not be assumed that the cement setting time, often given on mill certificates, is equivalent to concrete setting time.

Compressive Strength

Compressive strength data are presented in tabular format in Tables 5 and 6 and in graphical format in Figs. 4 through 7. To aid in data analyses, four graphs are presented for concrete made with each cement type. The first graph is simply compressive strength development versus age for each test condition. The four test conditions included concrete cast and cured at 23°C (73°F), concrete cast and cured at 32°C (90°F), concrete cast and cured at 10°C (50°F), and concrete cast at 23°C (73°F) and cured at 10°C (50°F). The second graph shows compressive strength development normalized to 28-day strength for each test condition. The third graph shows compressive strength development as a percentage of compres-

Table 5. Compressive Strength of Concrete Made With Cement A

SI Units, MPa

Age,	Casting temperature/curing temperature, °C			
days	23/23	32/32	10/10	23/10
3	25.8	27.4	22.4	23.0
7	30.3	30.3	32.6	30.8
14	36.2	34.2	40.5	37.3
28	40.0	38.4	47.2	43.2
56	44.3	40.1	50.0	43.6

Values represent the average of three 102x203-mm specimens.

USC Units, psi

Age,	Casting temperature/curing temperature, °F			
days	73/73	90/90	50/50	73/50
3	3740	3970	3250	3340
7	4400	4400	4730	4460
14	5250	4960	5880	5410
28	5800	5570	6850	6270
56	6420	5820	7250	6330

Values represent the average of three 4x8-in. specimens.

% Strength of 23°C/23°C (73°F/73°F) Mix

Age,	Casting temperature/curing temperature, °C (°F)			
days	23/23 (73/73)	32/32 (90/90)	10/10 (50/50)	23/10 (73/50)
3	100	106	87	89
7	100	100	108	101
14	100	94	112	103
28	100	96	118	108
56	100	91	113	99

% 28-Day Strength

Age,	Casting temperature/curing temperature, °C (°F)			
days	23/23 (73/73)	32/32 (90/90)	10/10 (50/50)	23/10 (73/50)
3	64	71	47	53
7	76	79	69	71
14	91	89	86	86
28	100	100	100	100
56	111	104	106	101

Table 6. Compressive Strength of Concrete Made With Cement B

SI Units, MPa

Age, days	Casting temperature/curing temperature, °C 23/23	32/32	10/10	23/10
3	23.3	26.3	15.3	22.0
7	32.5	31.0	24.8	30.0
14	37.3	34.7	32.2	33.9
28	43.4	38.5	39.4	37.4
56	45.4	41.7	44.7	44.2

Values represent the average of three 102x203-mm specimens.

USC Units, psi

Age, days	Casting temperature/curing temperature, °F 73/73	90/90	50/50	73/50
3	3380	3810	2220	3190
7	4710	4500	3590	4350
14	5410	5030	4670	4920
28	6290	5580	5720	5420
56	6580	6050	6480	6410

Values represent the average of three 4x8-in. specimens.

% Strength of 23°C/23°C (73°F/73°F) Mix

Age, days	Casting temperature/curing temperature, °C (°F) 23/23 (73/73)	32/32 (90/90)	10/10 (50/50)	23/10 (73/50)
3	100	113	66	94
7	100	96	76	92
14	100	93	86	91
28	100	89	91	86
56	100	92	98	97

% 28-Day Strength

Age, days	Casting temperature/curing temperature, °C (°F) 23/23 (73/73)	32/32 (90/90)	10/10 (50/50)	23/10 (73/50)
3	54	68	39	59
7	75	81	63	80
14	86	90	82	91
28	100	100	100	100
56	105	108	113	118

sive strength at an equivalent age of the concrete cast and cured at 23°C (73°F). The fourth graph shows the influence of casting and curing temperature on compressive strength at each of the five ages. This graph does not include data from the concrete cast at 23°C (73°F) and cured at 10°C (50°F). Test results are the average of three 102x203-mm (4x8-in.) cylinders.

Compressive strength development at 23°C (73°F) after seven days for these concretes was similar to concretes tested by Klieger[2] and Wood.[6] In the current work, each concrete had gained 75% of its 28-day strength at seven days, whereas for Type I cement Klieger's concretes gained 75% of its 28-day strength and Wood's concretes gained 70% of its 28-day strength. Klieger and Wood both reported lower strength development at three days as compared to the current work. This is likely due to the coarser grind of the earlier cements evaluated by Klieger and Wood, most of which were produced in the 1940s and 1950s. In the current work the concrete made with Cement B had somewhat lower relative strength at three days as compared to the concrete made with Cement A, 54 and 64%, respectively.

In general, the effect of low temperature casting and curing was lower early age strength and comparable or higher later age strength than concrete cast and cured at 23°C (73°F). Concrete cast and cured at 10°C (50°F) had three-day strengths of 66 to 87% of concrete cast and cured at 23°C (73°F). Under similar conditions Klieger found three-day strength of concrete cast at low temperature [13°C (55°F)] to be 62% of concrete cast at 23°C (73°F). After 56 days, concrete cast at low temperature had compressive strength nearly equal to or in excess of concrete cast and cured at 23°C (73°F). Klieger found similar results for the concretes he evaluated. For concrete cast at 23°C (73°F) and subsequently cured at low curing temperature 10°C (50°F), the effect on compressive strength was relatively small.

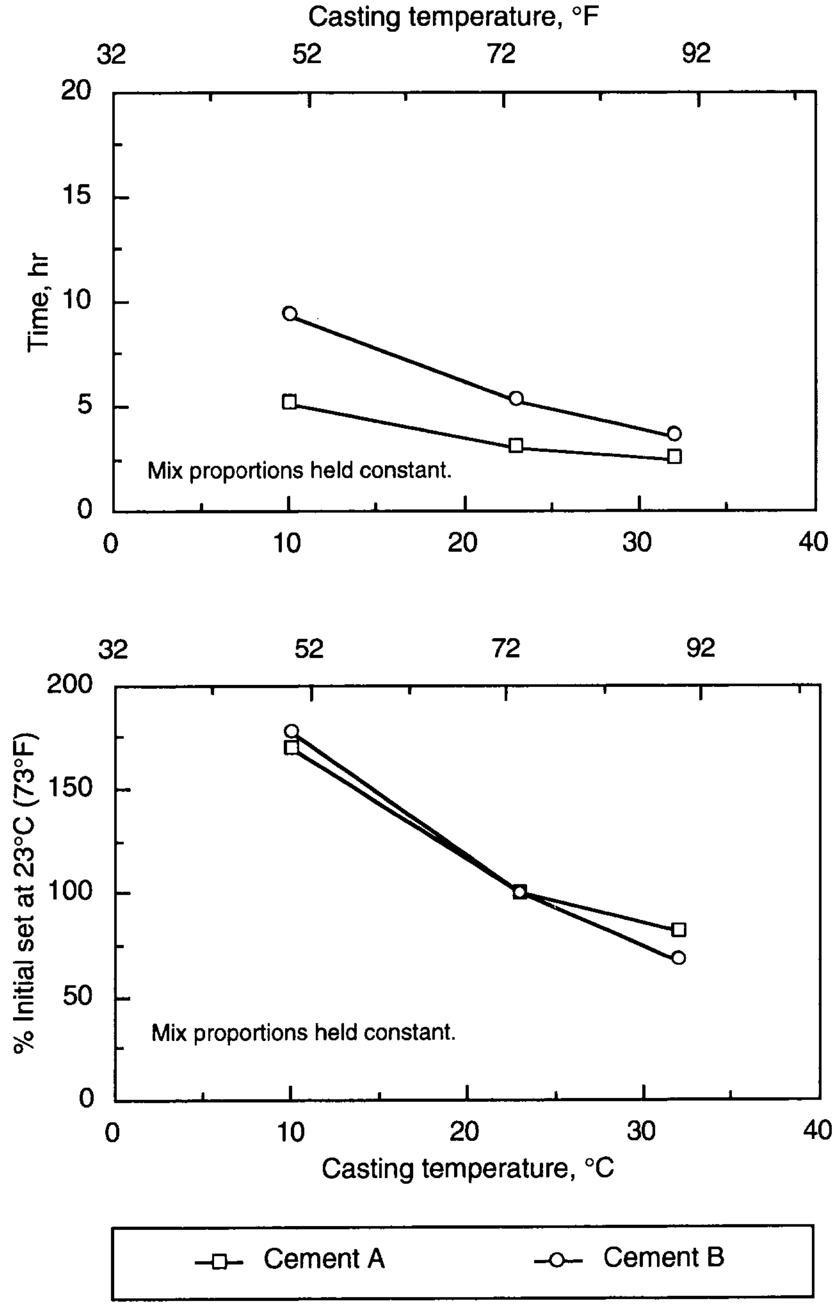

Fig. 2. Initial set characteristics as a function of casting temperature.

The effect of elevated temperature was the opposite of that of low temperature. Earlier age strength was higher than that of concrete cast and cured at 23°C (73°F), while later age strength was lower. After three days concrete cast and cured at 32°C (90°F) had developed 71% of its 28-day strength when made with Cement A and 68% of its 28-day strength when made with Cement B. Three-day relative strength development of concrete cast and cured at 32°C (90°F) was similar to seven-day relative strength development of concrete cast and cured at 23°C (73°F). In all cases, after

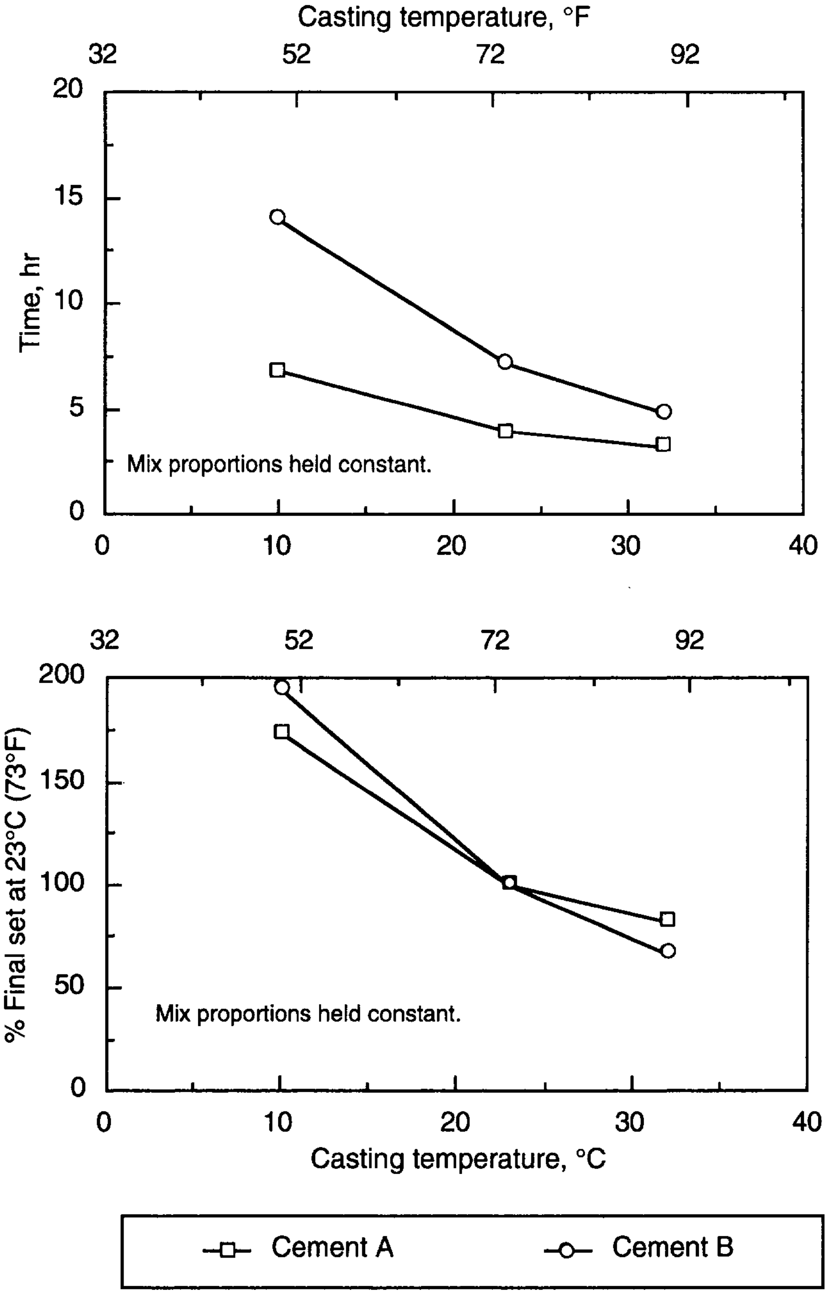

Fig. 3. Final set characteristic as a function of casting temperature.

seven days the absolute strength of concrete cast and cured at 32°C (90°F) was lower than concrete cast and cured at 23°C (73°F). At 56 days, strength of concrete cast and cured at 32°C (90°F) was approximately 10% less than concrete at the same age cast and cured at 23°C (73°F). Klieger found similar results for Type I cement, however, he found slightly higher later age strength for concretes made with Type II cement when cast and cured at 32°C (90°F).

CONCLUSIONS

Based on the results of this laboratory program, the following conclusions can be drawn with respect to the performance of non-admixtured portland cement concrete.

1. As concrete mix temperature is increased from 23°C (73°F), slump will decrease approximately 20 mm for each 10°C increase in temperature (0.8 in. slump decrease for each 20°F temperature increase).
2. As concrete mix temperature is decreased from 23°C (73°F), slump will increase approximately 20 mm for each 10°C decrease in temperature (0.8 in. slump increase for each 20°F temperature decrease).
3. As a first order approximation, setting time can be anticipated to change approximately 50% for each 10°C change (30% for each 10°F change) in temperature from a base temperature of 23°C (73°). Lower temperatures increase set time; higher temperatures decrease set time.
4. For most concretes cast and cured at 23°C (73°F), 7-day compressive strength will be approximately 75% of 28-day compressive strength.
5. With respect to strength development, the effect of a low curing temperature of 10°C (50°F) was relatively small for concrete cast at 23°C (73°F).
6. Later age strength of concrete cast and cured at low temperature was nearly equal to or exceeded that of concrete cast and cured at 23°C (73°F).
7. For most concretes cast and cured at 32°C (90°F), 3-day compressive strength will be approximately 70% of 28-day compressive strength of concrete cast and cured at 32°C (90°F). The effect of casting and curing at 32°C (90°F) roughly results in 3-day compressive strength similar to seven-day compressive strength for concrete cast and cured at 23°C (73°F).
8. The effects of high temperature

on the early age strength are reversed after seven days when absolute strength of concrete cast and cured at 32°C (90°F) is lower than concrete cast and cured at 23°C (73°F).

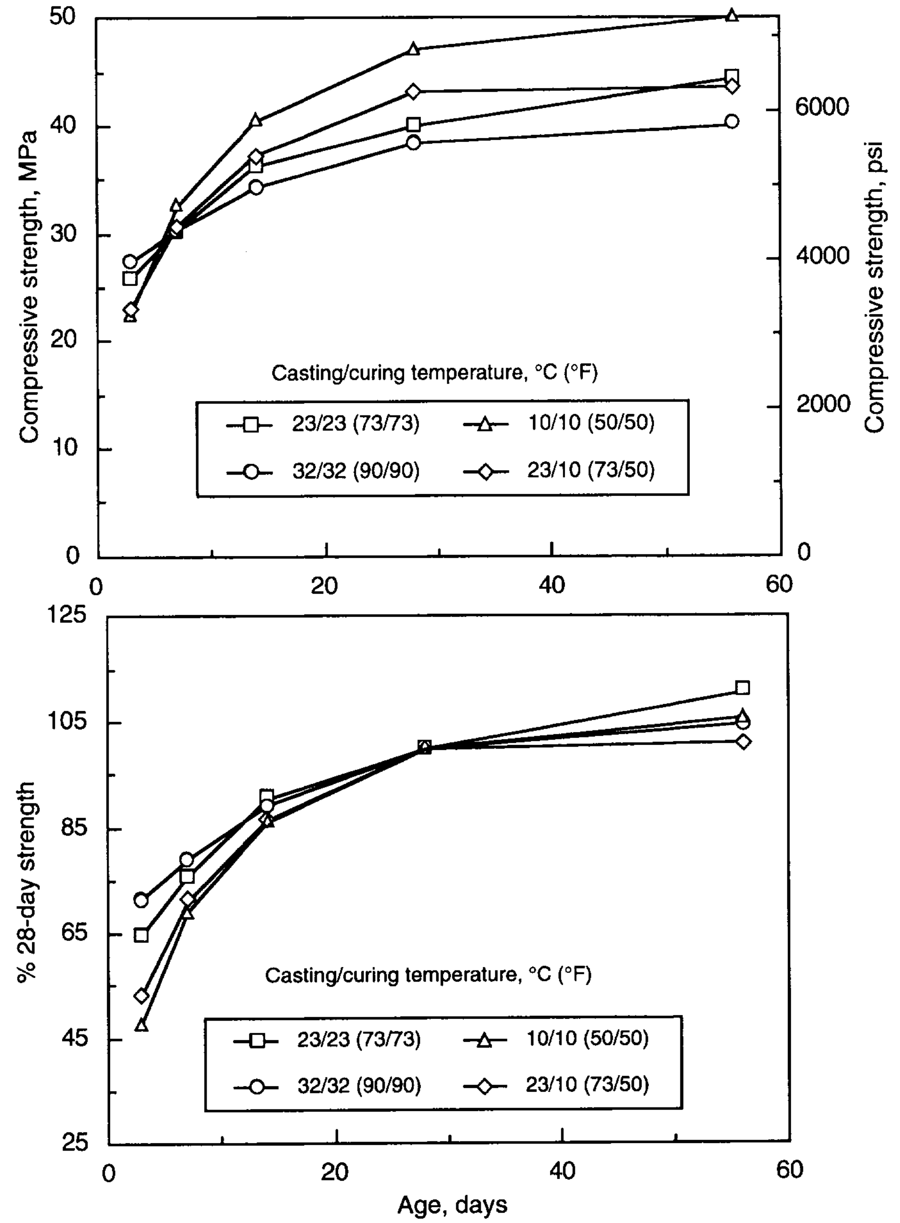

Fig. 4. Compressive strength development of concrete made with Cement A.

ACKNOWLEDGMENT

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REFERENCES

1. Burg, R. G., *The Influence of Cement Sulfate Level on the Properties of Fresh and Hardened Concrete*, Research and Development Serial No. 2030, Portland Cement Association, Skokie, Illinois, 1995.
2. Klieger, Paul, *Effect of Mixing and Curing Temperature on Concrete Strength*, Research Bulletin RX103, Portland Cement Association, Skokie, Illinois, 1958.
3. Sprouse, J. H. and Peppler, R. B., "Setting Time," *Significance of Tests and Properties of Concrete Making Materials*, STP 169B, American Society for Testing and Materials, Philadelphia, 1978, pages 105-121.
4. Steinhour, H.H., *The Setting of Portland Cement - A Review of Theory, Performance, and Control*, Research Bulletin RX098, Portland Cement Association, Skokie, Illinois, 1958.
5. Lea, F.M., *The Chemistry of Cement and Concrete*, Arnold Press, London, 1970.
6. Wood, S. L., "Evaluation of the Long-Term Properties of Concrete," *ACI Materials Journal*, American Concrete Institute, Detroit, Nov-Dec 1991, pages 630-643. [Also published as same title in a more comprehensive form as Research and Development Bulletin RD 102, Portland Cement Association, Skokie, Illinois, 1992].

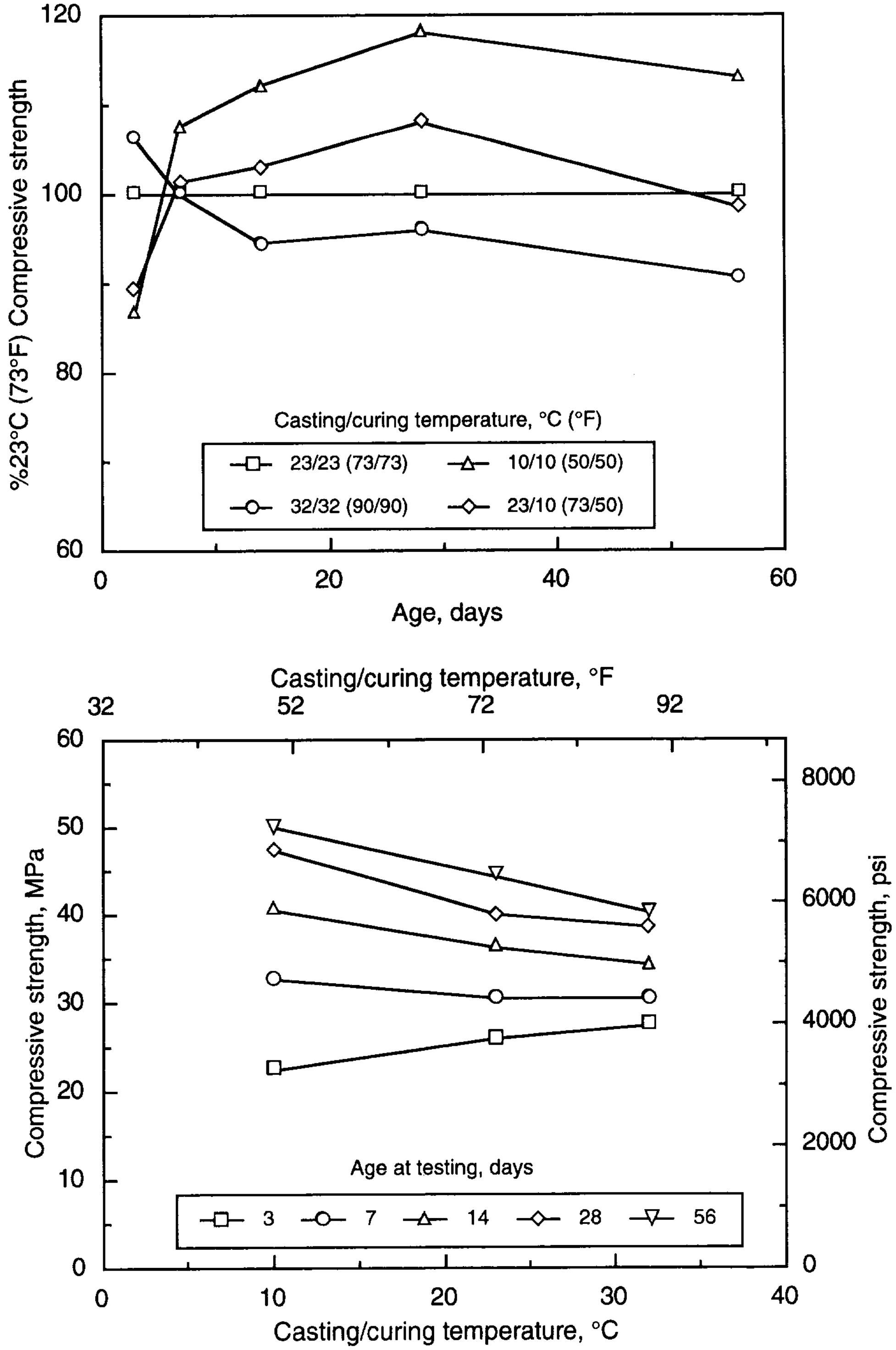

Fig. 5. Compressive strength of concrete made with Cement A.

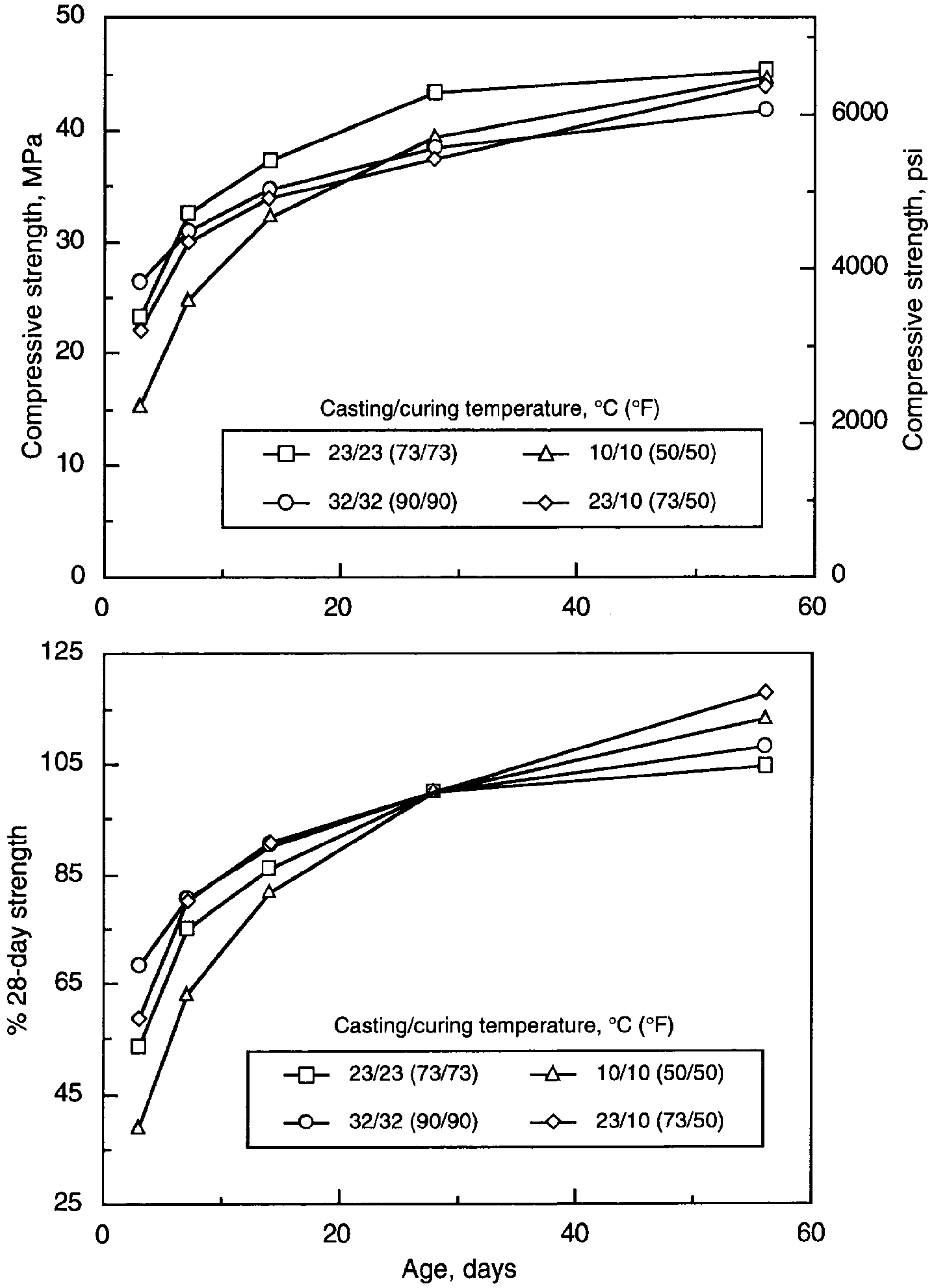

Fig. 6. Compressive strength development of concrete made with Cement B.

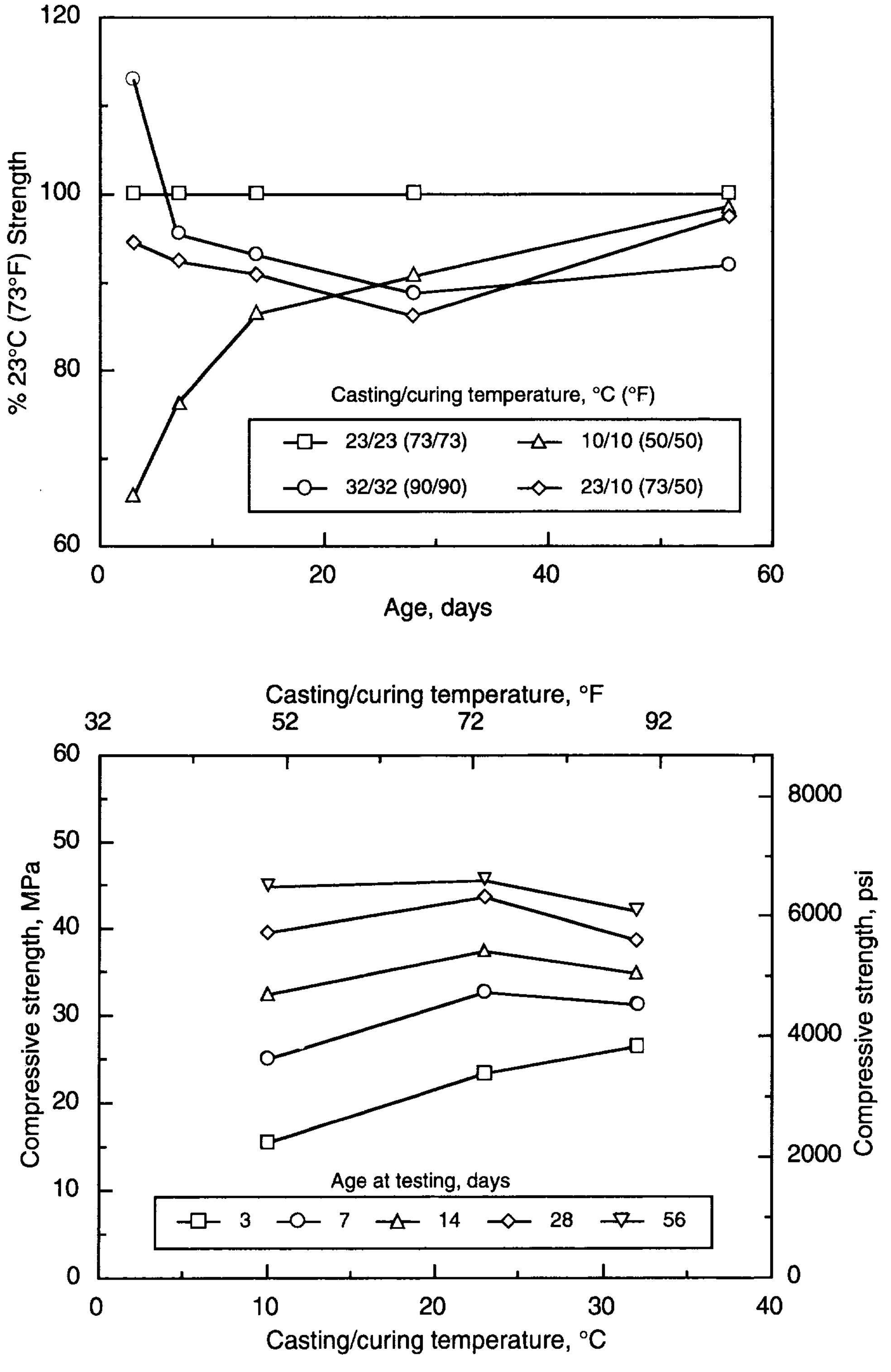

Fig. 7. Compressive strength of concrete made with Cement B.

MOTS CLÉS: affaissement, béton de ciment portland, cure, effet de la température, maniabilité, mise en place, moulage, prise finale, prise initiale, résistance à la compression

RÉSUMÉ: Des bétons ont été moulés en laboratoire à des températures de 10, 23 et 32°C (50, 73 et 90°F). Les propriétés du béton plastique incluant l'affaissement, la teneur en air ainsi que le temps de prise initial et final ont été mesurées. La résistance à la compression a été déterminée à des périodes variant de trois à 56 jours. Les résultats d'essais montrent que la maniabilité, telle que mesurée par l'affaissement, est de beaucoup affectée par la température de mise en place. L'affaissement à 10°C (50°F) était de 214% plus élevé que celui à 23°C (73°F) tandis que l'affaissement à 32°C (90°F) n'était qu'à 80% de celui à 23°C (73°F). Les temps de prise étaient affectés de façon similaire. Le temps de prise aux températures faibles était de 195% plus long que celui à 23°C (73°F). Le temps de prise aux hautes températures n'était que de 68% de celui à 23°C (73°F). Tel qu'anticipé, la résistance à la compression en bas âge du béton moulé et mûri à haute température était plus élevée que celle du béton moulé et mûri à 23°C (73°F). Cependant, après 7 jours, la résistance à la compression du béton moulé et mûri à haute température était plus faible que celle du béton moulé et mûri à 23°C (73°F). Le béton moulé et mûri à bases température avait quant à lui une résistance initiale plus faible que celle du béton coulé et mûri à 23°C (73°F) mais sa résistance à plus long terme égalait ou excédait celle du béton moulé à 23°C (73°F).

RÉFÉRENCE: Burg, Ronald G., *The Influence of Casting and Curing Temperature on the Properties of Fresh and Hardened Concrete*, Research and Development Bulletin RD113T, Portland Cement Association [Influence des températures de mise en place et de cure sur les propriétés du béton plastique et du béton durci, Bulletin de Recherche et Développement RD113T, Association du Ciment Portland], Skokie, Illinois, U.S.A., 1996.

STICHWÖRTER: Gießen, Nachbehandlung, Druckfestigkeit, Erstarrungsende, Erstarrungs- anfang, Positionierung, Portlandzementbeton, Ausbreitungsmaß, Temperaturauswirkung, Verarbeitungszeit

AUSZUG: Betone wurden im Labor bei 10, 23 und 32°C gegossen. Die Verhaltensmerkmale von Frischbeton, wie das Ausbreitungsmaß, Luftgehalt und Erstarrungsbeginn und -Ende wurden gemessen. Druckfestigkeit wurde mehrmals zwischen 3 und 56 Tagen gemessen. Testergebnisse zeigen, daß das Verarbeitungsverhalten, durch Ausbreitungsmaß gemessen, stark von der Gießtemperatur beinflußt wird. Das Ausbreitungsmaß bei 10°C war 214% des Ausbreitungsmaßes bei 23°C, während das Ausbreitungsmaß bei 32 °C war mindestens 80% des Ausbreitungsmaßes bei 23 °C war. Die Erstarrungszeit wurde ähnlich beinflußt. Die Erstarrungszeit bei niedriger Temperatur war bis 195% der Erstarrungszeit bei 23 °C. Die Erstarrungszeit bei hoher Temperatur war mindestens 68% der Erstarrungs-zeit bei 23 °C. Wie erwartet war die frühe Druckfestigkeit von Beton, der bei hohem Temperatur gegossen und nachbehandelt wurde, höher als die von Beton, der bei 23 °C gegossen und nachbehandelt wurde. Nach sieben Tagen aber war die Druckfestigkeit von Beton, der bei hoher Temperatur gegossen und nachbehandelt wurde, niedriger als die von Beton, der bei 23 °C gegossen und nachbehandelt wurde. Beton, der bei niedriger Temperatur gegossen und nachbehandelt wurde, hatte anfangs niedrigere Druckfestigkeiten als Beton, der bei 23 °C gegossen und nachbehandelt wurde. Die Enddruckfestigkeiten waren gleich oder sogar noch höher als die von Beton, der bei 23 °C gegossen wurde.

REFERENZ: Burg, Ronald G., *The Influence of Casting and Curing Temperature on the Properties of Fresh and Hardened Concrete*, Research and Development Bulletin RD113, Portland Cement Association, [Der Einfluß von Gieß-und Nachbehandlungstemperatur auf das Verhalten von Frisch-und Festbeton, Forschungs-und Entwicklungsbulletin RD113, Portlandzementverband], Skokie, Illinois, U.S.A., 1996.

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