Effect of Hot Climate on Slump Loss and Setting Times for Superplasticized Concretes

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The results of a laboratory investigation of slump loss, setting times, and workability at low and high concrete temperatures for superplasticized concretes are presented. There was a substantial reduction in the initial and final setting times when there was a 16°F increase in the initial concrete temperature. Results of the slump-loss study indicated that there was adequate working time (2 to 3.5 hr) when a superplasticizer was used for concretes made at a temperature of 70°F (21.2°C). For the same concretes mixed at a temperature of 86°F (30°C), however, there was a considerable reduction in slump and available working time.

Concrete having desirable properties in the hardened state is normally made with a low water/cement ratio and with the least possible amount of cement paste in the mix. Such a concrete usually has a low slump and requires intensive and careful compaction. In order to produce concrete of the same quality with less vibration, very effective plasticizers, known as superplasticizers, have been developed for making flowing and self-compacting concretes. Superplasticizers are added to concrete to cause a vast increase in its workability or allow a large reduction in mixing water and thus produce high-strength concrete. Such a change in concrete properties would result in reduced placement costs or reduction in the cement requirement. A well-designed mix with a superplasticizer will have good flowability and sufficient cohesiveness and would not cause bleeding or segregation or strength reduction either during or after placement of the concrete.

The introduction of superplasticizers has opened up new possibilities for the use of concrete in construction, particularly for bridge-deck repair and resurfacing, pavement rehabilitation, and construction of other highway facilities.

Slump loss is an inherent property of concrete even with the addition of superplasticizers. The high slumps of superplasticized concretes are not sustained over long periods (1-3; 4, pp. 389-402; 5, pp. 137-157; communication from D.A. Whiting, Portland Cement Association), especially at higher temperatures. Hence a delay in the discharge of concrete from truck mixers could cause stiffening to the point of unworkability and loss in air content, which would affect the desired air-void system.

OBJECTIVES AND RESEARCH PROGRAM

The objectives of this research program were to study

1. The initial and final setting times at two different concrete temperatures approximately equal to the spring and summer concreting conditions in Rapid City, South Dakota, and
2. Slump and air-content losses for superplasticized concrete with time at two different concrete temperatures.

Two concretes, one with a high workability and medium cement content [6.5 sacks/yd^3 (363 kg/m^3)] and another with medium workability and high cement content [8.5 sacks/yd^3 (474 kg/m^3)] were studied. The former (mix 13) will be suitable for general structural work and for construction of highway pavements and airport runways, and the latter (mix 33) will be suitable for bridge-deck overlays and for construction where high strength and highly impermeable concretes are needed. Identical mixes were made in the spring (March) and in the summer (July).

The research program consisted of two parts. In the first, the initial and final setting times for the selected concretes were determined at different temperatures. In the second part, a study of slump-loss characteristics of superplasticized concrete was carried out.

MATERIALS AND MIXES

Cement

Type 1 portland cement satisfying ASTM C 150 was used.

Aggregates

The fine aggregate used was natural sand. A sample sieve analysis of the fine aggregate is shown in Table 1. It had a water absorption coefficient of 1.6 and a saturated surface-dry specific gravity of 2.62. The coarse aggregate used was crushed limestone. A sample sieve analysis of the coarse aggregate is also given in Table 1. It had a water absorption coefficient of 0.45 and a saturated surface-dry specific gravity of 2.69.

Water

The water used was from the municipal water supply.

Air-Entraining Agent

The air-entraining agent (AEA) used was neutralized vinsol resin (Protex).

Table 1. Sieve analysis of aggregates.

Sieve Size		
Passing Through	Retained on	Percent by Weight
Fine Aggregate		
1/4 in.	No. 4	0
No. 4	No. 8	14.30
No. 8	No. 16	24.94
No. 16	No. 30	28.87
No. 30	No. 50	17.88
No. 50	No. 100	10.55
No. 100	No. 200	2.80
No. 200	Pan	0.66
Coarse Aggregate		
1 1/2 in.	1 in.	1.0
1 in.	3/4 in.	28.8
3/4 in.	1/2 in.	50.8
1/2 in.	3/8 in.	15.3
3/8 in.	1/4 in.	3.0
1/4 in.	No. 4	0.5
No. 4	No. 8	0.3
No. 8	Pan	0.3

Note: 1 in. = 25 mm.

Table 2. Properties of superplasticizer.

Property	Lot No. 1	2	3	4	5
pH	9.6	9.7	9.7	9.7	9.7
Specific gravity	1.23	1.25	1.23	1.24	1.22
Percent residue by oven drying	44.50	42.85	42.41	42.48	42.49

Table 3. Mix proportions for selected mixes.

Item	Mix 13	Mix 33
Water/cement ratio by weight	0.38	0.28
Aggregate content (%)		
Coarse	54	51
Fine	46	49
Cement content (sacks/yd^3)	6.5	8.5
Superplasticizer	Mighty RDI	Mighty RDI
Dosage (% by weight of cement)	1.0	1.2
Air-entraining agent	NVR (Protex)	NVR (Protex)
Dosage (% by weight of cement)	0.08	0.18

Notes: NVR, neutralized vinsol resin.
1 sack/yd^3 = 55.77 kg/m^3.

Superplasticizer

The superplasticizer used for this study was Mighty RDI. It is a salt of a naphthalene sulfonate formaldehyde condensate and a standard retarding agent. It is a dark-brown liquid with a viscosity of 35 in./sec (90 cm/sec) at 150°F (68°C), pH value 10 ± 1.0 (5 percent aqueous solution), and a specific gravity of 1.2 ± 0.1. Five lots of superplasticizers received on different occasions were used in the entire investigation. They were tested and found to have the same chemical composition and physical properties within the allowable variations according to ASTM requirements (Table 2). All the lots showed the same characteristic absorption peak at the same wavelength in the infrared analysis.

Mixes

The mix proportions used for the selected concretes are given in Table 3. All the mixes were blended in a drum that had 6 ft^3 (0.17 m^3) of mixer capacity. The mixing sequence was as follows:

1. Coarse aggregates,
2. Fine aggregates,
3. Two-thirds of water and mix for 1 min to allow for absorption of water,
4. Cement,
5. Remaining water with air-entraining admixture,
6. Superplasticizer,
7. Mix for 3 min,
8. Rest for 3 min, and
9. Additional mixing for 2 min.

A total of 12 mixes was made by using the mix proportions designated 13 and 33. Six mixes were made to study the setting times of concrete. Original mixes prepared in the spring were designated FSET and the replicate mixes were designated FRSET. Mixes made in the summer were designated HTSET.

Six mixes were made for the slump-loss study. Original mixes made in the spring were designated SL and replicate mixes were designated SLR. Mixes made in the summer were designated HTSL.

TESTS AND SPECIMENS

The properties of fresh concrete--temperature, slump (ASTM C 143-78), air content (ASTM C 231-81), vebe time (ACI Standard 211-65), flow-table spread, and unit weight (ASTM C 138-81)--were determined immediately after mixing. To determine the rate of slump and air-content loss, slump and air content were determined and recorded at various time intervals. These tests were conducted until a zero slump was reached.

The setting time of the concrete was determined according to ASTM C 403-77.

The test specimens, 4 x 8-in. (101.6 x 203-mm) cylinders, were cast in steel molds immediately after mixing and at other time intervals when air content was determined. The cylinder-casting sequence and the time of casting of these cylinders are given in tables in the next section. Cylinders were unmolded after 24 hr and cured in lime-saturated water according to ASTM C 192-76.

After the dry unit weight had been determined, the cylinders were tested for compressive strength at the age of 3, 7, and 28 days.

ANALYSIS AND DISCUSSION OF RESULTS

Setting Times

First, during the month of March [concrete temperature 69°F (20.6°C)] the concrete setting times (ASTM C 403) were studied for the two selected mixes FSET13 and FSET33, which had water/cement ratios of 0.38 and 0.28, respectively. The setting-time studies were repeated for replicate mixes FRSET13 and FRSET33. Then during the month of July [concrete temperature 84°F (28.9°C)] the setting-time study was repeated for the same two mixes (HTSET13 and HTSET33).

The wet concrete mix was passed through sieve No. 4, which has 0.19-in. (4.75-mm) openings, to remove the coarse aggregates and the resulting mortar was used for the setting-time study. The mix proportions used are given in Table 3. The details of elapsed time, concrete temperature, air temperature, relative humidity, and penetration resistance are given for original and replicate mixes in Tables 4 and 5 and for the summer mixes in Table 6. The plastic properties of all the mixes are given in Table 7. The setting-time curves for mixes 13 and 33 are shown in Figures 1 and 2, respectively. The 3-, 7-, and 28-day compressive strengths for these concretes are plotted in Figure 3.

The slump and air content for the original mixes, FSET13 and FSET33, were 7 in. (178 mm) and 9.2 percent and 3 in. (76 mm) and 8.6 percent, respectively. The slump and air content for the replicate mixes FRSET13 and FRSET33 were 6 in. (152 mm) and 8.6 percent and 4 in. (102 mm) and 8.6 percent, respectively. The differences in initial and final setting times for the mixes FSET13 and FRSET13 were 48 and 25 min, respectively. The difference in initial and final setting times for the mixes FSET33 and FRSET33 were 55 and 34 min, respectively. The averages of the original and replicate mix results were taken as final values.

The slump and air content for the summer mixes HTSET13 and HTSET33 were 2.5 in. (64 mm) and 3.2 percent and 0 in. and 4 percent, respectively. The concrete temperature for these mixes was relatively high [84°F (28.9°C)] compared with the original and replicate mixes [70°F (21°C)]. The higher concrete temperature caused a considerable reduction in the slump, the air content, and the setting times.

Table 4. Setting time of concrete for original mixes.

Mix FSET13					Mix FSET33				
Elapsed Time (hr:min)	Air Temperature (°F)	RH (%)	Concrete Temperature (°F)	Penetration Resistance (psi)	Elapsed Time (hr:min)	Air Temperature (°F)	RH (%)	Concrete Temperature (°F)	Penetration Resistance (psi)
0:00	69	49	69	0	0:00	70	51	70	0
3:10	69	51	63	0	3:30	67	52	63	11
5:00	66	56	63	0	4:00	66	56	63	16
5:50	64	69	63	26	5:10	64	68	63	24
6:10	64	68	63	33	5:36	65	61	63	30
6:30	65	61	63	60	5:56	66	60	63	52
6:50	66	60	63	90	6:29	64	59	63	122
7:20	64	59	63	150	7:10	64	59	64	320
7:40	65	59	64	240	7:26	64	59	64	400
8:03	64	59	64	500	7:41	64	59	64	520
8:40	64	59	64	880	8:16	66	58	64	910
9:10	66	58	64	1,240	8:46	64	58	64	1,480
9:40	64	58	64	1,960	9:06	64	58	64	2,200
10:00	64	58	64	3,360	9:20	62	58	64	3,520
10:10	62	58	64	4,120	9:40	63	58	64	4,160

Notes: RH, relative humidity.
1 psi = 145 MPa.
1°F = (1°C ÷ 0.55) + 32.

Table 5. Setting time of concrete for replicate mixes.

Mix FRSET13					Mix FRSET33				
Elapsed Time (hr:min)	Air Temperature (°F)	RH (%)	Concrete Temperature (°F)	Penetration Resistance (psi)	Elapsed Time (hr:min)	Air Temperature (°F)	RH (%)	Concrete Temperature (°F)	Penetration Resistance (psi)
5:22	70	51	64.0	0	5:17	69	53	64	0
6:19	67	54	64.0	0	6:02	70	51	65	22
6:45	68	54	64.5	22	6:27	68	53	65	43
7:16	69	53	65.0	52	6:57	67	54	65	70
7:42	69	53	65.0	90	7:27	68	54	65	148
8:07	68	53	65.0	200	7:57	69	53	65	244
8:47	67	53	65.0	360	8:22	69	53	66	400
9:07	67	53	65.0	570	8:37	68	53	66	540
9:27	66	53	65.0	800	9:30	67	53	66	1,220
9:47	66	53	65.0	1,320	9:49	67	53	66	2,120
10:28	66	53	65.0	3,200	10:10	66	53	66	3,200
10:34	66	53	65.0	4,120	10:20	66	53	66	4,000

Notes: RH, relative humidity.
1 psi = 145 MPa.
1°F = (1°C ÷ 0.55) + 32.

Table 6. Setting time of concrete for summer mixes.

Mix HTSET13					Mix HTSET33				
Elapsed Time (hr:min)	Air Temperature (°F)	RH (%)	Concrete Temperature (°F)	Penetration Resistance (psi)	Elapsed Time (hr:min)	Air Temperature (°F)	RH (%)	Concrete Temperature (°F)	Penetration Resistance (psi)
2:00	83	40	81	40	1:05	83	40	80	0
2:25	85	40	80	50	1:25	85	40	80	30
2:45	86	38	81	81	1:45	86	38	81	60
3:15	85	37	82	103	2:00	86	38	81	100
3:45	87	36	83	178	2:15	86	37	82	184
4:15	88	34	84	610	2:45	87	36	83	340
4:30	89	33	86	790	3:15	88	34	84	740
4:50	90	33	87	1,960	3:30	89	33	84	1,110
5:05	90	33	87	3,600	3:45	90	33	85	1,420
5:15	90	33	87	4,440	4:00	90	33	85	2,560
					4:15	90	33	85	3,760
					4:25	90	33	85	4,320

Notes: RH, relative humidity.
1 psi = 145 MPa.
1°F = (1°C ÷ 0.55) + 32.

Table 7. Plastic properties of mixes used in setting-time study.

Mix No.	Superplasticizer Dosage (% by weight of cement)	AEA (% by weight of cement)	Water/Cement Ratio by Weight	After Mixing: Temperature (°F)	Slump (in.)	Unit Weight (lb/ft^3)	Air Content (%)	Vebe Time (sec)	Flow-Table Spread (in.)
FSET13	1.0	0.08	0.38	69	7.0	138.2	9.2	0	16.54
FSET33	1.2	0.18	0.28	70	3.0	140.8	8.6	2.0	11.81
FRSET13	1.0	0.08	0.38	71	6.0	140.3	8.6	0.5	14.57
FRSET33	1.2	0.18	0.28	72	4.0	141.2	8.6	2.0	14.17
HTSET13	1.0	0.08	0.38	83	2.5	150.15	3.2	3.8	11.02
HTSET33	1.2	0.18	0.28	84	0.0	150.18	4.0	7.6	7.87[a]

Notes: FR = replicate mixes.
1 in. = 25.4 mm.
$1°F = (1°C \div 0.55) + 32$.
$1\ lb/ft^3 = 16.03\ kg/m^3$.

[a]No flow of concrete; concrete crumbles.

Figure 1. Setting time of concrete for mix 13.

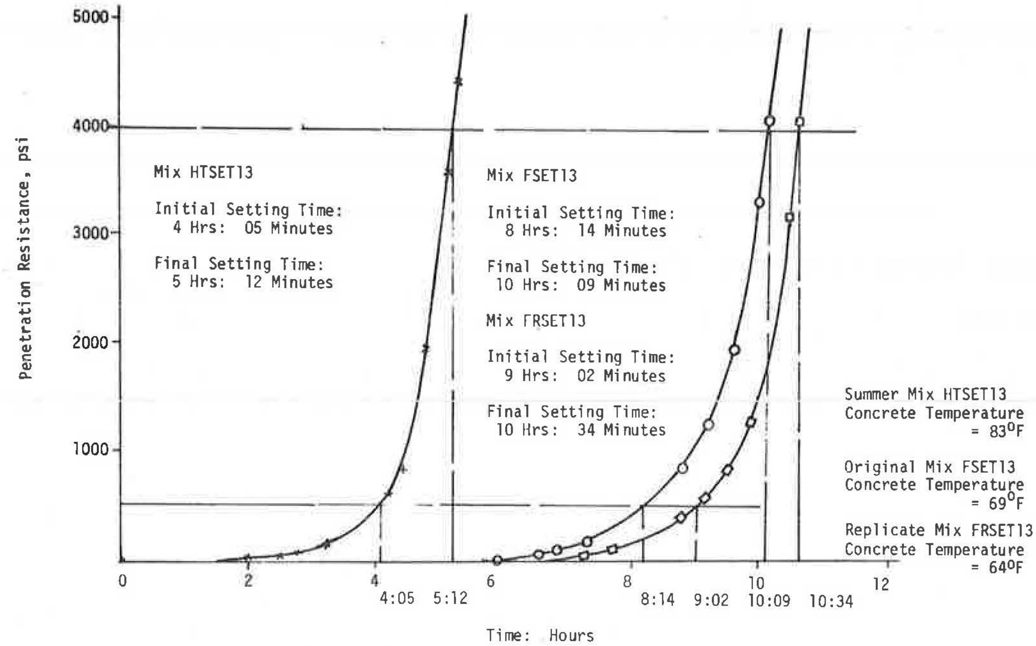


Figure 2. Setting time of concrete for mix 33.

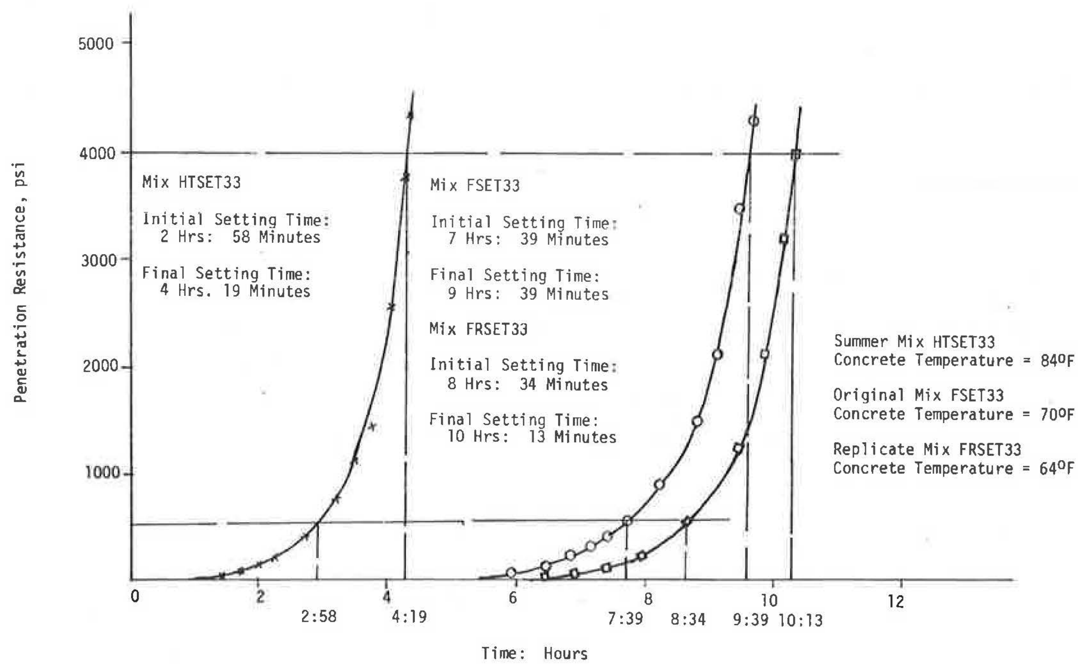


Figure 3. Compressive strength.

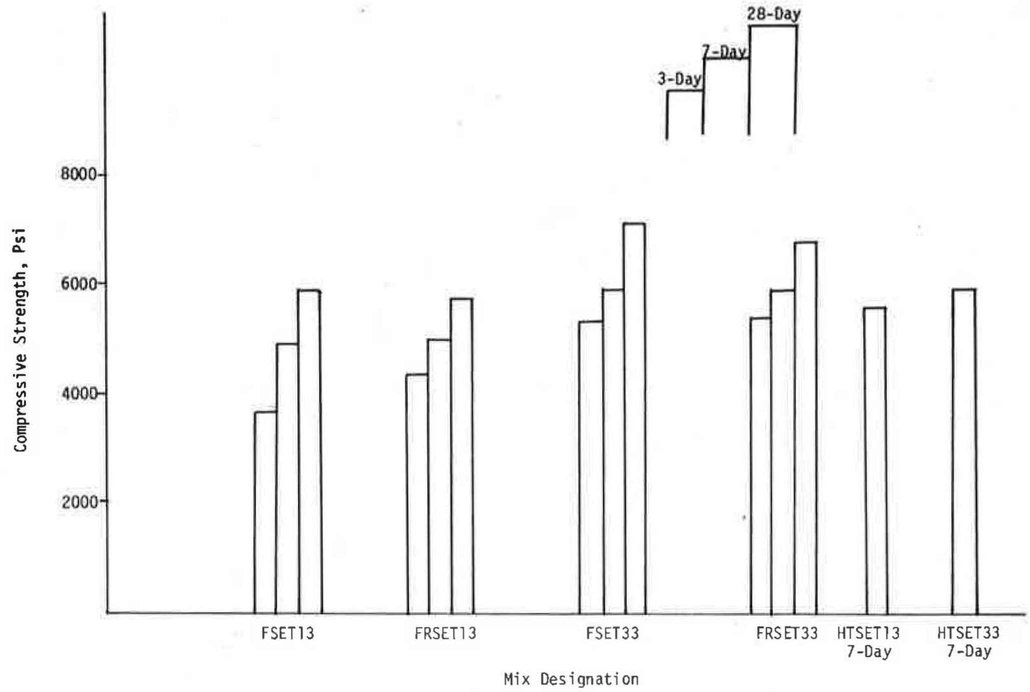


Table 8. Properties of fresh concrete mixes used in slump-loss study.

					After Initial Mixing							
					Temperature (°F)							
Mix No.	Superplasticizer	Dosage of Superplasticizer (% by weight of cement)	AEA Dosage (% by weight of cement)	Water/Cement Ratio	RT	CT	Slump (in.)	Unit Weight (lb/ft^3)	Air Content (%)	Vebe Time (sec)	Flow-Table Spread (in.)
SL33	Mighty RDI	1.2	0.18	0.28	65	72	5.125	148.41	6.4	2.0	12.96
SL13	Mighty RDI	1.0	0.08	0.38	65	70	9.000	133.80	14.4	0	20.82
SLR33	Mighty RDI	1.2	0.18	0.28	78	78	4.000	148.24	5.8	3.0	12.57
SLR13	Mighty RDI	1.0	0.08	0.38	67	70	9.250	136.71	10.4	0.0	16.89
HTSL13	Mighty RDI	1.0	0.08	0.38	84	84	6.750	144.15	8.0	0.5	14.14
HTSL33	Mighty RDI	1.2	0.18	0.28	91	88	0.000	150.84	3.8	7.2	7.86

Notes: RT, room temperature; CT, concrete temperature; AEA, air-entraining agent, vinsol resin (Protex).
1 in. = 25.4 mm.
$°F = (°C \div 0.55) + 32$.
$1\ lb/ft^3 = 16.03\ kg/m^3$.

Figure 4. Slump versus time for mix 13.

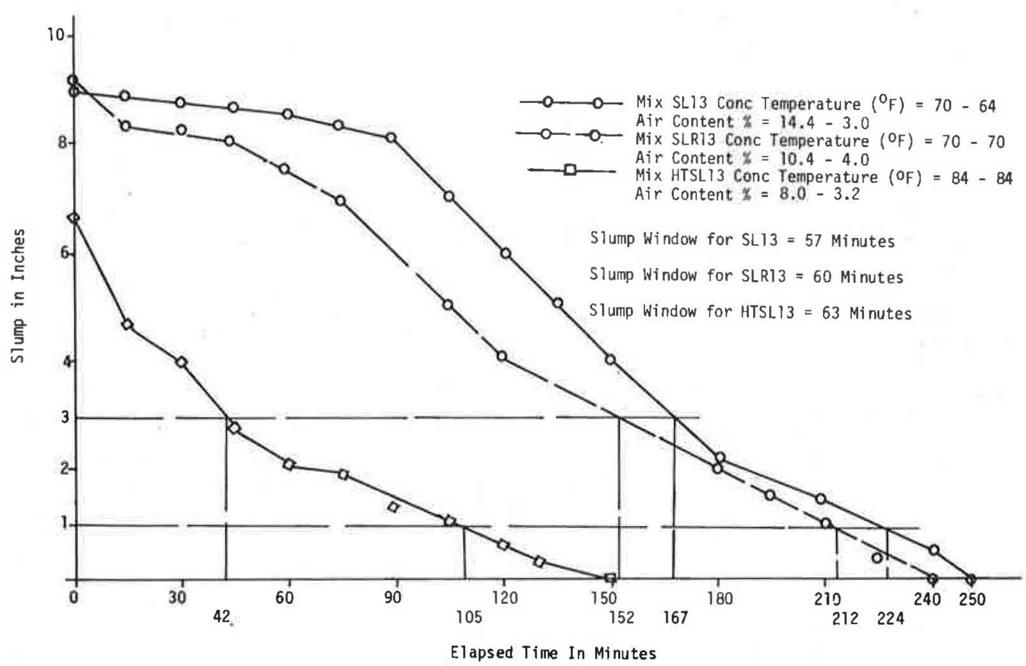


Figure 5. Slump versus time for mix 33.

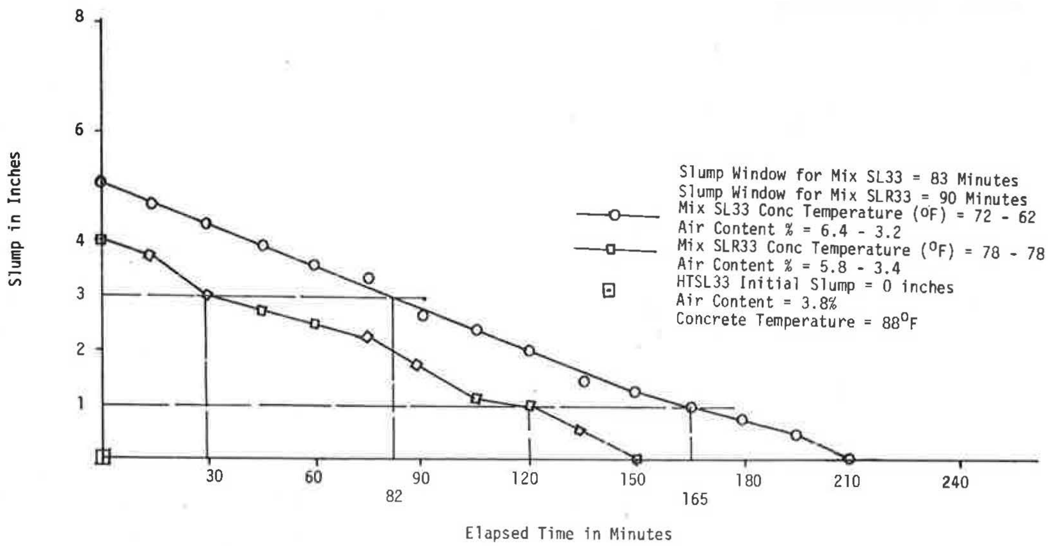
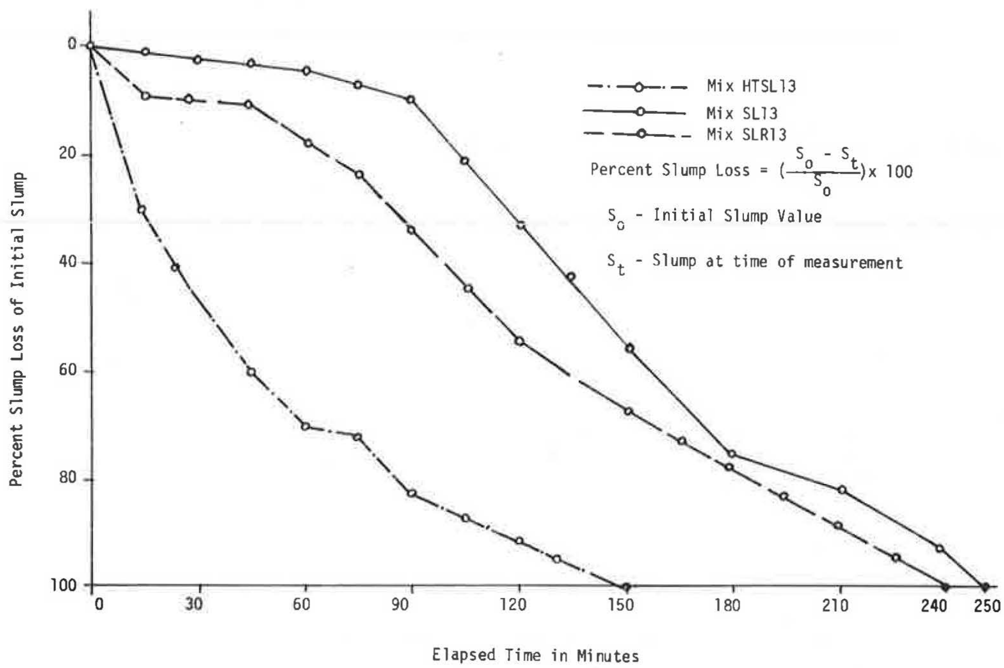


Figure 6. Percent slump loss versus time for mix 13.



Slump-Loss Study

During the spring (March) four mixes--SL13, SL33, and their replicates, SLR13 and SLR33--and during the summer two mixes--HTSL13 and HTSL33--were made for the slump-loss study. The mix proportions used are given in Table 8. Immediately after mixing, the concrete was transferred to a wheelbarrow and tests for slump, air content, flow-table spread, unit weight, and vebe time were made. The slump was measured at 15-min intervals. Before each slump measurement, the concrete was hand mixed. The concrete was kept covered in the wheelbarrow until the slump-loss study was over. The curves for slump loss with time are shown in Figures 4 and 5 for mixes 13 and 33, respectively. The initial slumps for mixes 13 and 33 were approximately 9 in. (228.6 mm) and 5 in. (127.0 mm), respectively. The initial slumps for mixes HTSL13 and HTSL33, which were made at a relatively higher temperature and lower humidity, were 6.75 in. (171.5 mm) and 0, respectively.

The initial slump for mix SLR13 was 9.25 in. (235 mm), corresponding to a concrete temperature of 70°F and relative humidity of 52 percent. The initial slump for mix SL13 was 9 in. (228.6 mm), corresponding to a concrete temperature of 70°F and relative humidity of 52 percent. The initial slump for mix HTSL13 was 6.75 in. (171.5 mm), corresponding to a concrete temperature of 84°F and relative humidity of 40 percent.

The effect of concrete temperature on initial slump loss was clearly seen in the case of mix 33. The initial slumps for mixes SL33 and SLR33 were 5.125 in. (130 mm) and 4 in. (102 mm), corresponding to concrete temperatures of 72°F (22.2°C) and 78°F (25.6°C) and relative humidities of 51 and 32 percent. The initial slump of mix HTSL33 was 0, corresponding to a concrete temperature of 88°F (31°C) and relative humidity of 33 percent. This clearly shows the effect of the temperature and humidity on the initial slump of concrete.

The mixes that were made at lower temperatures

Table 9. Slump, temperature of concrete, air content, and unit weight at various time intervals for mix SL13.

Cylinder-Casting Sequence	Time After Mixing (min)	Concrete Temperature (°F)	Slump (in.)	Slump Loss (%)	Air Content (%)
1	0	70	9.000	0	14.4
	15	70	8.875	1.4	–
	30	67	8.750	2.8	9.8
	45	66	8.750	2.8	–
	60	66	8.625	4.2	–
	75	66	8.375	7.5	–
	90	66	8.125	9.2	7.2
	105	66	7.125	20.8	–
2	120	65	6.000	33.3	6.0
	135	65	5.125	43.1	–
	150	65	4.000	55.6	–
	165	65	2.375	73.6	–
3	180	65	2.250	75.0	4.4
	210	64	1.625	81.9	–
	240	64	0.500	94.4	–
4	250	64	0.000	100.0	3.0

Notes: Air temperature, 65°F; RH, 52 percent; and unit weight, 133.8 lb/ft^3.
1 in. = 25.4 mm. 1°F = (1°C ÷ 0.55) + 32. 1 lb/ft^3 = 16.03 kg/m^3.

had higher initial air contents, whereas the mixes that were made at high temperatures had low initial air contents. The loss in initial air content due to higher temperatures was also a contributing factor to the reduced initial slumps at higher temperatures.

The loss in slump was not rapid at low temperatures for the mixes evaluated, as shown in Figures 4 and 5. The percent slump loss is shown in Figures 6 and 7. For mixes SL13 and SLR13 the time taken for 100 percent slump loss was about 4 hr, whereas for mixes SL33 and SLR33 the time taken for 100 percent slump loss was about 3 hr. For mix HTSL13 the time taken for 100 percent slump loss was about 2.5 hr.

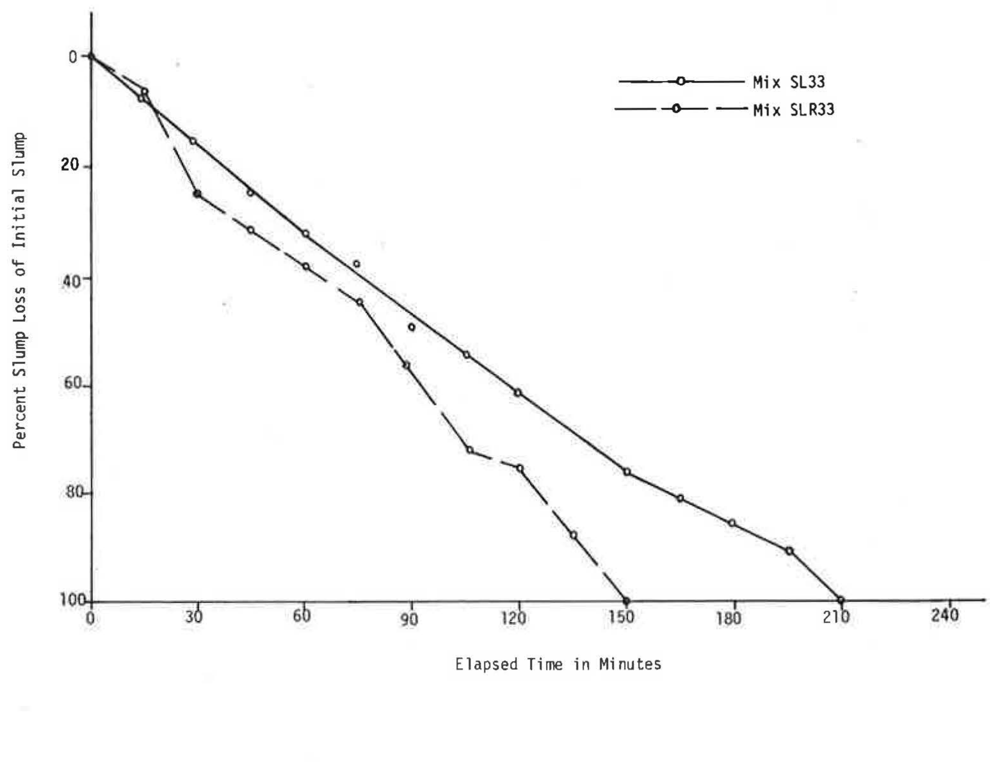
Room temperature and humidity affect the rate of loss of slump. For mixes SL13 and SLR13 the initial slump was the same, but the rate of loss of slump for SLR13 was higher compared with that for SL13 (Figure 6). The room temperature and concrete temperature for SLR13 were higher than those for SL13 (Tables 9 and 10). The same trend was observed for other mixes also (Tables 11-13). Similar findings of higher rate of slump loss at higher temperatures were reported by Mailvahanam (4).

Table 10. Slump, temperature of concrete, air content, and unit weight at various time intervals for mix SLR13.

Cylinder-Casting Sequence	Air Content (%)	Unit Weight (lb/ft^3)	Time After Mixing (min)	Air Temperature (°F)	Concrete Temperature (°F)	Relative Humidity (%)	Slump (in.)	Slump Loss (%)
1	10.4	136.71	0	67	70	52	9.250	0.0
			15	68	71	52	8.375	9.5
			30	69	71	51	8.375	9.5
			45	69	71	50	8.125	12.2
2	7.0	145.43	60	70	70	49	7.500	18.9
			75	70	70	48	7.000	24.3
			90	70	69	44	5.375	41.9
			105	71	70	41	5.000	45.9
3	5.2	148.27	120	73	70	39	4.125	55.4
			135	73	70	39	3.750	59.5
			150	73	70	40	3.000	67.6
			165	73	70	40	2.500	73.0
4	4.0	151.19	180	73	70	40	2.000	78.4
			195	73	70	40	1.500	83.8
			210	73	70	40	1.000	89.2
			225	73	70	40	0.375	95.9
5		151.50	240	73	70	40	0.000	100.0

Notes: 1 in. = 25.4 mm. 1°F = (1°C ÷ 0.55) + 32. 1 lb/ft^3 = 16.03 kg/m^3.

Figure 7. Percent slump loss versus time for mix 33.



Although useful trends can be deduced from such visual examination of the slump-loss curves, more quantitative parameters are needed. Two such parameters that have been found useful are the slump window and the total working time (5). The slump window is defined as the time taken for the slump to decay from 3 in. (76.2 mm) to 1 in. (25.4 mm) and would be useful to those interested in slipform operations, where high slumps could not be tolerated.

Table 11. Slump, temperature of concrete, air content, and unit weight at various time intervals for mix SL33.

Cylinder-Casting Sequence	Time After Mixing (min)	Concrete Temperature (°F)	Slump (in.)	Slump Loss (%)	Air Content (%)
1	0	72.0	5.125	0	6.4
	15	71.5	4.750	7.3	5.8
2	30	71.0	4.375	14.6	5.3
	45	70.5	3.875	24.4	4.6
3	60	68.0	3.500	31.7	4.4
	75	67.0	3.250	36.6	4.2
	90	67.0	2.625	48.8	–
	105	67.0	2.375	53.7	–
	120	65.0	2.000	61.0	–
	135	64.0	1.375	73.2	–
	150	64.0	1.250	75.6	–
	165	64.0	1.000	80.5	–
	180	63.0	0.750	85.4	–
	195	62.0	0.500	90.2	
4	210	62.0	0.000	100.0	3.2

Notes: Air temperature, 65°F; RH, 51 percent; and unit weight, 148.41 lb/ft^3.
1 in. = 25.4 mm.
1°F = (1°C ÷ 0.55) + 32.
1 lb/ft^3 = 16.03 kg/m^3.

The total working time is defined as the time needed for the slump to go from the initial value to 1 in. These two parameters are plotted in Figures 4 and 5, respectively, for mixes 13 and 33.

The total working time for mix 13 was 218 min (average of mixes SL13 and SLR13) and for mix 33, 143 min (average of mixes SL33 and SLR33). The total working time for mix HTSL13 was 105 min. These high total working times are possible because of the use of superplasticizer with a retarder.

Figures 4 and 5 show that for higher initial slump, the rate of slump loss is higher. Mix 13 took 240 min to go to zero slump from a high initial slump of 9 in. (228.6 mm), whereas mix 33 took approximately 180 min to go to zero slump from an initial high slump of 5 in. (127.0 mm). Similar findings were reported by Whiting (5) and Ramakrishnan, Coyle, and Pande (1).

The curves for loss of air content with time are shown in Figure 8. The higher the initial air content is, the higher is the rate of air-content loss. Mixes SL13 and SLR13 had high initial air contents of more than 10 percent when tested immediately after mixing and had about 3 percent air content when tested at zero slump. Mixes SL33 and SLR33 had initial air contents of about 6 percent and final air contents of about 3 percent at zero slump.

Properties of Hardened Concrete

The 7-day compressive strengths of cylinders cast at different time intervals after mixing are plotted in Figure 9. The compressive strength and dry unit weights were higher for cylinders that were cast long after mixing when compared with the compressive

Table 12. Slump, temperature of concrete, air content, and unit weight at various time intervals for mix SLR33.

Cylinder-Casting Sequence	Air Content (%)	Unit Weight (lb/ft^3)	Time After Mixing (min)	Air Temperature (°F)	Concrete Temperature (°F)	Relative Humidity (%)	Slump (%)	Slump Loss (%)
1	5.8	148.24	0	78	78	32	4.000	0
			15	80	76	29	3.750	6.3
2	5.2		30	80	76	28	3.000	25.0
			45	80	78	29	2.750	31.3
	4.2	149.65	60	80	77	31	2.500	37.5
			75	80	77	32	2.250	43.8
			90	80	77	32	1.750	56.3
			105	80	78	29	1.125	71.9
3	4.0	151.50	120	80	78	28	1.000	75.0
			135	81	78	27	0.500	87.5
4	3.4	151.81	150	82	78	26	0.000	100.0

Notes: 1 in. = 25.4 mm.
1°F = (1°C ÷ 0.55) + 32.
1 lb/ft^3 = 16.03 kg/m^3.

Table 13. Slump, temperature of concrete, air content, and unit weight at various time intervals for mix HTSL13.

Cylinder-Casting Sequence	Air Content (%)	Unit Weight (lb/ft^3)	Time After Mixing (min)	Air Temperature (°F)	Concrete Temperature (°F)	RH (%)	Slump (in.)	Slump Loss (%)
1	8.0	144.15	0	84	84	40	6.750	0.0
			15	86	85	37	4.750	29.6
2	5.0	146.50	30	86	85	37	4.000	40.7
			45	86	85	37	2.750	59.3
			60	87	84	36	2.063	69.4
			75	87	84	35	1.075	72.2
3	4.2	150.49	90	88	84	35	1.125	83.3
			105	88	84	34	0.875	87.0
			120	89	83	33	0.563	91.7
			130	90	84	33	0.313	95.4
4	3.2	151.75	150	90	84	33	0.000	100.0

Notes: RH, relative humidity.
1°F = (1°C ÷ 0.55) + 32.
1 in. = 25.4 mm.

Figure 8. Air content versus time.

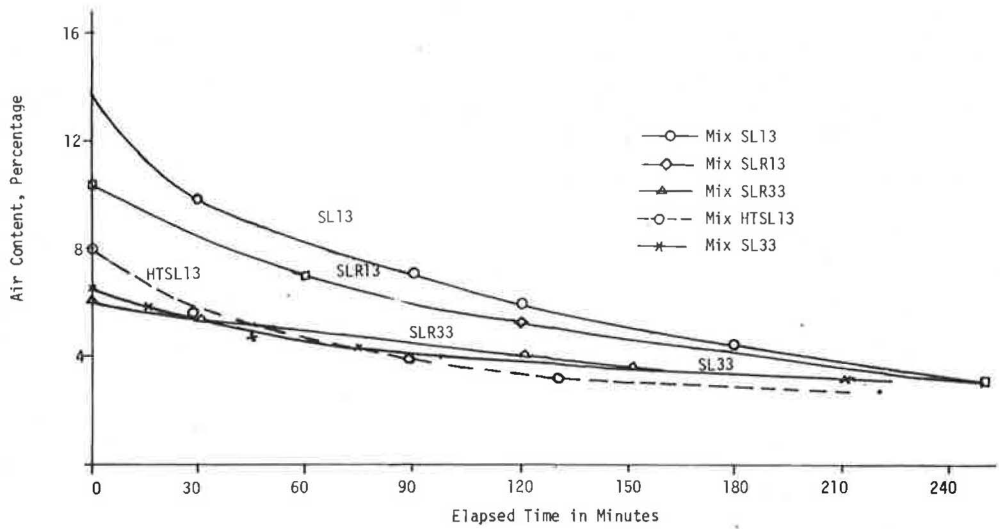
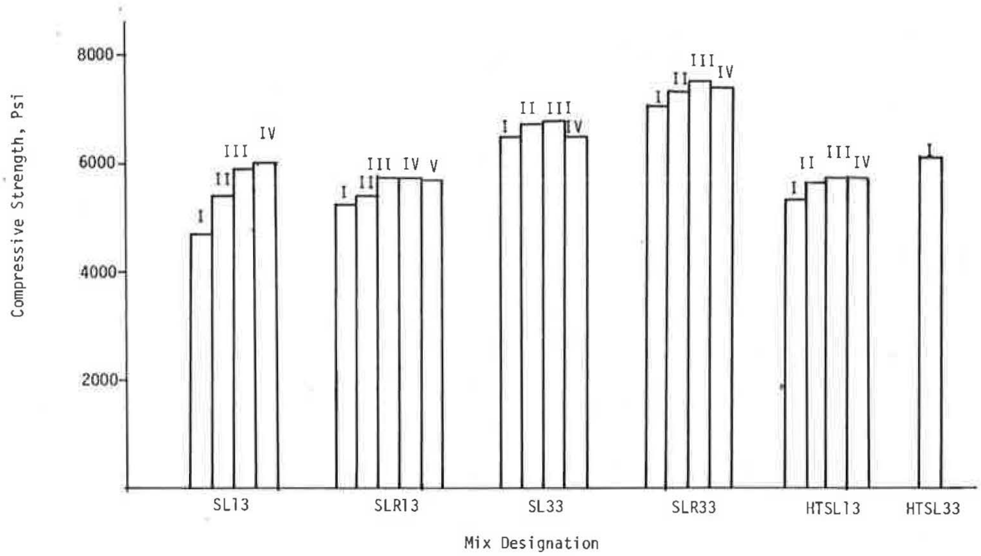


Figure 9. Seven-day compressive strength.



strengths of cylinders that were cast immediately after mixing. The compressive strengths and unit weights increased as the time after initial mixing increased. This trend was observed for all the mixes. The gain in compressive strength and unit weight can be attributed to the loss in air content with time. In contrast to this, the cylinders that were cast when the slump was zero show a drop in compressive strength compared with the compressive strength of previously made cylinders. This can be attributed to the poor workability of concrete at zero slump, because all the cylinders were hand compacted.

The increase in compressive strength from initial casting to final casting is about 15 percent for mix 13 and 5 percent for mix 33.

CONCLUSIONS

Based on the analysis of experimental results, the following conclusions are drawn:

1. Due to a 16°F increase in the initial concrete temperature and 10 percent reduction in the relative humidity, the initial setting time was reduced by 53 and 63 percent, respectively, for medium-cement-content and high-cement-content concretes; the corresponding reductions in the final setting times were 50 and 57 percent.

2. The rate of slump loss is low at low temperatures and the workability is maintained for several hours after mixing for the concrete mixes that were made at relatively low temperatures. The mixes with a water/cement ratio of 0.38 and 1.0 percent superplasticizer dosage maintained their workable slumps for 3 hr at low temperatures, whereas the mixes with a ratio of 0.28 and 1.2 superplasticizer dosage maintained their workable slumps for 2 hr.

3. The slump loss is proportional to the initial slump level for all the mixes; the higher the initial slump is, the higher the slump loss. The total time span to which concrete could be kept workable, however, is more for a concrete with a higher initial slump.

4. The air-content loss is proportional to the initial level of air content for all the mixes; the higher the initial air content is, the higher is the air-content loss.

5. Room temperature and humidity have a great influence on the level of initial slump as well as on the rate of loss of slump. The higher the room temperature is and the lower the relative humidity

is, the lower is the initial slump and the higher is the rate of loss of slump.

6. The compressive strength and the dry unit weight are higher for cylinders that were cast long after the mixing compared with the cylinders that were cast immediately after mixing. The gain in compressive strengths and dry unit weights can be attributed to the loss in air content with time.

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Effects of High Temperatures on the Properties of Fresh Concrete

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The effects of high temperature on the properties of fresh concrete and the mechanism of the setting of cement paste and concrete are described. The undesirable effects of high temperature on fresh concrete mentioned include increased water demand, increased rate of slump loss, increased rate of setting, and increased tendency for plastic shrinkage cracking. This is followed by a discussion of the methods to minimize the above effects; the roles of water-reducing and set-retarding admixtures, superplasticizers, and retempering of concrete are described.

The effects of high temperatures (that is, a hot climate) on the properties of fresh concrete are usually undesirable from the standpoint of construction. Frequently occurring phenomena such as accelerated slump loss or increased possibility of excessive moisture loss and the resulting shrinkage cause extra problems for the construction engineer. Such problems can be eliminated only by careful and sometimes expensive preventive measures.

The current status of the knowledge is still incomplete concerning the effects of high temperatures on the behavior of fresh cement paste or concrete. Some aspects have been published, such as those related to setting or effects of admixtures (1,2). Nevertheless, the seriousness of the problems of construction in tropical climates makes it worthwhile to provide additional details in a systematic fashion. In addition, the emphasis in this paper is on new aspects of the temperature effects.

EFFECTS OF TEMPERATURE ON HYDRATION OF CEMENT

Definitions

When portland cement is mixed with a limited amount of water, the cement particles become dispersed in the water. The result is cement paste, which is a material of considerable plasticity.

The setting and hardening processes are the results of a series of simultaneous and consecutive reactions between water and the constituents of portland cement. These reactions are described as the hydration of portland cement. The hydration of cement compounds is exothermic. The heat developed is called the heat of hydration.

Reactions in Early Hydration and Setting

The measurement of heat evolution is particularly suitable for the investigation of the early stages of hydration (3). During a short period beginning when portland cement and water are first brought into contact at room temperature and during the time of mixing, relatively rapid chemical reactions occur, primarily between the water and the tricalcium aluminate (C_3A) of the cement.

When portland cement is insufficiently retarded, the time of initial setting is considerably less than 1 hr at normal temperature.

Another factor that can cause rapid setting is elevated temperature. The higher the curing temperature is, the faster are the reactions between cement and water, and consequently the shorter becomes the setting time. The effects of curing temperature on the intensity (rate) of hydration can be seen in Figures 1 through 4 (4;5, pp. 1-32; 6, pp. 259-273). It can also be seen from Figure 1 that a change appears in the hydration process at a temper-