Workability and Strength of Retempered Superplasticized Concretes

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This paper presents the results of a comparative laboratory investigation of the workability of retempered concrete with and without superplasticizer. The effect of mixing time on the strength of superplasticized concrete is also discussed. Both superplasticizer and water were used as retempering agents, and the variables were type of superplasticizer and initial slump of the concrete. Fresh concrete was tested for slump, air content, and unit weight up to 150 min after initial mixing. The hardened concrete was tested for compressive strength and modulus of elasticity. The slump of retempered concrete both with and without superplasticizer decreased about equally with time. However, increased workability and subsequent slump loss depended on the type of superplasticizer used and the initial slump level. The results indicate that extended mixing time does not adversely affect the compressive strength of concrete. The large increases in slumps of superplasticized concretes can be maintained for several hours by retempering, which does not reduce the strength of the concrete. The properties of hardened retempered concrete are comparable to those of corresponding unretempered concretes.

Concrete that has desirable properties in the hardened state is normally made with a low water-to-cement (w/c) ratio and with the least possible amount of cement paste in the mix. Such a concrete usually has a low slump and requires the careful compaction needed for the high-density, low-slump concrete used in the Iowa method of bridge deck resurfacing.

In order to produce concrete of the same quality that requires less vibration, very effective plasticizers known as superplasticizers have been developed to make flowing and self-compacting concrete. Superplasticizers are added to concrete to greatly increase its workability or to allow a large reduction in mixing water and thus produce high-strength concrete (1, 2). Such a change in concrete properties would result in reduced placement costs or a reduction in the cement requirement. A well-designed mix with superplasticizer will have good flowability and sufficient cohesiveness and will not cause bleeding, segregation, or strength reduction during or after placement.

Though new to North America, superplasticizers have been successfully used in Japan since the late 1960s and in Germany since 1972 (1). The introduction of these superplasticizers has opened up new possibilities for the use of concrete in construction, particularly for resurfacing bridge decks and constructing other highway facilities. A few research establishments in the United States are performing laboratory studies on the use of these admixtures and are attempting to delineate their uses and limitations (3-9). Since 1976, investigations have been in progress at the Concrete Technology Research Center of the South Dakota School of Mines and Technology to determine the effects of superplasticizers on the properties of plastic and hardened concrete (7, 10-12).

Because 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. Hence delay in the discharge of concrete from the truck mixers could cause stiffening to the point of unworkability.

In actual field applications of superplasticizers, it may be necessary to add additional dosages—retempering—to maintain increased slump. The effects of extended mixing and of repeated dosages of superplasticizers to maintain a given slump need further study. Some retempering studies (13-16) investigated the effect of mixing time and retempering on conventional concrete by using water as the retempering agent. This paper presents the results of a comparative study of the workability and strength of retempered concretes with and without superplasticizer.

OBJECTIVES

The objectives of this research program are to study

1. Slump-loss characteristics for retempered superplasticized concretes,
2. The effect of retempering on the workability and strength of superplasticized concretes, and
3. The effect of mixing time on the workability and strength of superplasticized concretes.

RESEARCH PROGRAM

The research program consisted of three parts. First, water was used as the retempering agent, then superplasticizer was used, and finally the effect of mixing time on workability and strength was explored.

In part 1, water was used as the retempering agent for both control and superplasticized mixes. The control mixes were identical to the superplasticized mixes but lacked superplasticizers. Two control mixes, C1 and C2, were made, and 150 min after initial mixing, when the first workability study was over, these mixes were retempered with water. The retempered mixes were designated RC1 and RC2. Two corresponding superplasticized mixes, S1 and S2, were also retempered with water 150 min after initial mixing; these retempered mixes were designated RS1 and RS2.

The details of all eight mixes are given in Table 1. The same procedure was used for retempering all of them. When the first workability study was over, the concrete was weighed and put back in the mixer for 3 min. Retempering was done while the drum was rotating by adding a specific quantity of water according to judgment; the intent was to add enough to achieve a reasonably high initial slump.

In part 2 of the study, superplasticizer was used as the retempering agent. Two superplasticized mixes, PRS3 and PRS4, were made to study the effect of repeated dosages of superplasticizers on the workability and strength of concrete. Each mix was retempered three times, and the retempered mixes were designated PRS3-1, PRS3-2, and PRS3-3 and PRS4-1, PRS4-2,

Table 1. Properties of fresh and hardened concretes.

				Fresh Concrete				Hardened Concrete		
Mix	Dosage of Superplasticizer (%)	AEA[a] (%)	w/c Ratio	Temperature (°C)	Slump (mm)	Unit Weight (kg/m^3)	Air (%)	Unit Weight (kg/m^3)	Compressive Strength (MPa)	Modulus of Elasticity (MPa)
C1	-	0.12	0.65	22	172.7	2335.3	3.2	2365.8	23.16	31.92×10^3
RC1	-	0.12	0.80	20.5	107.9	-	-	2412.6[b]	25.00	32.95×10^3
								2448.3[c]	29.44	34.48×10^3
S1	Lomar-D 1.5	0.12	0.65	23	241.3	2374.90	3.6	2367.9	23.58	30.54×10^3
RS1	Lomar-D 1.5	0.12	0.77	18	193.0	2344.81	-	2379.7[b]	23.23	32.54×10^3
								2395.9[c]	25.23	33.16×10^3
C2	-	0.14	0.66	23	81.3	2301.44	5.0	2332.5	24.40	30.95×10^3
RC2	-	0.14	0.77	19	71.1	2342.41	-	2341.3[b]	24.61	31.51×10^3
								2462.0[c]	25.92	37.64×10^3
S2	Melment 1.5	0.14	0.66	25	233.7	2283.21	3.7	2360.2	25.23	32.13×10^3
RS2	Melment 1.5	0.14	0.86	20.5	195.6	2347.78	2.7	2357.6[b]	25.16	29.44×10^3
								2376.3[c]	26.54	31.64×10^3

Notes: t°C = (t°F - 32)/1.8; 1 mm = 0.039 in; 1 kg/m^3 = 0.062 lb/ft^3; 1 MPa = 145 lbf/in^2.
[a]AEA = air-entraining agent, Protex. [b]Molded 2.5 h after mixing. [c]Molded 5.0 h after mixing.

Table 2. Properties of fresh concretes.

Mix	Dosage of Superplasticizer (%)	AEA[a] (%)	w/c Ratio	Temperature (°C)	Slump (mm)	Unit Weight (kg/m^3)	Air Content (%)
TS1	Lomar-D 1.50	0.14	0.48	23	144.8	2266.8	-
TS2	Melment 1.50	0.14	0.48	23	119.4	2406.7	-
PS3	Melment 1.50	0.14	0.51	23	188.0	2395.6	5.0
PRS3-1	Melment 2.16	0.14	0.51	20	198.1	2413.5	3.8
PRS3-2	Melment 2.75	0.14	0.51	19.5	132.1	2448.5	1.6
PRS3-3	Melment 4.28	0.14	0.51	19	78.7	2434.2	1.6
PS4	Melment 1.50	0.14	0.49	22	165.1	2385.8	4.9
PRS4-1	Melment 2.62	0.14	0.49	20.5	129.5	2427.9	1.8
PRS4-2	Melment 3.15	0.14	0.49	19	0.0[b]	2440.0	2.0
PRS4-3	Melment 3.59	0.14	0.49	19	149.9	2432.8	1.7

Notes: t°C = (t°F - 32)/1.8; 1 mm = 0.039 in; 1 kg/m^3 = 0.062 lb/ft^3.
[a]AEA = air-entraining agent, Protex.
[b]This was not a true representative slump because all the mortar separated out from the aggregates.

and PRS4-3. Details for these eight mixes are given in Table 2.

Retempering was done when the slump was about 0-25 mm (0-1 in). The amount of superplasticizer added each time was again a matter of judgment; the intent was to add a sufficient quantity to increase the slump to a reasonable level. The remixing was done for 3 min at each retempering. After the initial mixing and at each interval, a known quantity of concrete was taken out for fresh concrete tests. Cylinders were cast after initial mixing and after each retempering.

In part 3, mixes TS1 and TS2 were used to study the effect of extended mixing time on the workability and strength of superplasticized concretes. The details of these mixes are given in Table 2. For these mixes, the concrete was left undisturbed and covered in the mixer for the entire period of testing. The fresh concrete tests were conducted, and specimens were cast immediately after initial mixing and after every elapsed hour.

MATERIALS, MIXES, SPECIMENS, AND TESTS

Materials

The materials used in the study are listed below.

1. Cement: The type 1 portland cement used satisfied ASTM C150-77 and was produced by the South Dakota State Cement Plant in Rapid City.
2. Aggregate: The fine aggregate was natural stone with a fineness modulus of 2.95, water absorption coefficient of 1.6 percent, and a saturated surface-dry specific gravity of 2.62; the coarse aggregate used was crushed limestone with a water-absorption coefficient of 0.45 percent and a saturated surface-dry specific gravity of 2.69.
3. Water: The water used was from the municipal water supply.
4. Air-entraining agent: The admixture Protex was used in constant dosage to entrain air.
5. Superplasticizers: Two types of superplasticizers were used: (a) Lomar-D, a high-molecular-weight condensed naphthalene sulfonate that meets all ASTM C494, type A admixture standards and (b) Melment L10, a 20 percent aqueous solution, clear to slightly milky to dark yellowish, with a density of 1.1 g/cm^3 (0.53 oz/in^3). Melment is a modified polycondensation product of melamine and formaldehyde. It contains no calcium chloride or other accelerating salts. Melment conforms to ASTM C494, type A standards.

Mixes

The same mix proportions were used for all mixes with an aggregate-to-cement ratio of 7.3 by weight. The different w/c ratios used are reported in Tables 1 and 2. The total initial mixing time was 8 min for all mixes: 3-min mixing, 3-min rest, and then 2-min mixing (ASTM C192-76).

Lomar-D was added along with water, and Melment was added during the last 2-min mixing. The first dosage of superplasticizer was added at the recommended rate given in Tables 1 and 2.

Specimens and Tests

The fresh concrete was tested for slump, air content, and unit weight. The temperature and slump of the concretes were recorded at fixed time intervals up to 150 min after initial mixing. Similar tests were carried out on fresh retempered concrete. For all the mixes, the hardened concrete was tested for 28-day compressive strength, modulus of elasticity, and unit weight.

The test specimens, 150x300-mm (6x12-in) cylinders, were cast in steel molds, compacted, and cured for 28 days in lime-saturated water according to ASTM C192. When the slump was less than 38 mm (1.5 in), the concrete was compacted with an internal vibrator.

ANALYSIS AND DISCUSSION OF TEST RESULTS

The results are discussed in three different parts corresponding to the three parts of the study undertaken in this investigation.

Part 1: Using Water as a Retempering Agent

Fresh Concrete

The slump and temperature measurements taken at 30-min intervals for eight mixes are given in Table 3. The slump-loss-with-time curves for control concrete, retempered control concrete, superplasticized concrete, and retempered superplasticized concrete are shown in Figures 1 and 2. As expected, there is a considerable increase in the slump of superplasticized concrete at recommended dosage. The slumps reached 229 mm (9 in), and even at these high slumps the concretes did not show any sign of segregation or excessive bleeding. This was true for both the superplasticizers, Lomar-D and Melment.

At the given w/c ratio and the dosage of air-entraining agent, the air content of both the control and the superplasticized concrete (with Lomar-D) was almost the same. The plastic unit weights were slightly higher for superplasticized concretes. For the concrete superplasticized with Melment, the air content was less than the corresponding control concrete.

The loss in slump in percentage-versus-time curves for one mix is plotted in Figure 3 and was calculated with respect to the initial slump. The slump-loss values are recorded elsewhere (12). In general, it was found that there was normal slump loss with time for all mixes. The slump of retempered control concretes reduced to a zero slump in about 90 min regardless of the initial level of slump for the control concretes. The initial temperature for these two control concretes was almost the same. For a higher initial slump of control concrete, the corresponding superplasticized concrete and the retempered superplasticized concrete took about 45-60 min to return to the initial slump of control concrete. As against this, for a lower initial slump of control concrete, the corresponding superplasticized concrete and retempered superplasticized concrete took longer, about 150 min, to come back to the initial slump of control concrete.

The results indicate that for all the mixes studied, the slump is lost in proportion to the initial slump level; the higher the initial slump, the higher the slump loss.

Table 3. Slump and temperature at various time intervals.

Mix	Time After Initial Mixing and Retempering (min) 0	30	60	90	120	150
C1						
Temperature (°C)	22	21.5	21	20.5	19.5	19.5
Slump (mm)	172.7	107.9	81.3	69.9	50.8	12.7
RC1						
Temperature (°C)	20.5	18.5	18	18	17	16.5
Slump (mm)	107.9	57.2	12.7	0	0	0
S1						
Temperature (°C)	23	22	21	20.5	19.5	19
Slump (mm)	241.3	190.5	133.4	101.6	73.7	68.6
RS1						
Temperature (°C)	18	17	16.5	16.5	15.5	15.5
Slump (mm)	193.0	146.1	134.6	94.0	76.2	58.4
C2						
Temperature (°C)	23	21	20	17	16.5	16.5
Slump (mm)	81.3	66.0	33.0	27.9	22.9	12.7
RC2						
Temperature (°C)	19	18.5	18	18	18	18
Slump (mm)	71.1	30.5	7.6	0	0	0
S2						
Temperature (°C)	25	23	21.5	20.5	20	19.5
Slump (mm)	233.7	193.0	170.2	114.3	91.4	50.8
RS2						
Temperature (°C)	20.5	19	17.5	15	14	14
Slump (mm)	195.6	180.3	114.3	88.9	81.3	61.0

Notes: t°C = (t°F - 32)/1.8; 1 mm = 0.039 in.

Figure 1. Slump versus time for S1, RS1, C1, and RC1.

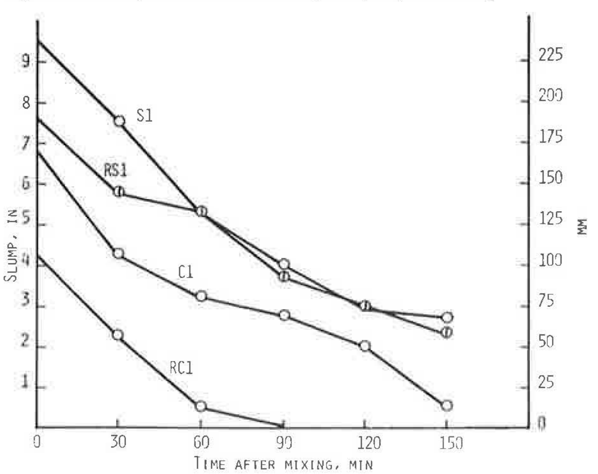


Figure 2. Slump versus time for S2, RS2, C2, and RC2.

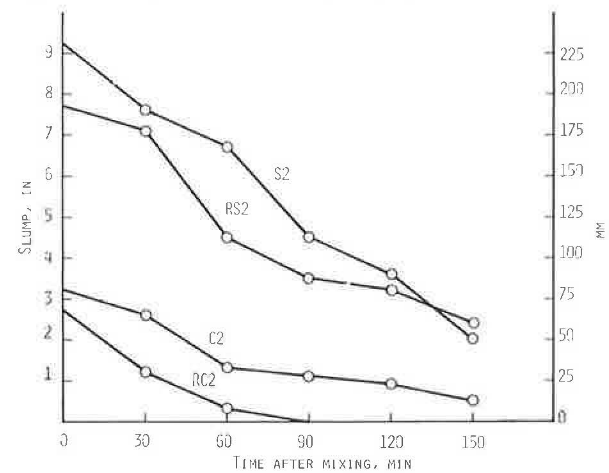
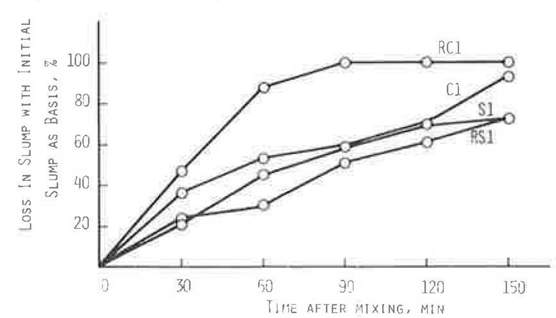


Figure 3. Loss in slump versus time for RC1, C1, S1, and RS1.

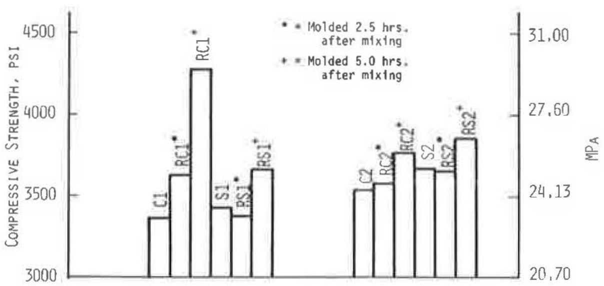


The same conclusion was drawn from the study by Previte (16).

The superplasticized concretes have less slump loss than the control concretes at all time intervals. The difference in the slump loss for control and retempered control concrete was maximum between 60-90 min, during which most of the slump was lost. The rate of slump loss for retempered control concrete was more than that of the control mix. However, the rate of slump loss is almost the same for both superplasticized and retempered superplasticized concretes.

The initial temperature of retempered mixes was always less than that of the corresponding control mixes. The amount of reduction in the temperature of fresh concrete during the 150-min period does not show any definite trend, but it was the same for both control and superplasticized concretes.

Figure 4. Comparison of compressive strength at 28 days for all mixes.



Hardened Concrete

Compressive strengths at 28 days are compared in Table 1 and Figure 4. In general, the compressive strengths of retempered concretes are equal to or greater than those of corresponding control concretes. This agrees with the results reported by Hawkins (14). The compressive strengths of cylinders cast from retempered concrete and molded 2.5 and 5.0 h after mixing are about 5 and 13 percent more than those of the respective control concretes. However, the cylinders cast from retempered superplasticized concretes and molded 5.0 h after mixing have shown an increase of 6 percent in the compressive strength, compared to the compressive strength of superplasticized concretes for both types of superplasticizers. A similar trend is shown in regard to dry unit weights.

The test results for modulus of elasticity are given in Table 1. In general it can be stated that retempering concrete does not adversely affect its modulus of elasticity. Also, the modulus of elasticity of retempered concrete cylinders molded 5 h after mixing is higher than that of those molded 2.5 h after.

Part 2: Repeated Dosages of Superplasticizer

Fresh Concrete

The slump, temperature, unit weight, and air content for the superplasticized and retempered superplasticized concrete mixes are reported in Table 4. A few typical slump-versus-time curves are plotted in Figures 5, 6, and 7, where it is clear that, regardless of the initial slump of the superplasticized concretes, the subsequent

Table 4. Temperature, slump, unit weight, and air content at various time intervals.

	Time After Initial Mixing and Retemperings (min)					
Mix	0	30	60	90	120	150
PS4						
Temperature (°C)	22	21	21	20	-	-
Slump (mm)	165.1	76.2	38.1	0	-	-
Unit weight (kg/m^3)	2385.8	2362.9	2387.6	2383.4	-	-
Air content (%)	4.9	5.0	5.0	-	-	-
PRS4-1						
Temperature (°C)	20.5	19.5	19.5	19	-	-
Slump (mm)	129.5	68.6	28.0	0	-	-
Unit weight (kg/m^3)	2427.9	2436.3	2413.0	2373.5	-	-
Air content (%)	1.8	2.0	2.0	-	-	-
PRS4-2						
Temperature (°C)	19	19	-	-	-	-
Slump (mm)	0[a]	12.7	-	-	-	-
Unit weight (kg/m^3)	2440.0	2425.8	-	-	-	-
Air content (%)	2.0	-	-	-	-	-
PRS4-3						
Temperature (°C)	19	19	-	-	-	-
Slump (mm)	149.9	0	-	-	-	-
Unit weight (kg/m^3)	2432.8	2427.9	-	-	-	-
Air content (%)	1.7	-	-	-	-	-
S3						
Temperature (°C)	23	22	21.5	21	20.5	20
Slump (mm)	188.0	162.6	111.8	101.6	50.8	33.0
Unit weight (kg/m^3)	2395.6	2331.8	2338.9	2352.7	2386.2	2382.7
Air content (%)	5.0	4.8	4.8	4.8	4.4	3.7
PRS3-1						
Temperature (°C)	20	19.5	19.5	-	-	-
Slump (mm)	198.1	48.3	22.9	-	-	-
Unit weight (kg/m^3)	2413.5	2408.4	2422.9	-	-	-
Air content (%)	3.8	2.8	-	-	-	-
PRS3-2						
Temperature (°C)	19.5	-	19	-	-	-
Slump (mm)	132.1	-	12.7	-	-	-
Unit weight (kg/m^3)	2448.5	-	2401.0	-	-	-
Air content (%)	1.6	-	-	-	-	-
PRS3-3						
Temperature (°C)	19	18.5	-	-	-	-
Slump (mm)	78.7	0	-	-	-	-
Unit weight (kg/m^3)	2434.2	-	-	-	-	-
Air content (%)	1.6	-	-	-	-	-

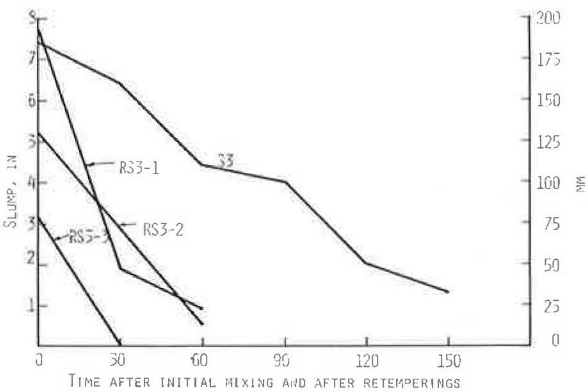
Notes: t°C = (t°F - 32)/1.8; 1 mm = 0.039 in; 1 kg/m^3 = 0.062 lb/ft^3.

[a]This was not a true representative slump because all the mortar separated out from the aggregates.

retemperings yield concrete that is workable for about 25-45 min.

The rate of loss of slump for the retempered concrete is considerably greater compared to the superplasticized concrete. Almost all the slump of retempered superplasticized concrete is lost in 30-60 min after retempering (Figure 6). For mix PS3, of high initial slump, the first retempering is done at 175 min after initial mixing; the second, third, and fourth retemperings are done after 80, 60, and 40 min, respectively. Thus the time between two successive retemperings shortens as the number of retemperings increases.

Figure 5. Slump versus time for S3, RS3-1, RS3-2, and RS3-3.



The amount of superplasticizer added at each retempering is recorded in Table 2, from which, with Figure 6, it is clear that the capacity of superplasticizer to make the concrete workable decreases as the number of retemperings increases. From Table 4, it is observed that the repeated addition of superplasticizer results in loss of entrained air. This results in a gain in plastic unit weight. There is a progressive decrease in temperature at each retempering.

It is very interesting to note that, when retempered with higher precentages of Melment (more than 3 percent), the concrete segregated immediately and the slump could not be measured properly. The cylinder cast with such a segregated concrete yielded a honeycombed specimen.

Figure 6. Loss in slump versus time for S3, RS3-1, RS3-2, and RS3-3.

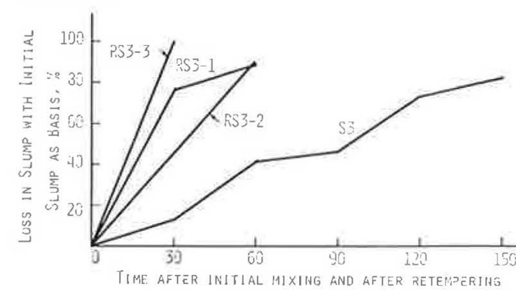


Figure 7. Slump-time retempering study for mix S3.

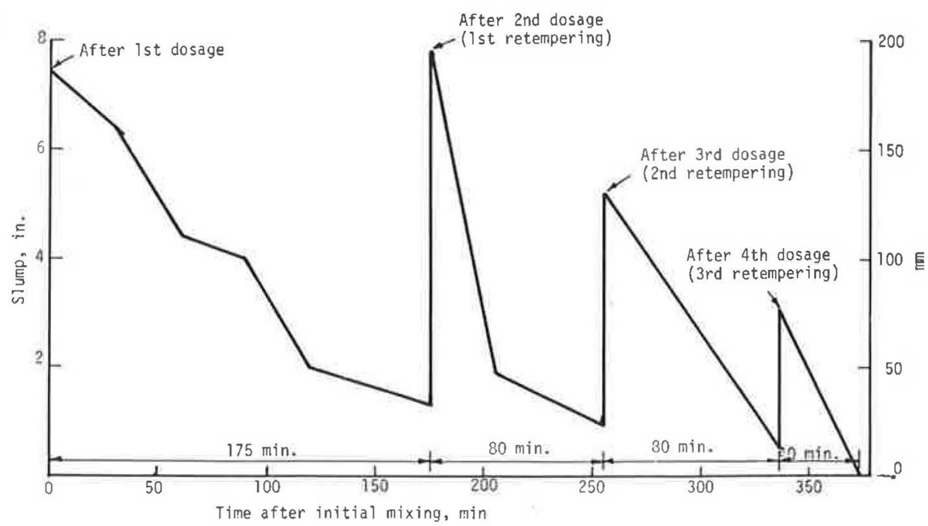


Figure 8. Comparison of compressive strength at 28 days.

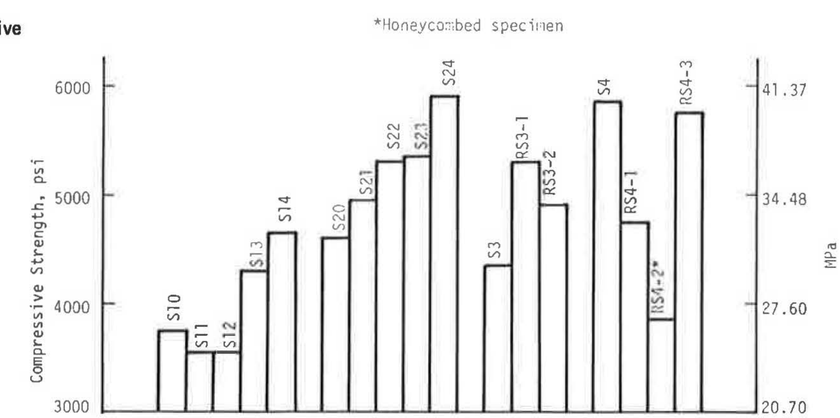


Table 5. Properties of hardened concrete.

Mix[a]	w/c Ratio	Unit Weight (kg/m^3)	Compressive Strength (MPa)	Modulus of Elasticity (MPa × 10^3)	Ratio $E_c/f'_c \times 10^3$ [b]
TS10	0.48	2326.1	25.78	32.0	1.24
TS11	0.48	2322.9	24.54	30.5	1.24
TS12	0.48	2340.5	24.54	29.2	1.19
TS13	0.48	2403.0	29.79	32.8	1.10
TS14	0.48	2431.8	31.92	34.3	1.07
TS20	0.48	2436.6	31.85	34.4	1.08
TS21	0.48	2435.0	34.00	37.2	1.09
TS22	0.48	2438.2	36.61	40.6	1.10
TS23	0.48	2449.5	36.75	36.6	1.00
TS24	0.48	2451.1	40.75	34.5	0.85
PS3	0.51	2441.4	29.92	35.8	1.20
PRS3-1	0.51	2447.8	36.41	36.1	1.00
PRS3-2	0.51	2508.7	33.72	41.4	1.23
PRS3-3	0.51	2461.1	19.31[c]	-	-
PS4	0.49	2441.9	40.47	40.1	1.00
PRS4-1	0.49	2521.7	32.60	39.9	1.22
PRS4-2	0.49	2470.2	26.61	31.9	1.20
PRS4-3	0.49	2527.6	39.65	42.8	1.08

Notes: 1 kg/m^3 = 0.062 lb/ft^3; 1 MPa = 145 psi.

[a] TS14 is superplasticized mix 1 at 4 h after initial mixing; PRS4-3 is retempered superplasticized mix 4 at third retempering.

[b] E_c = modulus of elasticity and f'_c = 28-day compressive strength.

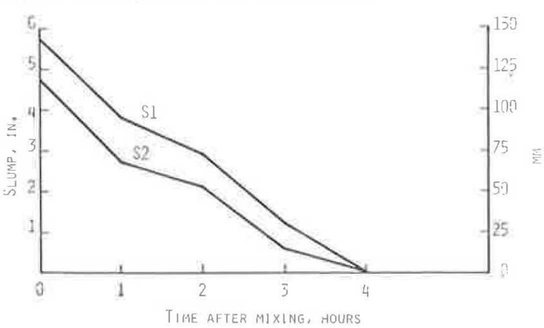
[c] Honeycombed specimen.

Table 6. Temperature, slump, and unit weight at various time intervals.

	Time After Initial Mixing (h)				
Mix	0	1	2	3	4
TS1					
Temperature (°C)	23	21.5	21	21	21
Slump (mm)	144.8	96.5	73.7	30.5	0
Unit weight (kg/m^3)	2266.8	2273.9	2290.0	2325.0	2282.0
TS2					
Temperature (°C)	23	23	23	23	23
Slump (mm)	119.4	68.6	53.3	15.2	0
Unit weight (kg/m^3)	2406.7	2409.1	2407.4	2401.7	-

Notes: $t°C = (t°F - 32)/1.8$; 1 mm = 0.039 in; 1 kg/m^3 = 0.062 lb/ft^3.

Figure 9. Slump versus time for S1 and S2.



Hardened Concrete

The comparison of compressive strengths at 28 days is shown in Table 5 and Figure 8. In general, the compressive strengths of retempered superplasticized concretes are equal to or greater than the strengths of superplasticized concretes. This is attributed mainly to the loss of entrained air from concrete. Similar results have also been reported by Hawkins (14) and Beaufait and Hoadley (15). Modulus of elasticity of concrete is not adversely affected by retempering.

Part 3: Time-Strength Study

Fresh Concrete

The temperature, slump, and unit weight measurements at 1-h intervals for mixes TS1 and TS2 are given in Table 6. After the initial mixing, the concrete was left undisturbed and covered in the mixer for the entire period of testing to prevent evaporation of water. A specific quantity of concrete was taken from the drum every hour until the concrete could no longer be either worked or removed from the drum without adding water. The slump-versus-time curves for both mixes are shown in Figure 9.

Under the experimental conditions, both superplasticized concretes behaved identically and reached zero slump in about 4 h. However, the concrete became very difficult to work after approximately 3 h. The temperature loss for superplasticized concrete with Lomar-D was more than that for the one with Melment. From Table 6 it is observed that the plastic unit weight increases at first and then, when compaction becomes difficult, it decreases.

Hardened Concrete

The results of the tests conducted to study the effect of mixing time on the compressive strength are presented in Figure 8, and Table 5. In general, mixing time did not adversely affect the strength, and concrete gained strength (25 percent) up to 4 h after mixing time. A similar gain was also reported by Hawkins (14) when water was used as the retempering agent.

The test results for modulus of elasticity are given in Table 5. The modulus of elasticity has not been influenced by extended mixing time. Table 5 gives the ratio of modulus of elasticity (E_c) to 28-day compressive strength (f'_c); it shows a definite trend. The ratio of E_c/f'_c decreases as the mixing time increases. The compressive strength might have been increased by a reduction in the air content, whereas the modulus of elasticity of concrete does not change after prolonged mixing; hence, the ratio E_c/f'_c decreases.

CONCLUSIONS

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

1. There is a normal loss of slump with time for all the mixes, including control mix, superplasticized mix, and the corresponding retempered concrete mixes. However, high slumps of superplasticized concretes can be maintained for several hours by retempering.
2. The slump loss is proportional to the initial slump level for all the mixes; the higher the initial slump, the higher the slump loss. However, the total time span during which concrete could be kept workable is longer for concrete with higher initial slump.
3. About 60-80 percent of the slump of control and retempered control concrete is lost in 60-90 min.
4. The capacity of the superplasticizer to keep the concrete workable is reduced as the number of retemperings is increased. Higher dosages of superplasticizer lead to segregation. The rate of slump loss is higher for retempered concretes.
5. Repeated dosages of superplasticizer cause a loss in entrained air.
6. An extended period of mixing does not have an adverse effect on the strength of superplasticized concrete; however, extended mixing time does affect the workability of the mix.
7. The properties of hardened retempered concrete such as compressive strength, dry unit weight, and modulus of elasticity are not adversely affected for both the mixes with and without the addition of the super-

plasticizer. This is true when water or different dosages of superplasticizer are used for retempering.

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Super-Water-Reduced Concrete Pavements and Bridge Deck Overlays

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In order to obtain mixtures that have (a) a consistency that would permit use of conventional placement equipment and (b) a water-to-cement ratio of 0.33-0.37, melamine- and naphthalene-sulfonated polymer admixtures were used in the concrete placed in two experimental pavements and four bridge deck overlays. With one exception, ready-mix trucks were used to mix the concrete, and placement methods included direct discharge, buggy, crane and bucket, and pump. Internal vibration was used for consolidation, and the screeding equipment included a wooden straightedge, an oscillating screed, a rotating-drum screed, and a metal vibrating straightedge. Compression-tested specimens from the projects showed significantly higher early and 28-day strengths than specimens without the admixture, and petrographic examinations of cores taken from the overlays indicated that, on the average, the concrete was properly consolidated and controlled. However, because of the extreme variability of the concrete, many portions of the completed structures exhibited inadequate consolidation, segregated mixture components, improperly entrained air, shrinkage cracks, and poor finishes. Also, specimens from freeze-thaw tests showed low durability factors that were attributed to an unsatisfactory air-voids system.

Super-water-reducing (SWR) admixtures were used experimentally by the Virginia Department of Highways and Transportation on a number of construction jobs between May 1974 and June 1977. The melamine- (M) and naphthalene-sulfonated (N) polymer admixtures were used to produce concrete of a water-to-cement (w/c) ratio of 0.33-0.37. This resulted in concrete that had high early and 28-day strengths.

On these jobs an effort was made to maintain a workability that would allow the concrete to be placed with conventional equipment. Concrete of conventional work-