The Effects of Superplasticizers on the Engineering Properties of Plain Concrete

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ABSTRACT

The effects of superplasticizers on fresh and hardened concrete were investigated. The experimental program included tests on the slump and slump loss, bleeding, setting time, air content, compacting factor, Vee Bee, compressive strength, tensile and flexural strength, permeability, shrinkage, and freeze-thaw durability. Properties of superplasticized concrete were compared with those of conventional (high-slump) and base (low-slump) concretes. Superplasticizers were observed to have an appreciable fluidifying action in fresh concrete. They permitted a significant water reduction while maintaining the same workability. Bleeding of superplasticized concrete was much lower than that of conventional concrete of the same consistency. The compacting factor and Vee Bee value of superplasticized concrete were not significantly different from those of conventional concrete of the same consistency. This indicates that the use of superplasticizers did not affect the tendency of segregation of fresh concrete. The compressive, tensile, and flexural strengths of superplasticized concrete were significantly higher than those of conventional concrete. The permeability and drying shrinkage of superplasticized concrete were significantly less than those of conventional concrete, but there were no significant differences between base and superplasticized concrete. Compared with base concrete, non-air-entrained superplasticized concrete had slightly higher freeze-thaw durability, and superplasticized concrete with an appropriate amount of entrained air gave even better resistance to freezing and thawing.

Superplasticizers, which include sulfonated melamine condensates developed in West Germany in 1968, naphthalene condensates developed in Japan in the latter half of the 1960s, and modified lignosulfonated condensates, have been used to produce high-strength concrete and water-reduced concrete (1). The term "superplasticized concrete" refers to a concrete with high fluidity and favorable workability made by adding superplasticizer to normal low-consistency concrete that has a low water content without producing any detrimental effects on the concrete (2). Superplasticizers not only have higher water-reducing effects as compared with those of the conventional water-reducing admixtures (ASTM Type A), but also do not cause retardation of setting and excessive air entrainment in spite of the large amount of superplasticizer added (3).

Superplasticized concrete was developed in West Germany around 1971 for the purpose of improving concrete workability, and guidelines for production and placement were established in 1974 (4). A report on this subject was published in England by the Cement and Concrete Association and the Cement Admixture Association in 1976 (1) and proposed guidelines for design and control of superplasticizer concrete were published by the Japan Society of Civil Engineers and the Japan Society of Architecture in Japan in 1980 (5). Symposia on superplasticized concrete were held in Canada in May 1978 and in June 1981, and the proceedings were published by the American Concrete Institute (6,7). Proposed guidelines for design and control of superplasticized concrete were also published in Canada in 1981. There has been increased interest in the use of superplasticized concrete for improved quality and workability due to the wide use of the concrete pump. The use of lower-quality aggregates also requires a higher-quality cement paste to produce concrete of suitable strength. Hence, further investigation in the production and practice of superplasticized concretes is needed for their effective application. The effects of four standard types of superplasticizers and an air-entraining (AE) water-reducing admixture on the flow properties of fresh concrete and on the strength, permeability, drying shrinkage, and durability of hardened concrete are presented. The properties of superplasticized concrete are compared with those of conventional high-slump concrete and base (low-slump) concrete.

MATERIALS AND TEST METHODS

Materials

Cement

Normal Type I portland cement was used in this study. The properties of the cement are shown in Table 1.

Aggregates

River gravel of 25-mm (1-in.) maximum size was used as coarse aggregate and river sand was used as fine aggregate. The aggregates consisted mainly of granite. Both were used in saturated-surface dry condition. The gradation of these aggregates is shown in

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TABLE 1 Properties of Type I Portland Cement

Property	Amount
Specific gravity	3.15
Specific surface area (cm^2/g)	3,250
Residue of 88 μ (%)	1.8
Soundness autoclave expansion (%)	0.17
Time of setting (hr:min)	
Initial	3:50
Final	6:30
Compressive strength (kg/cm^2)	
At 3 days	178
At 7 days	245
At 28 days	331
Composition (%)	
CaO	61.1
SiO	21.2
Al_2O_3	5.5
Fe_2O_3	3.2
MgO	3.1
SO_3	2.3
Insoluble	0.1
Ignition	2.1

Note: 1 kg/cm^2 = 14.23 psi.

Figure 1 and their physical properties are shown in Table 2.

Admixtures

Four superplasticizers were used in this study. They included the sulfonated naphthalene condensates (NP-10), the sulfonated melamine condensates (NP-20), and the combined sulfonated naphthalene and sulfonated lignin condensates (Sanflo FB and Sanflo FBF). An ASTM Type-D water-reducing AE admixture (Sanflo K) that contains mainly sulfonated naphthalene and modified lignin condensates was also used for comparison purposes. The properties of these admixtures are given in Table 3.

Concrete Mixes

A total of 13 mixes were used in this study. They included a conventional high-slump concrete, a base (low-slump) concrete, eight non-air-entrained superplasticized concretes (using the four superplasticizers and two levels of dosage), two air-entrained superplasticized concretes (using the superplasticizer Sanflo FBF and the AE water-reducing admixture Sanflo K, and the two levels of dosage), and an air-entrained concrete (using the AE water-reducing admixture, Sanflo K). The proportions of these 13 mixes are shown in Table 4. A fixed cement content of 350 kg/m^3 (590.6 lb/yd^3) and a fixed sand-aggregate ratio of 43 percent were used for all the mixes. The base concrete was made to have a target slump of 12 cm (4.7 in.) and the rest of the mixes were made to have a target slump of 18 cm (7.1 in.). The two levels of dosage of superplasticizer used were 0.4 and 1.0 percent by weight of cement. For the air-entrained concretes, 0.25 percent (by weight of cement) of the AE water-reducing admixture, Sanflo K, was used.

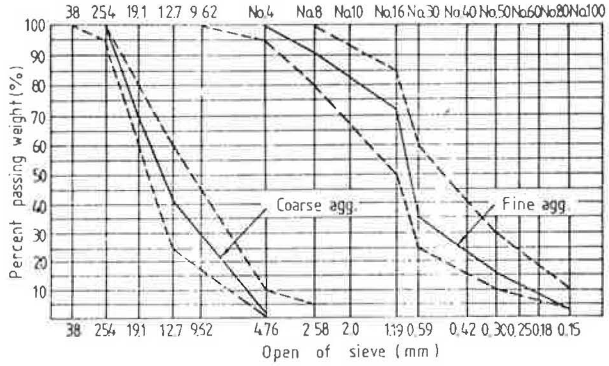


FIGURE 1 Gradation curves of fine and coarse aggregate.

Testing Methods

Concrete Mixing

The water requirements for the concrete mixes were determined by trial mixes to obtain the target slump of 12 cm for the base concrete and 18 cm for the other 12 mixes. A tilting mixer of 54-L (1.9-ft^3) capacity was used. The base concrete was made by a 3-min mixing. In accordance with the recommendations of the manufacturers, superplasticizers of 0.4 or 1.0 percent (by weight of cement) were added to the base concretes and mixed again for 1 min to make the non-air-entrained superplasticized concretes. The superplasticizer Sanflo FBF (0.4 or 1.0 percent by weight of cement) and the ASTM Type-D AE water-reducing admixture Sanflo K (0.25 percent by weight of cement) were mixed and added at the same time to make the air-entrained superplasticized concretes. The AE concrete (Mix 13) was made by adding 0.25 percent (by weight of cement) of Sanflo K to a high-consistency concrete. Concretes were tested for slump and air content immediately after mixing. The temperature of the laboratory and concretes was in the range of 20° to 25°C (68° to 77°F).

Slump Test

Slump in conventional high-consistency concrete, base concrete, and superplasticized concrete was measured every 30 min up to 120 min after mixing to study the change of slump with time.

Air-Content Test

The air content of freshly mixed concrete was measured by the pressure method according to ASTM C231-82.

TABLE 2 Physical Properties of Aggregates

Type of Aggregate	Specific Gravity	Absorption (%)	Fineness Modulus	Unit Weight (kg/m^3)	Degradation Loss (%)	Sodium Sulfate Soundness Loss (%)	Organic Purity
Fine	2.57	1.01	2.82	1630	–	0.14	Good
Coarse	2.63	1.39	6.61	1680	14.2	0.20	Good

Note: 1 kg/m^3 = 0.0625 lb/ft^3.

TABLE 3 Physical Properties of Admixtures

Admixture	Appearance	Specific Gravity	pH	Viscosity[a] (cp)	Total Solids[b] (%)
NP-10	Dark brown liquid	1.18	8	20	37-43
NP-20	Dark brown liquid	1.13	7	10	38-42
Sanflo FB	Brown liquid	1.20	9	25	37-40
Sanflo FBF	Light brown liquid	1.14	9	–	33-40
Sanflo K	Brown liquid	1.21	9	–	36-41

Note: Testing temperature = 20°C (68°F).

[a] Approximate.

[b] ASTM C 494.

Setting-Time Test

Setting time was measured by means of the Proctor penetration-resistance test according to ASTM C803-82. Times of initial set and final set are defined as the times at which the penetration resistances are 35 kg/cm² (500 psi) and 280 kg/cm² (4,000 psi), respectively.

Bleeding, Compacting Factor (CF), and Vee Bee Consistency (VB) Tests

The bleeding test was done with the cylindrical container having an inside diameter of 25 cm (9.84 in.) and an inside height of 28 cm (11.02 in.) and made of metal in accordance with ASTM C232-71, Method A. The amount of bleeding water was expressed as a percentage of the net mixing water contained within the test specimen. Compacting factor and Vee Bee tests were done according to British Standard 1881, Part 2 (9).

Compressive, Tensile, and Flexural Strength Tests

Compressive, tensile, and flexural strength tests were conducted according to ASTM C39-83, C496-71, and C293-79 test methods. For flexural strength tests, specimens of 15 x 15 x 55 cm (5.9 x 5.9 x 22 in.) were molded and tested at ages of 7 and 28 days. Three replicate samples were tested for each mix combination.

Permeability Test

The permeability test was done with an output-pressure type of tester. Cylindrical specimens of 15 cm (5.9 in.) in diameter and 30 cm (11.8 in.) in height having a center hole of 2 cm diameter were used. The coefficient of permeability was calculated by using the following equation:

$$K = [\rho \log(r_o/r_i)/2\pi h] \cdot [Q/(P_o - P_i)]$$

where

K = coefficient of permeability,
Q = quantity of water flow,
P_o, P_i = external and internal water pressure of specimen,
r_o = radius of specimen, and
r_i = radius of center hole.

Drying Shrinkage Test

According to the ASTM C157 testing method, specimens of 10 x 10 x 40 cm (3.94 x 3.94 x 15.75 in.) were made and the change in length was measured at an accuracy of 1/1,000 mm (4 x 10^{-5} in.) by the use of a comparator with a microscopic readout at ages of 7, 28, 60, 91, and 180 days. A small deviation from the ASTM method was that shrinkage was presented in decimals rather than in percentages.

Freezing-and-Thawing Test

In accordance with ASTM C666-84, Procedure A, Test Method for Resistance of Concrete to Rapid Freezing and Thawing, specimens of 7.62 x 7.62 x 35.56 cm (3 x 3 x 14 in.) were made and the relative dynamic modulus of elasticity was measured at 20-cycle intervals. The relative dynamic modulus is defined as the ratio of the retained dynamic modulus to the initial dynamic modulus, expressed as a percentage. One cycle of freezing and thawing takes 3.5 to 4.0 hr and the range of temperature was -18° to 4°C (0° to 39°F). The test was continued until the relative dynamic modulus of elasticity reached 60 percent.

RESULTS AND DISCUSSION

Physical Properties of Fresh Concrete

Slump and Air Content

Slump and air content of fresh concrete after mixing are shown in Table 4. It may be noted that the air

TABLE 4 Mix Proportions of Concrete

Mix No.	Type of Concrete	Dosage of Superplasticizer[a] (%)	AE Water-Reducing Agent (%)	S/A[b] (%)	W/C[c] (%)	Unit Weight (kg/m³) Water	Cement	Sand	Gravel	Slump (cm)	Air (%)
1	Conventional	–	–	43	53.7	188	350	775	1051	18.4	1.1
2	Base	–	–	43	50.3	176	350	788	1069	12.1	1.3
3	Sanflo FBF	0.4	–	43	49.7	174	350	790	1072	19.5	1.2
4	Sanflo FBF	1.0	–	43	47.4	166	350	799	1084	18.6	1.4
5	Sanflo FB	0.4	–	43	50.0	175	350	789	1070	19.9	1.0
6	Sanflo FB	1.0	–	43	47.7	167	350	798	1082	18.1	1.3
7	NP-10	0.4	–	43	49.1	172	350	792	1075	17.7	1.1
8	NP-10	1.0	–	43	48.3	169	350	796	1079	17.4	1.2
9	NP-20	0.4	–	43	49.7	174	350	790	1072	18.5	1.0
10	NP-20	1.0	–	43	48.0	168	350	797	1081	19.1	1.4
11	Sanflo FBF and	0.4	0.25	43	48.6	170	350	750	1018	18.5	4.3
12	Sanflo K	1.0	0.25	43	46.0	161	350	760	1031	19.1	4.7
13	Sanflo K	–	0.25	43	50.9	178	350	749	1004	18.7	4.1

Note: 1 kg/m³ = 0.0625 lb/ft³; 1 cm = 0.3937 in.

[a] Amount of admixture solution expressed as a percentage by weight of cement.

[b] Sand-aggregate ratio.

[c] Water-cement ratio.

content of all the non-air-entrained concretes is around 1 percent, whereas that of the air-entrained concretes is around 4.5 percent. The added superplasticizers did not have any significant effects on the air contents of the concretes. The initial slumps were close to the target slumps for all the 13 mixes.

The water content of all 13 mixes is also shown in Table 4. It may be seen that when the dosage of superplasticizer was 0.4 and 1.0 percent, the average water reduction was 8 and 12 percent, respectively. The water reduction was within the expected range for the types of superplasticizers used. When the AE water-reducing admixture was used at the dosage of 0.25 percent (for Mix 13), water reduction was only about 6 percent. Therefore, the superplasticizers were noted to have excellent water reduction efficiency.

Change of slump with respect to elapsed time for dosages of 0.4 and 1.0 percent of superplasticizers is shown in Figures 2 and 3, respectively. The rate of slump loss for the concretes with a dosage of 1.0 percent is significantly higher than that for the concretes with a dosage of 0.4 percent. The results are similar to the test results of Mailvaganam (10) and Murray and Lynn (11), which indicated that slump loss was more rapid when the dosage of superplasticizer was higher.

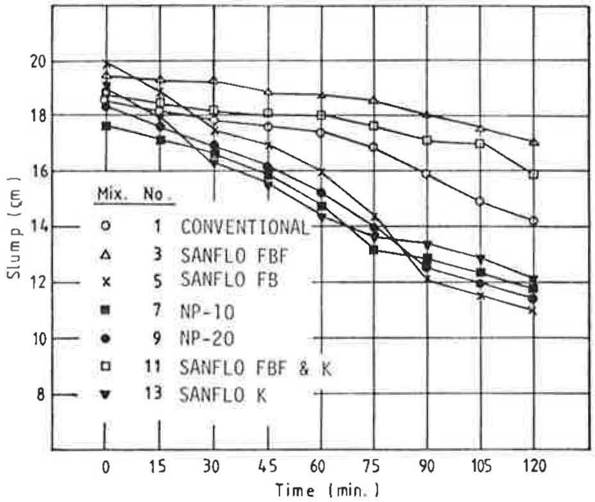


FIGURE 2 Change in slump by time elapsed at 0.4 percent dosage of superplasticizers.

Setting Time

Figures 4 and 5 show test results for setting time by Proctor penetration-resistance tester for concretes at dosages of 0.4 and 1.0 percent of superplasticizers, respectively. No noticeable delay of set with increased dosage of superplasticizer was found, although noticeable delay of set was found in the concrete containing AE water-reducing admixture (Mix 13). Therefore, when hydration delay and strength decrease caused by delay of cement hydration are considered, concrete with superplasticizers will be more desirable than concrete with water-reducing admixtures.

Bleeding

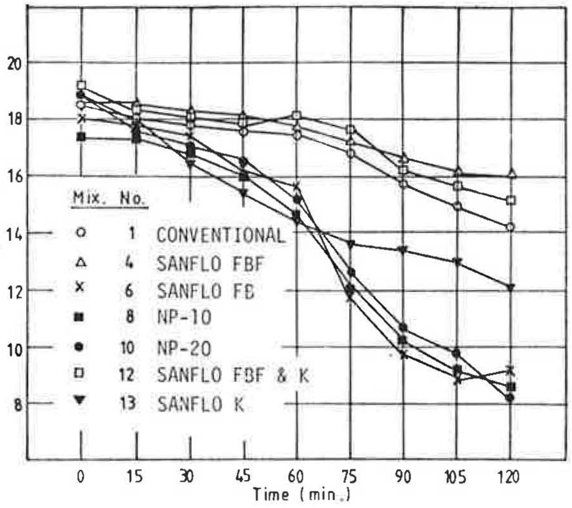


FIGURE 3 Change in slump by time elapsed at 1.0 percent dosage of superplasticizers.

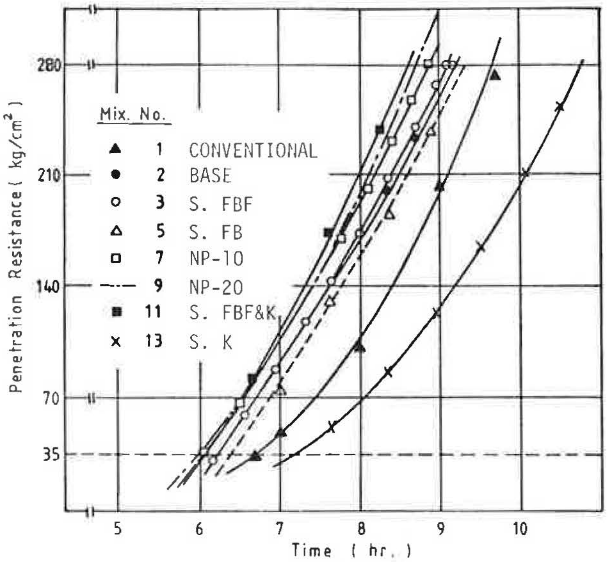


FIGURE 4 Comparison of setting time at 0.4 percent dosage of superplasticizers.

Test results for bleeding of concretes at dosages of 0.4 and 1.0 percent of superplasticizers are shown in Figures 6 and 7, respectively. It can be seen that bleeding of the superplasticized concretes was significantly lower than that of conventional high-consistency concrete of the same slump and that bleeding decreased as the dosage of superplasticizer increased. It can also be noted from results of Mixes 11 and 12 that the addition of AE water-reducing admixture further reduced the bleeding of fresh concrete.

A lower bleeding value generally indicates a lower amount of settlement or subsiding of concrete after placement. Thus, the bleeding results indicate that superplasticizers may be used to reduce subsiding of concrete (Table 5).

CF- and VB-Values

Table 6 gives the CF- and VB-values of all 13 concrete mixes. It can be noted that the CF-values of the superplasticized concretes are not significantly different from those of the conventional high-consistency concrete (Mix 1) and the concrete with AE water-reducing admixture (Mix 13) but are much higher

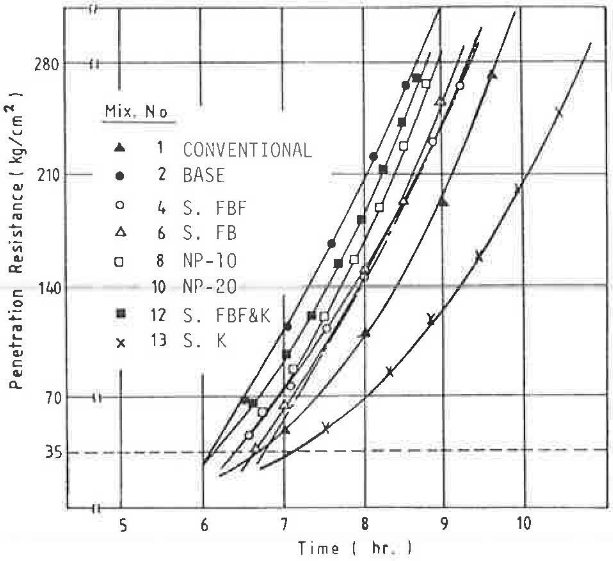


FIGURE 5 Comparison of setting time at 1.0 percent dosage of superplasticizers.

than that of the base concrete (Mix 2). The VB-values of the superplasticized concretes are not significantly different from those of the conventional high-consistency concrete and the concrete with AE water-reducing admixture but are much lower than that of the base concrete. A higher CF-value generally indicates a higher tendency for segregation, whereas a lower VB-value generally indicates a higher tendency for segregation. However, no apparent segregation of fresh concrete was observed for any of the mixes in this study. As the quantity of superplasticizer increased from 0.4 to 1.0 percent, the CF-value showed a slight reduction whereas the VB-value showed a slight increase. This indicated that an increase in dosage of superplasticizer did not affect the tendency of segregation. However, results by Moon (12) indicate that an excessive dosage of superplasticizer causes segregation of fresh concrete. Therefore, the dosage of superplasticizer should be within the range where segregation would not be created.

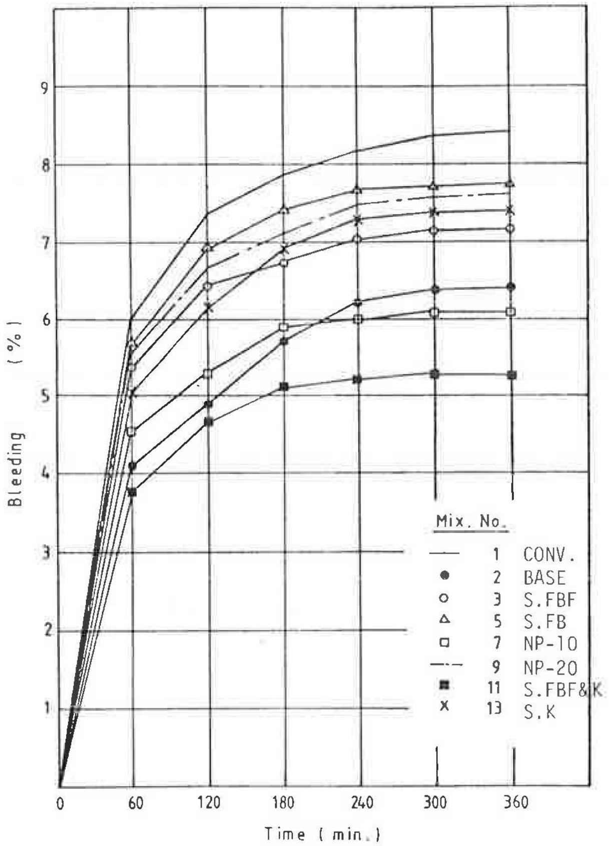


FIGURE 6 Comparison of bleeding ratio at 0.4 percent dosage of superplasticizers.

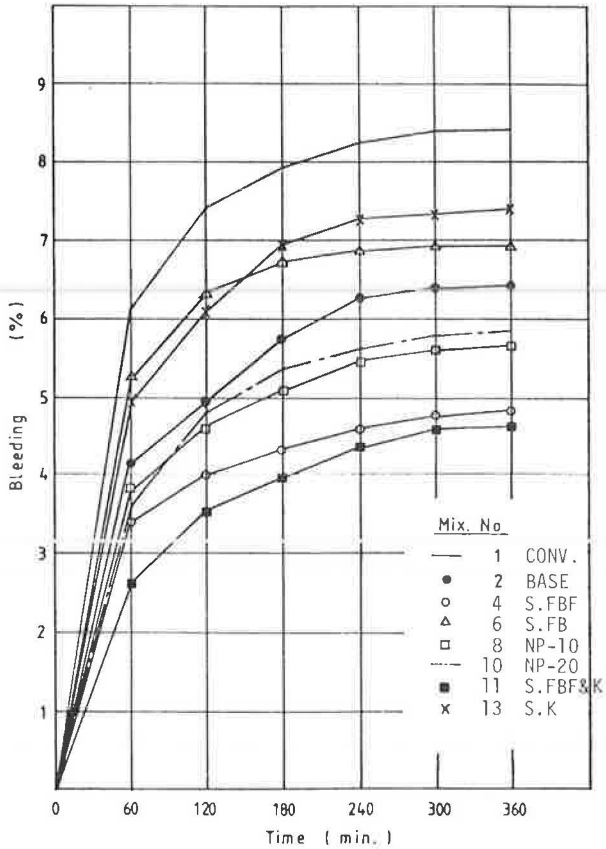


FIGURE 7 Comparison of bleeding ratio at 1.0 percent dosage of superplasticizers.

Physical Properties of Hardened Superplasticized Concrete

Compressive Strength

Table 6 shows the test results of compressive strength in standard curing conditions at 7 and 28 days. The compressive strengths are compared and displayed in Figures 8 and 9. The compressive strength of the superplasticized concretes was significantly higher than that of the conventional concrete. At 7 days, the compressive strength of superplasticized concrete was nearly the same or somewhat higher than that of the base concrete. At 28 days, the compressive strength of superplasticized concretes was about 4 percent higher than that of the base concrete. This result is similar to the test results of Roberts, which indicated that the use of superplasticizer can significantly increase the strength of concrete (13). The difference in compressive strength between superplasticized concrete and base concrete was increased by an increased dosage of superplasticizer. The superplasticized

TABLE 5 Test Results for Concrete-Bleeding Tests

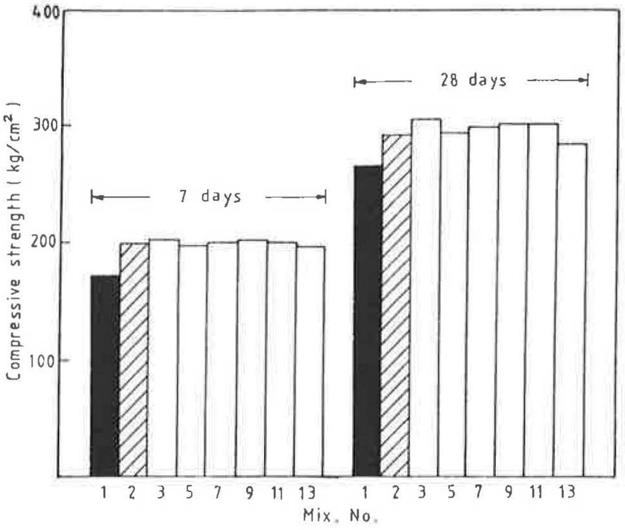
	Bleeding (%) by Time (min)										
Mix No.	10	20	30	40	50	60	120	180	240	300	360
1	3.15	3.90	4.46	5.07	5.62	6.05	7.43	7.89	8.21	8.39	8.41
2	2.17	2.46	3.13	3.59	3.87	4.13	4.92	5.78	6.34	6.35	6.39
3	2.46	3.19	3.84	4.66	5.05	5.48	6.42	6.77	7.08	7.12	7.14
4	0.94	1.49	2.13	2.67	3.01	3.36	4.05	4.11	4.60	4.78	4.81
5	2.59	3.32	4.06	4.79	5.27	5.75	6.89	7.42	7.59	7.65	7.69
6	1.16	1.72	2.26	2.86	3.12	5.19	6.32	6.74	6.82	6.87	6.91
7	2.08	2.50	3.37	3.78	4.15	4.67	5.36	5.82	6.05	6.07	6.11
8	1.23	1.87	2.44	2.92	3.24	3.86	4.58	5.04	5.48	5.52	5.68
9	2.47	3.26	4.02	4.55	5.13	5.57	6.64	7.09	7.47	7.55	7.59
10	1.29	1.92	2.49	3.07	3.31	3.63	4.76	5.32	5.61	5.79	5.83
11	1.94	2.31	2.78	3.18	3.45	3.81	4.67	5.06	5.16	5.23	5.28
12	0.89	1.07	1.45	2.05	2.31	2.64	3.51	3.98	4.35	4.60	4.63
13	2.16	2.89	3.52	4.37	4.85	5.08	6.14	6.96	7.28	7.31	7.37

TABLE 6 Test Results for Concrete: Other Tests

Mix No.	CF	VB (sec)	Setting Time (hr:min) Initial	Setting Time (hr:min) Final	Compressive Strength (kg/cm^2) 7 Days	Compressive Strength (kg/cm^2) 28 Days	Tensile Strength (kg/cm^2) 7 Days	Tensile Strength (kg/cm^2) 28 Days	Flexural Strength (kg/cm^2) 7 Days	Flexural Strength (kg/cm^2) 28 Days	K[a]
1	0.963	2.4	6:40	9:40	172	268	16	24	32	44	32.70
2	0.930	4.5	6:05	8:40	201	295	19	29	40	50	14.62
3	0.980	2.1	6:15	9:05	203	309	20	31	41	52	12.15
4	0.970	2.5	6:25	9:20	205	318	23	33	42	54	11.65
5	0.976	2.0	6:20	9:15	200	296	19	28	39	49	13.08
6	0.968	2.7	6:40	9:10	203	307	20	30	40	50	12.84
7	0.965	1.9	6:05	8:50	201	302	20	29	39	51	12.46
8	0.950	2.4	6:35	8:55	204	309	22	30	43	53	11.23
9	0.967	1.8	6:15	9:05	202	306	19	30	42	51	12.30
10	0.960	2.5	6:45	9:20	206	310	22	33	43	54	11.57
11	0.981	1.9	6:05	8:35	201	305	21	20	40	53	13.05
12	0.970	2.1	6:15	8:50	207	316	23	32	42	55	12.06
13	0.985	2.0	7:10	10:45	198	287	18	26	37	48	12.80

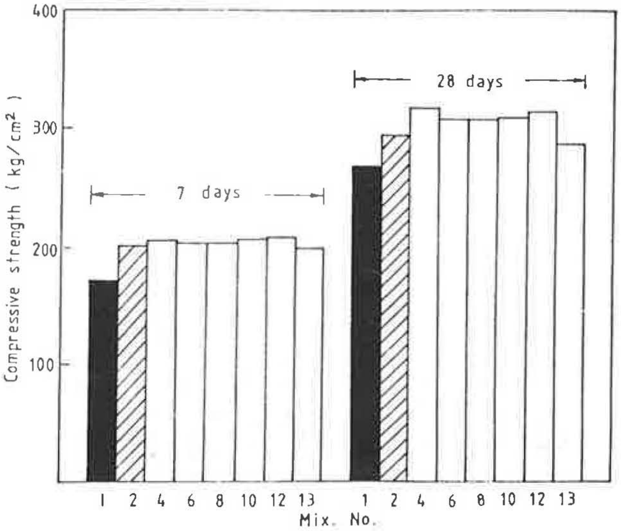
Note: 1 kg/cm^2 = 14.23 psi.

[a] K = coefficient of permeability (unit x 10^{-3} cm/sec).



MIX NO.	TYPE OF CONCRETE
1	CONVENTIONAL
2	BASE
3	SANFLO FBF
5	SANFLO FB
7	NP-10
9	NP-20
11	SANFLO FBF & SANFLO K
13	SANFLO K

FIGURE 8 Comparison of compressive strength at 0.4 percent dosage of superplasticizers.



MIX NO.	TYPE OF CONCRETE
1	CONVENTIONAL
2	BASE
3	SANFLO FBF
5	SANFLO FB
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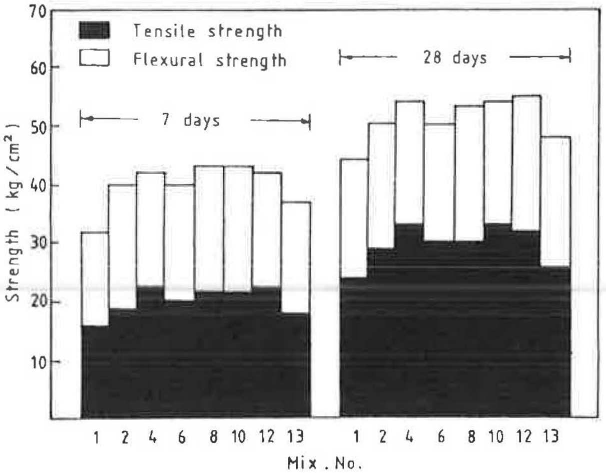
9	NP-20
11	SANFLO FBF & SANFLO K
13	SANFLO K

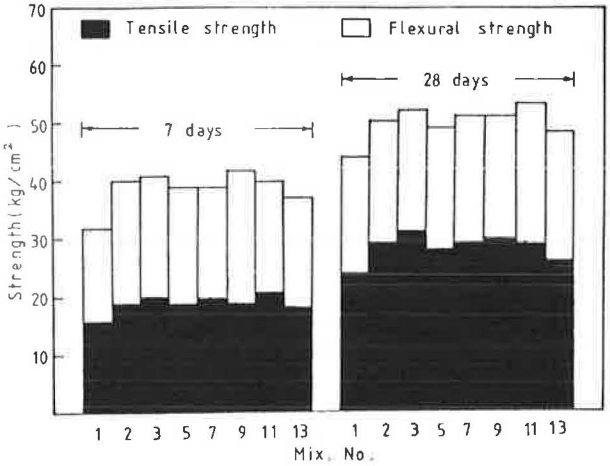
FIGURE 9 Comparison of compressive strength at 1.0 percent of superplasticizers.



MIX NO.	TYPE OF CONCRETE
1	CONVENTIONAL
2	BASE
4	SANFLO FBF
6	SANFLO FB
8	NP-10
10	NP-20
12	SANFLO FBF & SANFLO K
13	SANFLO K

FIGURE 10 Comparison of tensile and flexural strength at 0.4 percent dosage of superplasticizers.

concretes also showed a higher strength as compared with that of the concrete with water-reducing AE admixture (Mix 13). Therefore, it can be concluded that using superplasticizers can increase the workability by improving the flow properties without reducing the strength of the base concrete.



MIX NO.	TYPE OF CONCRETE
1	CONVENTIONAL
2	BASE
3	SANFLO FBF
5	SANFLO FB
7	NP-10
9	NP-20
11	SANFLO FBF & SANFLO K
13	SANFLO K

FIGURE 11 Comparison of tensile and flexural strength at 1.0 percent dosage of superplasticizers.

Tensile and Flexural Strength

Tensile and flexural strength at 7 and 28 days are shown in Table 6 and Figures 10 and 11. The superplasticized concretes had significantly higher tensile and compressive strengths than those of the conventional concrete. No significant difference in tensile and flexural strength between the base concrete and the superplasticized concretes was noted at 7 days. However, the 28-day strength of superplasticized concretes was about 5 percent higher than that of the base concrete.

Drying Shrinkage and Permeability

Figures 12 and 13 show the drying shrinkage of the concretes at dosages of 0.4 and 1.0 percent of superplasticizers, respectively. It may be noted that the drying shrinkage of the superplasticized concretes decreased slightly as the dosage of superplasticizer increased from 0.4 to 1.0 percent. The drying shrinkage of the superplasticized concretes was slightly lower than that of the conventional high-consistency concrete but was about the same as that of the base concrete and that of the concrete

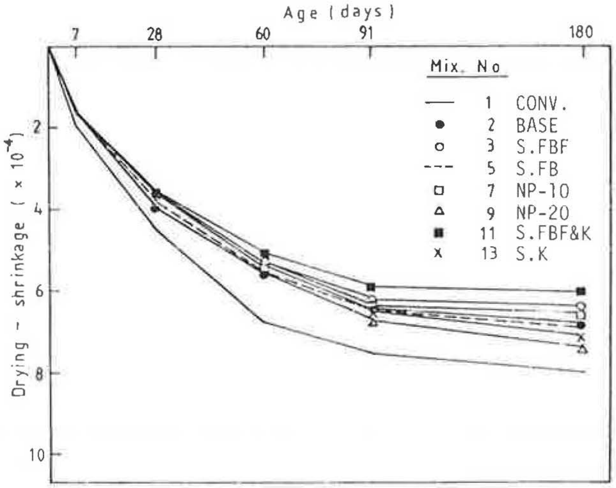


FIGURE 12 Comparison of drying shrinkage at 0.4 percent dosage of superplasticizers.

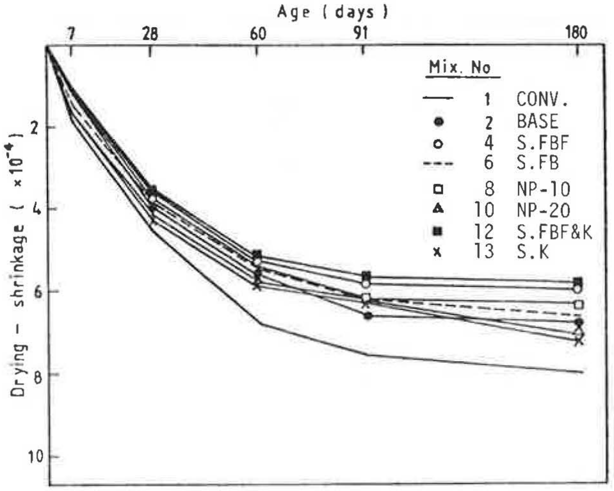


FIGURE 13 Comparison of drying shrinkage at 1.0 percent dosage of superplasticizers.

TABLE 7 Test Results of Drying Shrinkage

	Length Change (10^{-4} cm/cm)				
Mix No.	7 Days	28 Days	60 Days	91 Days	180 Days
1	1.98	4.54	6.86	7.50	7.91
2	1.53	3.92	5.54	6.31	6.81
3	1.42	3.85	5.36	6.07	6.48
4	1.31	3.61	5.12	5.83	5.95
5	1.57	3.97	5.68	6.49	7.01
6	1.45	3.85	5.47	6.23	6.54
7	1.51	3.89	5.49	6.24	6.56
8	1.36	3.74	5.36	6.12	6.27
9	1.57	4.13	5.80	6.58	7.42
10	1.40	4.02	5.53	6.31	6.90
11	1.31	3.76	5.28	5.99	6.02
12	1.28	3.57	5.06	5.76	5.81
13	1.59	4.04	5.57	6.28	7.04

with AE water-reducing admixture. By a close examination of the mix proportions of these concretes (shown in Table 4), it may be noted that drying shrinkage generally increased as the water content increased (Table 7). When two concretes have about the same water content, their drying shrinkage would be about the same, regardless of the dosage or type of superplasticizer used.

As shown in Table 6, the permeability coefficient of superplasticized concretes was about 10 percent less than that of the conventional high-consistency concrete and decreased with increased dosage of plasticizer. The permeability coefficient of superplasticized concretes was not significantly different from that of the base concrete or that of the concrete with AE water-reducing admixture.

Freezing-and-Thawing Resistance

Table 8 shows the freezing-and-thawing-test results of the 13 concrete mixes used in this study. Figures 14 and 15 present the relative dynamic elastic moduli as functions of freezing-and-thawing cycles for concretes with 0.4 and 1.0 percent dosage of superplasticizers, respectively. The relative dynamic modulus of elasticity of the superplasticized concretes increased as the dosage of superplasticizer increased. As compared with the non-air-entrained concretes, the air-entrained concretes showed higher relative dynamic modulus at the same number of freezing-and-thawing cycles. The results of the freezing-and-thawing tests indicated that superplasticizers can improve the durability of concrete, whereas an AE admixture along with superplasticizers can further improve the durability of concrete.

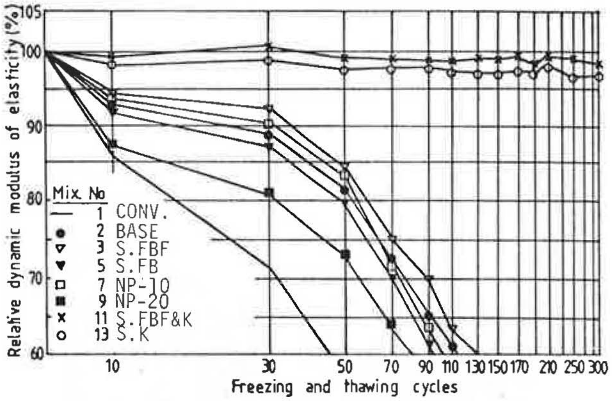


FIGURE 14 Resistance of concrete to rapid freezing and thawing at 0.4 percent dosage of superplasticizers.

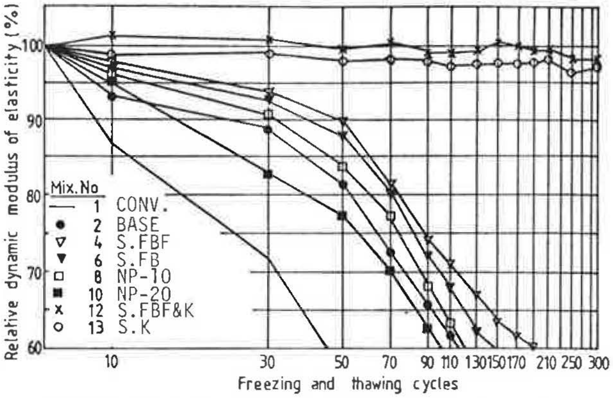


FIGURE 15 Resistance of concrete to rapid freezing and thawing at 1.0 percent dosage of superplasticizers.

CONCLUSION

This study investigated the fundamental engineering properties of superplasticized concrete, including

TABLE 8 Test Results on the Resistance of Concrete to Rapid Freezing and Thawing

Mix No.	Dynamic Modulus[a] of Elasticity (kg/cm^2)	Final Cycle No.	Relative Dynamic Modulus[b] of Elasticity (%)	DF (%)	Weight[a] (kg)	Decreased Ratio of Weight (%)
1	3.561×10^5	45	60	9	4.817	−8.7
2	3.718×10^5	117	60	23	4.858	−5.7
3	4.162×10^5	132	60	26	4.865	−4.9
4	4.369×10^5	189	60	38	4.891	−2.4
5	3.605×10^5	93	60	19	4.860	−5.0
6	4.184×10^5	147	60	29	4.867	−3.1
7	3.798×10^5	101	60	20	4.871	−5.8
8	4.076×10^5	123	60	25	4.881	−5.2
9	3.621×10^5	77	60	15	4.865	−7.4
10	3.983×10^5	98	60	20	4.885	−6.3
11	4.158×10^5	300	99.6	100	4.662	−1.3
12	4.217×10^5	300	99.8	100	4.691	−0.8
13	3.605×10^5	300	98.7	99	4.629	−1.5

Note: 1 kg/cm^2 = 14.23 psi; 1 kg = 2.2 lb.

[a] Measured before test.

[b] Measured at end of cycle.

flow; compressive, tensile, and flexural strength; drying shrinkage; permeability; and freezing and thawing resistance.

The results obtained in this study are summarized as follows:

1. The use of superplasticizer can significantly reduce the water requirement for workability in concrete. The amount of water reduction increases with the dosage of superplasticizer. However, slump loss with elapsed time is more rapid when the dosage of superplasticizer is higher.

2. An increased dosage of superplasticizer has no effect on setting time. However, an increase in dosage of a lignin-base AE water-reducing admixture can cause significant retardation of setting time. Therefore, use of superplasticizer rather than AE water-reducing admixture will be more desirable in terms of setting and hardening of concrete.

3. Bleeding of superplasticized concrete is significantly lower than that of conventional high-consistency concrete of the same slump. This indicates that superplasticized concrete has a lower tendency for settlement.

4. CF- and VB-values of the superplasticized concrete are not significantly different from those of conventional concrete of the same consistency. This indicates that the tendency for segregation of fresh concrete is not affected by the superplasticizers.

5. Compressive, tensile, and flexural strengths of superplasticized concrete are much higher than those of conventional concrete of the same consistency.

6. Drying shrinkage of superplasticized concrete is less than that of conventional high-consistency concrete and similar to that of base concrete and concrete using a lignin-base AE water-reducing admixture.

7. The permeability coefficient of superplasticized concrete is about 10 percent less than that of base concrete and much less than that of conventional high-consistency concrete. Therefore, it should be desirable to use superplasticizer in the production of watertight concrete.

8. Freezing-and-thawing resistance of superplasticized concrete increases slightly with increase in dosage of superplasticizer. The use of an AE admixture in superplasticized concrete can greatly increase the freezing-and-thawing resistance. Therefore, using superplasticizer together with an AE admixture will produce superplasticized concrete with sufficient flowability and good durability.

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