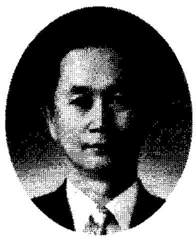
The Effects of Superplasticizers on the Engineering Properties of Plain Concrete



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ABSTRACT

The effects of superplasticizers on fresh and hardened concrete were investigated. The experimental program included tests on the workability and slump loss, bleeding, setting time, air content, compressive, tensile and flexural strength, permeability, shrinkage, freeze-thaw durability and creep deformation. Properties of superplasticized concrete were compared with those of conventional and base 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. 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 and creep of superplasticized concrete were 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.

Keywords : superplasticizers, base concrete, conventional concrete, workability, slump loss, bleeding, permeability, freeze-thaw durability, drying shrinkage, creep

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1. INTRODUCTION

Superplasticized concrete retains the cement content and water/cement ratio of its normal control mix, but has its workability, ease of compaction and cement particle dispersion enhanced by the addition of the superplasticizers. Superplasticizers, which include sulfonated melamine condensates developed in Germany in 1968, naphthalene condensates developed in Japan in the latter half of the 1960's, 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 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, creep and durability of hardened concrete are presented. The properties of superplasticlzed concrete are compared with those of conventional concrete(high-slump) and base (low-slump) concrete.

Table 1 Properties and Composition of Ordinary Portland Cement (Type Ⅰ)

Specific gravity	Blaine (cm^2/g)	Setting time (h:min.)		Compressive Sstrength (kgf/cm^2)			SiO_2 (%)	Al_2O_2 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig. Loss (%)	K_2O (%)	Na_2O (%)
		Initial	Final	3 days	7 days	28 days									
3.16	3,252	3:52	6:31	179	247	333	21.7	5.4	3.3	60.9	3.0	2.4	2.0	1.08	0.22

2. EXPERIMENTAL INVESTIGATION

2.1 Material

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

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

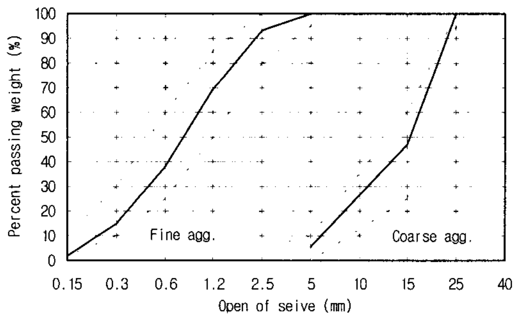

Fig.1 Gradation curves of fine and coarse aggregate

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 admix ture(Sanflo K) that contains mainly sulfonated naph thalene and modified lignin condensates was also used for comparison purposes. The properties of these admixtures are given in Table 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℃ (68°F)
a : Approximate
b : ASTM C 494

2.2 Mixing and Fabrication of Concrete

A total of 13 mixes were used in this study. They included a conventional concrete, a base concrete, eight non-air-entrained superplasticized con-cretes (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 350kgf/m^3 (590.6 1b/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 12cm(4.7 in.) and the rest of the mixes were made to have

Table 2 Physical Properties of Aggregates

Type of Aggregates	Specific Gravity	Absorption (%)	Fineness Modulus	Unit Weight (kgf/m^3)	Degradation Loss (%)	Sodium Sulfate Soundness Loss (%)	Organic Purity
Fine	2.56	1.03	2.84	1632	-	0.15	Good
Coarse	2.64	1.40	6.62	1684	14.4	0.21	Good

Table 4 Mix Proportions of Concrete

Mix No.	Type of Concrete	S/A[a] (%)	W/C[b] (%)	Slump (cm)	Air (%)	Unit Weight (kgf/m^3)				Admixture[c]	
						Water	Cement	Sand	Gravel	S.P.[d] (%)	AE WRA[e] (%)
1	Conventional	42	54.0	18	1.0	189	350	740	1,054	-	-
2	Base	42	51.0	12	1.0	179	350	749	1,067	-	-
3	Sanflo FBF	42	49.2	18	1.0	172	350	757	1,078	0.5	-
4	Sanflo FBF	42	48.0	18	1.0	168	350	760	1,083	1.0	-
5	Sanflo FB	42	49.5	18	1.0	173	350	758	1,079	0.5	-
6	Sanflo FB	42	48.2	18	1.0	169	350	762	1,085	1.0	-
7	NP-10	42	49.0	18	1.0	172	350	758	1,079	0.5	-
8	NP-10	42	47.8	18	1.0	167	350	765	1,090	1.0	-
9	NP-20	42	49.2	18	1.0	172	350	759	1,081	0.5	-
10	NP-20	42	48.2	18	1.0	169	350	761	1,083	1.0	-
11	Sanflo FBF	42	48.0	18	4.5	168	350	727	1,035	0.5	0.26
12	Sanflo K	42	46.5	18	4.5	163	350	730	1,039	1.0	0.26
13	Sanflo K	42	51.0	18	4.5	179	350	712	1,013	-	0.26

a : Sand-aggregate ratio.
b : Water-cement ratio.
c : Amount of admixture solution expressed as a percentage by weight of cement.
d : Superplasticizer
e : Water Reducing AE Admixtures

a target slump of 18cm(7.1 in.). The two levels of dosage of superplasticizer used were 0.5 and 1.0 percent by weight of cement. For the air-entrained concretes, 0.25 percent(by weight of cement) of the water-reducing AE admixture, Sanflo K, was used.

The water requirements for the concrete mixes were determined by trial mixes to obtain the target slump of 12cm for the base concrete and 18cm for the other 12 mixes. A tilting mixer of 54 ℓ ($1.9ft^3$) capacity was

used. In accordance with the recommendation of the manufacturers, superplasticizers of 0.5 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 super-plasticized concretes. The superplasticizer Sanflo FBF(0.5 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℃ (68° to 77°F).

2.3 Testing Methods

(1) Workability Test

Slump in conventional high-consistency concrete, base concrete, and super-plasticized concrete was measured every 30min up to 120 min after mixing to study the change of slump with time. Compacting factor and Vee Bee tests were done according to British standard 1881, part 2[(9)].

(2) Air-content Test

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

(3) Setting-Time Test

Setting time was measured by means of the Proctor penetration resistance test according to ASTM C803. Times of initial set and final set are defined as the times at which the penetration resistances are $35kgf/cm^2$(500psi) and $280kgf/cm^2$(4,000 psi), respectively.

(4) Bleeding Tests

The bleeding test was done with the cylindrical container having an inside diameter of 25cm(9.84 in.) and an inside height of 28cm(11.02 in.) and made of metal in accordance with ASTM C232, Method A. The amount of bleeding water was expressed as a percentage of the net mixing water contained within the test specimen.

(5) Strength Tests

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

(6) Permeability Test

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

$$K=[\rho \log(r_0 / r_i)/2\pi h] \cdot [Q/(Po-Pi)]$$

where

K= coefficient of permeability,
Q= quantity of water flow,
Po, Pi= external and internal water pressure of specimen,
ro= radius of specimen, and
ri= radius of center hole.

(7) Freezing-and-Thawing Test

In accordance with ASTM C666, Procedure A, Test Method for Resistance of concrete to Rapid Freezing and Thawing, specimens of 7.62×7.62×35.56cm(3×3×14 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℃(0° to 39°F). The test was continued until the relative dynamic modulus of elasticity reached 60 percent.

(8) Drying Shrinkage Test

Drying shrinkage test was performed according to the ASTM C157 testing method, specimens of 10×10×40cm(3.94×3.94×15.75in.) were made and the change in length was measured at an accuracy of 1/1,000mm(4×10-5in.) by the use of a comparator with a microscopic read out 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.

(9) Creep Test

Creep test was conducted according to ASTM C512. The frame was loaded to a 30% of compressive strength to the age of 12 months. Results were recorded using whittemore strain gage at stage of aging.

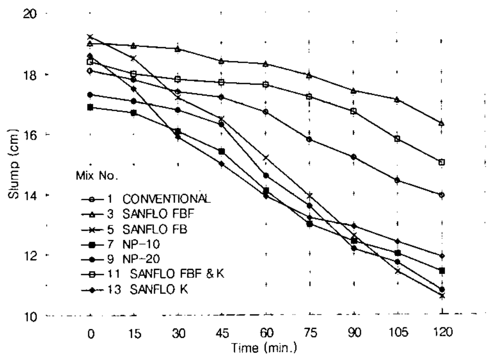

Fig.2 Change in slump by time elapsed at 0.5% dosage of superplasticizers.

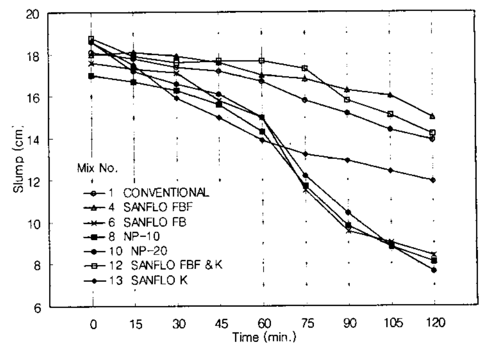

Fig.3 Change in slump by time elapsed at 1.0% dosage of superplasticizers.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Fresh Concrete

(1) Workability Test

Table 5 Test Results for Fresh Concrete

Mix No.	Slump (cm)	Air (%)	CF	VB (sec)	Setting Time (hr:min)	
					Initial	Final
1	19.0	1.2	0.945	2.70	6:35	9:30
2	12.8	1.4	0.913	5.06	6:00	8:30
3	19.0	1.3	0.962	2.36	6:10	8:95
4	18.5	1.4	0.952	2.81	6:20	9:10
5	19.5	1.1	0.958	2.25	6:15	9:05
6	18.6	1.2	0.950	3.04	6:35	9:00
7	17.5	1.3	0.947	2.14	6:00	8:40
8	17.0	1.0	0.932	2.70	6:30	8:45
9	18.0	1.1	0.949	2.03	6:10	8:95
10	18.5	1.3	0.942	2.81	6:40	9:10
11	18.2	4.5	0.963	2.14	6:00	8:25
12	19.4	4.8	0.952	2.36	6:10	8:40
13	19.0	4.9	0.967	2.25	7:05	10:35

The water content of all 13 mixes is also shown in Table 5. It may be shown that when the dosage of superplasticizer was 0.5 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 0.25percent (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 0.5 and 1.0percent of superplasticizers is shown in Figs. 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 0.5 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.

Table 5 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 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 0.5 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.

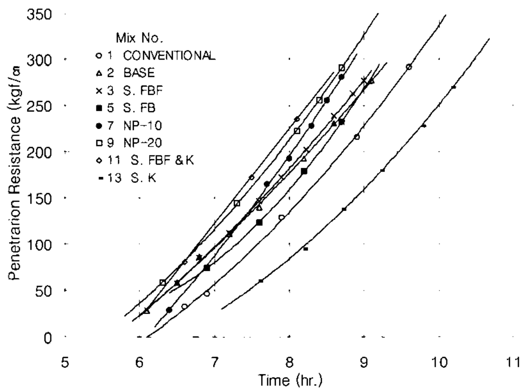

Fig.4 Comparison of setting time at 0.5% dosage of superplasticizers.

Therefore, the dosage of superplasticizer should be with in the range where segregation would not be created.

(2) Air Content

Air content of fresh concrete after mixing are shown in Table 5. It may be noted that the air 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.

(3) Setting Time

Table 5 and Fig.4~5 show test results for setting time by proctor penetration-resistance tester for concretes at dosages of 0.5 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

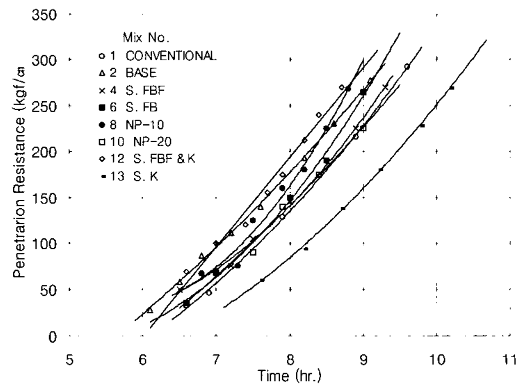

Fig.5 Comparison of setting time at 1.0% dosage of superplasticizers.

with superplasticizers will be more desirable than concrete with water-reducing admixtures.

(4) Bleeding

Test results for bleeding of concretes at dosages of 0.5 and 1.0 percent of superplasticizers are shown in Figs. 6 and 7, respectively. It can be seen that bleeding of the superplasticized concretes

Table 6 Test Results for Concrete-Bleeding Tests

Mix No.	Bleeding(%) by time(min)										
	10	20	30	40	50	60	120	180	240	300	360
1	3.20	3.87	4.50	5.12	5.70	6.20	7.19	7.67	7.98	8.14	8.33
2	2.20	2.44	3.16	3.63	3.93	4.23	4.89	5.71	6.12	6.28	6.46
3	2.50	3.17	3.87	4.50	5.12	5.62	6.38	6.69	7.00	7.04	7.22
4	0.95	1.48	2.15	2.70	3.05	3.44	4.02	4.33	4.80	4.95	5.14
5	2.63	3.29	4.10	4.84	5.35	5.89	6.84	7.34	7.51	7.57	7.77
6	1.18	1.71	2.28	2.89	3.16	5.32	6.00	6.51	6.75	6.80	6.98
7	2.11	2.48	3.40	3.82	4.21	4.49	5.32	5.75	5.98	6.16	6.18
8	1.25	1.86	2.46	2.95	3.29	3.96	4.55	4.98	5.42	5.60	5.74
9	2.51	3.23	4.06	4.59	5.20	5.71	6.60	7.01	7.23	7.47	7.67
10	1.31	1.91	2.51	3.10	3.36	3.72	4.73	5.26	5.72	5.86	5.89
11	1.97	2.29	2.80	3.21	3.50	3.90	4.64	5.00	5.47	5.58	5.80
12	0.90	1.06	1.46	2.07	2.34	2.71	3.49	4.12	4.40	4.67	4.77
13	2.19	2.87	3.55	4.41	4.92	5.21	6.10	6.53	6.91	7.23	7.45

was significantly lower than that of conventional high-consistency concrete of the same slump and that bleeding decreased as the dosage of super-plasticizer 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 6).

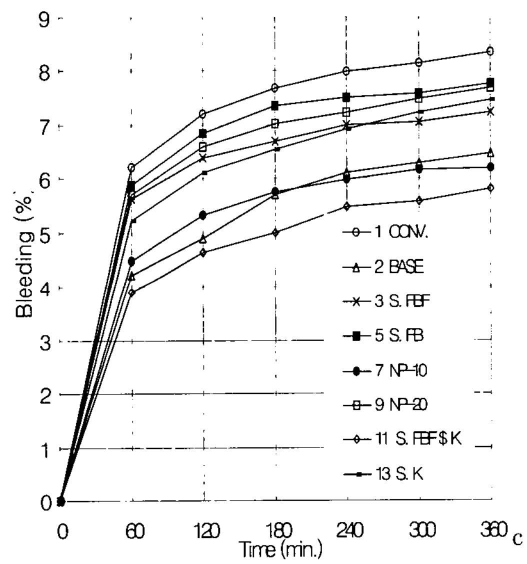

Fig.6 Comparison of bleeding ratio at 0.5% dosage of superplasticizers.

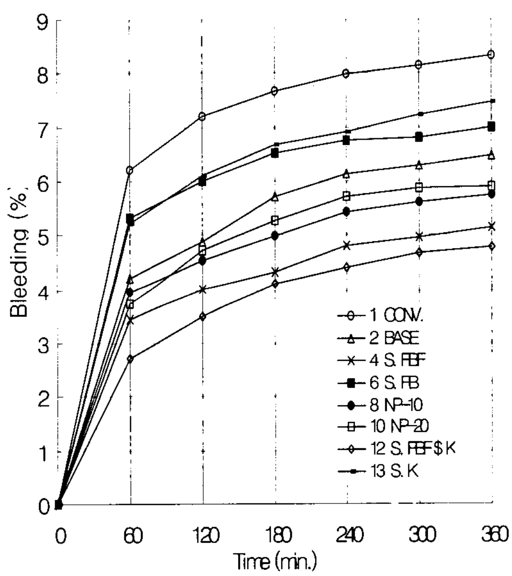

Fig.7 Comparison of bleeding ratio at 1.0 % dosage of superplasticizers.

Table 7 Test Results for Hardened Concrete

	Compressive Strength (kgf/cm^2)		Tensile Strength (kgf/cm^2)		Flexural Strength (kgf/cm^2)		Coefficient of Permeability
Mix No.	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	K ($\times 10^{-3}$cm/sec)
1	169	270	17	25	30	46	32.21
2	198	297	20	30	38	52	14.40
3	200	311	21	32	38	54	11.97
4	202	320	24	34	39	56	11.48
5	197	298	20	29	37	51	12.89
6	200	309	21	31	38	52	12.56
7	198	304	21	30	37	53	12.28
8	201	311	23	31	40	55	11.06
9	199	308	20	31	39	53	12.12
10	203	312	23	34	40	56	11.40
11	198	307	22	213	38	55	12.86
12	203	318	24	33	39	58	11.88
13	195	289	19	27	35	50	12.61

3.2 Physical Properties of Hardened Superplasticized Concrete

(1) Compressive Strength

Table 7 shows the test results of compressive strength in standard curing conditions at 7 and 28 days. The compressive strengths are compared and displayed in Figs. 8 and 9.

The compressive strength of the superplasticized concretes was significantly higher than that of the conventional concrete. At 7 days, the compressive base concrete was increased by an 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

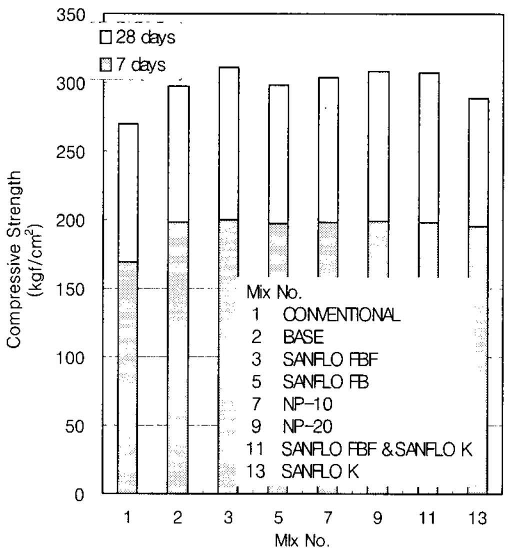

Fig.8 Comparison of compressive strength at 0.5% dosage of superplasticizers.

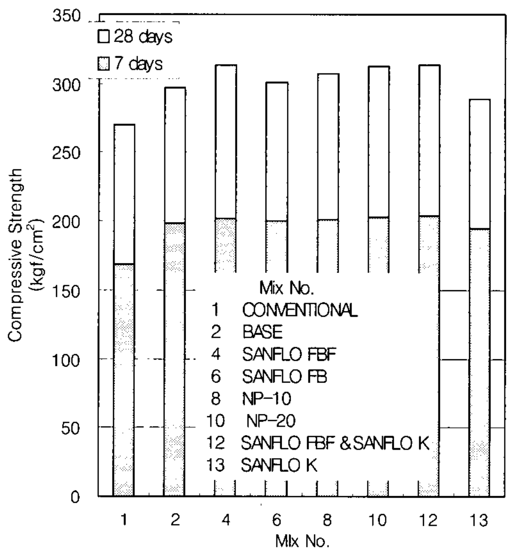

Fig.9 Comparison of compressive strength at 1.0% dosage of superplasticizers.

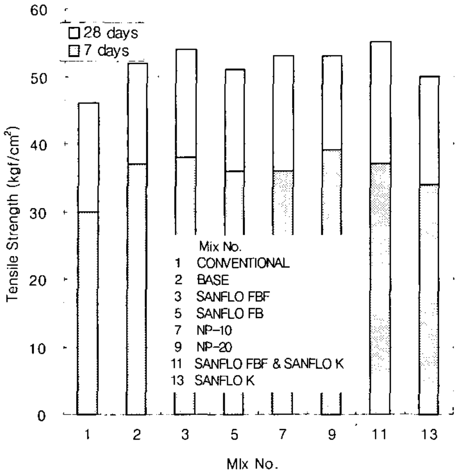

Fig.10 Comparison of tensile strength at 0.5% dosage of superplasticizers.

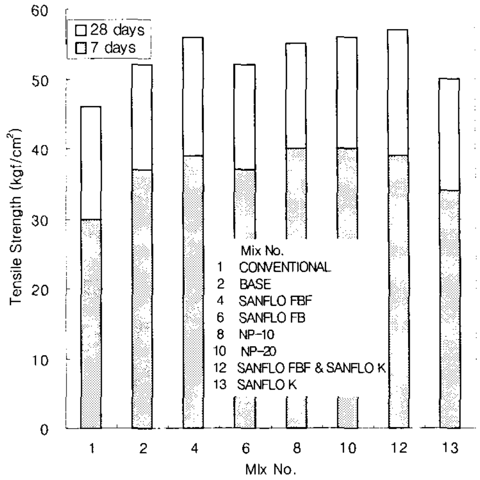

Fig.11 Comparison of tensile strength at 1.0% dosage of superplasticizers.

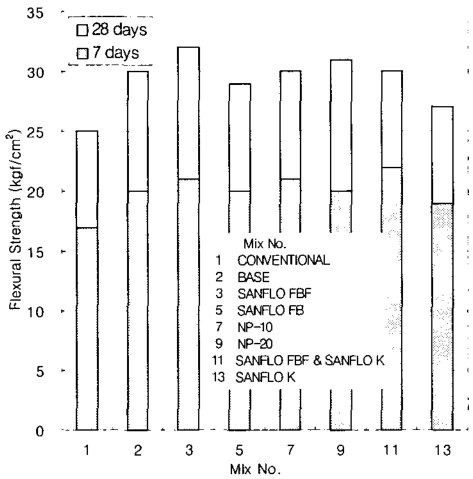

Fig.12 Comparison of flexural strength at 0.5% dosage of superplasticizers.

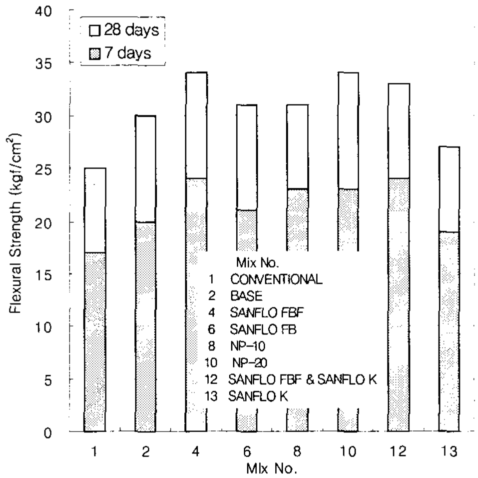

Fig.13 Comparison of flexural strength at 1.0% dosage of superplasticizers.

concretes was about 4 percent higher than that of the base concrete. This result is similar to the testresults 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 increased dosage of superplasticizer.

The superplasticized 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.

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

Mix No.	Dynamic Modulusa of Elasticity (kgf/cm^2)	Final Cycle No.	Relative Dynamic Modulus[a] of Elasticity (%)	DF (%)	Weight[b] (kg)	Decreased Ratio of Weight (%)
1	3.602×105	47	60	9	4.826	-8.9
2	3.761×105	122	60	24	4.867	-5.8
3	4.210×105	138	60	28	4.874	-5.0
4	4.419×105	197	60	39	4.900	-2.5
5	3.647×105	97	60	19	4.869	-5.1
6	4.232×105	154	60	31	4.876	-3.1
7	3.842×105	105	60	21	4.880	-5.9
8	4.123×105	128	60	26	4.890	-5.3
9	3.663×105	80	60	16	4.874	-7.6
10	4.029×105	102	60	20	4.894	-6.4
11	4.206×105	300	99.7	100	4.671	-1.3
12	4.175×105	300	99.8	100	4.700	-0.8
13	3.647×105	300	98.9	99	4.638	-1.5

a : Measured at end of cycle
b : Measured before test.

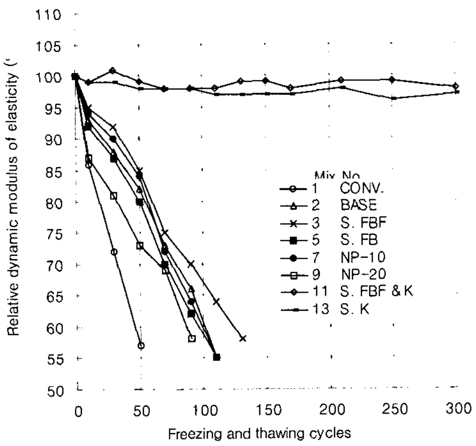

Fig.14 Resistance of concrete to rapid freezing and thawing 0.5% dosage of superplasticizers.

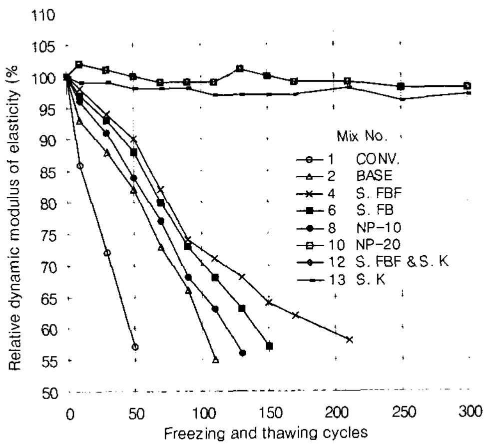

Fig.15 Resistance of concrete to rapid freezing and thawing 1.0% dosage of superplasticizers.

(2) Tensile and Flexural strength

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

(3) Permeability

As shown in Table 7, 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.

Table 9 Test Results of Drying Shrinkage

Mix No.	Length Change (10-4cm/cm)				
	7 Days	28 Days	60 Days	91 Days	180 Days
1	1.87	4.38	6.50	7.46	8.02
2	1.44	3.78	5.25	6.28	6.90
3	1.34	3.71	5.08	6.04	6.57
4	1.24	3.48	4.85	5.80	6.03
5	1.48	3.83	5.38	6.46	7.11
6	1.37	3.71	5.18	6.20	6.63
7	1.43	3.75	5.20	6.21	6.65
8	1.28	3.61	5.08	6.09	6.36
9	1.48	3.98	5.50	6.54	7.52
10	1.32	3.88	5.24	6.28	7.00
11	1.24	3.63	5.00	5.96	6.10
12	1.21	3.44	4.79	5.73	5.89
13	1.50	3.90	5.28	6.25	7.14

(4) Freezing-and-Thawing Resistance

Table 8 shows the freezing-and-thawing test results of the 13 concrete mixes used in this study. Figs. 16 and 17 present the relative dynamic elastic moduli as functions of freezing-thawing cycles for concretes with 0.5 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-thawing cycles. The results of the freezing-thawing tests indicated hat superplasticizers can improve the durability of concrete, whereas an AE admixture along with superplasticizers can further improve the durability of concrete.

(5) Drying Shrinkage

Table 9 and Figs. 16, 17 show the drying shrinkage of the concrete at the dosage og 0.5 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 0.5 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 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 9). When two concretes have aboutthe same water content, their drying shrinkage would be about the same,

Table 10 Creep Test Results of Concrete at Six Months Under Load

Mix No.	Applied Stress (kgf/cm^2)	% of f′c	Total Strain ($\times 10^{-6}$)	Total Specific Creep ($10^{-6}/kgf/cm^2$)	Basic Strain ($\times 10^{-6}$)	Basic Specific Creep ($10^{-6}/kgf/cm^2$)	Drying Creep ($\times 10^{-6}$)	Elastic Strain ($\times 10^{-6}$)
1	81.0	30	1,935	23.89	1,334	16.47	601	328
2	89.1	30	1,775	19.92	1,258	14.12	517	335
3	93.3	30	1,769	18.96	1,276	13.86	493	356
4	96.0	30	1,683	17.53	1,231	12.82	452	330
5	89.4	30	1,789	21.01	1,256	14.05	533	326
6	92.7	30	1,754	18.92	1,257	13.56	497	345
7	91.2	30	1,746	19.14	1,247	13.67	499	339
8	93.3	30	1,735	18.60	1,258	13.48	477	356
9	92.4	30	1,912	20.69	1,348	14.59	564	354
10	93.6	30	1,844	19.70	1,319	14.09	525	360
11	92.1	30	1,689	18.34	1,231	13.37	458	353
12	95.4	30	1,679	17.60	1,237	12.97	442	364
13	86.7	30	1,833	21.14	1,297	14.96	536	344

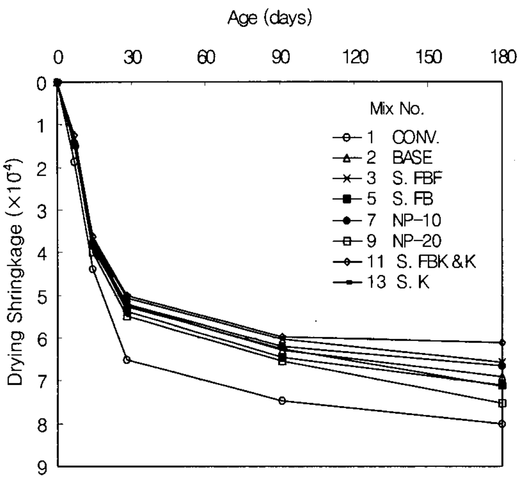

Fig.16 Comparison of drying shrinkage at 0.5% dosage of superplasticizers.

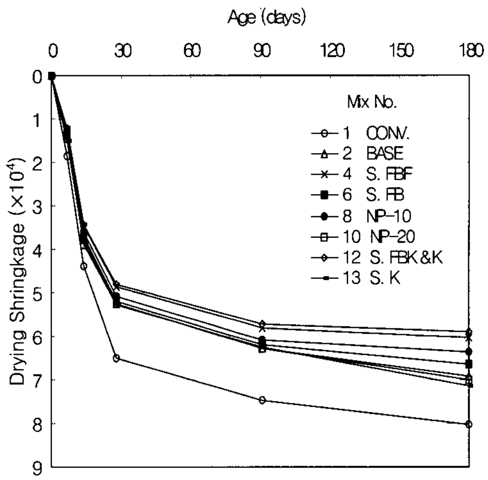

Fig.17 Comparison of drying shrinkage at 1.0% dosage of superplasticizers.

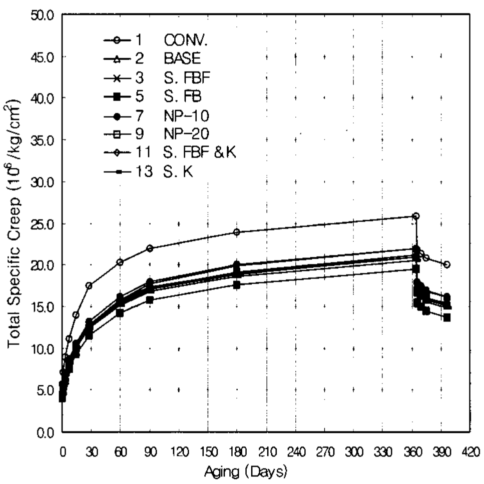

Fig.18 Comparison of total specific creep at 0.5% dosage of superplasticizers.

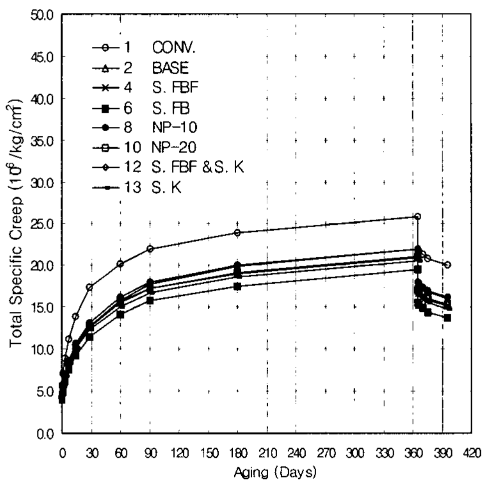

Fig.19 Comparison of total specific creep at 1.0% dosage of superplasticizers.

regardless of the dosage or type of superplasticizer used.

(6) Creep Test

The test results obtained for creep deformation of superplasticized concrete are given in Table 10 and Fig.18, 19. Test results in Table 10 show that total and total specific creep for the super-plasticized concrete were about 10% less than those of the conventional concrete. This is similar to the trend as reported by Dhir[15] that superplasticized concrete exhibited lower total specific creep that the conventional concrete. It is the super-plasticized concrete has a lower water/cement ratio, which should decrease specific creep, since creep is a paste property. comparison of specific creep at differing dosages levels showed no consistent trends, although the other supoerplasticizers exhibits less creep under both dosage levels of 0.5% and 1.0% than that of superplasticizer of NP-20. The property of the superplasticized concrete is considered to be favorable for the production of prestressed concrete. The creep ecovered after a period of 30days since unloading is shown if Figs. 18 and 19. There are no significant differences between the conventional concrete and the superplasticized concretes.

4. CONCLUSION

This study investigated the fundamental engineering properties of superplasticized concrete, including flow; strengths; drying shrinkage; permeability; and freezing-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. And CF-and VB-values of the superplasticized concrete are not significantly different fron those of conventional concrete of the same consistency. This indicates that the tendency for segregation of fresh concrete is not affected by the superplasticizers.
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. Compressive, tensile, and flexural strengths of superplasticized concrete are much higher than those of conventional concrete of the same consistency.
5. 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.
6. Freezing-thawing resistance of superplasticized concrete increases slightly with increase in dosage of super plasticizer. The use of an AE admixture in superplasticized concrete can greatly increase the freezing-thawing resistance. Therefore, using superplasticizer together with an AE admixture will produce superplasticized concrete with sufficient flowability and good durability.
7. 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.

8. It was found that the basic specific creep of superplasticized concrete were lower than that of conventional concrete for the levels of superplasticizer dosage used. Total creep and total specific creep of superplasticized concrete were slightly less than those of the conventional concrete.

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