高性能減水劑가 콘크리트의 工學的 特性에 미치는 影響(Ⅱ)

A Study on the Effects of Superplasticizers on the Engineering Properties of Plain Concrete (Ⅱ)

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적요

유동화콘크리트의 공학적 특성에서 시간—의존거동을 확인하기 위하여, 나프타렌 설폰산염 폴리머 고축합물인 Rheobuild 1000과 메라민 설폰산염 고축합물인 NP-20의 고성능감수제를 사용한 유동화콘크리트와 보통콘크리트를 제조하여 비교·고찰을 행하였으며, 고성능감수제의 종류 및 함량이 콘크리트의 공학적 특성에 미치는 영향을 구명하기 위하여 재령 3일, 14일, 28일, 60일, 90일, 180일의 압축강도를 측정, 조기 및 장기압축강도를 조사하였고, 인장강도 및 탄성변형에 미치는 영향을 조사하였다.

또한 습윤 및 에어콘디션의 양생조건하에서 시간의 경과에 따른 건조수축 및 크리이프 변형을 조사·분석함으로써 유동화콘크리트의 시간—의존거동을 확인하였다.

실험결과, 사용 고성능 감수제의 종류에 따라 차이는 있으나, 고성능 감수제의 사용은 일반적으로 워커빌리티 성능을 개선하고 압축 및 인장강도를 크게 향상시키며, 탄성계수는 보통의 콘크리트에 비하여 높게 나타났다. 또한 건조수축 및 크리프 변형의 감소에 매우 양호한 결과를 나타내어 앞으로 건설용 용도로써 효과적인 것으로 판단되었다.

Ⅰ. Introduction

Superplasticizers, which include sulphonated melamine condensates developed in West Germany in 1963 and naphtalene condensates developed in Japan in the latter half of 1960's, have been used to produce high-strength concrete and water-reduced concrete[1]. Superplasticized concrete was developed for the purpose of improving concrete workability in West Germany in about 1971 and a guideline for production and placement was established in 1974[2]. A proposed guideline for design and control of superplasticized concrete was also published in Canada in 1981[3]. There have been increased interests in the use of superplasticized concrete for improved quality and workability due to the wide use of the concrete pump, the practical and economic reasons for using a superplasticizer in precast and ready mixed concrete. Hence, further investigation in the production and practice of superplasticized concrete are needed for their effective applications. Based on the previous report[4,5], the primary purpose of this study is to investigate the engineering properties of superplasticized concrete including shrinkage and creep deformation. Generally, for plasticizing admixtures, the limited experimen-

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tal data on the shrinkage and creep deformation are not clear [6,8,10]. This paper presents the effects of two standard types of superplasticizers on the compressive strength, indirect tensile strength, static modulus of elasticity, drying shrinkage and creep of hardened concrete. The properties of superplasticized concrete were compared to those of control concrete.

Ⅱ. Materials

The materials used were Normal Type I portland cement, Miami Oolite coarse and fine aggregates. The properties of the cement are shown in Table-1. The gradation of these aggregates are shown in Fig.1 and their physical properties are shown in Table-2. Two different brands of superplasticizer were used. Rheobuild-1000 is sulphonated naphthalene polymer formaldehyde condensate admixture and NP-20 is a sulphonated melamine formaldehyde codensate admixture. The physical properties of these admixtures are shown Table.3.

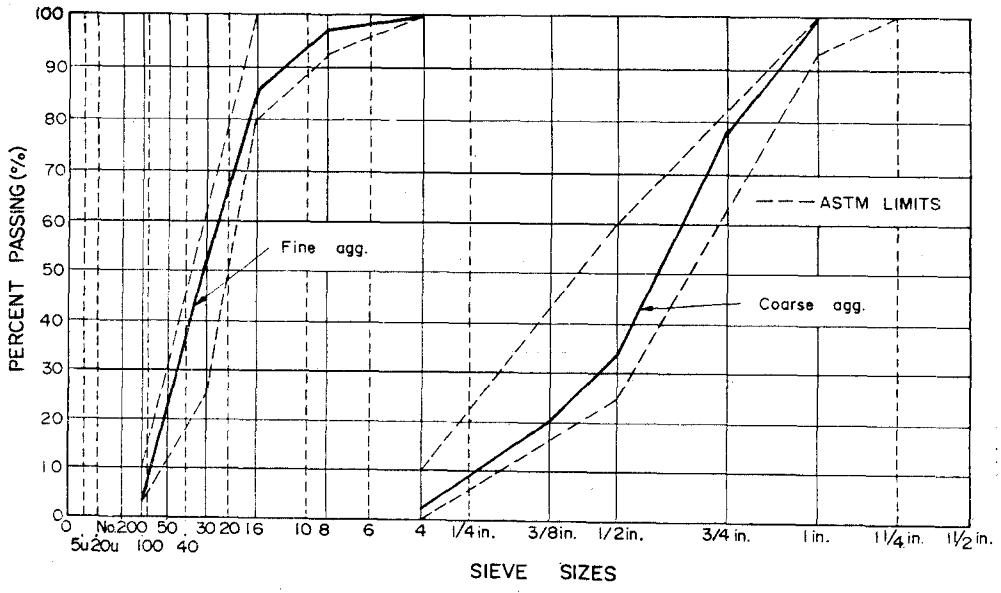

Fig.1. Gradation Curve of Fine and Coarse Aggregate

Table-1. Properties of type I portland cement

Specific gravity	Specific Surface area (m²/kg)	88μ residue (%)	Soundness (%)	Time of Setting		Compressive strength (psi)		
				Initial (hr:min)	Final (hr:min)	3days	7days	28days
3.18	339	0.5	0.06	3 : 05	5 : 10	2358	3526	5541

CaO(%)	SiO_2(%)	Al_2O_3(%)	Fe_2O_3(%)	MgO(%)	SO_3(%)	Insoluble (%)	Ignition (%)
64.5	21.1	5.6	3.3	2.9	2.6	0.3	2.6

Table-2. Physical properties of aggregates

Kind of aggregate	Specific Gravity	Absorption (%)	Fineness Modulus	Unit weight (lb/ft^3)	Degradation Loss(%)	Soundness (%)	Organic impurity
Fine agg.	2.64	1.60	2.41	78.0	—	good	None
Coarse agg	2.52	2.10	7.15	78.4	14.2	good	None

Table-3. Physical properties of the admixtures

Admixture	Appearance	Specific Gravity (Avg.)	PH (Avg.)	ASTM C484 Solids(%)
Rheobuild-1000	Dark brown liquid	1.13	7	38—42
NP-20	Dark brown oily liquid	1.18—1.22	6—9	40—43
A.E. Agent(Darex)	Dark brown liquid	1.00—1.05	7.3	N/A

NOTE: Testing temperature=20°C (68°F)

Ⅲ. Mixing and Test procedures

(a) Mix proportions

Mix proportions were classified into five experimental series as displayed in Table-4.

(b) Testing Methods

Slump test was conducted according to ASTM C143-74. The air content of fleshly mixed concrete was measured by the pressure method according to ASTM C231-82. Compressive and Tensile strength tests were conducted according to ASTM C39-83 and C496-71. The values of the static modulus of elasticity was measured according to ASTM C469-65. Shrinkage and creep test were conducted according to ASTM C157 and C39-72 test methods.

Table-4. Mix Proportions of Concrete

Kind of Concrete	Dosage* (%)	S/A (%)	W/C (%)	Unit Weight(lb/yd^3)				Darex (ml)	Slump (in.)	Air Content (%)
				Water	Cement	Sand	Gravel			
Control	—	44.77	41	269.8	658	1231.4	1518.6	80	2.75	4.0
NP-20	0.5	47.37	43	283.8	658	1366.7	1518.3	143	2.25	4.5
	1.0	47.37	38	251.0	658	1366.7	1518.3	119	2.25	4.0
Rheobuild —1000	0.5	47.37	37	246.12	658	1369.7	1518.3	90	2.50	4.25
	1.0	47.37	29	187.85	658	1369.7	1518.3	90	2.33	4.0

*Amount of admixture solution expressed as a percentage by weight of cement

(c) Concrete Mixing and Fabrication of Specimen

The water requirements for the concrete mixes were determined by trial mixes to obtain a target slump of 2.75 in. for the control concrete and a target slump of 2.75±0.5 in. for the other four mixes. The concrete was mixed in a rotary type mixer with a capacity of 25 cubic ft. The aggregate and cement were added and mixed for 3 minutes with approximately 80% of the mixing water After. 3 minutes, the mixer was shut off and the concrete was allowed to rest for 2 minutes. After 2 minutes, the mixing was continued for another 2 minutes and the remaining water together with the air entraining agent and the superplasticizer was added to the mixture. After mixing a st-

Photo.1. Creep Test Under the Condition of Air-Conditioned and Moist Room

andard slump cone, entrained air and unit weight tasks were performed. If more water was needed to achieve the desired slump, it was added at this stage and the mixing was continued for an additional 2 minutes. After mixing, the concrete was placed in 6″×12″ cardboard cylinder molds. The molds were placed on a vibration table and vibrated while the cylinders were being filled. Three pairs of gage seats were cast into the cylinders as needed for shrinkage and compressive creep tests.The number of test cylinders for the various tests are displayed in Table-5.

(d) Test procedures

In addition to the type of superplasticizer used, the principal variables was the dosage of the superplasticizer used (1.0% or 0.5% by weight of cement) and the environment in which the specimens are stored. The moist environment conforms to ASTM requirements of greater than 98% relative humidity and 73°±3°F temperature. The air-conditioned environment was an air-conditioned room maintained at 70°±3°F temperature with a 55%±15% relative humidity. Variabilities in the environments were minimized by storing the specimens for all mixes side-by-side, such that they all experienced the same variations. After casting, the cylinder specimens were left for approximately 24 hours before the cardboard cylinder molds were stripped off and the cylinders placed in either the moist room or the air-conditioned environment where they would remain throughout the testing period. Note that no moist curing was done for the specimens stored in the air-conditioned room.

Table-5. Number of cylinders casted

Superplasticizer	Rheobuild-1000				NP-20			
Dosage (%wt. of cement)	0.5		1.0		0.5		1.0	
Storage condition	AC	MR	AC	MR	AC	MR	AC	MR
Creep test	2	2	2	2	2	2	2	2
Shrinkage test	2	1	2	1	2	1	2	1
fc′	24	24	24	24	24	24	24	24
Splitting tensile test	4	4	4	4	4	4	4	4
Total	32	31	32	31	32	31	32	31

As soon as the cylindrical specimens were sufficiently strong (1 to 3 days) the stainless steel gage seats were installed by screwing them into the brass inserts that were cast into the cylinders. Monitoring of shrinkage deformations was begun as soon as the seats were installed. Immediately prior to installing the specimens in the creep frames, two to four cylinder specimens from each concrete mixture were tested in direct compression to determine the compressive strength, and two of the cylinders were tested in accordance with ASTM standards to obtain a stress-strain relation. The compressive strength of the cylinders tested at 28 days was averaged and used to determine the test loads. In the case of the specimens without superplasticizer(the control mixture), four specimens were tested at 25% and 50% of the compressive strength of the specimens. For the specimens using superplasticizers, four specimens were loaded in a frame, but two specimens had 1% dosage and two specimens had 0.5% dosage of superplasticizers. The frame was loaded to a compressive strength of 25% of the strength of the 1% dosage at the age of five months. Splitting tensile tests on four cylinders was performed at 28 days on all mixtures.

Ⅳ. Test Results and Discussion

(a) Compressive Strength

For concrete stored in air-conditioned and moist rooms, the development of compressive strength with ages are shown in Table. 6 and Fig. 2. The compressive strength of superplasticized concrete is consistently greater than the control concrete for all ages and cure conditions. The amount of increase above the control strength is affected by the type and dosage level of superplasticizer, and by the curing conditions. It can be seen that, because of its lower water/cement ratio, the strength of the superplasticized concrete is always higher than that of its respective control concrete.

At the ages of 3 days and 14 days, the compressive strength of the superplasticized concrete at a 1% dosage level averaged 37% greater than the control concrete for air-condition cured concrete and 39% greater for the moist room curing concrete. At a 0.5% dosage level, the air-condition cured concrete was 9% greater than the control concrete, and moist room curing yielded concrete with a compressive strength 12% greater than the control concrete. Comparing compressive strength at 28 days, a 1% dosage level with air-condition storage showed average compressive strengths 38% greater than the control concrete. With moist room storage and a 1% dosage level, the superplasticized concretae averaged 23% above that of the control. At a 0.5% dosage with air-condition curing, the superplasticized concrete averaged 26% greater compressive strengths, while under moist room storage at a 0.5% dosage level, a 7% increase in compressive strength was obtained. For long term compressive strength (60 days, 90 days, and 180 days) at a 1% dosage level, air-condition cured concrete showed a 22% increase and the moist room cured concrete showed a 21% increase above that of the control concrete. At a 0.5% dosage, the air-condition cured concrete was 3% greater, and the moist room cured concrete was 6% greater than the control concrete. Comparing compressive strengths for the two types of superplasticizer tested reveals that at a 1% dosage level the Rheobuild-1000, a supersulphonated naphthalene polymer formaldehyde condensate admixture, showed greater increases in compressive strength than the NP-20, a sulphonated melamine formaldehyde condensate admixture, at all ages and curing conditions. At 1.0% dosage levels, the Rheobuild-1000 compressive strengths ranged from 13 to 46% greater than the NP-20 strengths. The difference tends to increase with age. At a 0.5% dosage, the differences are less consistent and smaller in magnitude. For ages of 3, 7 a nd 14 days, no significant trend is established for either type of superplasticizer sho-

Table-6. Test Results of Compressive Strengths

Unit: psi

Kind of concrete	3 days		14 days		28 days	
	AC	MR	AC	MR	AC	MR
Control concrete (Miami Oolite)	3469.225	3512.213	4928.369	4649.204	5340.997	5152.989
NP-20-1%	4865.426	4802.943	5506.961	5654.127	5963.005	5928.578
NP-20-0.5%	4693.438	4088.514	5216.745	4919.656	5670.632	5375.900
Rheobuild-1,0000 1%	8308.702	5499.687	6926.777	6553.647	7485.588	6963.913
Rheobuild-1,0000.5%	3848.811	4123.881	4817.090	5061.127	6000.141	5665.916

Kind of concrete	60 days		90 days		180 days	
	AC	MR	AC	MR	AC	MR
Control concrete (Miami Oolite)	5481.075	5351.963	5852.484	6051.468	5593.385	6052.352
NP-20-1%	6118.623	6396.850	5965.363	6382.703	5863.695	5992.218
NP-20-0.5%	5616.401	5681.242	5700.105	6143.381	5831.27	5641.14
Rheobuild-1,000 1%	7657.121	7305.212	7818.044	7924.148	7536.85	8079.24
Rheobuild-1,000 0.5%	5589.875	5987.763	6100.939	6350.767	5960.38	7035.73

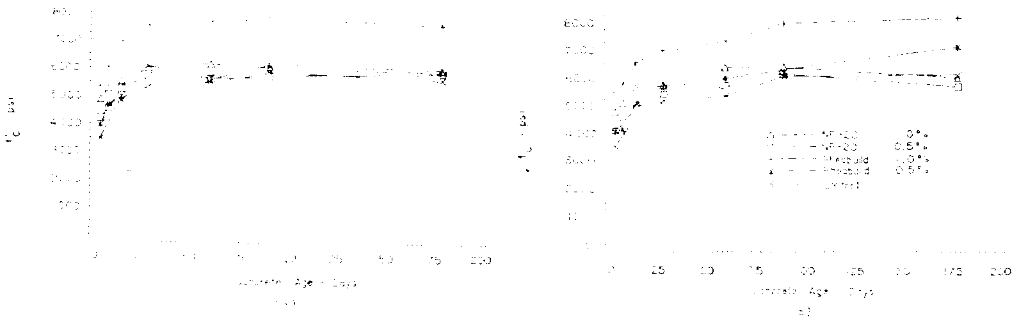

Fig.2. Influence of Superplasticizer on the Compressive Strength(fc′) of Concrete Stored in the (a) Air Conditioned Room and(b) the Moist Room

wing consistently higher strengths. For ages of 28 days and older the Rheobuild-1000 showed an increased compressive strength generally 50% greater than that of the NP-20.

Thus, both early and long term compressive strengths are improved by the addition of a superplasticizer. The level of dosage is particularly influential in determining how great an improvement in strength will be achieved, with the 1% dosage yielding compressive strengths generally 21% greater than the 0.5% dosage level. The type of superplasticizer also affects the amount of strength increase, with the Rheobuild-1000 type shown to be more effective particularly at the larger dosage level. Curing conditions appear to have a negligible affect on compressive strengths as at most ages or dosage levels the values of compressive strength for air-condition cured concrete was usually within 7% of the moist room cured concrete of similar age and dosage level. According to test results, the use of superplasticizers to permit reductions in water content and to increase compressve strength is very favorable to the design of massive concrete structures.

(b) Indirect Tensile Strength

The results of test for indirect tensile strength at 28 days are given in Table 7. Generally, the pattern of the behavior of indirect tensile strength is similar to that of compressive strength. The results of test indicate that moist room storage showed strengths which ranged from 95% to 116% of those which were air-conditioned cured. Comparing results of test with these of the control concrete under air-conditioned conditions the tensile strength of the Rheobuild-1000 concrete was 21% greater at 1.0% dosage and 11% greater at 0.5% dosage than the control concrete. The tensile strength of the NP-20 concrete was 11% greater than that of the control concrete at both 1.0% and 0.5% dosages with air-conditioned curing. With moist room curing the Rheobuild-1000 concrete exceeded the NP-20 concrete by 14% for a 1.0% dosage and by 4% at 0.5% dosage. For air-conditioned curing, Rheobuild-1000 concrete was 20% higher than the NP-20 concrete at 1.0% dosage and 80% of that of the NP-20 concrete at 0.5% dosage.

Table-7. Test Results of Indirect Tensile Test

Unit : psi

Kind of Concrete	Air-conditioned Cured	Moist Room Cured
Control concrete	1533.428	N/A
NP-20-1.0%	1730.810	1778.564
NP-20-0.5%	1730.810	1650.159
Rheobuild-1000-1.0%	1920.764	2222.497
Rheobuild-1000-0.5%	1711.355	1785.639

The results of indirect tensile strength at a 1.0% and 0.5% dosage indicate that the higher dosage level consistently produce greater indirect tensile strength for all type of superplasticizer and curing condition.

(c) Static Modulus of Elasticity

There were some differences between the elastic behavior of control and superplasticized concretes. The values of the static modulus of elasticity for the two superplasticized concretes are generally close and no definite trends in variability can be distinguished between NP-20 and Rheobuild-1000. But regardless of the level of dosage of superplasticizer or curing condition, the addition of a superplasticizer to control concrete resulted in an increased value of the modulus of elasticity. The results obtained for moduli of elasticity are given in Table 8 and show in Fig. 3.

The addition of 1.0% dosage of superplasticizer showed a greater increase in modulus of elasticity relative to the control concrete than the addition of 0.5% dosage. Similarly, the Rheobuild-1000 concretes consistently showed larger increase than NP-20 concretes. There are not significant differences in increase of the moduli of elasticity between the moist room

Table-8. Static Modulus of Elasticity

Kind of Concrete	Storage Condition	Modulus of Elasticity (×10^{+6} psi)			Avg. Increa Relative to Control(%)
		28	90	180	
Control	AC	3.68	3.76	3.56	—
Control	MR	3.68	4.43	4.02	—
NP-20-0.5%	AC	4.43	4.41	4.40	20
NP-20-1.0%	AC	4.24	4.28	4.49	12
NP-20-0.5%	MR	4.67	4.67	4.85	14
NP-20-.10%	MR	5.42	4.74	5.15	27
Rheobuild-1,000 0.5%	AC	4.61	4.49	4.46	22
Rheobuild-1,000 1.0%	AC	5.51	5.64	5.61	50
Rheobuild-1,000 0.5%	MR	4.70	5.37	5.52	25
Rheobuild-1,000 1.0%	MR	5.64	6.06	6.25	45

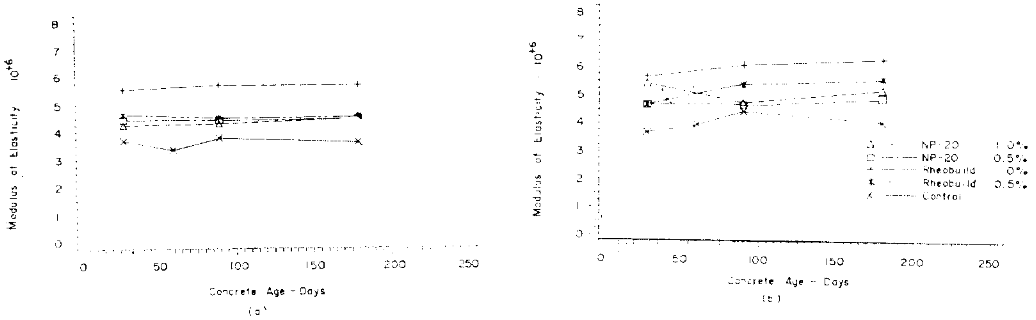

Fig.3. Influence of a Superplasticizer on the Modulus of Elasticity of Concrete Stored in (a) the Air Conditioned Room and (b) the Moist Room

cured and the air-conditioned cured concretes.

(d) Drying Shrinkage

Table 9 and Fig. 4-7 present the drying shrinkage of superplasticized concretes at dosages of 0.5% and 1.0% of superplasticizer, respectively. The effect of the addition of superplasticizer on drying shrinkage at five months was evaluated for concrete with a slump that ranged from 2.25 in. to 2.75 in. In general, the drying shrinkage of superplasticized concrete cured in air-conditioned room is lower than control concrete and increases with the superplasticizer dosage used. For moist room cured concrete drying shrinkage is essentially zero. At a 0.5% dosage level, the drying shrinkage of the air-conditioned cured concrete was approximately 30% lower than the control for both types of superplasticizers. At a 1.0% dosage level the Rheobuild-1000 concrete showed a 58% decrease

Table-9. Test Results of Shrinkage and Creep at Five Months

Kind of Concrete	Applied Stress (psi)	% of fc′	Total Strain 10^{-6}	Total Specific Creep 10^{-6}/psi	Basic Strain 10^{-6}	Basic Specific Creep 10^{-6}/psi	Shrinkage 10^{-6}	Elastic Strain 10^{-6}
Control AC	1323.8	25.0	1254.7	.948	951.2	.716	303.5	454.8
Control MR	2576.2	50.0	1247.0	.484	1247.0	.484	0	396.1
NP-20 AC 0.5%	1490.8	26.3	1089.6	.731	866.2	.581	212.6	372.9
NP-20 AC 1.0%	1490.8	25.0	1150.0	.771	900.2	.604	237.5	389.5
NP-20 MR 0.5%	1432.4	26.7	585.4	.409	585.4	.409	0	323.0
NP-20 MR 1.0%	1432.4	25.0	597.9	.417	597.9	.417	0	327.1
Rheo. AC 0.5%	1871.0	31.2	1300.0	.695	1019.9	.545	267.1	508.3
Rheo. AC 1.0%	1871.0	25.0	991.7	.530	857.1	.458	127.5	383.3
Rheo. MR 0.5%	1740.1	30.7	691.7	.398	691.7	.398	0	435.4
Rheo. MR 1.0%	1740.1	25.0	612.5	.352	612.5	.352	0	400.0

in drying shrinkage while the NP-20 concrete decreased drying shrinkage by 22%. As reported by Hattori6), it is thought that a decrease in drying shrinkage with the addition of a superplasticizer is generally attributed to the decrease in specific area of the hydrated gel. It may be considered that the small amount of additional water which forms an integral part of the superplasticizer will decrease the cement paste content and probably induce correspondingly lower shrinkage.

The results of this test are similar to the results obtained by Brooks7) and Shoya8) who argued that the addition of superplasticizer reduce the shrinkage of plain concrete. Based on the previous discussion, it is therefore very important to select the type of superplasticizer carefully and to execute to wet curing fully in order to reduce shrinkage by the application of superplasticizer.

(e) Creep

The test results obtained for creep deformation of superplasticized concrete are given in

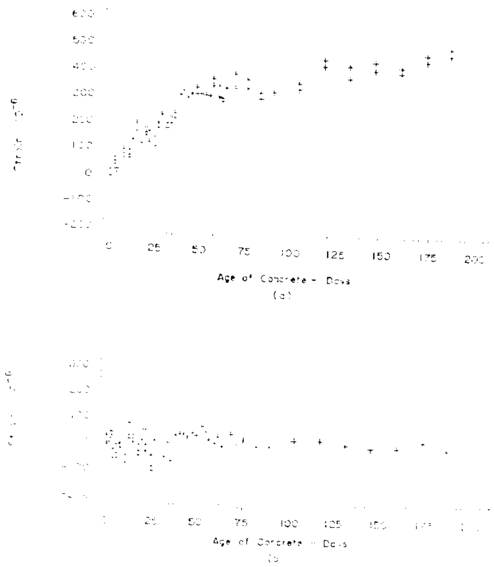

Fig. 4. Shrinkage Strain for 0.5% Dosage of NP-20 Superplasticized Concrete Stored in the (a) Air Conditioned Room and (b) the Moist Room

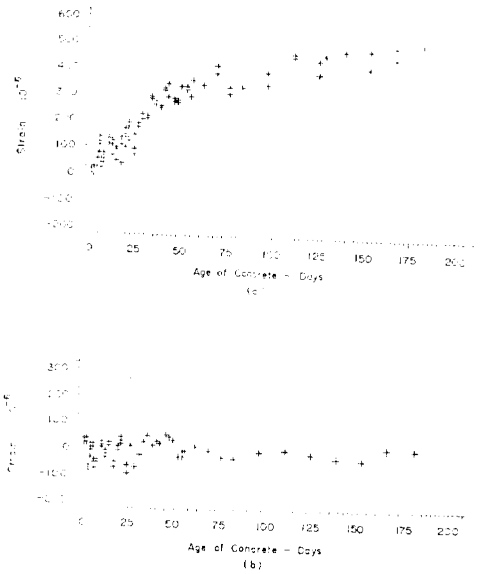

Fig. 5. Shrinkage Strain for 0.5% Dosage of Rheobuild-1000 Superplasticized Concrete Stored in the (a) Air Conditioned Room and (b) the Moist Room

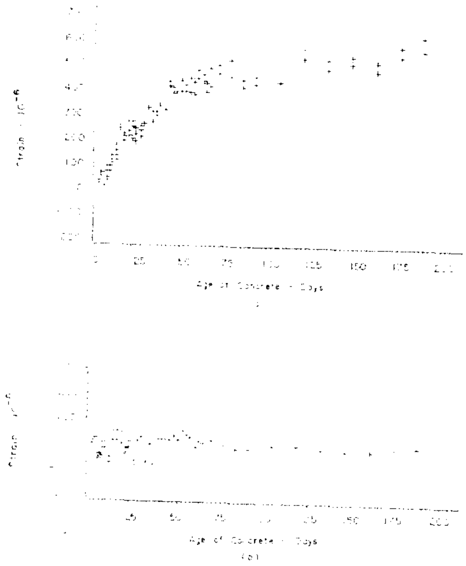

Fig. 6. Shrinkage Strain for 1.0% Dosage of NP-20 Superplasticized Concrete Stored in the (a) Air Conditioned Room and (b) the Moist Room

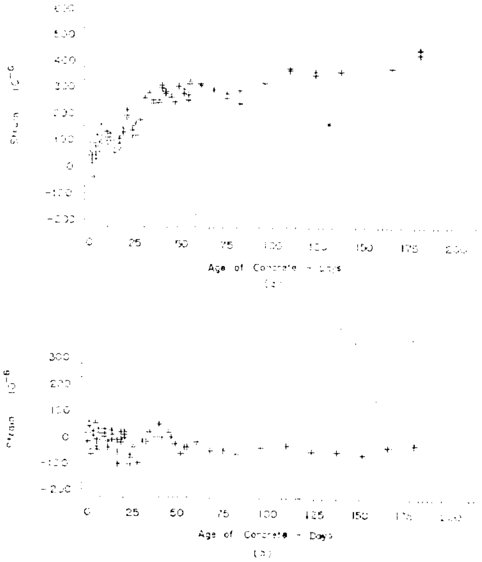

Fig. 7. Shrinkage Strain for 1.0% Dosage of Rheobuild-1000 Superplasticized Concrete Stored in the (a) Air Conditioned Room and (b) the Moist Room

Table 9 and Fig. 8-13. Table 8 shows the test results of creep at a constant initial stress/strength ratio and Fig. 8-13 for superplasticized concrete cured in moist room and air-conditioned room.

For moist room cured concrete, the specific creep decreased by an average of 19% with the addition of a superplasticizer over the specific creep of the control concrete. In contrast, the air-conditioned cured concrete decreased in specific creep by 24% above that of the control concrete. This may indicate that the greatest influence upon creep is that of moisture. That is, creep is increased by adsorption of water. This decrease in creep is concurrent with decrease in drying shrinkage. This is similar to the trend as reported by Mindess and Young9). It is generally stated that superplasticizers that decrease drying shrinkage also decrease specific creep, since, like shrinkage, creep is a paste property. A comparison of specific creep at differing dosage levels showed no consistent trends, although the superplasticizer Rheobuild-1000

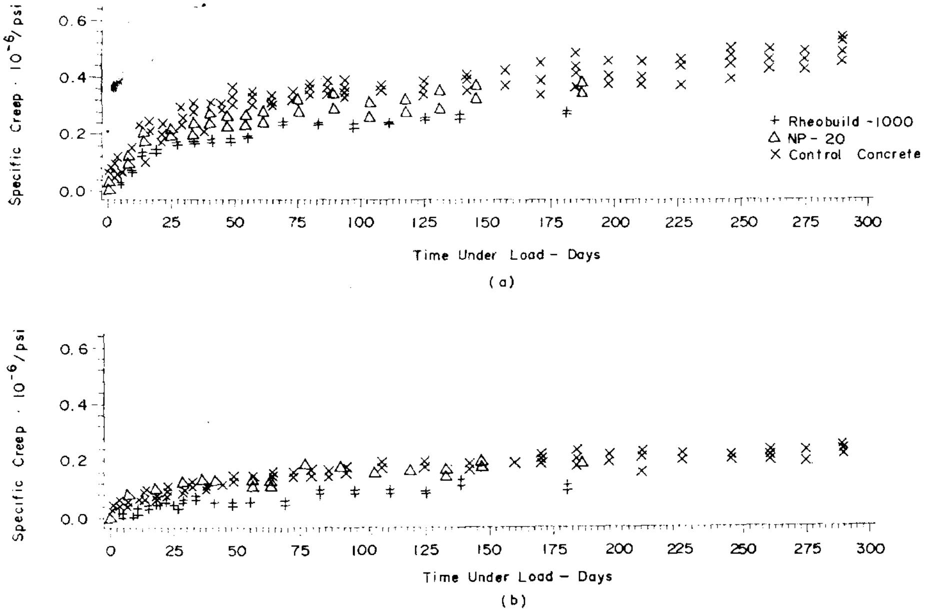

Fig. 8. Specific Creep at 1.0% Dosage Level Stored in the (a) Air Conditioned Room and (b) the Moist Room

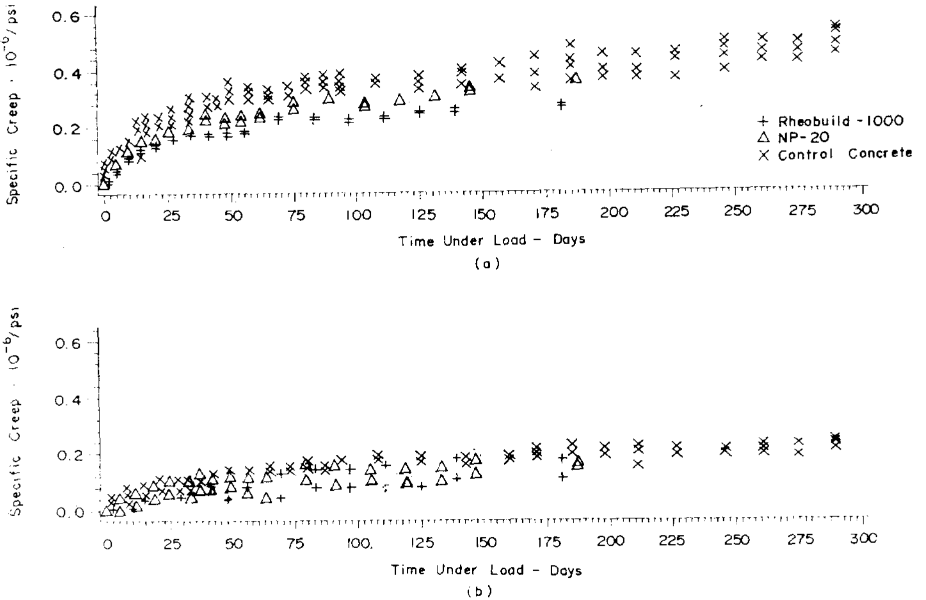

Fig. 9. Specific Creep at 0.5% Dosage Level Stored in the (a) Air Conditioned Room and (b) the Moist Room

exhibits less creep under both dosage levels of 0.5% and 1.0% and all storage conditions, than that of the superplasticizer of NP-20.

Test results in Table 9 show that total creep and total specific creep for the superplasticized concrete are significantly less than those for the control concrete, by an average 22% and 25%, respectively.

This is similar to the trend as reported by Dhir[10] that superplasticized concrete exhibited

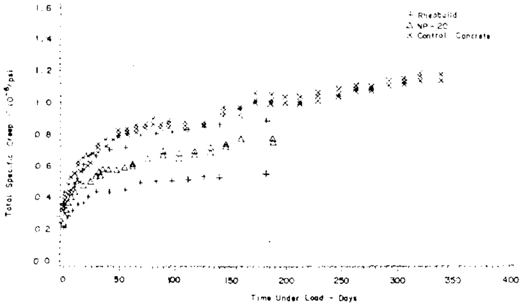

Fig. 10. **Total Specific Creep at 0.5% Dosage Level Stored in the Air Conditioned Room**

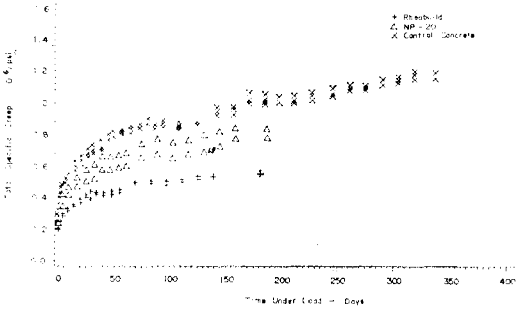

Fig. 11. **Total Specific Creep at 1.0% Dosage Level Stored in the Air Conditioned Room**

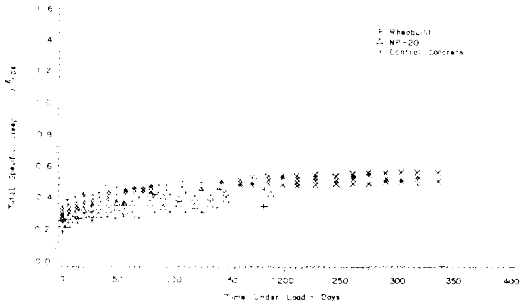

Fig. 12. **Total Specific Creep at 0.5% Dosage Level Stored in the Moist Room**

lower total specific creep than the control concrete. This property of the superplasticized concrete is considered to be favorable for the production of prestressed concrete. On the other hand, it is thought that the many different factors which affect the specific behavior of those superplasticizers in concrete are often closely interrelated and they are not completely understood or quantitatively predictable.

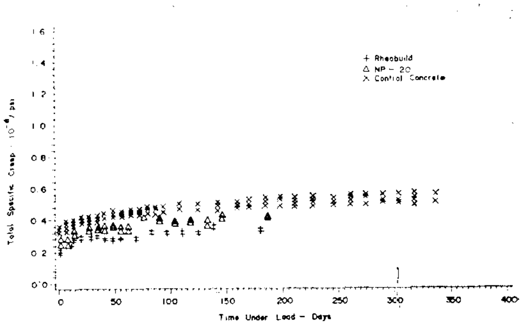

Fig. 13. **Total Specific Creep at 1.0% Dosage Level Stored in the Moist Room**

Ⅴ. Conclusion

Experimental attempts were made to investigate the water reduction, compressive and tensile strengths, modulus of elasticity, drying shrinkage and creep of rich-mix concrete with Miami Oolite aggregates by the use of superplasticizers. Superplasticizers permitted a significant water reduction while maintaining the same workability. The compressive and tensile strengths of superplasticized concrete were significantly higner than those of the control concrete and the modulus of elasticity of superplasticized concrete trends to be slightly higher than that of control concrete for the levels of superplasticizer dosage used.

It was found that the drying shrinkage and basic specific creep of superplasticized concrete were lower than those of control concrete for the levels of superplasticizer dosage used. Total creep and total specific creep of superplasticized concrete were significantly less than those of the control concrete.

In summary, it is thought that a suitable choice of superplasticizer and dosage level as well as wet curing for sufficient period are needed to obtain optimum results. The performance in concrete of a superplasticizer should therefore be evaluated by preliminary site trials under various conditions in order to establish the appropriate mix proportion, and superplasticizer dosage, to ensure that the superplasticizer produces the required effect without adverse secondry influences upon any other properties of the concrete.

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