DENKA Σ1000®

DENKA

DENKI KAGAKU KOGYO KABUSHIKI KAISYA

I. DENKA Σ1000

DENKA Σ1000 is a revolutionary additive for super-high-strength concrete products developed by Denki Kagaku Kogyo, a manufacturer of leading-edge chemicals, as a result of intense research and a wealthy experience in the manufacture of Portland cement and various additives for cement.

DENKA Σ1000 is an additive which achieves super-high-strength concrete of compressive strength over 75 N/mm^2 at 1-day age, over 85 N/mm^2 at 3-days age, and ultimately, over 100 N/mm^2 when added in the proportion of 8 to 13% of cement and steam-cured at normal pressure.

DENKA Σ1000 reacts with aluminate phases in cement such as C_3A and C_4AF to form ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$), and the reaction is completed during steam curing.
Hydration of calcium silicate phase, which is principal hydraulic mineral of cement, is accelerated during the formation of this ettringite, and an hydration degree of cement is accelerated.
As a result, chemically combined water is increased and voids are reduced, thus achieving not only super-high strength, but also chemical resistance and durability against freezing and thawing.

DENKA Σ1000 is used for concrete piles, spun pipes, box culverts, and various other concrete products, when its striking effects are fully demonstrated.

As DENKA Σ1000 is used, super-high strength is obtained in a short time with only steam curing, enabling concrete products to be shipped quickly.
Consequently, DENKA Σ1000 offers great merits including:
① Design changes can be quickly coped with.
② Construction procedures can be greatly simplified.
③ Factory production can be made more efficient.

For instance, for concrete piles,
① When used for prestressed concrete piles, piles equal to or better than autoclaved piles, can be manufactured without autoclave curing, making possible early shipment.
② When used in prestressed concrete piles, high-quality products can be manufactured.
Introduction of higher prestress is made possible by DENKA Σ1000 with quick super-high strength.

Photo 1 High-strength Ettringite generated by Σ1000 (Needle Crystal)

×8500

Ettringite crystals have higher strength than hydrated cement.
The compressive strength and modulus of elasticity of ettringite are estimated to range from 120 N/mm^2 to 200 N/mm^2 and from 4×10^4 N/mm^2 to 7×10^4 N/mm^2 respectively, whereas those of hydrated cement are 100 N/mm^2 and 3.3×10^4 N/mm^2 respectively.

II. FEATURES OF DENKA Σ1000

① **Super-High-Strength Concrete is Quickly Obtained**
Strength of 85 N/mm² or higher is obtained in just 72 hours through steam curing at normal pressure. This super-high strength is attained even more quickly if high-early-strength cement is used.

② **High Durability against Freezing and Thawing**
Equal to or better than air-entrained concrete.

③ **No Effect on Set Time and Stable Properties**
Equivalent to ordinary Portland cement.

④ **Usable in Slurry Form**
Effectiveness is unchanged when Σ1000 is dissolved in water.

⑤ **High Weathering Resistance**
Effectiveness is not impaired with long-time storage.

⑥ **No Alkali Reduction in Hardened Mass**
DENKA Σ1000 contains no hazardous substances for cement such as chloride, so reinforcing bars will not rust.

III. APPLICATION EXAMPLE OF DENKA Σ1000

1. Test Results of Prestressed Concrete Piles with Σ1000

Table 1 Mix Proportions

Gmax (mm)	Slump (cm)	s/a (%)	w/c (%)	OPC (kg/m³)	Σ1000 (kg/m³)	Water (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Super-plasticizer (kg/m³)
20	5	38	29	480	48	132	652	1154	7.2

Note: W/C = (Water + Water Reducing Agent) / OPC

Figure 1 Curing Method

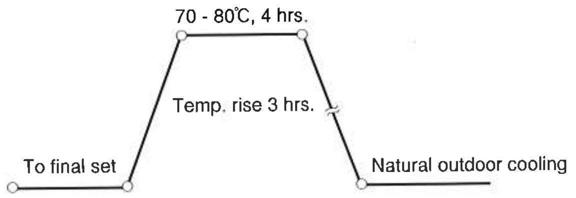


Table 2 Physical Properties of Specimens

Item \ Age (day)	Σ1000 added		Plain Concrete	
	1	7	1	7
Compressive strength (N/mm²)	84	94	58	67
Young's modulus (N/mm²)	3.8×10^4	4.5×10^4	—	—
Flexural strength (N/mm²)	7.5	9.0	5.2	6.4
Tensile strength (N/mm²)	5.3	7.5	—	—

Table 3 Dimensions and Test Result of Prestressed Concrete Pile

Dimensions		Type	Prestressing steel bars		Cross-sectional area of pile Ap (cm²)	Effective prestress		Flexural moment		Shear strength Qcr (t)	Bearing capacity (t)
D (mm)	Th (mm)		Diameter×number (mm)	Cross-sectional area As (cm²)		Standard	Design	Mcr (t-m)	Mu (t-m)		
400	70	A	8×10	4.00	765.8	40	43	6.7	8.4	17.9	129
		B	10×14	8.96		80	85	9.2	17.8	23.3	132
		D	14×12	15.00		120	125	11.9	27.2	28.0	132
		F	14×16	20.00		160	165	14.6	33.0	32.4	126
600	100	A	8×20	8.00	1570	40	42	22.1	34.8	36.2	264
		B	10×28	17.92		80	85	30.5	55.3	47.4	270
		D	12×32	28.80		120	125	38.8	84.5	56.8	269
		F	14×32	40.00		160	165	47.7	111.2	65.8	259

2. Test Results of Box Culvert with Σ1000

Table 4 Mix Proportions

Gmax (mm)	Slump (cm)	s/a (%)	w/c (%)	OPC (kg/m³)	Σ1000 (kg/m³)	Water (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Super-plasticizer (kg/m³)
25	12	38	32	460	36.8	141.7	658	1143	5.52

Figure 2 Curing Method (Curing with sheet)

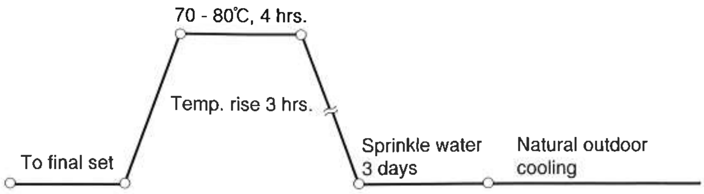
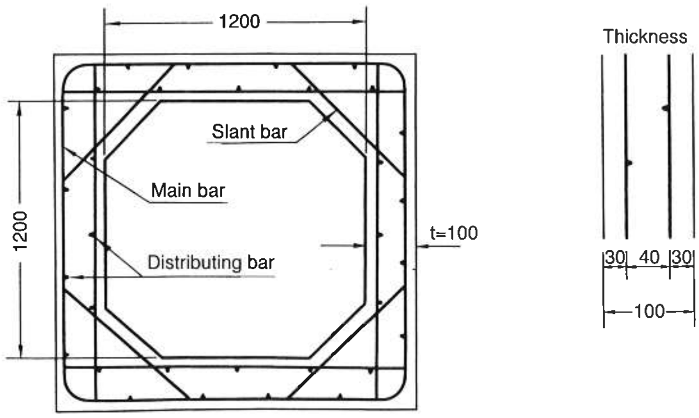


Table 5 Reinforcing Bar Arrangement

		Main bar												Distributing bar		Slant bar	
		Pile cap part				Base part				Side wall part							
		Pos.		Neg.		Pos.		Neg.		Pos.		Neg.					
H×W×L	t	Dim.	Num.	Dim.	Num.	Dim.	Num.	Dim.	Num.	Dim.	Num.	Dim.	Num.	Dim.	Num.	Dim.	Num.
1200×1200×1500	100	D13	10	D10	10	D13	10	D10	10	D10	10	D10	10	D10	32	D10	40

Figure 3 Sectional Drawing



Note: In case of plain concrete, the specifications of the distributing bar are the same as in Table 5; the thickness of both the cap part and side wall part is 16 cm.

Table 6 Test Result (Age: 7 days)

Strength of specimens (N/mm²)				Cracking load when using real box culvert (t)	
Σ1000 added		Plain concrete			
Compressive	Flexural	Compressive	Flexural	Load	Σ1000 added
75	6.8	50.3	4.5	10.4	11.5

Note: In the cracking load test, point loading is applied by using 50×20 cm square timber.

3. Test Results of Sheet Pile with Σ1000

Table 7 Mix Proportions

Gmax (mm)	Slump (cm)	s/a (%)	w/c (%)	OPC (kg/m³)	Σ1000 (kg/m³)	Water (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Super-plasticizer (kg/m³)
25	2	40	31	460	36.8	137	700	1113	5.52

Figure 4 Curing Method

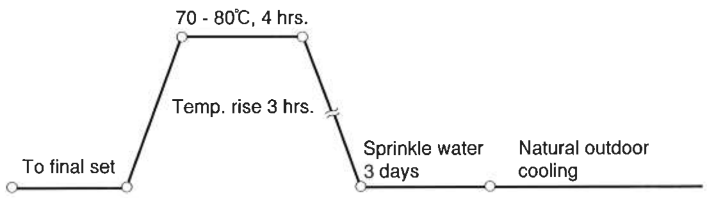


Figure 5 Sectional Drawing

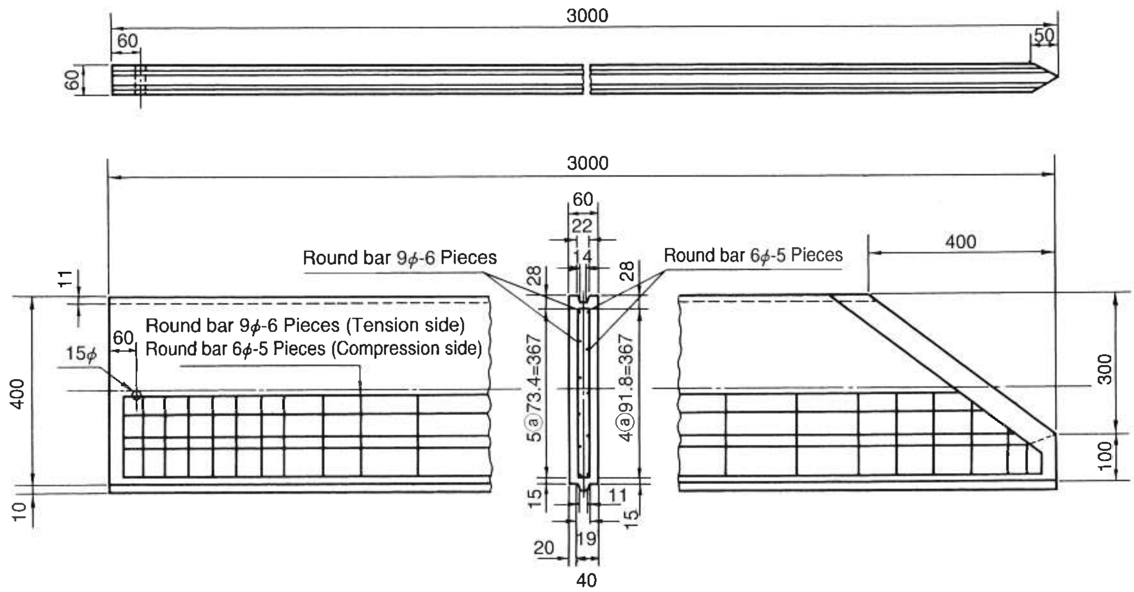


Table 8 Test Result (Age: 7 days)

	Age (days)	Strength of specimens (N/mm²)				Cracking moment using real sheet pile (t-m)	
		Σ1000 added		Plain concrete			
		Comp.	Flex.	Comp.	Flex.	per piece	per meter
Sheet pile with Σ1000	7	79.5	7.2	53.5	4.8	0.37	0.95
Sheet pile standard (Thickness : 60mm)	28	40<	—	—	—	0.32	0.82

IV. Technical Information

1. Chemical and Physical Composition of Σ1000

Table 9 Chemical Composition and Physical Properties

Ig-loss (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	SO_3 (%)	Density (g/cm^3)	Specific space/surface (cm^2/g)
5≧	12 - 22	8≧	3≧	30 - 40	30 - 48	≧2.5	≧5000

2. Setting Time

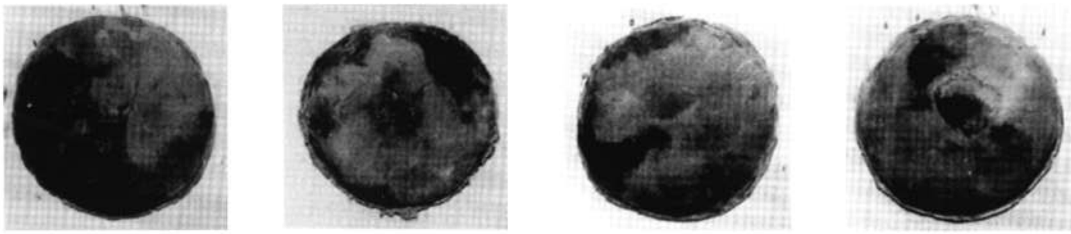
Table 10 Correlation of Setting Time and Dosage with Σ1000 (JIS R-5201)

Setting Time \ Dosage	0%	5%	7.5%	10%	12.5%
W/C	26.0%	25.6%	25.4%	25.0%	24.8%
Initial setting time (hrs.—min.)	2—28	2—26	2—25	2—23	2—22
Final setting time (hrs.—min.)	3—33	3—35	3—40	3—54	4—00

The setting time of cement paste is slightly delayed by the addition of Σ1000.

3. Soundness Properties

Photo 2 Pat Test Results (JIS R-5201 Boiling Method)



Σ1000 = 0% Σ000 = 5% Σ1000 = 10% Σ1000 = 12.5%

Soundness is good in both the immersion and boiling tests according to JIS R-5201.

4. Strength Characteristics

Table 11 Mix Proportions

Gmax (mm)	Slump (cm)	s/a (%)	w/c (%)	OPC (kg/m^3)	Σ1000 (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Super-plasticizer (kg/m^3)
20	5	38	29	486	48.6	132	697	1154	7.2

Note: Σ1000 is replaced with sand. No slump change in this case.
Sand, Gravel: Hime River Cement: DENKA

Figure 6 Curing Method

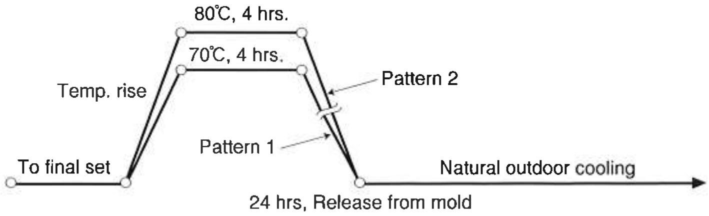
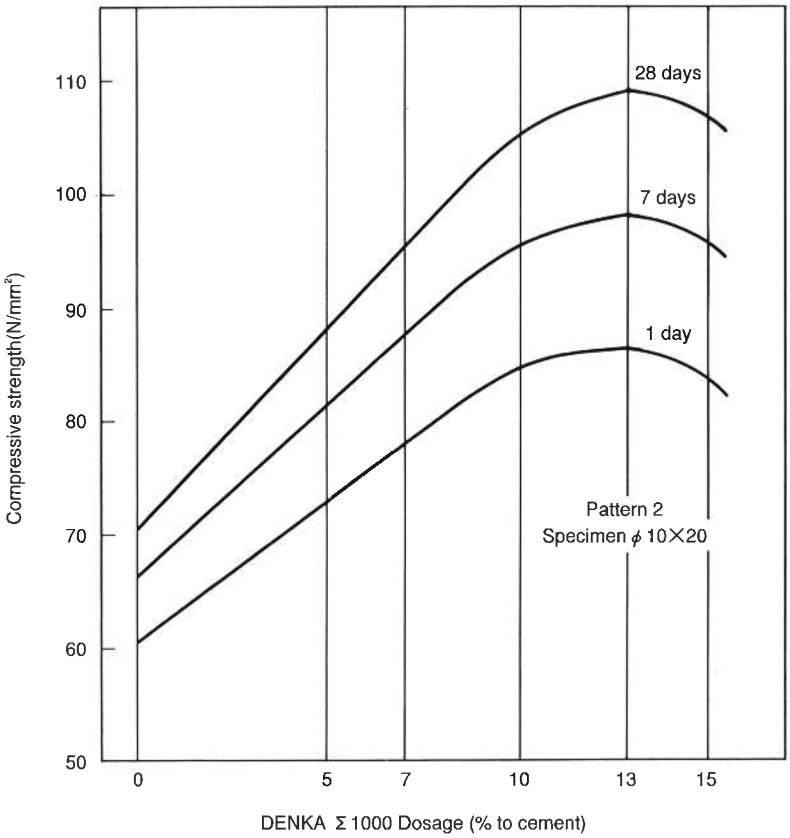
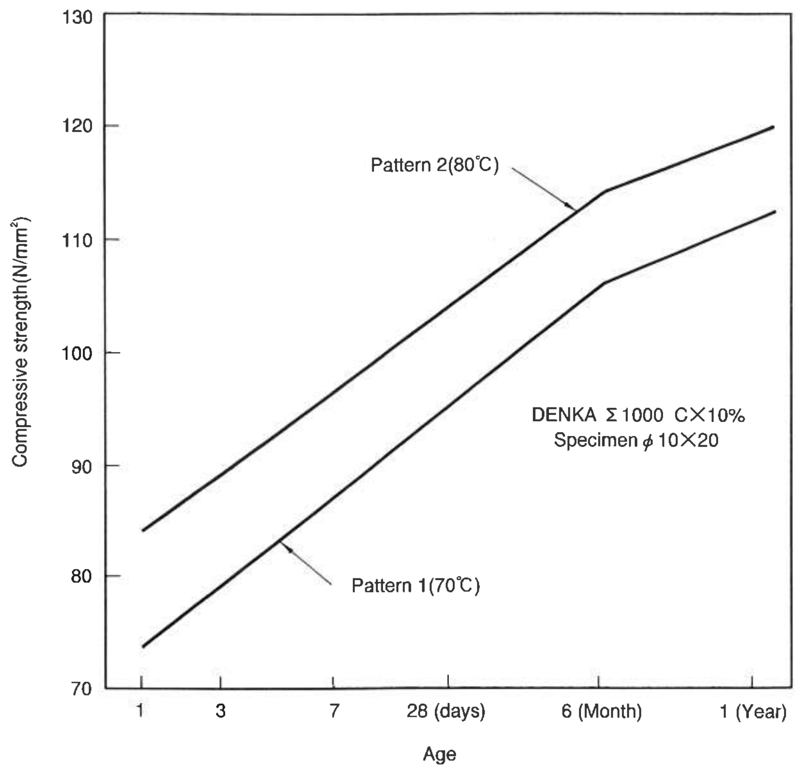


Figure 7 Correlation between DENKA Σ1000 Dosage and Compressive Strength



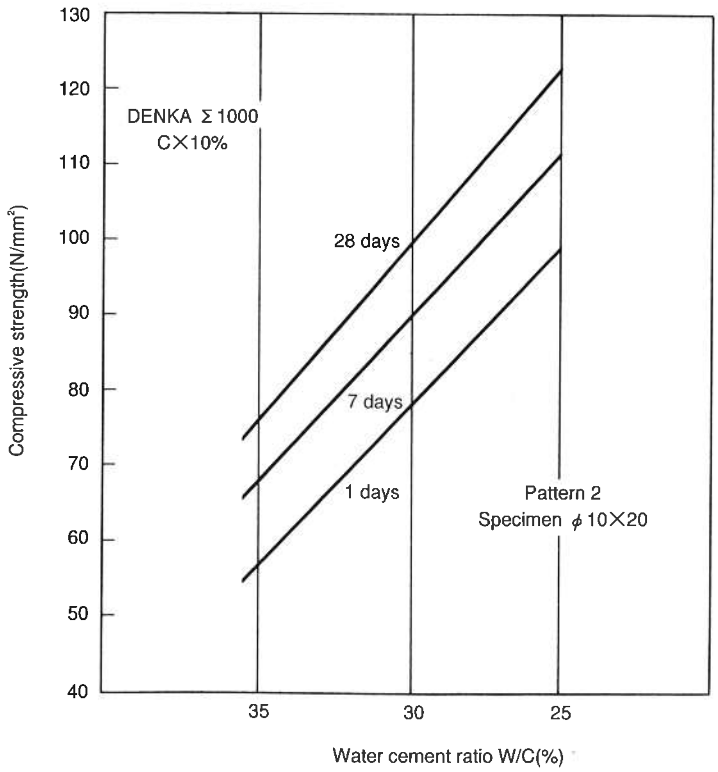
The optimum dosage of DENKA Σ1000 is from 7 to 10% to cement by weight.

Figure 8 Correlation between Steam Curing and Compressive Strength



More than 70℃ is suitable for curing concrete with DENKA Σ1000.

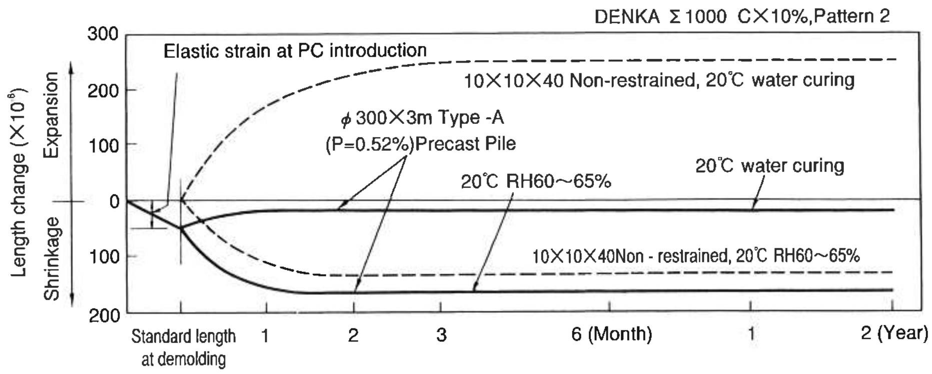
Figure 9 Correlation between Water Cement Ratio and Compressive Strength



DENKA Σ1000 shows proportional strength development corresponding to the water cement ratio.

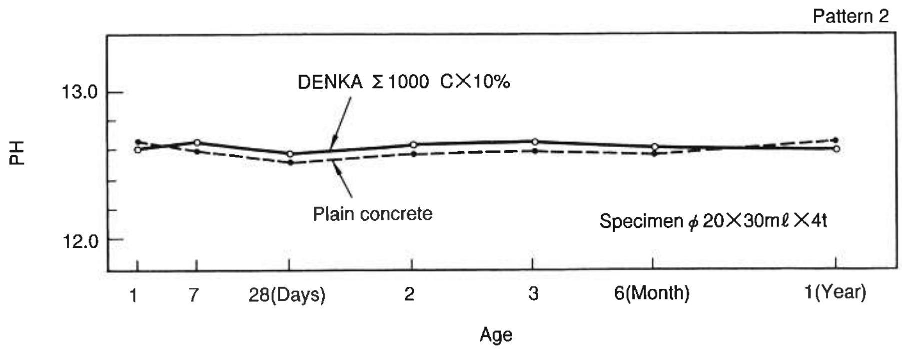
5. Change of Length

Figure 10 Change of Length



6. PH of Concrete

Figure 11 PH of Concrete



Σ1000 does not affect alkalinity.
Σ1000 contains no hazardous substances for cement such as chloride, so reinforcing bars will not rust.

7. Acid Resistance

Figure 12 Acid Resistance

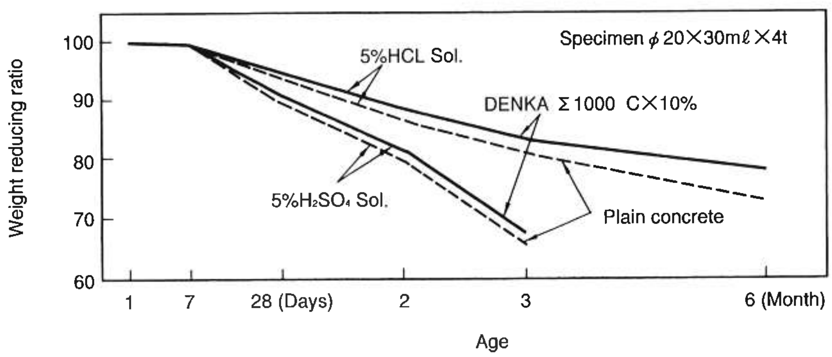
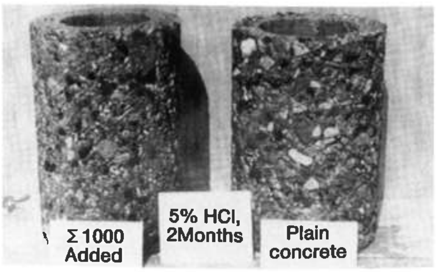
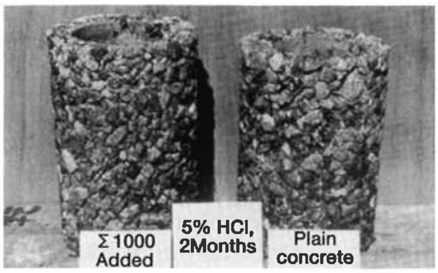


Photo 3 Test Results of Acid Resistance



5% HCL Sol.



5% H_2SO_4 Sol.

8. Durability against Freezing and Thawing

Figure 13 Test Results of Durability against Freezing and Thawing (ASTM C-666)

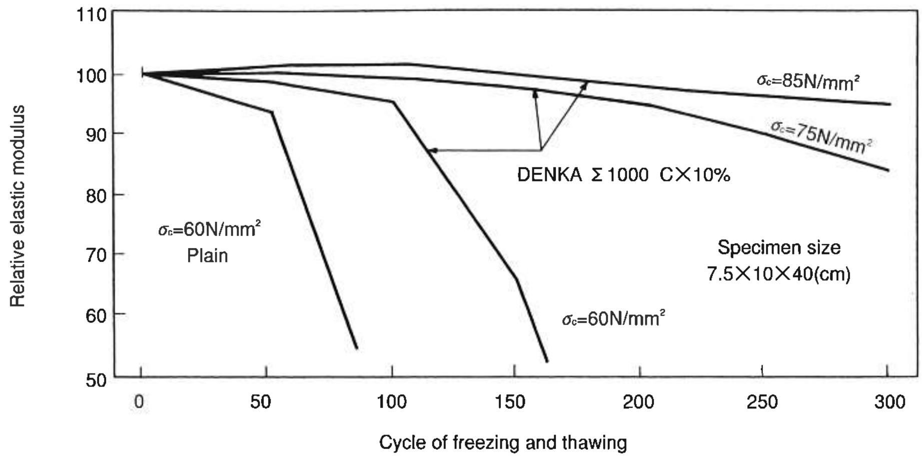
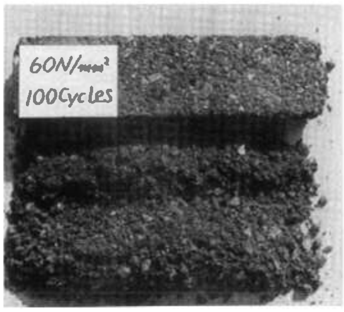
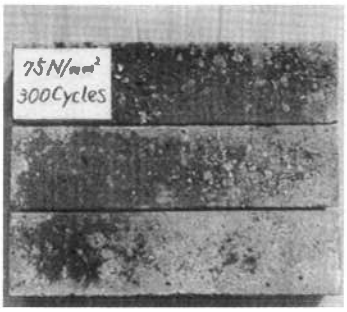


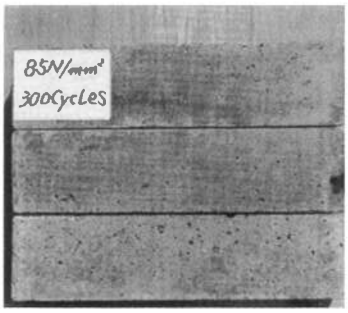
Photo 4 Specimens after Freezing and Thawing Test



σ c = 60 N/mm²
100 cycles (Plain)



σ c = 75 N/mm²
300 cycles



σ c = 85 N/mm²
300 cycles

Durability against freezing and thawing is remarkably improved by DENKA Σ1000.

V. Precautions When Using Σ1000

1. Control of water cement ratio is important.

(1)It is important to control the water cement ratio for controlling concrete strength.

(2)For making super-high-strength concrete, the water cement ratio should be lowered as much as possible in the combination with super-plasticizers.

2. Steam curing conditions

(1)Pre-curing before prestressing requires more than two hours.
Pre-curing before final setting of concrete is recommended.
If steam curing is started before setting is complete, the strength will be reduced due to physical heat-expansion.

(2)Steam curing should be performed for more than four hours at a temperature of 70° C
The higher the maturity, the higher the strength.

3. Selection of materials

(1)Cement
Strength development will differ somewhat depending upon the brand of cement.

(2)Water reducing agent
Strength will not change depending upon the type of super-plasticizer, provided the water cement ratio is fixed.

(3)Fine aggregate
Trial mixing is required in order to determine the mix proportion, taking into consideration the fact that fine particle aggregate and shell contained aggregate tend to have lower strength.

(4)Coarse aggregate
Adequately crushed sound rock should be used.

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ISO 14001 UKAS ENVIRONMENTAL MANAGEMENT 008

ISO 9001 UKAS QUALITY MANAGEMENT 008

Head Office

Sanshin Bldg.,
1-4-1,Yuraku-cho, Chiyoda-ku, Tokyo 100-8455, Japan
Telephone:(03)3507-5368
Facsimile:(03)3507-5085
URL:http://www.denka.co.jp
E-mail:denkaadd@mb.infoweb.ne.jp

Branches

Osaka, Nagoya, Fukuoka, Niigata, Hokuriku, Sapporo, Nagano, Tohoku

Research Center

Machida(Tokyo)

Plants

Omi, Omuta, Chiba, Shibukawa

Denka Corporation

780 Third Avenue, 32nd Floor,
New York, NY 10017, U.S.A.
Telephone:(212)688-8700
Facsimile:(212)688-8727

Denka Chemicals Gmbh

Konigsallee 60, 40212 Dusseldort, F.R.Germany
Telephone:(0211)130990
Facsimile:(0211)329942

Denka Chemical Asia Private Limited

Hong Leong Building,
16 Raffles Quay #18-03, Singapore 0104
Telephone:62241305
Facsimile:62243840

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