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March 1995

Preliminary Investigation of Ash Bonding Chemicals Corporation Cement in High-Early Strength Concrete

by *Billy D. Neeley*

Prepared for Federal Highway Administration

and Concrete Technology Information Analysis Center
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3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for Federal Highway Administration
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and Concrete Technology Information Analysis Center
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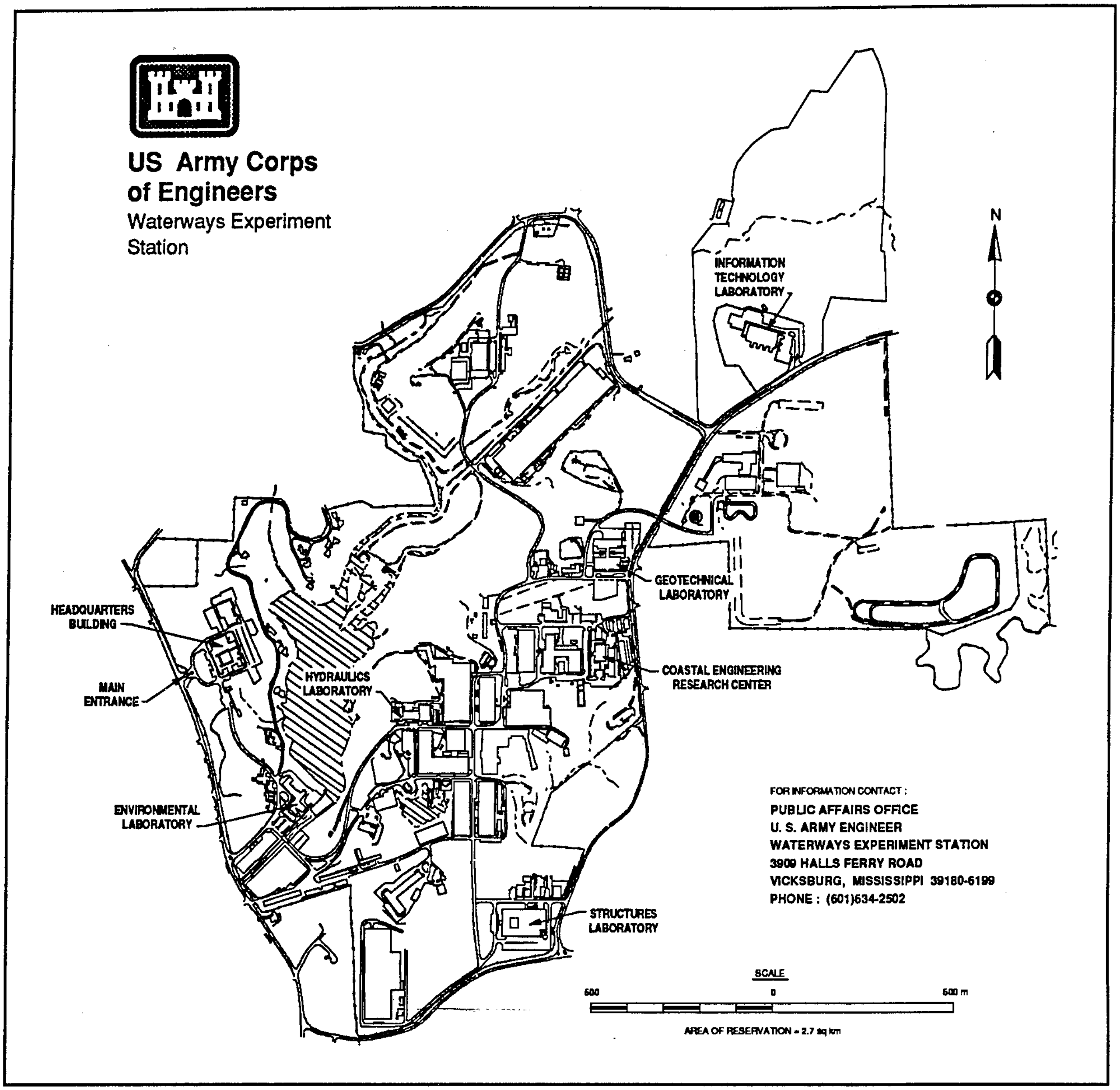

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Preface

The investigation described in this report was conducted for the Federal Highway Administration under the oversight of Mr. Thomas Pasko, Jr., Director, Office of Advanced Research. The work was funded under authority granted in Federal Highway Administration Form DOT F 2300.1, agreement No. DTFH61-94-Y-00070. The funds for publication of this report were provided by the Concrete Technology Information Analysis Center (CTIAC); this is CTIAC Report No. 90.

The research was performed at the U.S. Army Engineer Waterways Experiment station (WES), Structures Laboratory (SL), under the general supervision of Messrs. Bryant Mather, Director, SL; James T. Ballard, Assistant Director, SL; and Dr. Tony C. Liu, Acting Chief, Concrete Technology Division (CTD), SL. Direct supervision was provided by Mr. Steven A. Ragan, Chief, Engineering Mechanics Branch (EMB), CTD. The Principal Investigators were Messrs. Billy D. Neeley, EMB, and Tony B. Husbands, Engineering Sciences Branch (ESB). The concrete mixtures were proportioned by Mr. Neeley and Mr. William D. Kirkpatrick, Ash Bonding Chemicals (ABC) Corporation. The concrete mixtures were batched, mixed, and tested for fresh properties by Messrs. Neeley, Mike Lloyd, and Jimmy Hall, EMB, and Mr. Kirkpatrick, ABC Corp. Compressive strength and freezing-and-thawing tests were conducted by Messrs. Lloyd and Hall. Chloride permeability tests were conducted by Mrs. Linda Mayfield and Ms. Bobbie Guerrero, EMB. Length change measurements were made by Messrs. Melvin Sykes and Ron Robinson, ESB. This report was prepared by Mr. Neeley.

At the time of preparation of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins[1]
fluid ounces per cubic yard	38.6738	millilitres per cubic metre
fluid ounces	29.57353	millilitres
inches	25.4	millimetres
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain kelvin (K) readings, use K = (5/9) (F - 32) + 273.15.

Preliminary Investigation of Ash Bonding Chemicals Corporation Cement in High-Early Strength Concrete

The Federal Highway Administration requested that the U.S. Army Engineer Waterways Experiment Station (WES) test concrete mixtures produced with the cementitious material from Ash Bonding Chemicals Corporation (ABC Corp.). Two cementitious materials from ABC Corp. were included in the study. Concrete mixtures produced with Type III portland cement, including a water-reducing admixture (WRA) and a high-range water-reducing admixture (HRWRA), were tested for comparison. A test matrix is shown in Table 1.

Table 1
Test Matrix

Type Cement[1]	Cement, pcy	Type[2] Coarse Aggregate	NMS Coarse Aggregate, in.	Air Content, %	Slump, in.	w/c[3]	No. of Replicate Batches
ABC1	752	LS	3/4	6 ± 0.5	4 ± 1	NS	3
ABC1	752	N	1	5.5 ± 0.5	4 ± 1	NS	3
ABC2	752	LS	3/4	6 ± 0.5	4 ± 1	NS	3
ABC2	752	N	1	5.5 ± 0.5	4 ± 1	NS	3
PC III	752	LS	3/4	6 ± 0.5	4 ± 1	0.4 max	3
PC III	752	N	1	5.5 ± 0.5	4 ± 1	0.4 max	3

[1] ABC1 - Fly ash source: Southwestern Electric Power, Gentry, AR
ABC2 - Fly ash source: Kansas Power & Light, St. Mary's, KS
PCIII - Type III portland cement
[2] LS - Crushed limestone
N - Natural siliceous river gravel
[3] NS - Not specified

ABC cement is a new, high-early strength, blended hydraulic cement. Both the material composition and the mixing process have been patented. However, the owners of the patent, who are also the owners of ABC Corp., state that they intend to make the technology available to the producers, marketers, and users of the subbituminous fly ash. According to ABC Corp., the ABC cementitious material is composed primarily of subbituminous Class C fly ash. The Class C fly ash generally makes up 77 to 95 percent by weight of the total material. The remaining part can be slag and/or portland cement. Four readily available chemical compounds are used in small quantities to control the workability and setting time of the cementitious material, to enhance the strength, and improve the durability. These admixtures are a set-suspending agent, an activator (A), a modifying retarder (B), and an accelerator (C). The set-suspending agent is added to the ABC cementitious material before it is mixed with water. ABC Corp. reports that a mixture of ABC cementitious material, water, and the set-suspending agent has been held in a plastic state for up to two weeks. The set-suspension can then be terminated with the addition of the A, B, and C admixtures. The order in which these admixtures are added and their respective quantities influence the working time and early-strength development of the hardened material. According to ABC Corp., when all three admixtures are added simultaneously, their quantities can be adjusted to provide whatever working time the customer desires. If the three admixtures are added individually in the order B, C, A, the working time is purported to be shortened. Or, if the three admixtures are added individually in the order B, A, C, the working time is purported to be lengthened.

A representative of ABC Corp. visited the WES on 11-14 Jul 94 during which time he worked with our staff to proportion and mix concrete mixtures using the ABC cementitious material. ABC cementitious material from two fly ash sources in sufficient quantity to produce 27 batches of concrete was delivered to WES. The goal for the effort during this week was to establish the initial mixture proportions for the ABC mixtures. This was the first time large batches of concrete mixtures had been produced using the ABC materials. The primary developmental work conducted by ABC Corp. had been with mortars without air entrainment. Therefore, the appropriate amount of set-suspending agent, A, B, and C, had to be determined for the concrete mixtures. Also, the concrete mixtures had to be air entrained. Ten batches of concrete were produced and tested for fresh properties during this week. The ABC Corp. representative was responsible for determining the amount of set-suspending agent, A, B, and C. A member of our staff calculated the proportions of cementitious material, fine aggregate, coarse aggregate, water, and AEA. In nine of the batches the A, B, and C admixtures were added to the concrete simultaneously. A brief summary of the information learned during this week is as follows:

a. The dosages of set-suspending agent, A, B, and C, cannot be translated directly from mortars to concrete.

b. We were unable to entrain air using a neutralized Vinsol resin air-entraining admixture (AEA). Air was entrained using a synthetic AEA, Micro-Air, made by Master Builders, Inc., Cleveland, OH. The dosage of AEA required is higher than typical for concrete made with Type I portland cement but similar to that required for concrete made with Type III portland cement.

c. It appears that air can be entrained by charging the AEA with the mixing water in accordance with ASTM C 192 or by adding the AEA directly to the freshly mixed concrete after the A, B, and C admixtures.

d. The working time of the fresh concrete can be changed by adjusting the amount of the set-suspending agent, A, B, and C.

e. The entrained air appears to become less stable when the concrete remains plastic for extended periods of time (1-1/2 hours or more) after all admixtures have been mixed into the concrete.

The ABC Corp. representative returned to WES on 8-11 Aug 94 during which time concrete was produced using the two ABC Corp. cementitious materials and two different coarse aggregates, a 19.0 mm (3/4-in.) nominal maximum size (NMS) crushed limestone and a 25.0-mm (1-in.) NMS natural river gravel. Test reports describing the two coarse aggregates and the fine aggregate are given in Plates 1-3. Again, the ABC Corp. representative was responsible for determining the amount of set-suspending agent, A, B, and C. A member of our staff was responsible for determining the proportions of cementitious material, fine aggregate, coarse aggregate, water, and AEA. Each 1.5-cu ft batch was initially mixed according to ASTM C 192. At the end of the specified mixing sequence, the A, B, and C admixtures were premixed and added to the fresh concrete. Mixing then continued for an additional 10 min, after which ~~the~~ concrete was discharged from the mixer and the fresh properties measured. The AEA was added with the mixing water in all mixtures. The test matrix (Table 1) called for 12 concrete mixtures using the two ABC cementitious materials and the two coarse aggregates. However, over the course of the week, 18 mixtures were produced. The extra mixtures were produced because the fresh properties of some of the mixtures did not meet the specified requirements for slump and air content (Table 1). During the week 15-18 Aug 94, our staff produced two additional mixtures using the ABC Corp. cementitious material and seven mixtures using a Type III portland cement with WRA and HRWRA and the two coarse aggregates. The A, B, and C admixtures were added individually in the two mixtures (GL5 and GL6) produced with the ABC Corp. cementitious materials, after the initial mixing sequence according to ASTM C 192. The concrete was mixed 3-1/2 minutes after addition of each admixture. The seven mixtures produced with Type III portland cement were mixed according to ASTM C 192. The concrete mixture proportions for all 27 mixtures are given in Table 2.

Table 2
Mixture Proportions

Mixture No.[1]	SSD Batch Weights, lb/cu yd									
	Cement	Fine Aggregate	Coarse Aggregate	Water	Air Entraining Admixture[2]	Set-Suspending Agent	(A) Activator	(B) Modifying Retarder	(C) Accelerator	w/c[3]
GL1	752	1199	1874	169	56.4	23.4	11.4	5.9	11.4	0.229
GL2	752	1199	1874	169	63.9	23.4	11.4	5.9	11.4	0.229
GL3	752	1199	1874	168	75.2	23.4	11.4	5.9	11.4	0.229
GL4	752	1199	1874	168	75.2	21.7	11.4	5.7	11.4	0.229
GL5	752	1199	1874	168	67.7	21.7	11.4	5.7	11.4	0.229
GL6	752	1199	1874	168	75.2	21.7	11.4	5.7	11.4	0.229
GN1	752	1162	1859	168	75.2	22.1	11.4	5.9	11.4	0.223
GN2	752	1162	1859	161	67.6	22.1	11.4	5.9	11.4	0.219
GN3	752	1162	1859	162	56.6	22.1	11.4	5.9	11.4	0.219
GN4	752	1162	1859	163	43.2	22.1	11.4	5.9	11.4	0.219
KL1	752	1199	1874	169	63.9	20.8	11.7	7.2	11.7	0.229
KL2	752	1205	1884	162	56.4	20.6	11.7	6.9	11.7	0.219
KL3	752	1205	1884	162	53.0	20.6	11.7	6.9	11.7	0.219
KL4	752	1205	1884	162	45.6	20.6	11.7	6.9	11.7	0.219
KL5	752	1205	1884	162	45.6	20.6	11.7	6.9	11.7	0.219
KN1	752	1162	1859	161	43.2	20.0	11.7	6.5	11.7	0.219
KN2	752	1162	1859	164	22.6	20.0	11.7	7.2	11.7	0.219
KN3	752	1169	1870	157	22.6	20.0	11.5	7.2	11.5	0.210
KN4	752	1169	1870	157	33.5	20.0	11.5	7.2	11.5	0.210
KN5	752	1173	1877	152	37.6	20.0	11.2	7.2	11.2	0.205
Mixture No.	**Cement**	**Fine Aggregate**	**Coarse Aggregate**	**Water**	**Air Entraining Admixture**	**WRA[2,4]**	**HRWRA[2,5]**	--	--	**w/c**
PL1	752	1102	1722	278	37.6	37.6	83.4	--	--	0.380
PL2	752	1094	1710	285	45.1	37.6	75.2	--	--	0.390
PL3	752	1094	1710	285	45.1	37.6	75.2	--	--	0.390
PL4	752	1094	1710	285	45.1	37.6	75.2	--	--	0.390
PN1	752	1056	1689	285	41.4	37.6	75.2	--	--	0.390
PN2	752	1056	1689	285	41.4	37.6	75.2	--	--	0.390
PN3	752	1056	1689	285	45.1	37.6	75.2	--	--	0.390

[1] G - ABC1 cement
K - ABC2 cement
P - Type III portland cement
L - Crushed limestone coarse aggregate
N - Natural siliceous river gravel coarse aggregate

[2] Fluid ounces per cu yd
[3] Water-cement ratio includes water fraction of liquid admixtures
[4] Type A water-reducing admixture
[5] Type F high-range water-reducing admixture

The fresh properties measured on the concrete mixtures were slump (ASTM C 143), unit weight (ASTM C 138), air content (ASTM C 231), temperature (ASTM C 1064), and time of setting (ASTM C 403). The test results are given in Table 3. Upon examination of the fresh properties data, the following observations can be made:

a. Concrete can be produced with the ABC Corp. cementitious material having fresh properties similar to those of concrete produced with Type III portland cement, WRA, and HRWRA.

b. The setting time of concrete made with the ABC Corp. cementitious materials can be controlled by adjusting the dosages of the set-suspending agent, A, B, and C. The specified range for this investigation was for a final set in 60 to 90 min. Mixtures GL4, GL5, GL6, GN1, GN2, GN4, KL2, KL3, KL5, KN2, and KN3 met this requirement. Mixtures GL1, GL2, and GL3, had a longer setting time. Notice that when the set-suspending agent and B were reduced in the three subsequent mixtures, the setting time was shortened. Likewise, mixture KL1 had a delayed setting. In this case a reduction in B shortened the setting time in the four subsequent mixtures. The opposite effect can be seen in the KN mixtures. Mixture KN1 had a setting time that was too quick. An increase in B for mixture KN2 and a decrease in A and C for mixtures KN3 and KN4 delayed the setting time.

c. The amount of AEA required to entrain an appropriate amount of air into the concrete mixtures produced with the ABC Corp. cementitious material was different for the two fly ash sources. Approximately 50 percent more AEA was required to entrain air in concrete produced with the fly ash from Gentry, AR, than was required to entrain air in concrete made with the fly ash from St. Marys, KS. The dosage of AEA required to entrain air in the mixtures produced with Type III portland cement, WRA, and HRWRA was between those needed for the two ABC Corp. materials.

d. There was more variation in the slump and air content for the mixtures produced with the two ABC Corp. materials than for the mixtures produced with the Type III portland cement, WRA, and HRWRA. Part of this variation might be attributed to inexperience, both ours and the ABC Corp. representative's, in producing concrete mixtures using the ABC Corp. cementitious materials. As stated in paragraph 2 above, developmental work previously done by ABC Corp. had primarily been with mortars and without air entrainment. It appears that there may be some interaction between the various admixtures, as well as reaction to different charging sequences for the admixtures, that we do not yet fully understand. A few unexpected test results can likely be attributed to this. For example, notice the slump and air content for mixtures GL4, GL5, and GL6. The mixture proportions are identical except for a small change in the AEA for mixture GL5.

Table 3
Fresh and Hardened Properties

Mixture No.	Slump, in.	Unit Weight, lb/cu ft	Air Content, %	Temp, °F	Initial Time of Set hrs:min	Final Time of Set hrs:min	Compressive Strength, psi[1]			Durability Factor	Weight Loss, %	Length Change, %[4]	Charge Passed, coulombs	Chloride Ion Penetrability
							1-day	7-day	28-day					
GL1	3.75	150.4	4.5	77	3:01	3:32	3890	6000	8160	81	1.3	0.001	†[3]	†
GL2	2.5	149.6	4.8	75	1:35	1:52	4720	6160	8670	88	1.0	0.002	985	Very low
GL3	4	147.8	5.7	76	2:30	2:49	3490	5450	7640	81	1.5	0.000	1190	Low
GL4	5.25	146.0	7.2	74	1:06	1:16	3970	5550	7680	85	1.3	0.003	1065	Low
GL5	1.25	153.0	3.0	74	1:17	1:28	5080	7320	8830	82	0.4	-0.003	†	†
GL6	7.25	142.8	9.3	72	0:53	1:04	2640	4180	5250	91	0.7	-0.005	†	†
GN1	7.75	139.8	7.7	76	1:10	1:19	2920	4620	4960	28	0.1	-0.001	†	†
GN2	4.75	142.0	6.7	76	1:09	1:17	3430	4690	5870	23	0.0	-0.003	1255	Low
GN3	4.75	141.6	6.6	76	1:22	1:34	3070	4420	5250	18	0.0	0.004	1726	Low
GN4	6.5	144.2	4.9	77	1:10	1:20	4220	5940	7210	15	0.0	-0.003	1501	Low
KL1	5.5	144.6	7.8	77	1:44	1:58	3120	4830	7020	69	1.6	0.007	†	†
KL2	6.5	147.6	6.5	76	1:05	1:15	4420	6590	7700	85	0.3	0.009	597	Very low
KL3	7	147.6	6.5	77	0:55	1:02	5160	6360	7520	60	0.3	-0.001	751	Very low
KL4	6	144.2	8.3	77	**[2]	**	**	**	**	**	**	**	**	**
KL5	6	149.6	5.4	75	0:59	1:07	4820	7080	8560	86	0.4	0.010	774	Very low
KN1	8.25	139.6	8.1	77	0:35	0:40	3130	4360	5530	17	0.0	0.014	†	†
KN2	9	143.2	5.6	78	0:56	1:02	3610	5070	6510	19	0.1	0.012	984	Very low
KN3	4.75	147.0	3.4	77	1:05	1:15	4410	6320	8080	28	0.2	0.002	1210	Low
KN4	8.25	144.4	5.3	77	0:50	0:55	3850	6140	7460	24	0.0	0.006	1199	Low
KN5	3.5	143.8	5.5	78	**	**	5510	7680	8940	27	0.1	0.016	†	†
PL1	2	147.2	4.0	75	4:55	6:28	5200	7880	8970	55	0.7	-0.015	†	†
PL2	2.5	144.2	5.7	74	4:59	6:25	4660	6550	7630	73	0.9	-0.012	2588	Moderate
PL3	2.25	144.2	5.5	76	4:32	5:52	4530	6600	7290	79	1.1	-0.015	2354	Moderate
PL4	2.5	144.4	5.2	76	4:33	5:52	4200	6280	6610	80	0.9	-0.014	3549	Moderate
PN1	2.75	140.2	5.0	77	4:43	6:20	3600	5960	6370	24	0.0	-0.008	3068	Moderate
PN2	3	140.4	4.7	77	4:37	5:53	3960	5760	6790	32	0.2	-0.015	2863	Moderate
PN3	2.25	140.4	4.7	78	4:25	5:37	4150	5960	6420	19	0.1	-0.011	3071	Moderate

1 Each value represents the average of two test specimens.
2 ** Mixture flash set before specimens could be made.
3 † Not tested.
4 After 28 days of moist curing followed by 28-day curing at 50% Rh; (-) indicates shrinkage.

However, the charging sequence for the A, B, and C admixtures was different in each case. A, B, and C were premixed and added to the concrete simultaneously in mixture GL4. In mixtures GL5 and GL6, the A, B, and C admixtures were added individually with 3.5 min mixing time between each addition. The order of addition for mixture GL5 was B, A, C, and for GL6, the order of addition was B, C, A. While the different charging sequence for A, B, and C produced an expected reaction in the time of setting (longer for order B, A, C (GL5) and shorter for order B, C, A (GL6)), such large changes in the slump and air content were unexpected. Based upon this one comparison, it appears that the order that the A, B, and C admixtures are added can have a significant influence on the slump and air content of the fresh concrete. Similar observations made on mixtures KL3, KL4, and KL5 also support this conclusion. All three mixtures have identical mixture proportions except for a small change in the AEA. The A, B, and C admixtures were added simultaneously to each mixture. While mixtures KL3 and KL5 had similar fresh properties, mixture KL4 was quite different; the air content was high and the mixture flash set in approximately 15 min. Afterwards, the ABC Corp. representative realized that he had not premixed the A, B, and C admixtures before they were added to the concrete. Again, this supports the conclusion that the order of addition of the A, B, and C admixtures can have a significant influence on the fresh properties of the concrete.

e. The combination of the A and C admixtures together results in a powerful water-reducing effect. This water-reducing effect allows very low water-cement ratios (w/c) to be used, approximately 0.22 for the mixtures in this investigation. As was previously noted, the manner in which these two admixtures are charged into the concrete can have a significant effect on their water-reducing properties, as reflected by the slump. Due, in part, to the very low w/c, the concrete mixtures remain very cohesive even at high slumps.

Specimens were also fabricated from each mixture to determine hardened properties. Six 4-in.-diam by 8-in.-high (102- by 204-mm) cylindrical specimens were fabricated (ASTM C 192) from each batch to determine compressive strength (ASTM C 39) at 1, 7, and 28 days age. The specimens were removed from their molds at 1 day age and stored in a moist-curing room meeting the requirements of ASTM C 511 until time of test. One 4-in.-diam by 8-in.-high (102- by 204-mm) cylindrical specimen was fabricated (ASTM C 192) from each batch to determine the concrete's ability to resist chloride ion penetration (ASTM C 1202). The specimen was removed from its mold at 1 day age and stored in a moist-curing room meeting the requirements of ASTM C 511 until approximately 25 days age. At that time a 2-in. (50-mm) slice was cut from the top of each specimen to be tested. The chloride ion penetration test was conducted on each specimen at an age of 29 ± 1 days age. One 3-1/2- by 4-1/2- by 16-in. (89- by 114- by 406-mm) prism was fabricated (ASTM C 192) from each batch to determine frost resistance (ASTM C 666, Procedure A). Each specimen was removed from its mold at 1 day age and stored in lime-saturated water in a moist-curing room meeting the requirements of ASTM C 511 for 14 days. Tests for frost resistance were initiated at 14 days age. The nominal freezing-and-thawing cycle of lowering the temperature from 40 to 0 °F (4.4 to -17.8 °C) and raising it from 0 to 40 °F (-17.8 to 4.4 °C) required 2 hr. The relative dynamic modulus and mass of each test specimen was measured at regular intervals. Testing was continued until one of the following conditions occurred: (a) the relative dynamic modulus of elasticity (Relative E) reached 60 percent, or (b) 300 freezing-and-thawing cycles were accomplished. The durability factor was calculated after completion of the test. One 3- by 3- by 10-in. (76- by 76- by 254-mm) unrestrained prism was fabricated (ASTM C 192) from each batch to determine drying shrinkage (ASTM C 157). Each specimen was removed from its mold at 1 day age and cured in lime-saturated water in a moist-curing room meeting the requirements of ASTM C 511 for 28 days. The length change was determined, and the specimens were subsequently placed in air storage at 50 percent relative humidity for an additional 28 days. Length change measurements were made at 7, 14, and 28 days after the air storage began. All test results are given in Table 3.

Upon examination of the hardened properties data, the following observations can be made:

a. Concretes produced with the ABC Corp. cementitious material can achieve high compressive strengths at 1, 7, and 28 days age. Compressive strengths at these ages were similar to those of concrete produced with the Type III portland cement containing WRA and HRWRA. The compressive strengths typically ranged from 3,500 to 4,500 psi (24.1 to 31.0 MPa) at 1 day age and 6,000 to 8,000 psi (41.4 to 55.2 MPa) at 28 days age. Although not shown in Table 3, mixture GL6 had a compressive strength of 1,540 psi (10.6 MPa) at an age of 4 hours. Only mixture GL6 was tested prior to 1 day age. Plots of the compressive strengths for mixtures GL, GN, KL, KN, PL, and PN are shown in Figures 1-6. A plot of the average compressive strength for each mixture is shown in Figure 7. As with any concrete mixture, the entrained air content has a noticeable effect upon the compressive strength. This is especially evident in mixtures GN1, KL1, and KN1. These mixtures have unnecessarily high air contents which result in compressive strengths lower than typical for those sets of mixtures. The ABC Corp. representative indicated that the amount of set-suspending agent A, B, and C admixtures should also have an effect on the compressive strength. However, there are insufficient data in this investigation to verify this claim.

b. Most mixtures produced with the 19.0-mm (3/4-in.) NMS crushed limestone coarse aggregate exhibited good frost resistance. The durability factor of all GL mixtures was above 80 percent, indicating good frost resistance. Even mixture GL5, which had only 3.0 percent air content, had a durability factor of 82 percent. Although not quite as good as the GL mixtures, most of the KL and PL mixtures also exhibited good frost resistance; exceptions were mixtures KL1, KL3, and PL1. The poor performance of mixture PL1 can be attributed to a low entrained air content (4.0 percent). It is not clear why mixtures KL1 and KL3 performed poorly. Plots of the test results for mixtures GL, KL, and PL are shown in Figures 8-10.

c. None of the mixtures produced with the 25.0-mm (1-in.) NMS natural siliceous river gravel exhibited good frost resistance. This result was not unexpected. The severity of the freezing-and-thawing exposure in the vicinity of Vicksburg, MS, is mild. Hence, since it has long been known that local gravels make concrete of very low durability factor when tested according to ASTM C 666, Procedure A, such tests are now rarely performed. Buck (1972,[1] 1976[2], 1976A[3]), in connection with research on recycled concrete, made such tests on properly air-entrained concrete using as aggregate local gravel and the laboratory reference crushed limestone and crushed concrete in which each had been used. Two sets of tests were made using local gravel. The results were:

DFE 300					
Local Gravel				Crushed Limestone	
As aggregate		As crushed concrete		As aggregate	As crushed concrete
Test 1	Test 2	Test 1	Test 2		
3	15	73	80	62	45

Therefore, these test results should not reflect negatively on either of the three cementitious materials used. Plots of the test results for mixtures GN, KN, and PN are shown in Figures 11-13. The average frost resistance for the six mixtures is shown in Figure 14.

d. Concretes produced with the ABC Corp. cementitious materials exhibited better resistance to the passage of chloride ions than concrete produced with Type III portland cement. The charge passed through

[1] Buck, Alan D. 1972. "Recycled Concrete," WES MPC-72-14, 35 pp, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] Buck, Alan D. 1976. "Recycled Concrete as a Source of Aggregate," WES MP C-76-2, 17 pp, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Also published by ASTM)

[3] Buck, Alan D. 1976A. "Recycled Concrete as a Source of Aggregate," WES MP C-76-2, Report 2, "Additional Investigations," 27 pp, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

concretes produced with the ABC Corp. cementitious materials generally ranged from approximately 700 to 1,500 coulombs during a 6-hr test period. Qualitatively, mixtures GL, GN, and KN exhibited low chloride ion penetrability while mixture KL exhibited very low chloride ion penetrability. In comparison, the charge passed through the two concretes produced with Type III portland cement, WRA, and HRWRA generally ranged from approximately 2,500 to 3,000 coulombs during a 6-hr test period. Qualitatively, mixtures PL and PN exhibited moderate chloride ion penetrability. The better performance of the GL, GN, KL, and KN mixtures is probably due to the very low w/c used. Plots of individual and average test results for each mixture are shown in Figures 15-20.

e. Concretes produced with the ABC Corp. cementitious materials exhibited less drying shrinkage than concrete produced with Type III portland cement. All concrete mixtures tested exhibited expansion varying from approximately 0.005 to 0.015 percent after curing 28 days in a moist environment. Upon curing thereafter an additional 28 days at 50 percent relative humidity, the GL and GN mixtures exhibited shrinkage back to almost a neutral condition; the KL and KN mixtures exhibited only minimal shrinkage and maintained an expansion of approximately 0.005 to 0.01, while the PL and PN mixtures exhibited 0.01 to 0.015 percent shrinkage at the end of the test period. The shrinkage of the PL and PN concretes is typical of portland-cement concretes. The length change of the GL, GN, KL, and KN concretes is more like that of shrinkage-compensating cement mixtures. Further research is needed to determine the source of the shrinkage-compensating action. Plots of the test results for mixtures GL, GN, KL, KN, PL, and PN are shown in Figures 21-26. A plot of the average length change for each mixture is shown in Figure 27.

The two ABC Corp. cementitious materials were tested for density, percent retained on the 45-μm (No. 325) sieve, moisture content, and loss on ignition. The test results are given in Plates 4 and 5. The portland cement was tested for full compliance with ASTM C 150, Type III. The test results are given in Plate 6.

Based on this brief preliminary investigation, the following conclusions appear warranted:

a. Concrete produced with the ABC Corp. cementitious material has an advantage of being able to adjust the setting time of the concrete to whatever is appropriate for a given application (better control than Type III portland-cement concrete with WRA and HRWRA), low to very low chloride permeability (better than Type III portland-cement concrete with WRA and HRWRA), good frost resistance even with low air contents (better than Type III portland-cement concrete with WRA and HRWRA), minimal shrinkage at early ages (better than Type III portland cement concrete with WRA and HRWRA), and high 1-, 7-, and 28- day compressive strengths (similar to Type III portland-cement concrete with WRA and HRWRA).

b. Concrete produced with the ABC Corp. cementitious material has the disadvantage that the fresh properties of the concrete are more variable than those of concrete produced with Type III portland cement. This points to the need for additional research.

c. Concrete produced with the ABC Corp. cementitious material has the advantage that it is composed mainly of Class C fly ash, a waste product. Fly ash is less expensive than portland cement, and, according to the ABC representative, the total cost of a high-early strength concrete produced with the ABC Corp. cementitious material and admixtures can be less expensive than a high-early strength concrete produced with Type III portland cement with HRWRA, especially in high-cost markets. Use of the fly ash also has a positive impact on the environment.

d. Concrete produced with the ABC Corp. cementitious material has the disadvantage that additional equipment would be required on truck mixers to discharge the A, B, C, and possibly AEA into the mixing drum at the placement site. The concrete producer's personnel would have to be instructed in the use of the total ABC Corp. system. The admixture requirements would likely vary from concrete producer to concrete producer, depending upon his sources of fly ash and portland cement. While the expense of purchasing and installing the equipment, training personnel, and establishing mixture proportions would be a disadvantage initially, once the system was in operation the flexibility gained could become an advantage.

e. The ABC Corp. cementitious material appears to be a possible alternative to Type III portland cement for producing a high-early strength concrete. However, the interaction of the complete ABC Corp. system for producing concrete is not yet fully understood. Comprehensive research needs to be conducted to determine the amount of each admixture necessary to produce concrete having a given set of properties. Since there are numerous variables involved, such as source and amount of fly ash, source and amount of cement or slag, set-suspending agent A, B, and C admixtures, AEA, temperature, batch size, period of time before the A, B, and C admixtures are added to the concrete, and order of addition of A, B, and C admixtures, to name a few, this will not be a simple task. Yet, with the knowledge that the system will work, completing development of the system seems attainable given systematic research. The goal should be to develop appropriate models from which user friendly nomographs or databases can be developed that will enable a producer to quickly and easily determine the amount of each component in the system to use in any reasonable situation. Also, a more rigorous research program should investigate long-term mechanical properties, durability, and analysis of the concrete microstructure.

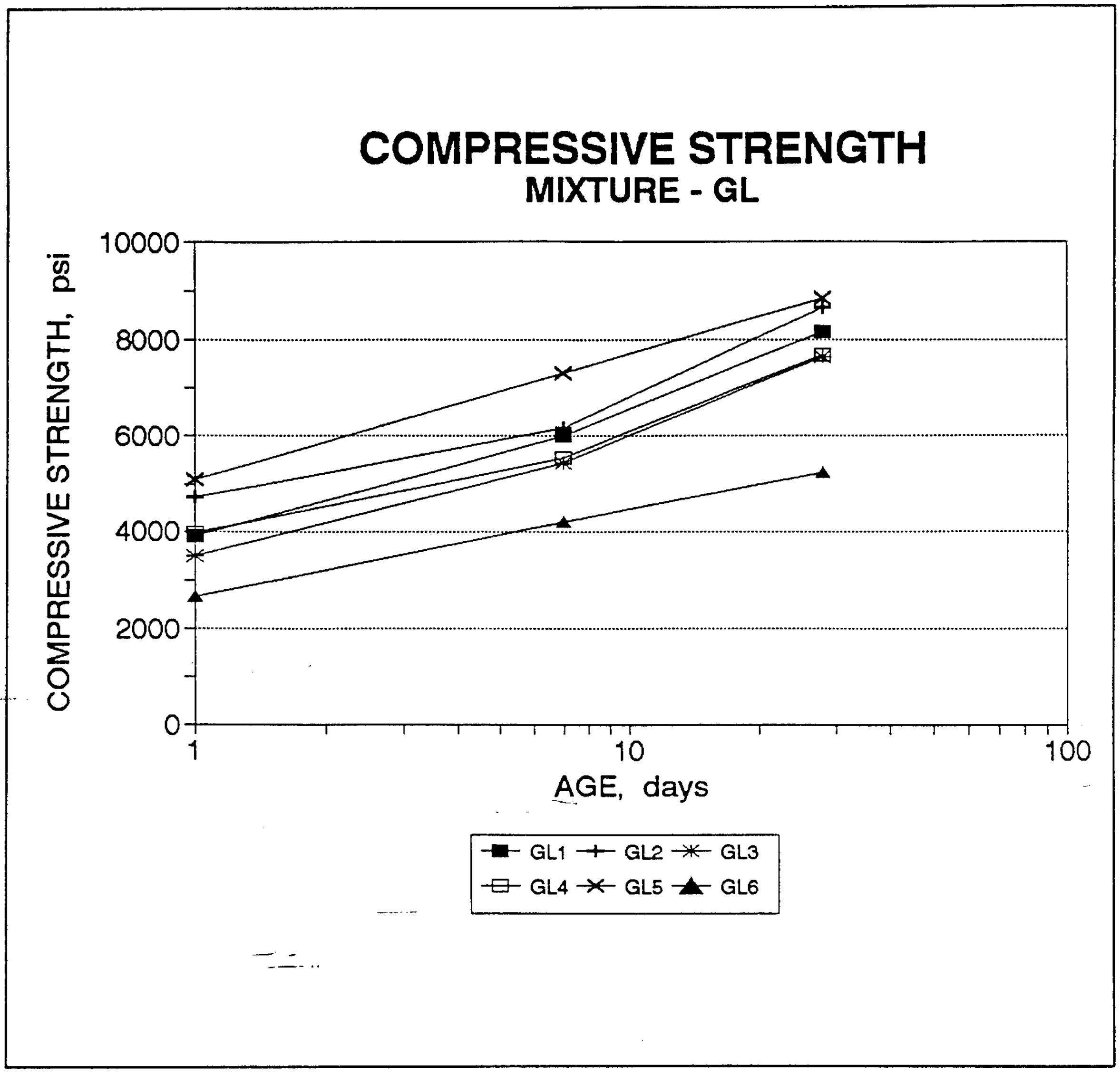

Figure 1. Compressive strength of GL mixture

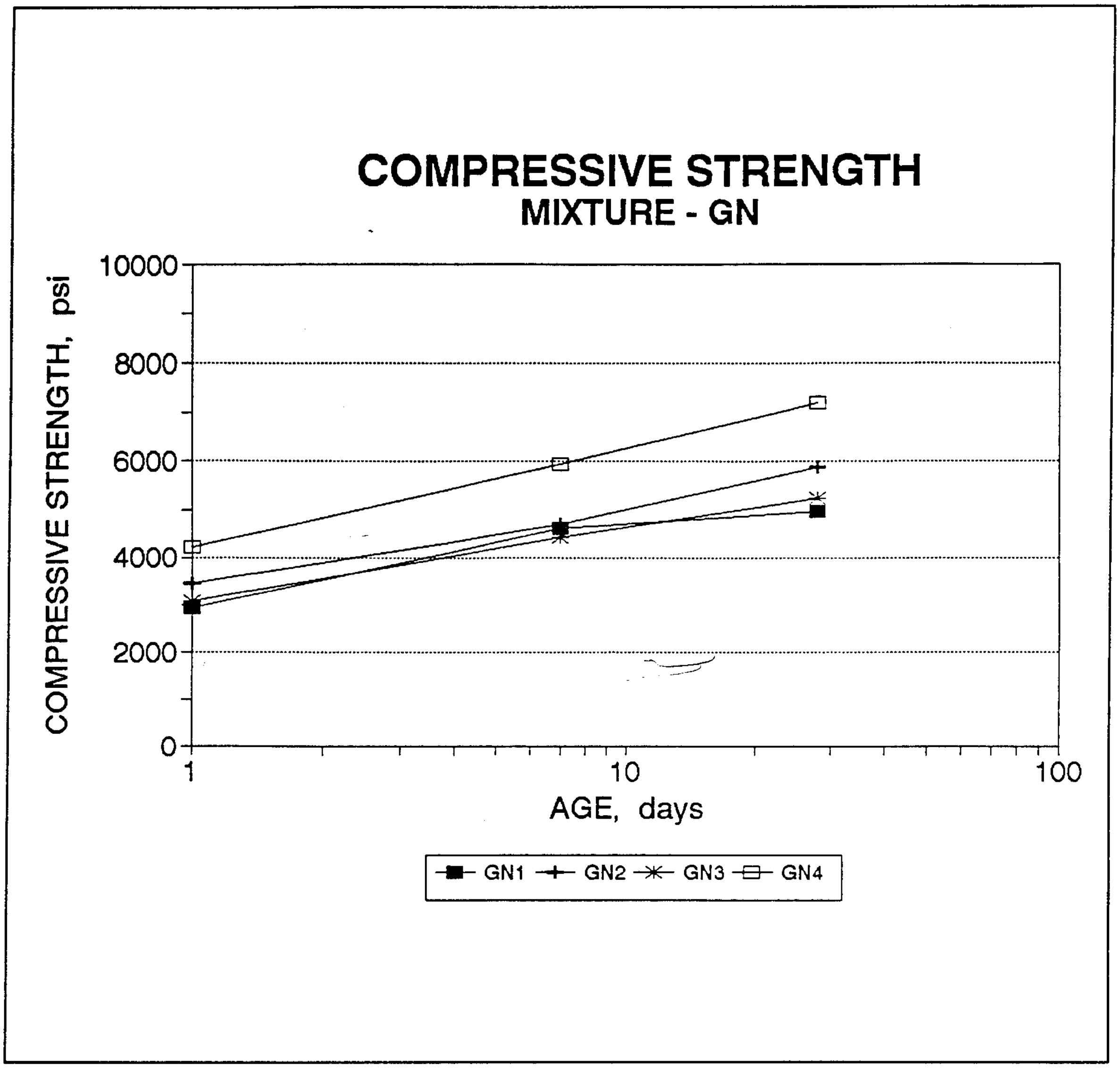

Figure 2. Compressive strength of GN mixture

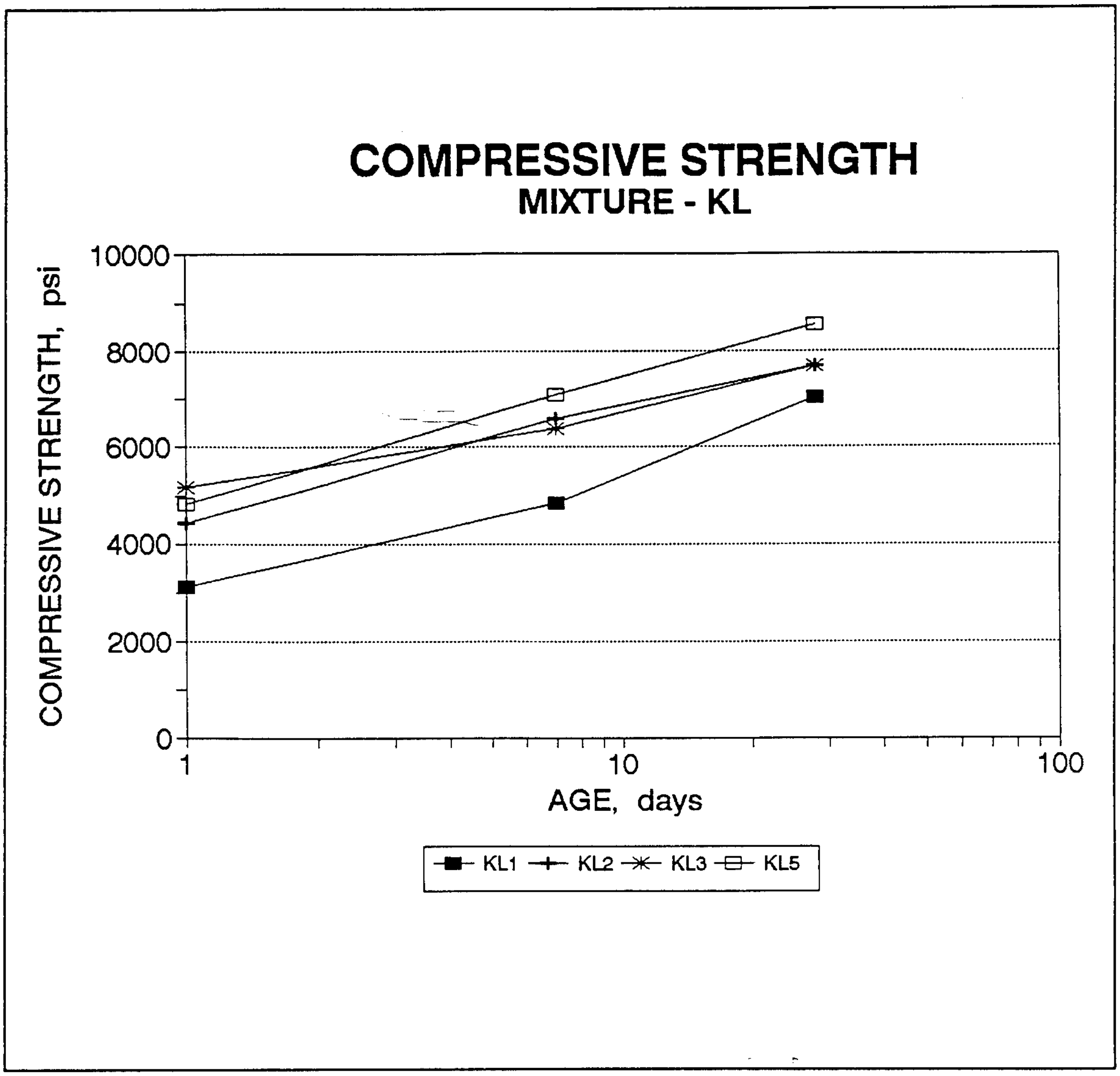

Figure 3. Compressive strength of KL mixture

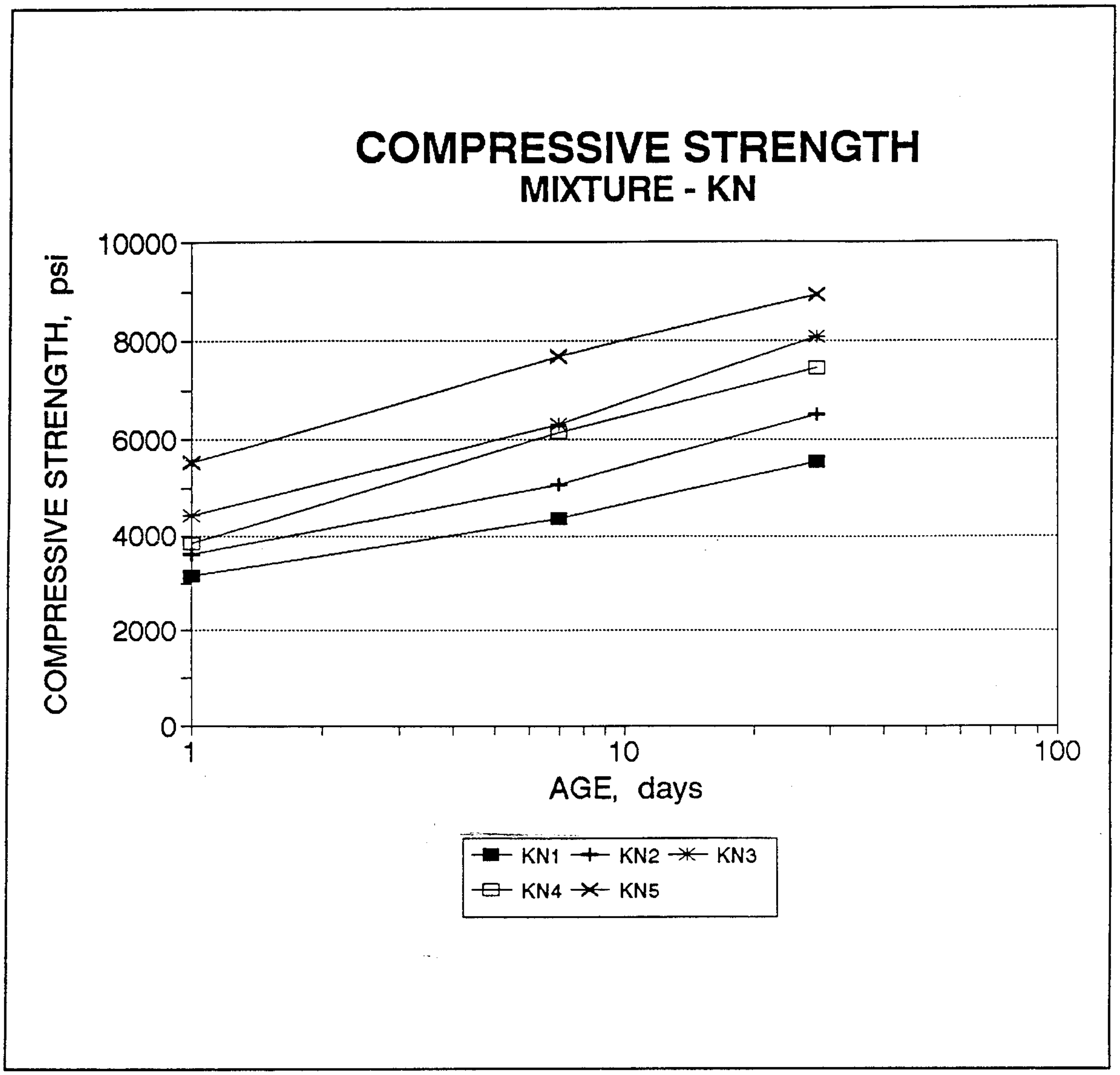

Figure 4. Compressive strength of KN mixture

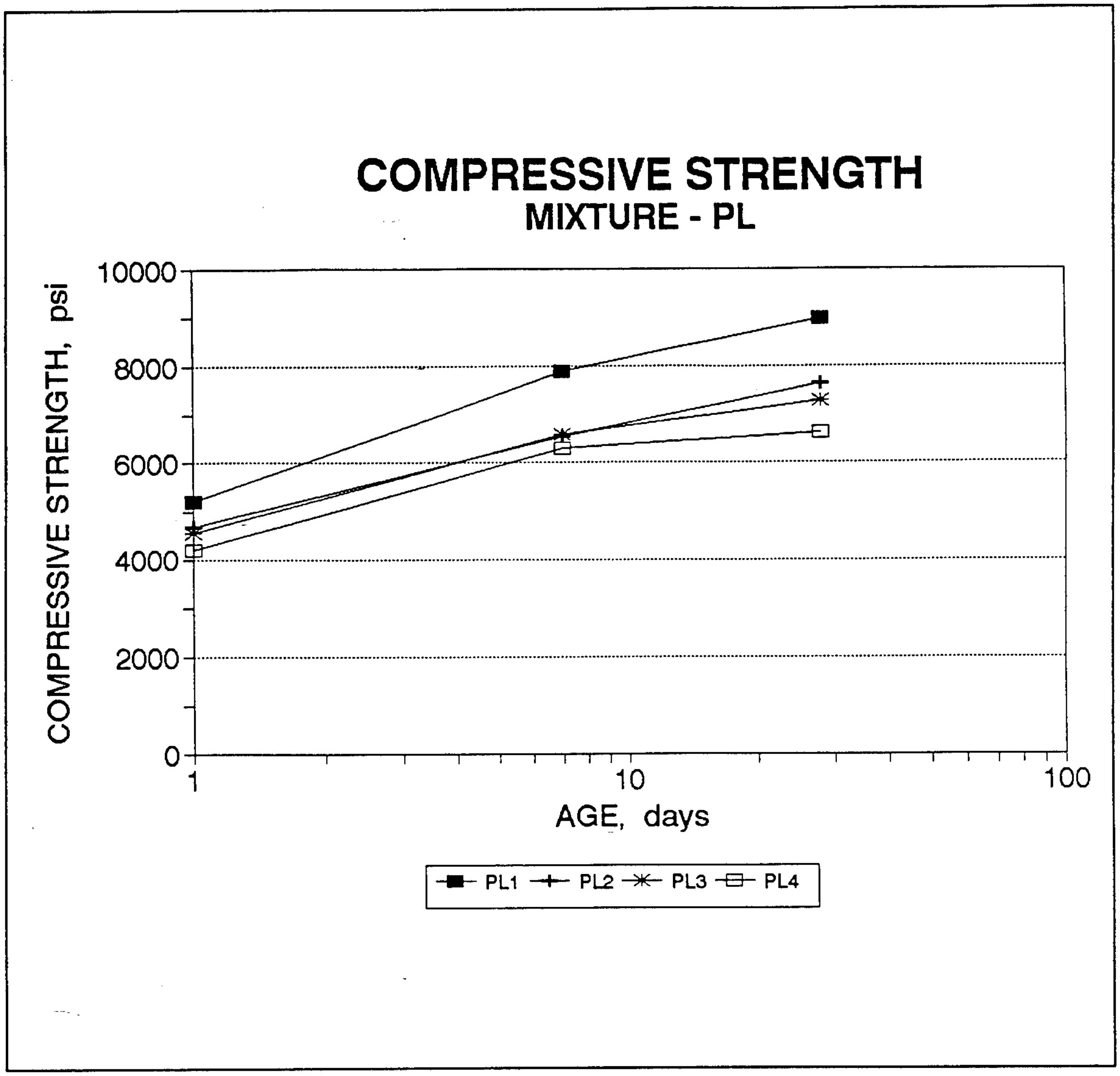

Figure 5. Compressive strength of PL mixture

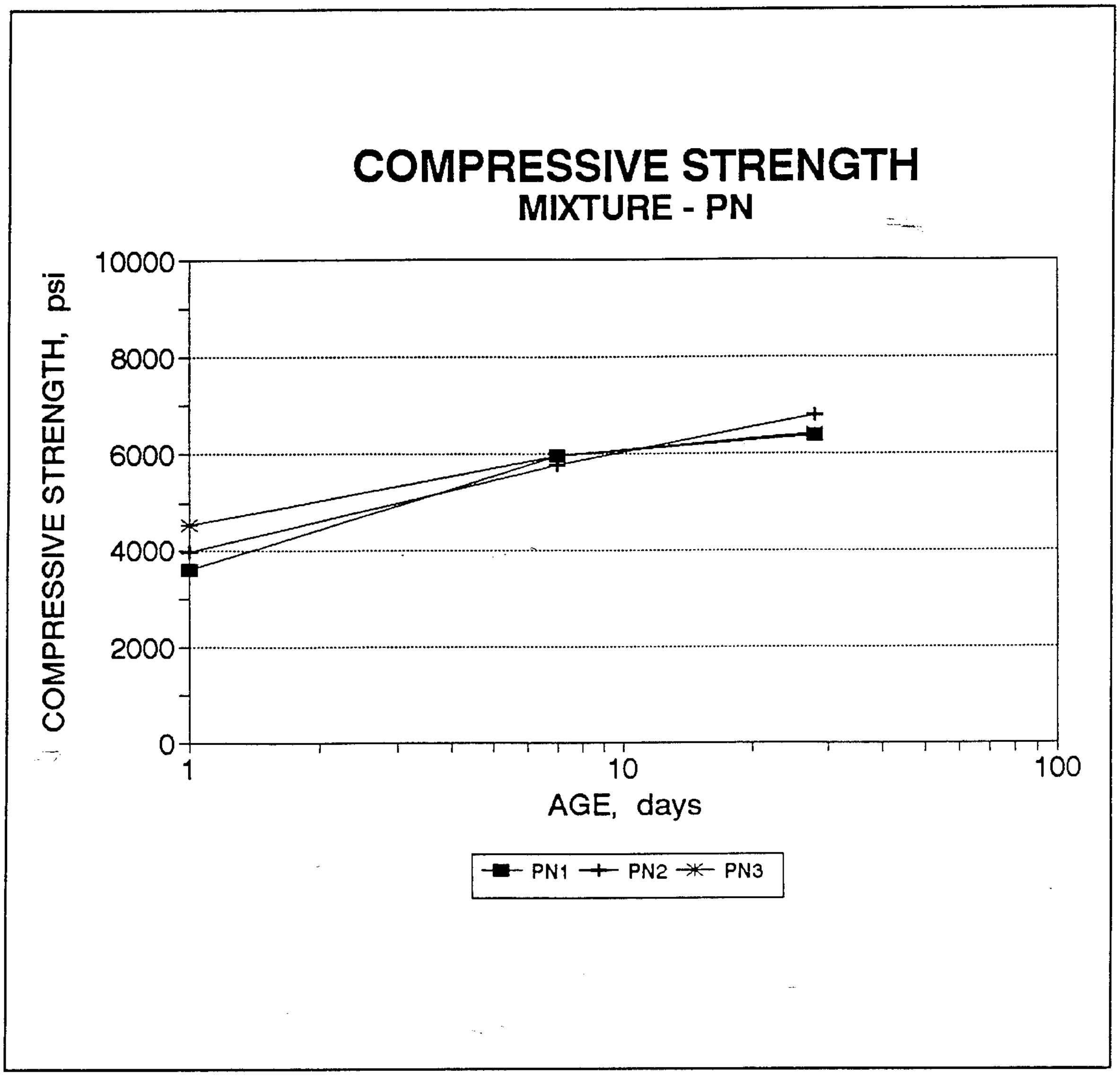

Figure 6. Compressive strength of PN mixture

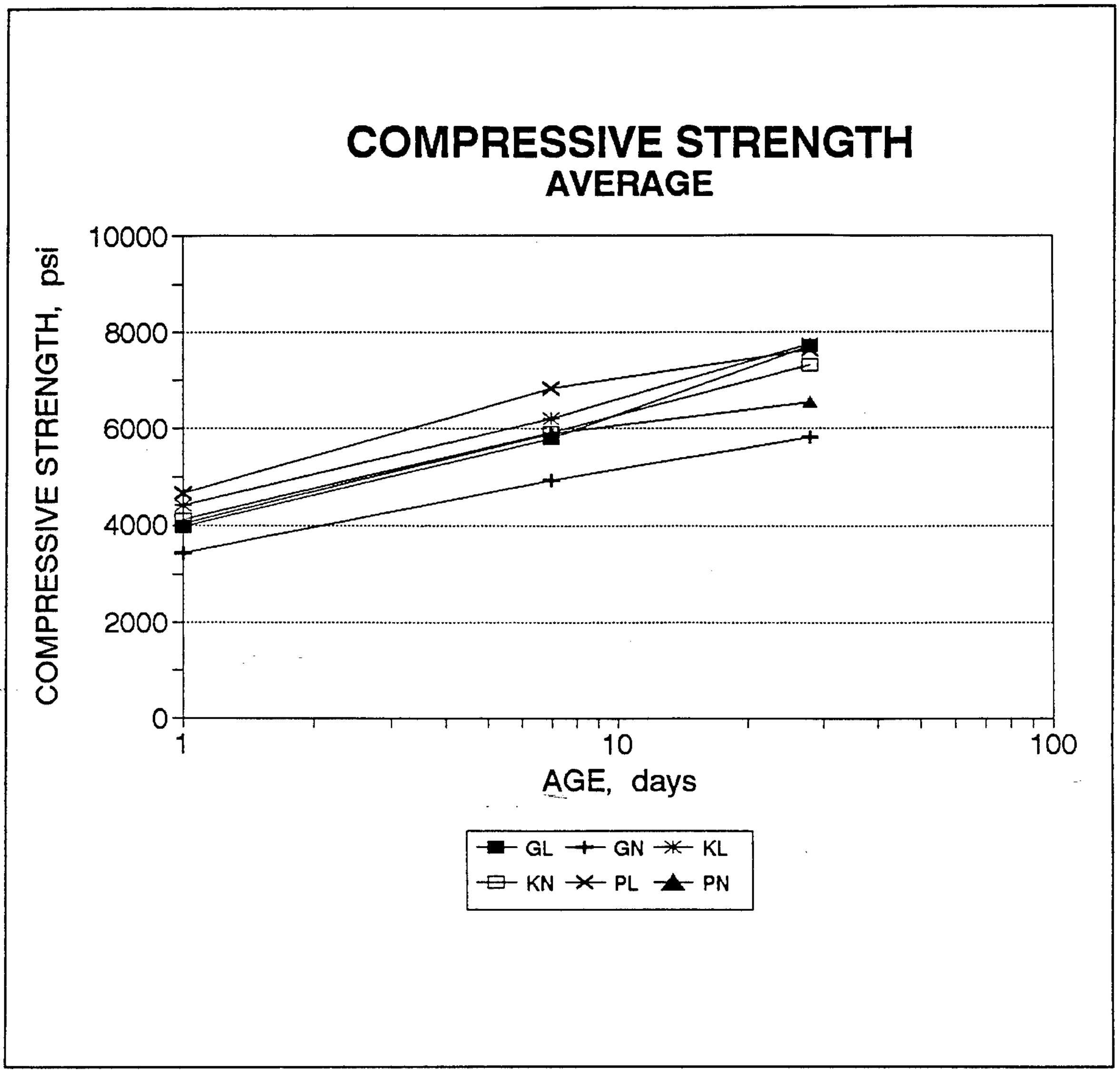

Figure 7. Average compressive strength

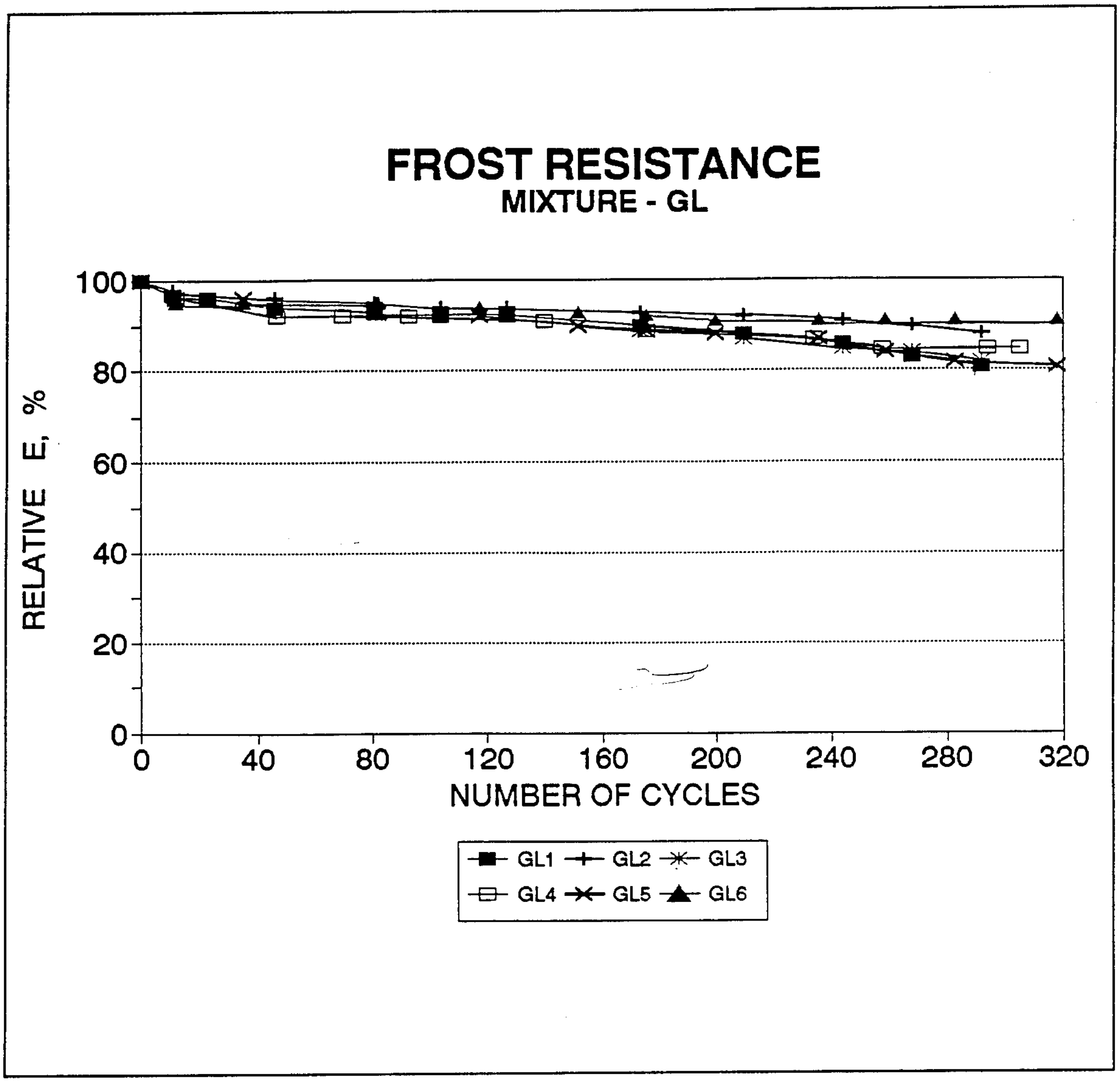

Figure 8. Frost resistance of GL mixture

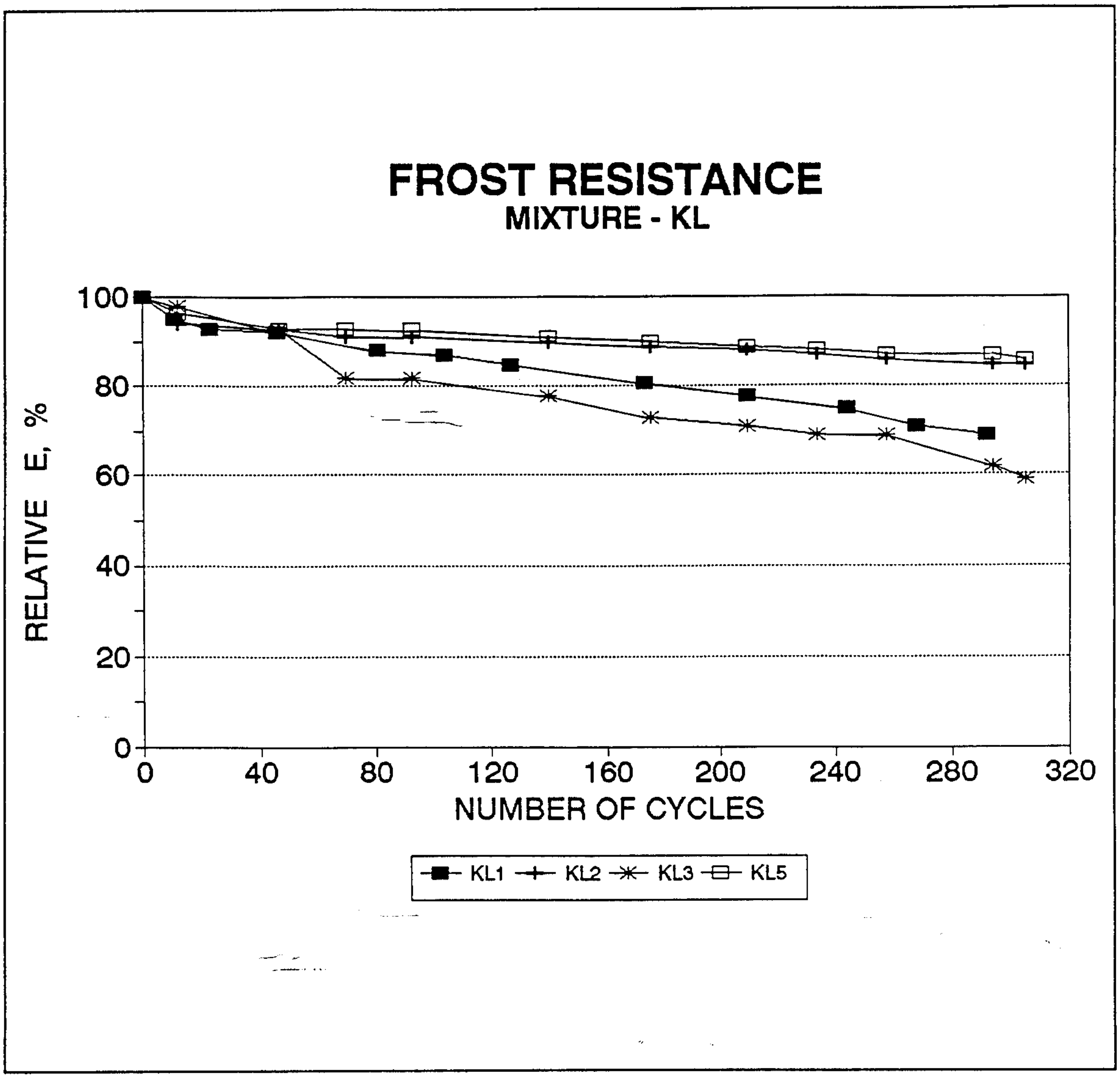

Figure 9. Frost resistance of KL mixture

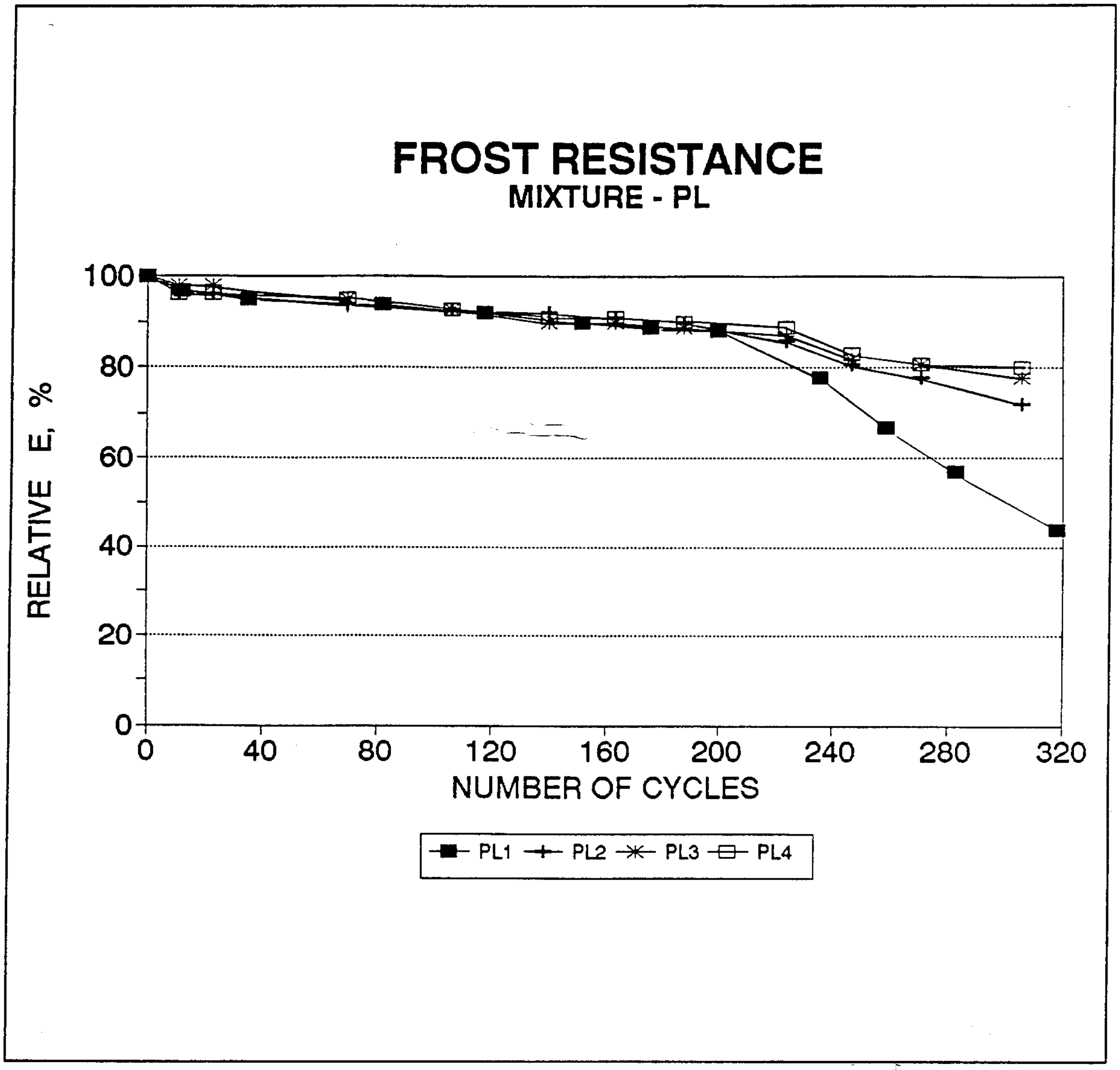

Figure 10. Frost resistance of PL mixture

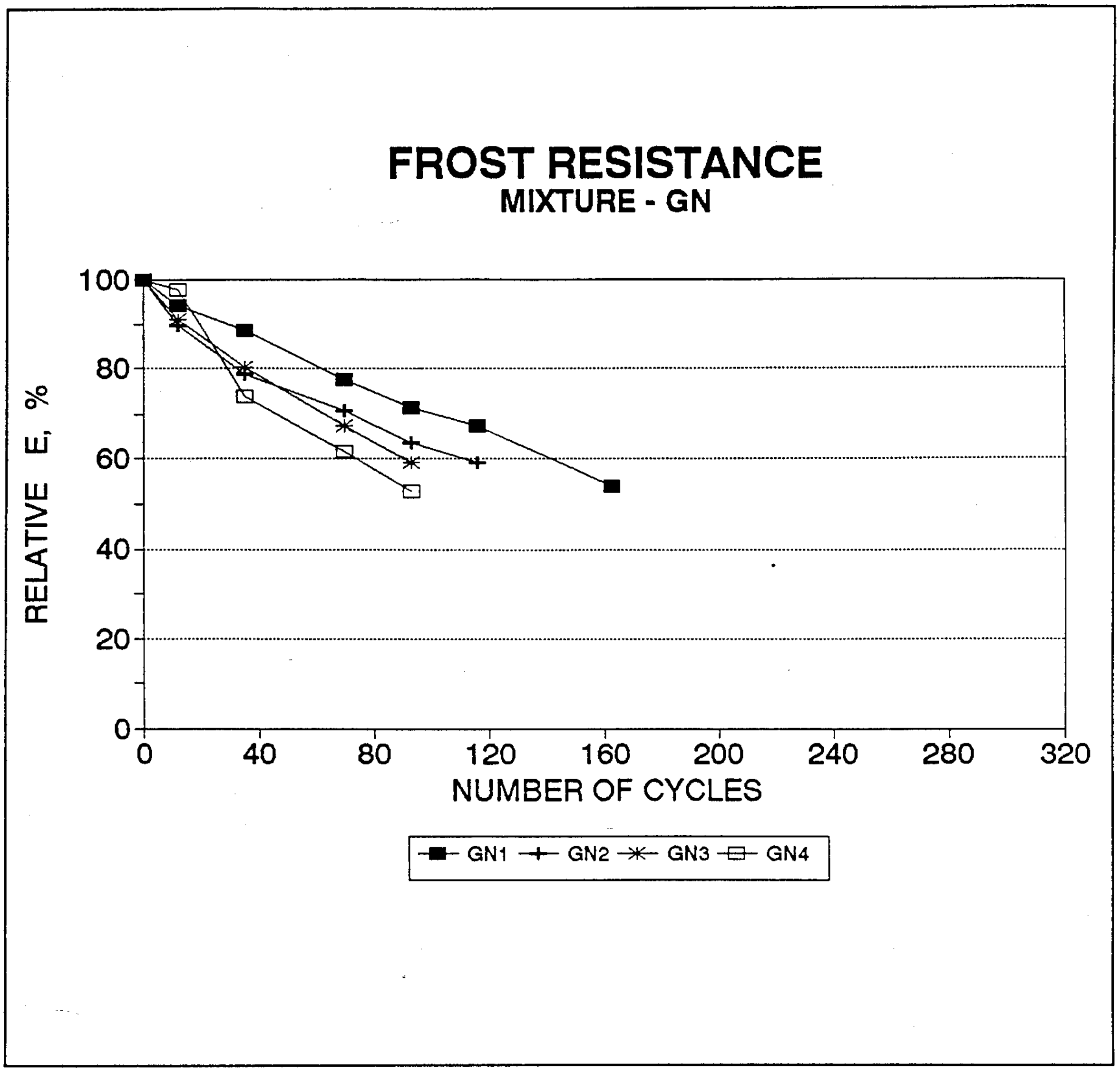

Figure 11. Frost resistance for GN mixture

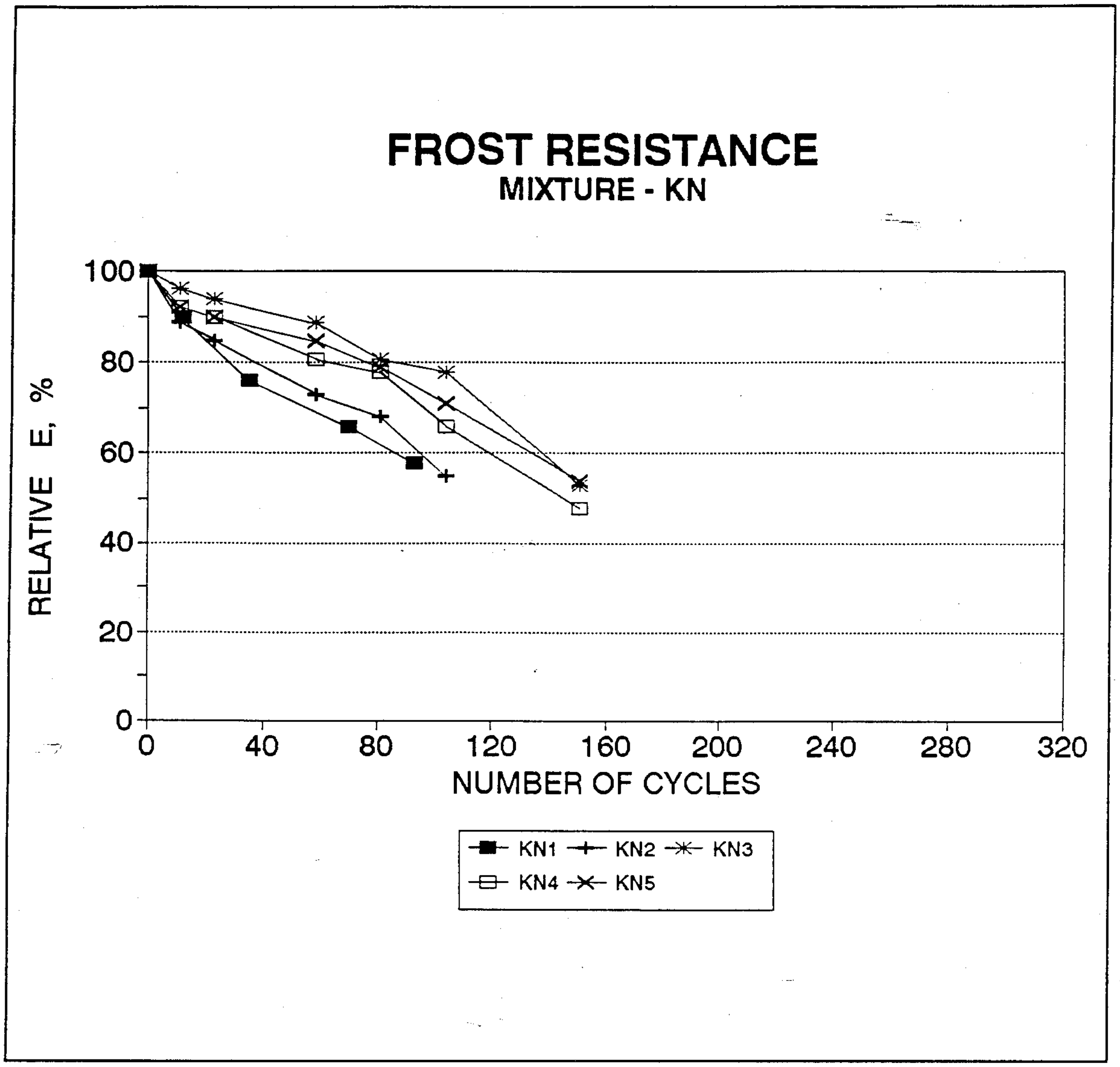

Figure 12. Frost resistance for KN mixture

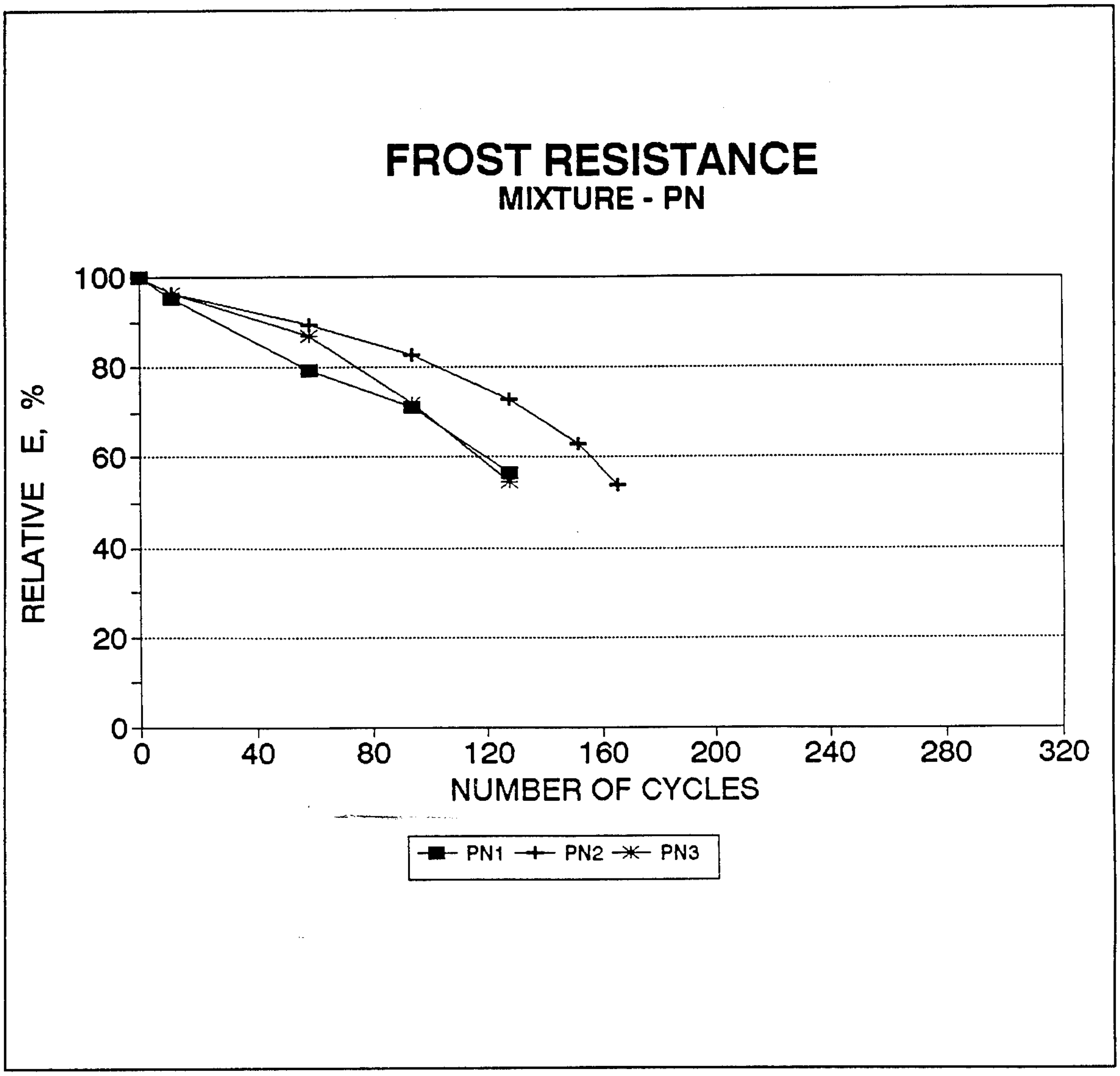

Figure 13. Frost resistance for PN mixture

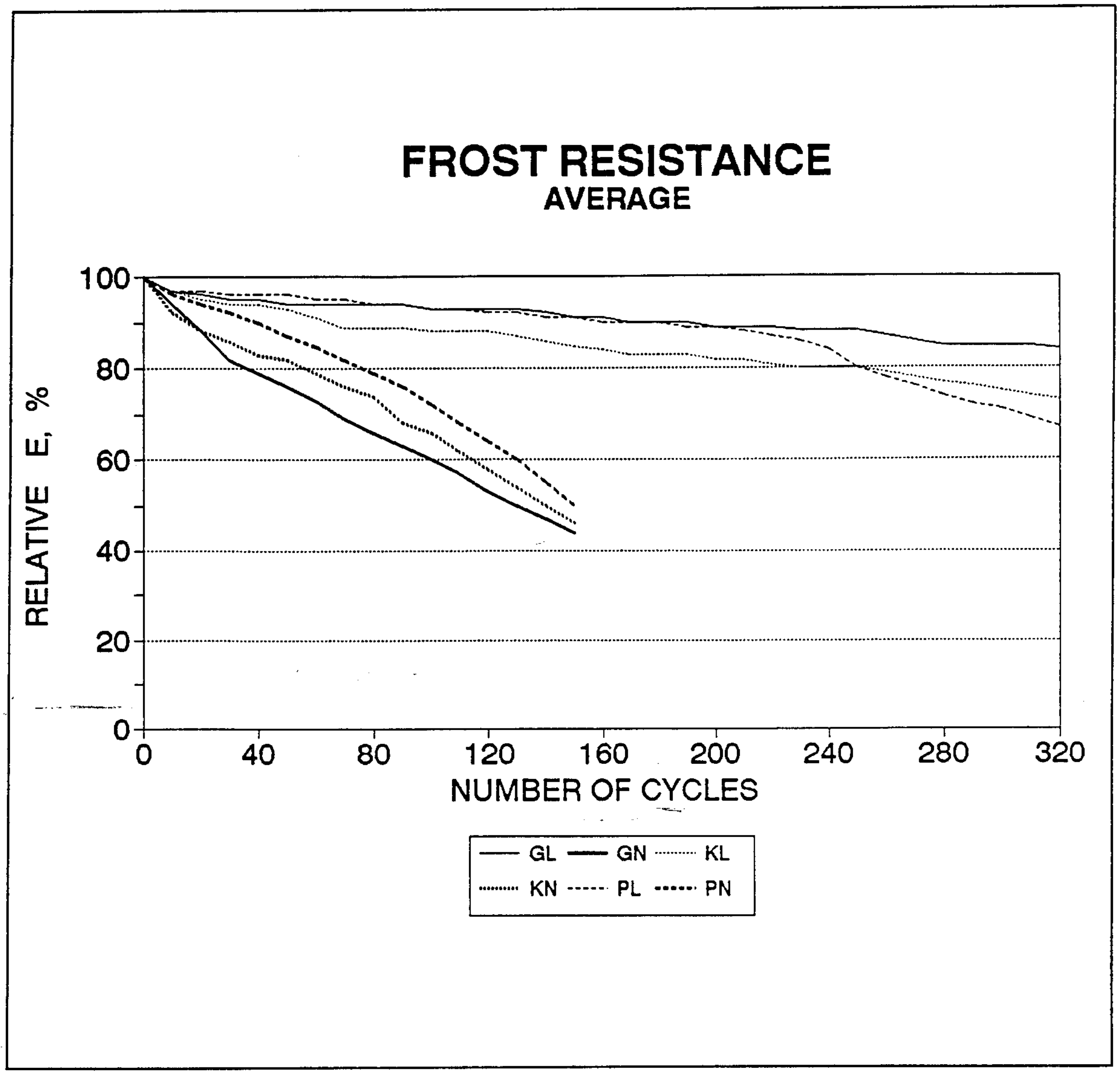

Figure 14. Average frost resistance

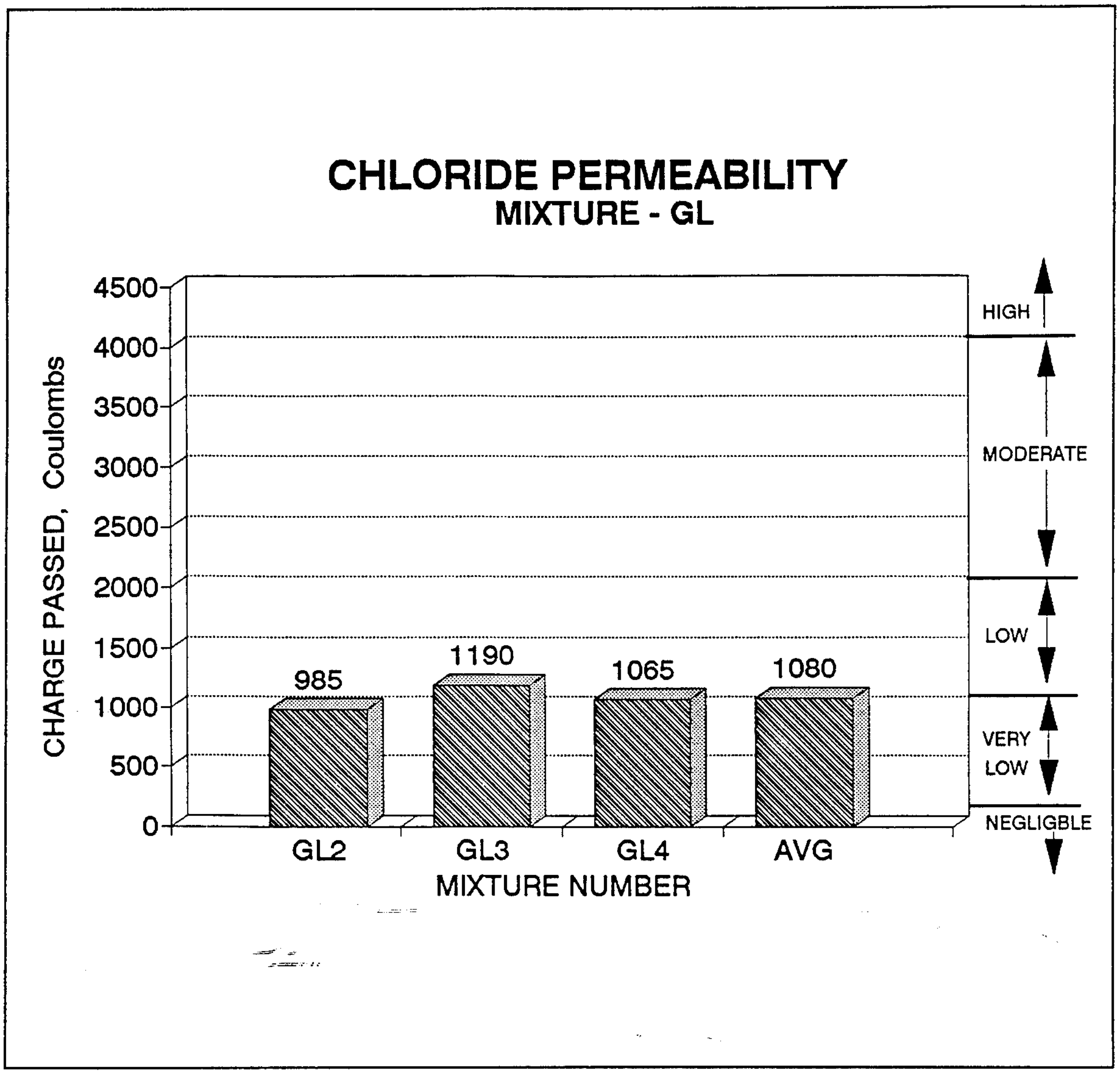

Figure 15. Chloride permeability of GL mixture

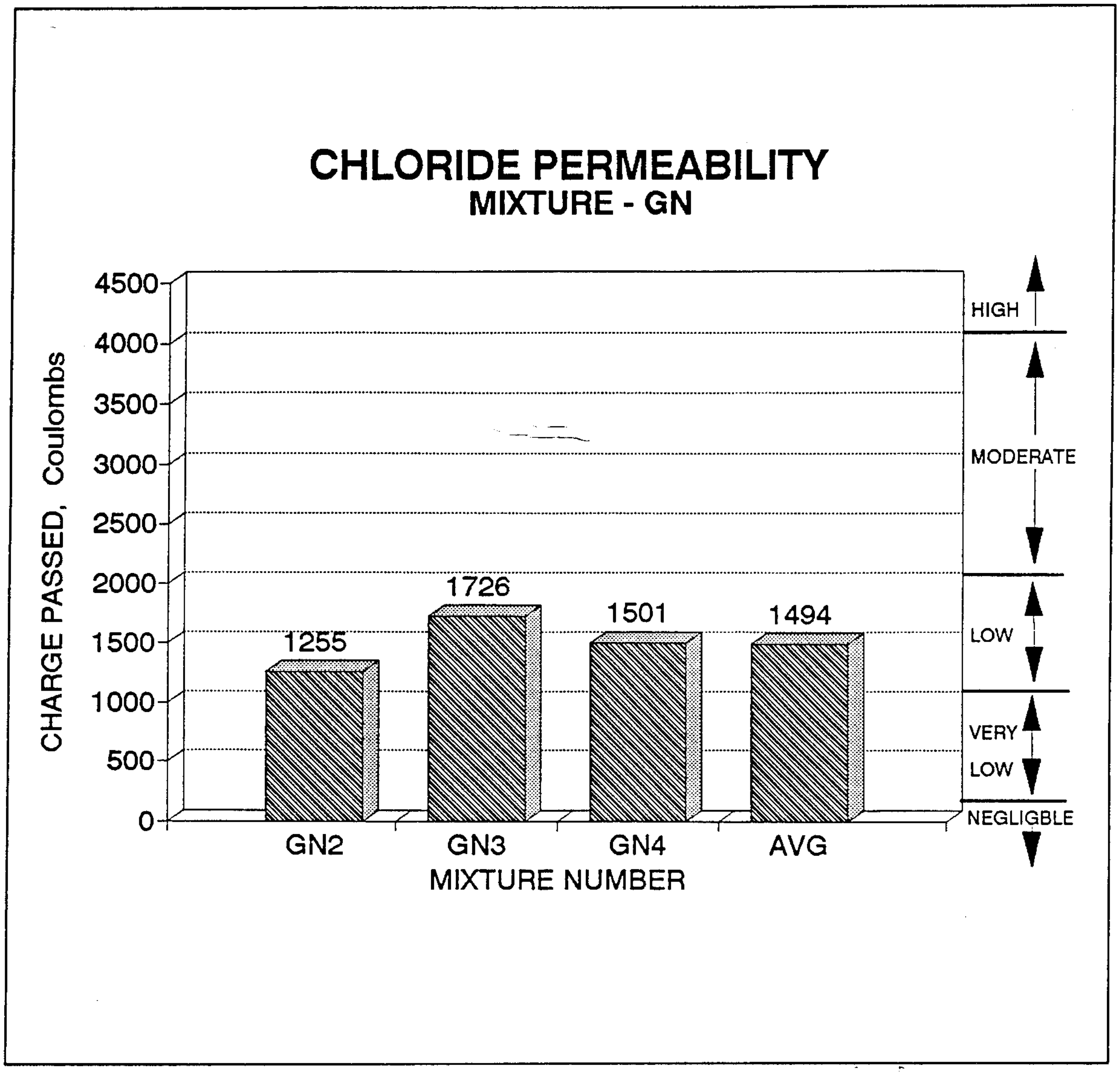

Figure 16. Chloride permeability of GN mixture

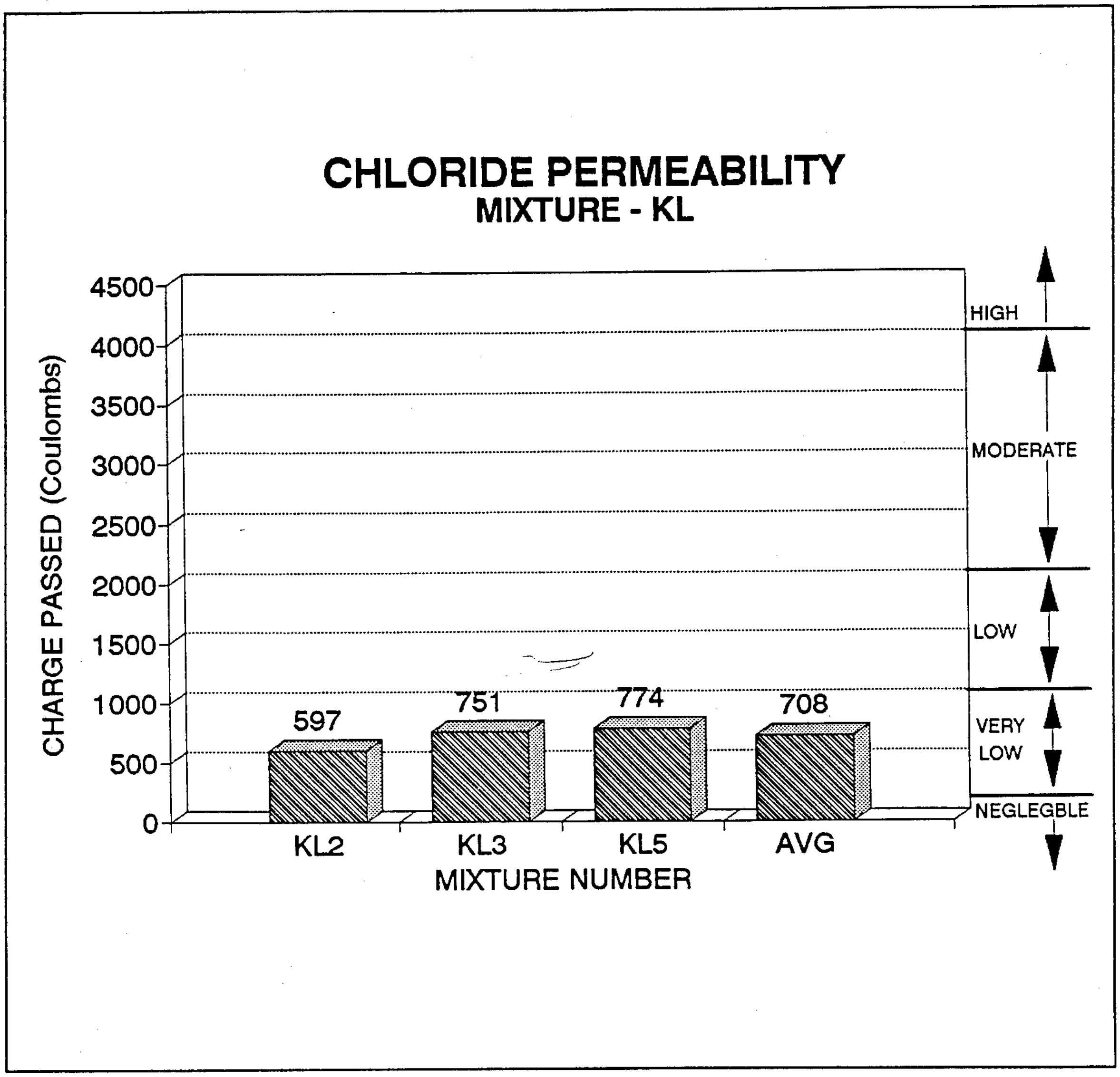

Figure 17. Chloride permeability of KL mixture

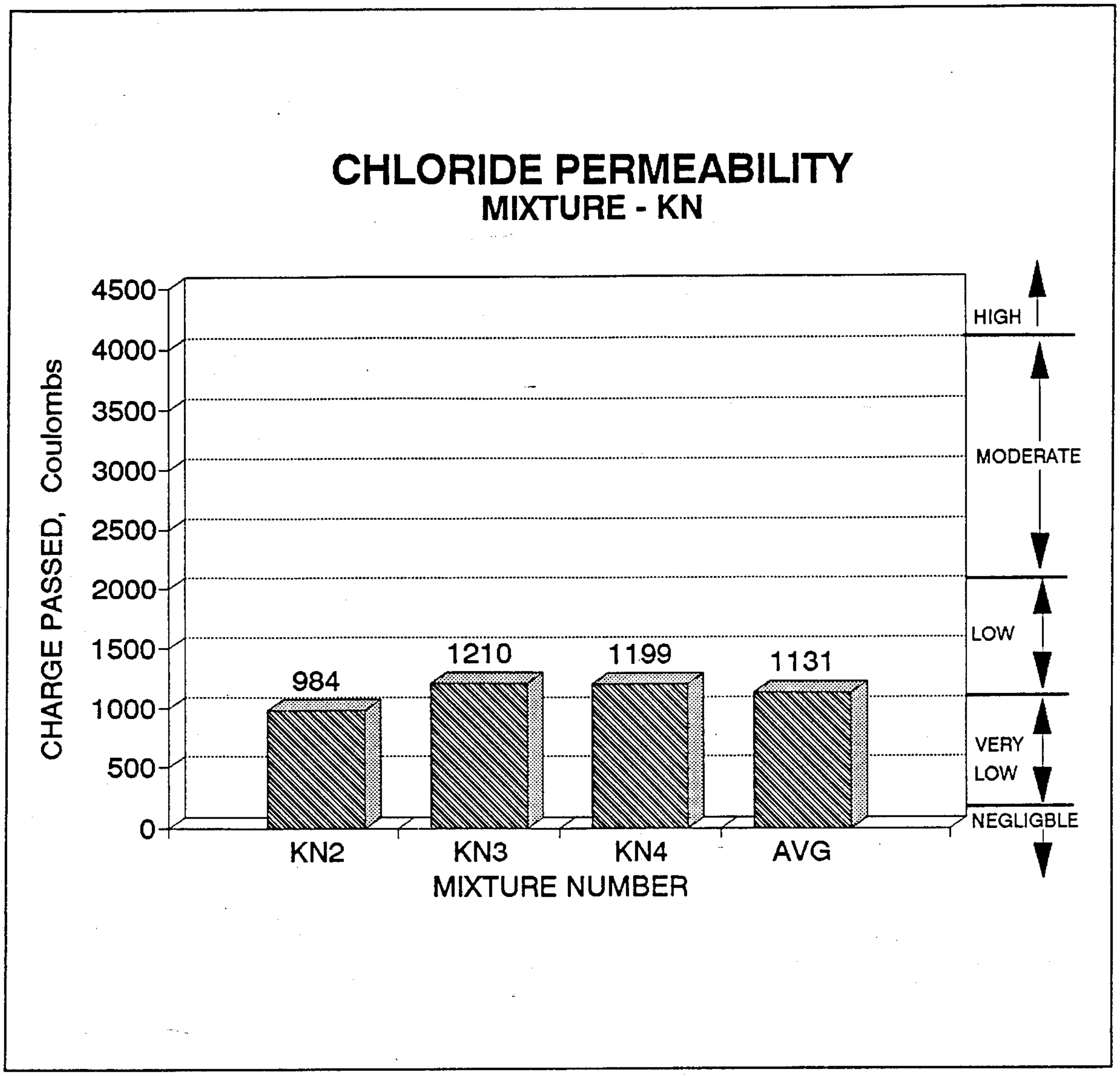

Figure 18. Chloride permeability of KN mixture

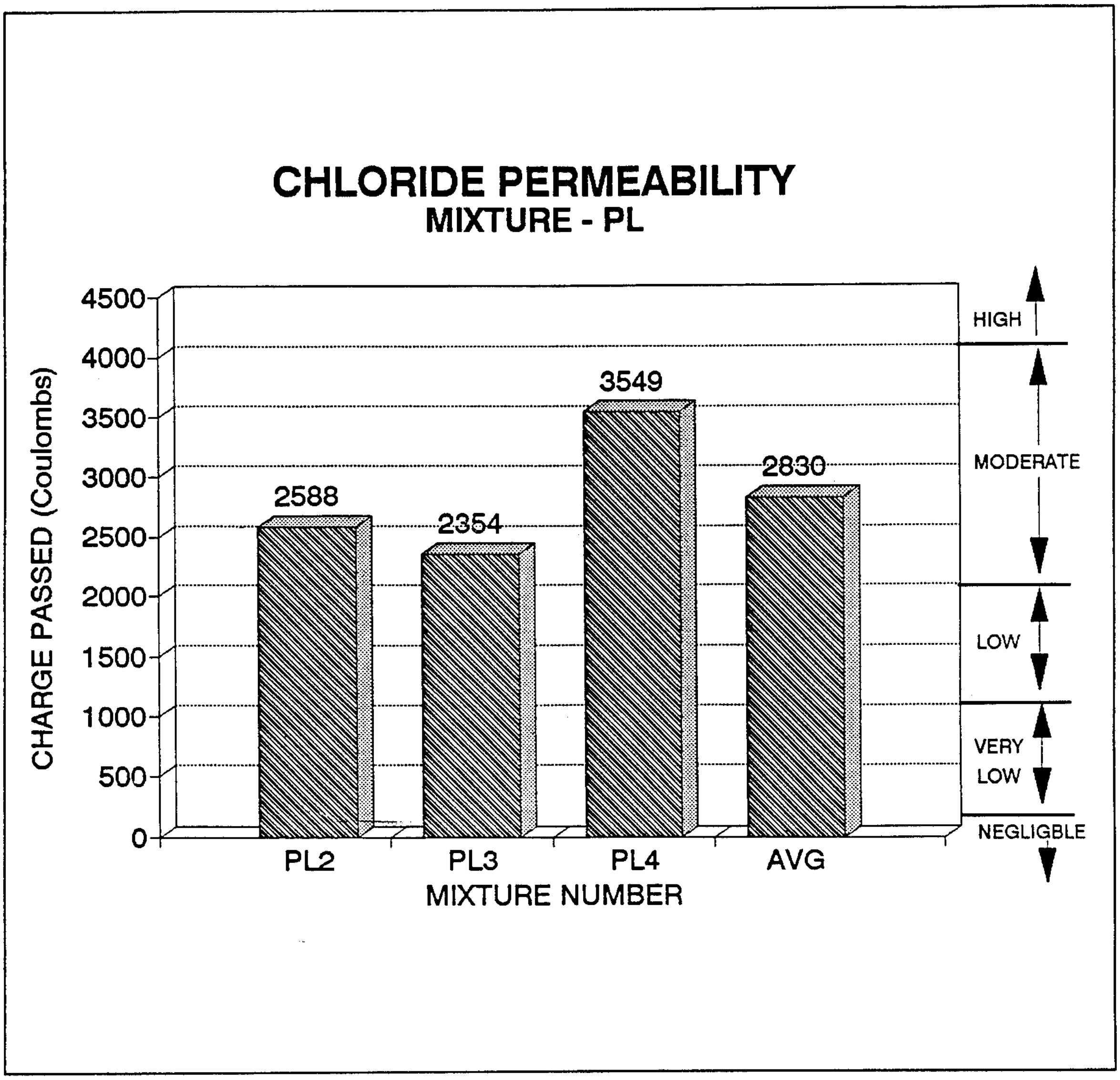

Figure 19. Chloride permeability of PL mixture

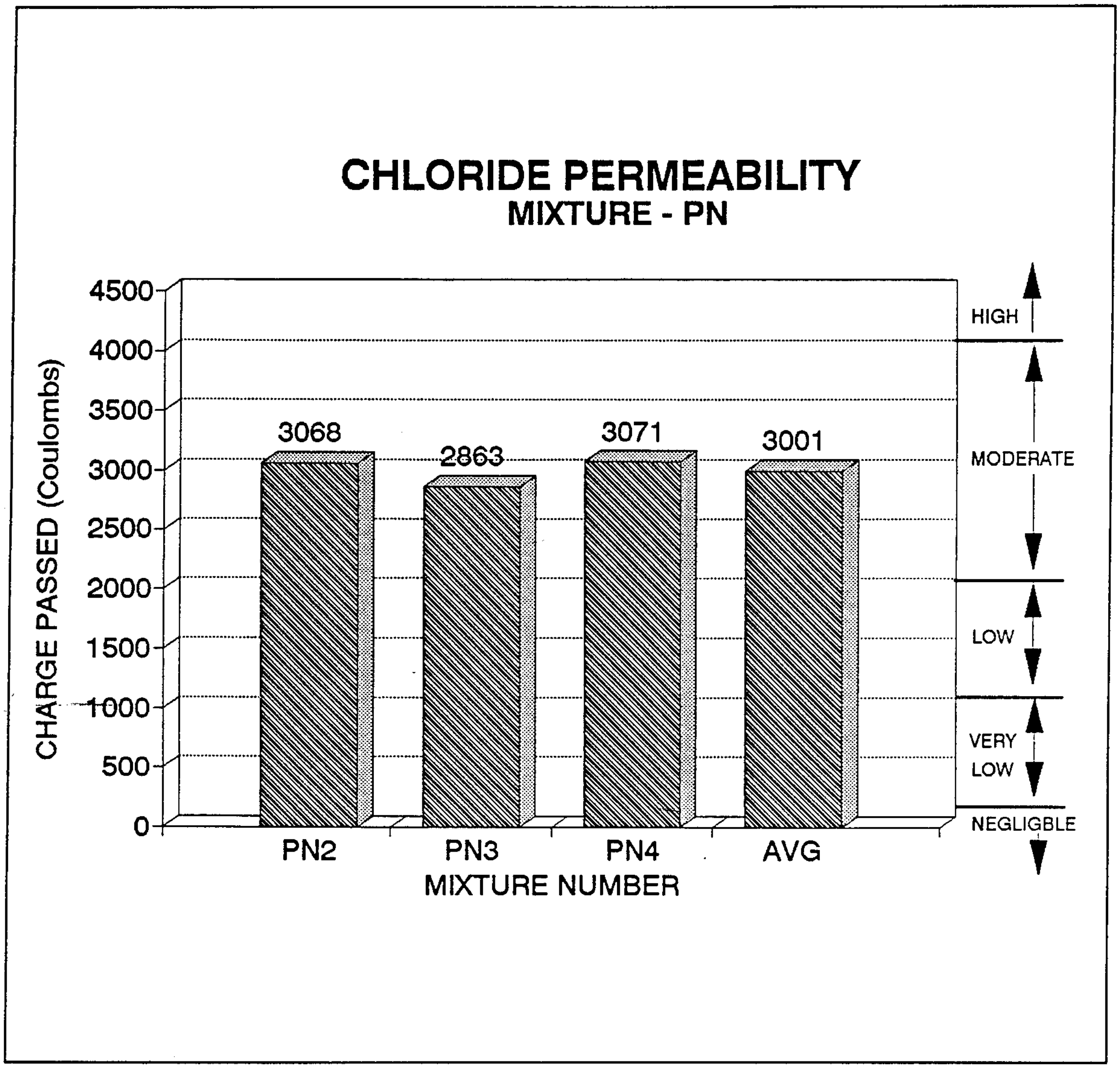

Figure 20. Chloride permeability of PN mixture

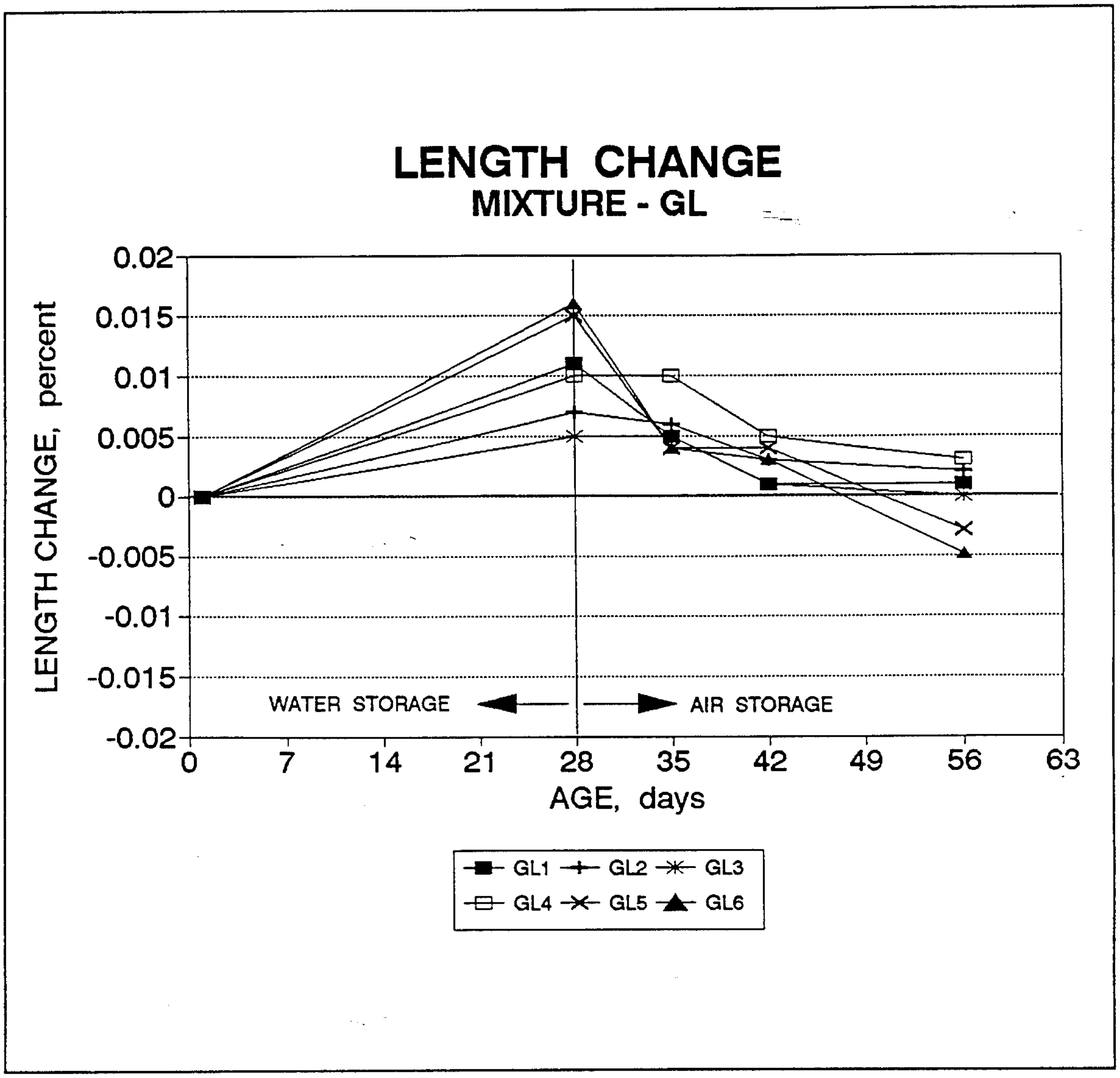

Figure 21. Length change of GL mixture

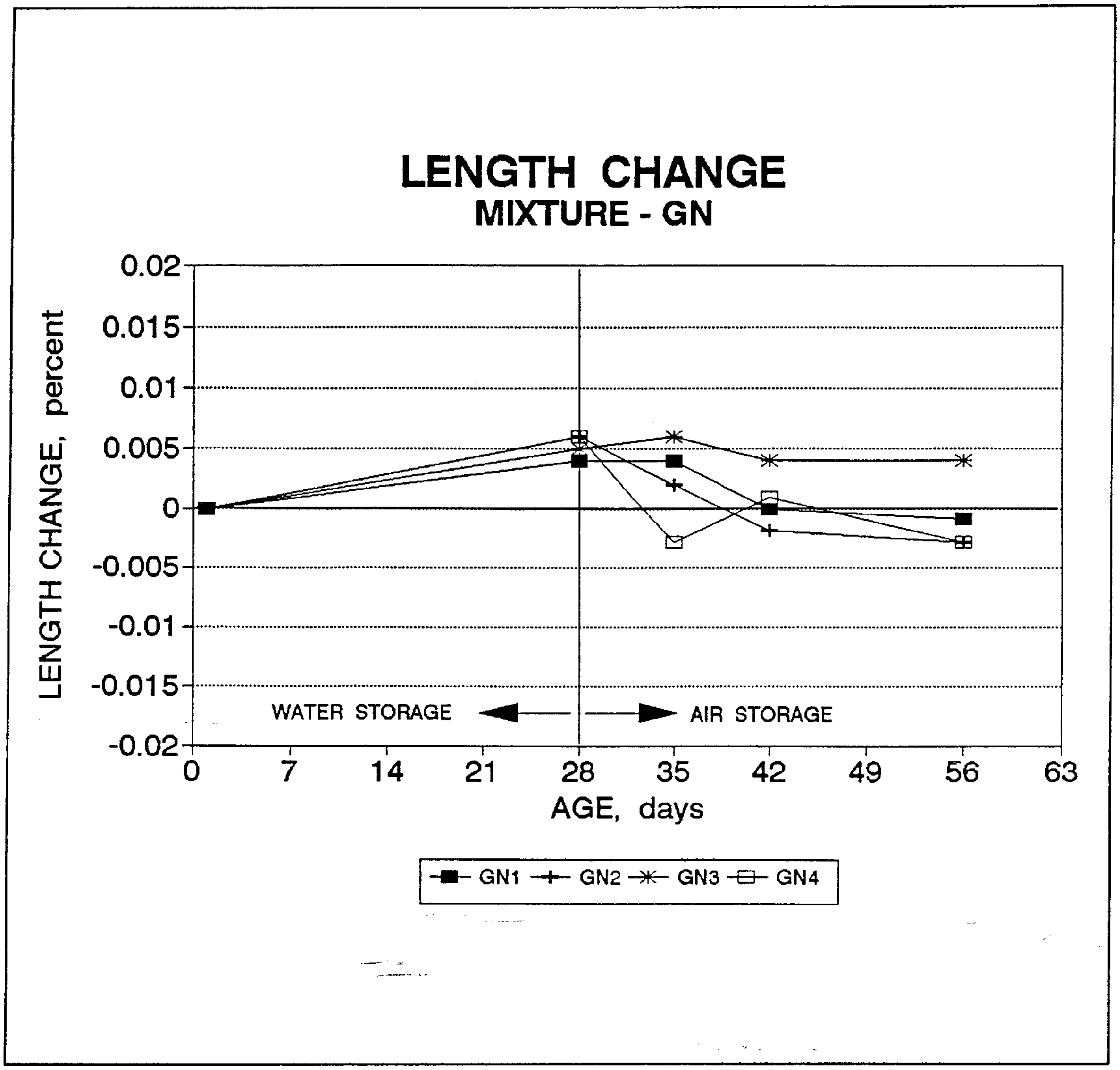

Figure 22. Length change of GN mixture

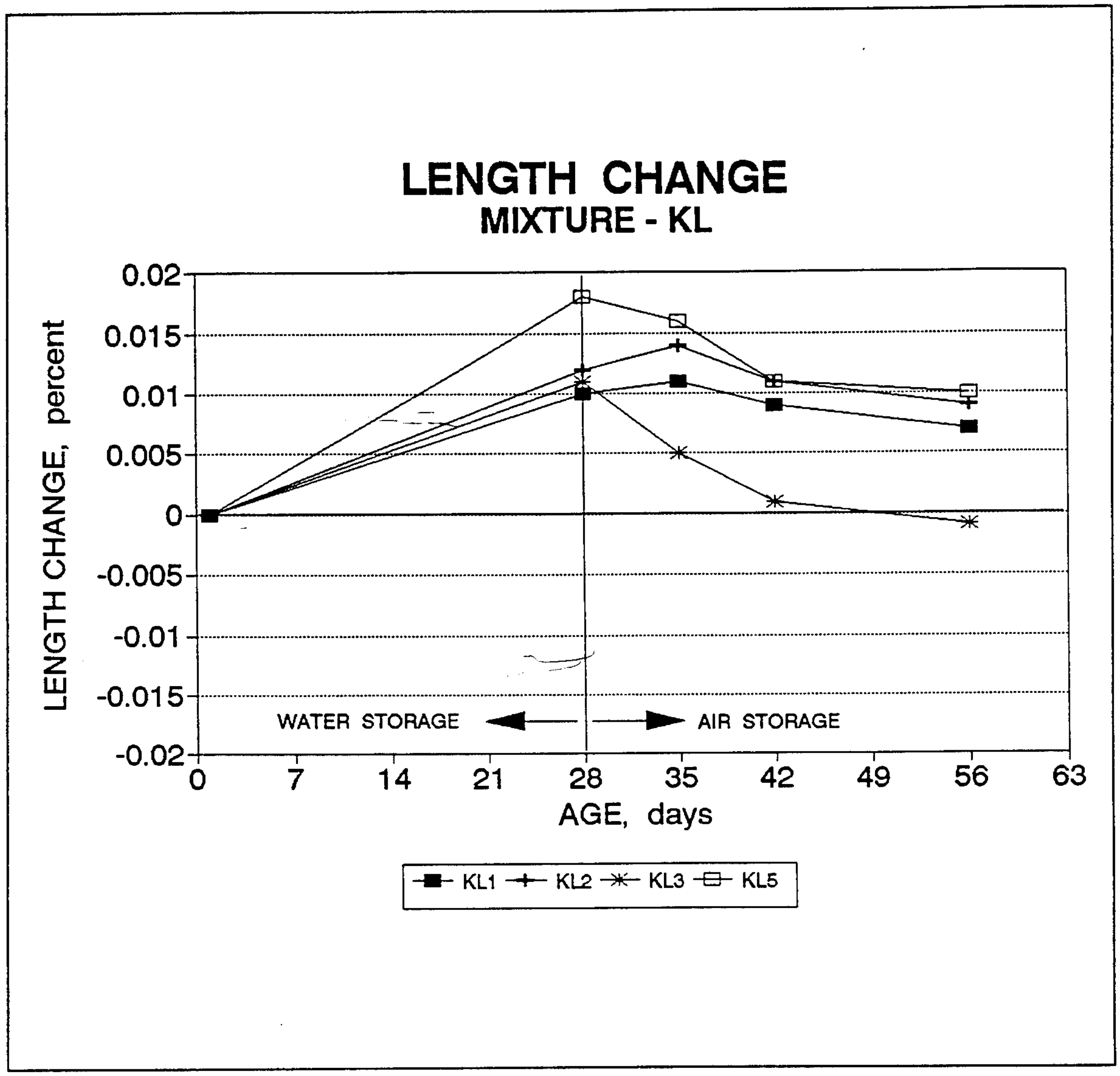

Figure 23. Length change of KL mixture

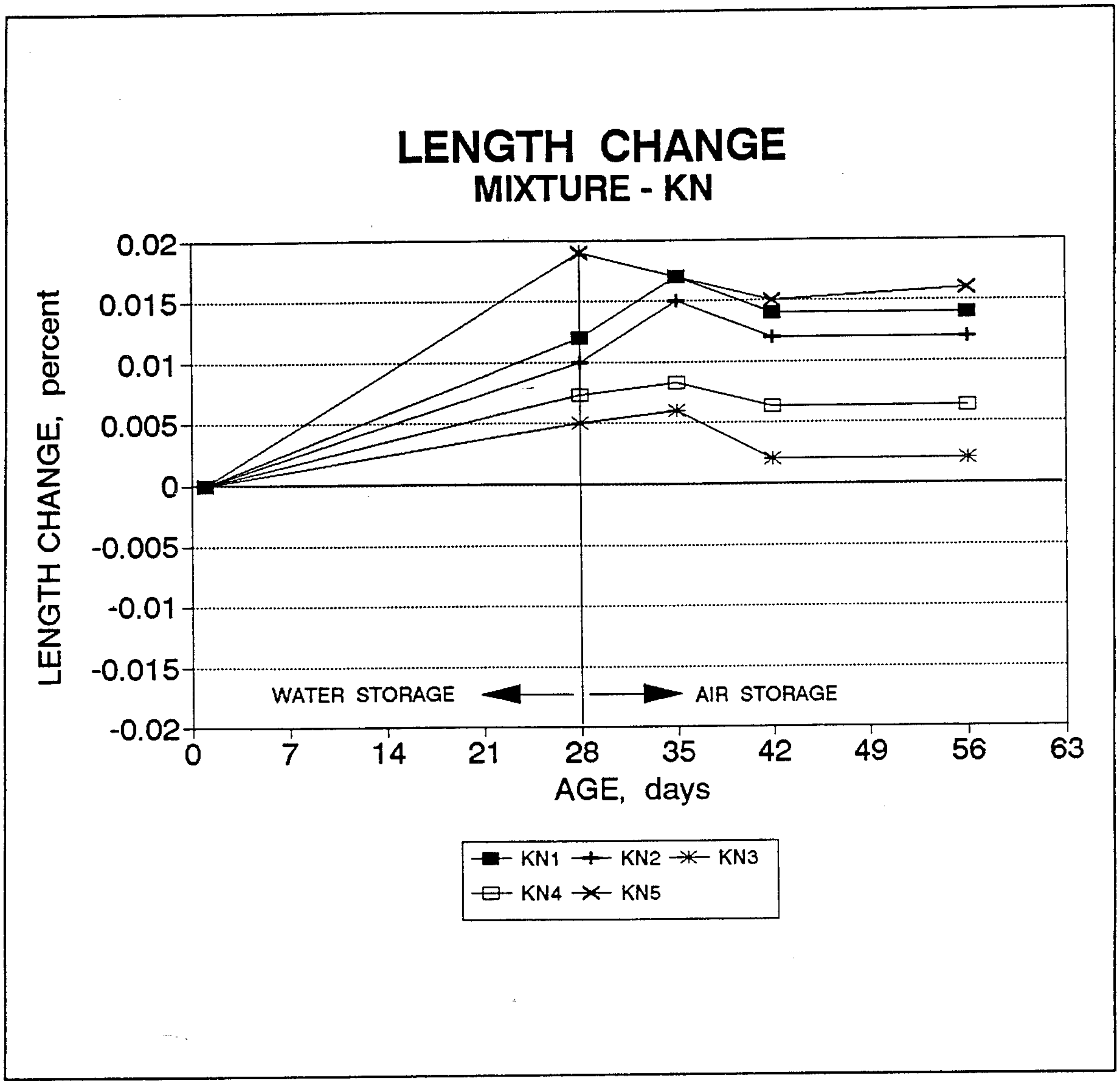

Figure 24. Length change of KN mixture

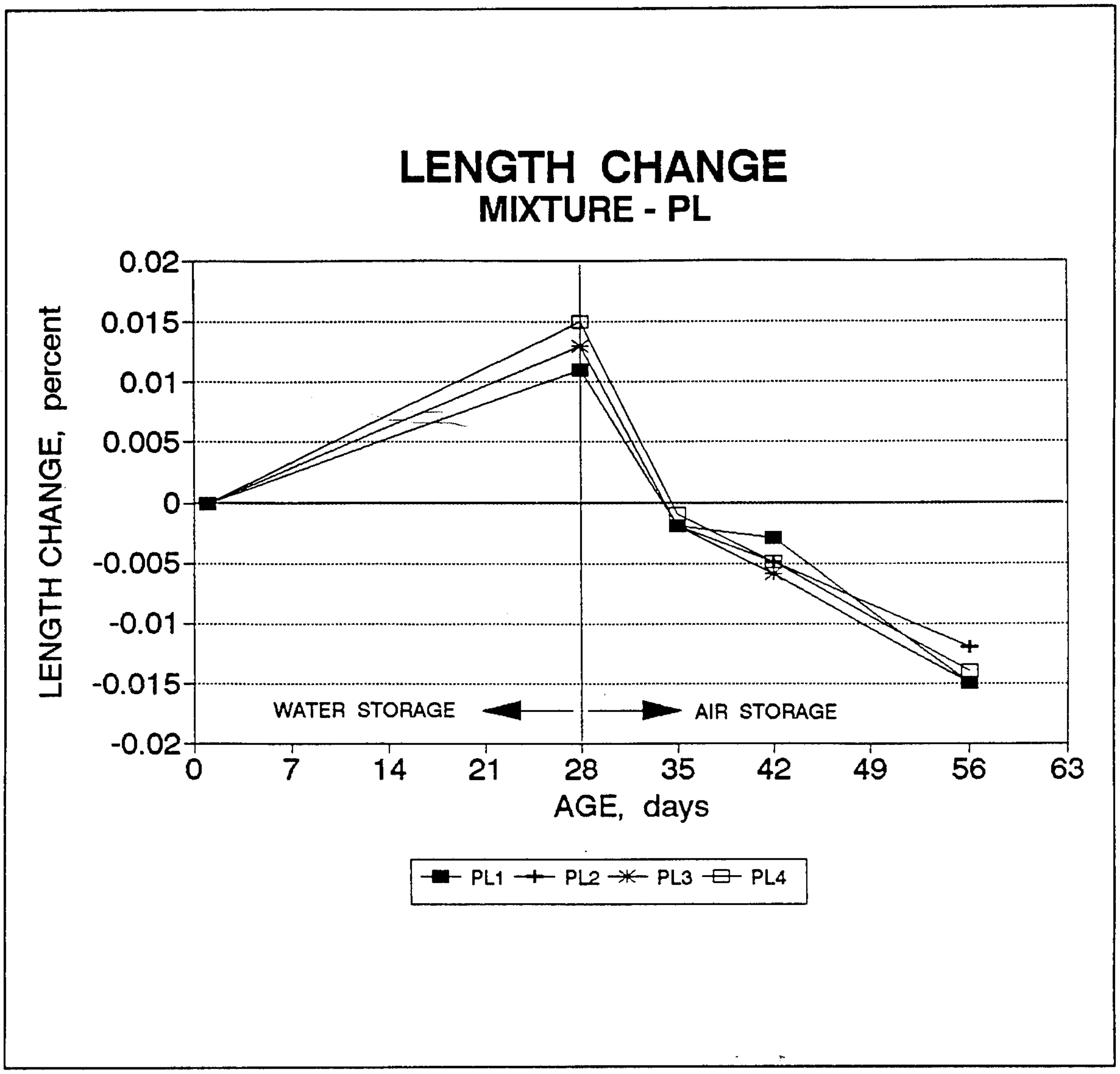

Figure 25. Length change of PL mixture

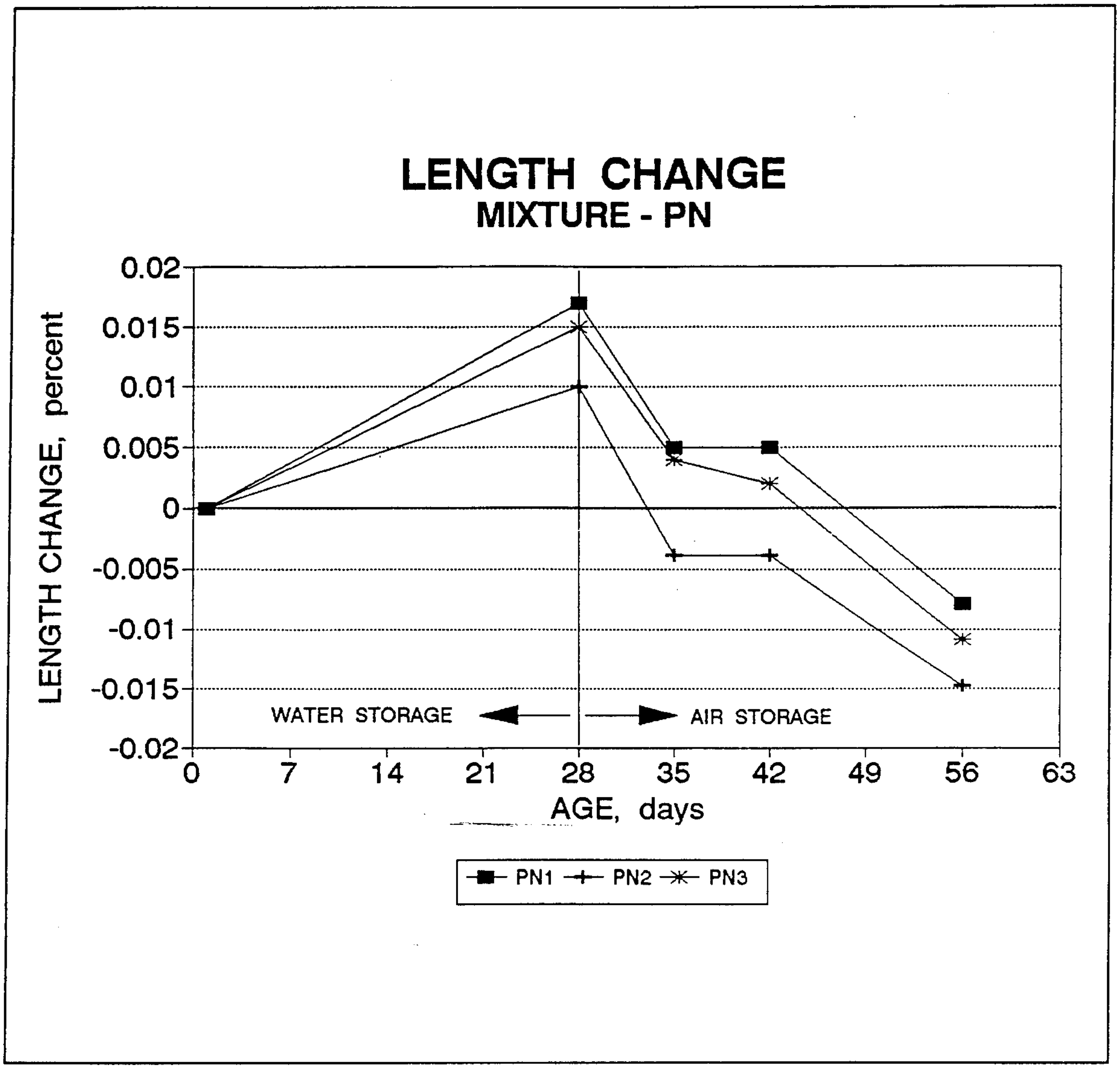

Figure 26. Length change of PN mixture

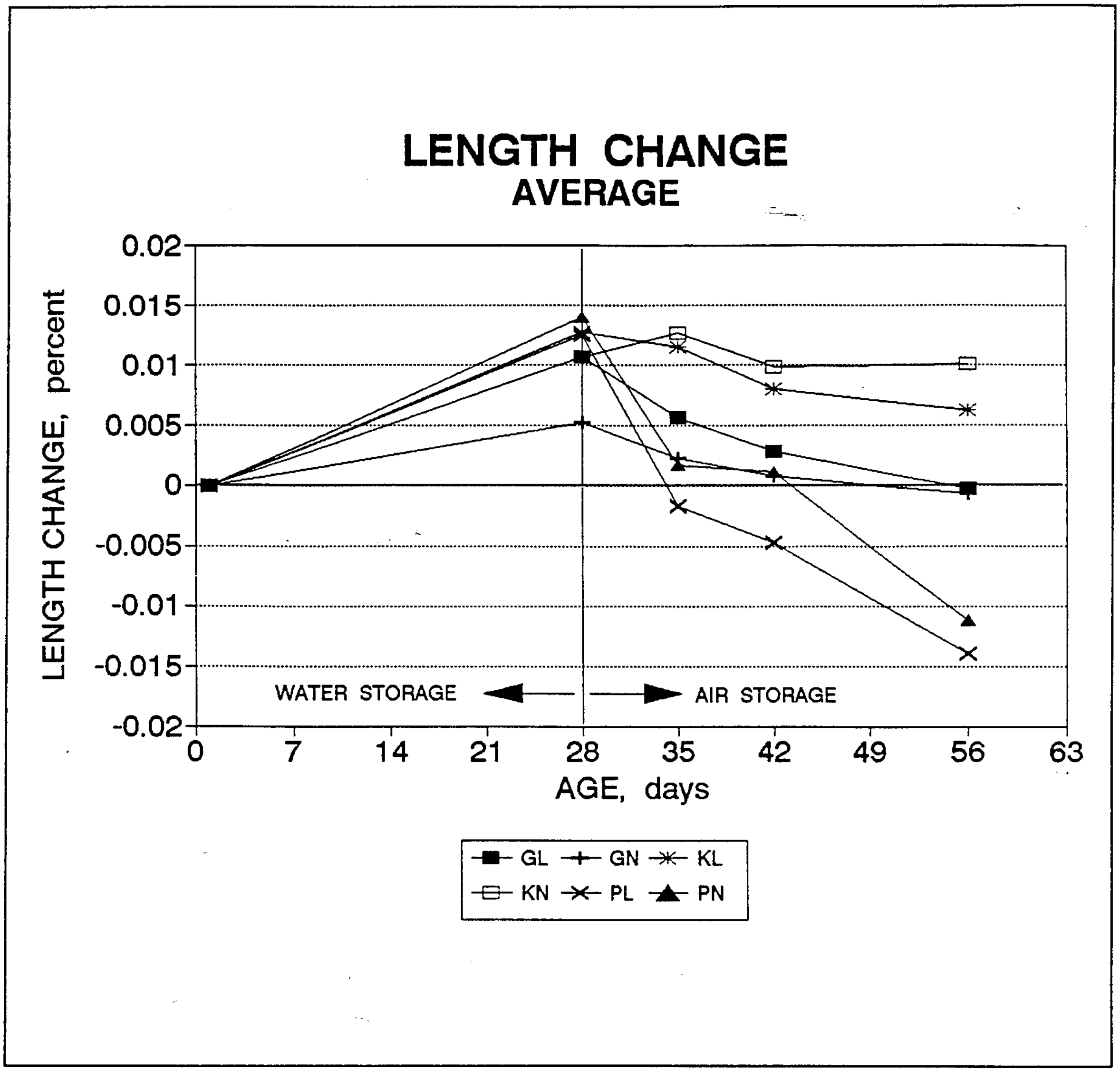

Figure 27. Average length change

STATE:	INDEX NO.:	AGGREGATE DATA SHEET	TESTED BY: FC
LAT.:	LONG.:		DATE: 3-9-93

LAB SYMBOL NO.: 920335 TYPE OF MATERIAL: Natural silicious sand

LOCATION:

PRODUCER: Arkadelphia Sand and Gravel Co.
Arkadelphia, AR

SAMPLED BY:

TESTED FOR:

USED AT:

PROCESSING BEFORE TESTING:

GEOLOGICAL FORMATION AND AGE:

GRADING (CRD-C 103) (CUM. % PASSING):

SIEVE	3-6"	1½-3"	¾-1½"	#4-¾"	FINE AGG.
6 IN.					
5 IN.					
4 IN.					
3 IN.					
2½ IN.					
2 IN.					
1½ IN.					
1 IN.					
¾ IN.					
½ IN.					
⅜ IN.					
NO. 4					100
NO. 8					75
NO. 16					66
NO. 30					59
NO. 50					30
NO. 100					4
NO. 200					
-200[a]					
F.M.[b]					2.65

(a) CRD-C 105 (b) CRD-C 104

TEST RESULTS

	3-6"	1½-3"	¾-1½"	#4-¾"	FINE AGG.
BULK SP GR, S.S.D. (CRD-C 107, 108)					2.60
ABSORPTION, % (CRD-C 107, 108):					0.84
ORGANIC IMPURITIES, FIG. NO. (CRD-C 121)	—	—	—	—	
SOFT PARTICLES, % (CRD-C 130)					—
% LIGHTER THAN SP GR ____ (CRD-C 122)					
% FLAT AND ELONGATED (CRD-C 119, 120)					
WT AV % LOSS, 5 CYC $MgSO_4$ (CRD-C 115)					
L.A. ABRASION LOSS, % (CRD-C 117, 145) GRADING ____					
UNIT WT, LB/CU FT (CRD-C 106):					
FRIABLE PARTICLES, % (CRD-C 142)					
SPEC HEAT, BTU/LB/DEG F. (CRD-C 124)					
REACTIVITY WITH NaOH (CRD-C 128): Sc, mM/L:					
REACTIVITY WITH NaOH (CRD-C 128): Rc, mM/L:					

MORTAR-MAKING PROPERTIES (CRD-C 116)
TYPE ____ CEMENT, RATIO: ____ DAYS, ____ %, ____ DAYS, ____ %

LINEAR THERMAL EXPANSION, MILLIONTHS/DEG F. (CRD-C 125, 126):

ROCK TYPE	PARALLEL	ACROSS	ON	AVERAGE

MORTAR:

MORTAR-BAR EXPANSION AT 100F, % (CRD-C 123):		FINE AGGREGATE 2 MO.	6 MO.	9 MO.	12 MO.	COARSE AGGREGATE 3 MO.	6 MO.	9 MO.	12 MO.
LOW-ALK. CEMENT:	% Na_2O EQUIVALENT:								
HIGH-ALK. CEMENT:	% Na_2O EQUIVALENT:								

SOUNDNESS IN CONCRETE (CRD-C 40, 114):			F&T	HW-CD	HD-CW
FINE AGG.	COARSE AGG:	DFE_{300}			
FINE AGG.	COARSE AGG:	DFE_{300}			

PETROGRAPHIC DATA (CRD-C 127):

REMARKS:

ENG FORM MAR 1966 6011-R

STATE:	INDEX NO.:	AGGREGATE DATA SHEET	TESTED BY: FC
LAT.:	LONG.:		DATE: 2-18-92

LAB SYMBOL NO.: 920048 TYPE OF MATERIAL: Crushed limestone

LOCATION:

PRODUCER: Vulcan
Calera, AL

SAMPLED BY:

TESTED FOR:

USED AT:

PROCESSING BEFORE TESTING:

GEOLOGICAL FORMATION AND AGE:

GRADING (CRD-C 103) (CUM. % PASSING):

SIEVE	3-6"	1½-3"	¾-1½"	#4-¾"	FINE AGG.
6 IN.					
5 IN.					
4 IN.					
3 IN.					
2½ IN.					
2 IN.					
1½ IN.					
1 IN.				100	
¾ IN.				97	
½ IN.				65	
⅜ IN.				39	
NO. 4				6	
NO. 8				1	
NO. 16					
NO. 30					
NO. 50					
NO. 100					
NO. 200					
-200(a)					
F.M.(b)					

(a) CRD-C 105 (b) CRD-C 104

TEST RESULTS	3-6"	1½-3"	¾-1½"	#4-¾"	FINE AGG.
BULK SP GR, S.S.D. (CRD-C 107, 108)				2.71	
ABSORPTION, % (CRD-C 107, 108):				0.2	
ORGANIC IMPURITIES, FIG. NO. (CRD-C 121)	—	—	—	—	
SOFT PARTICLES, % (CRD-C 130)					—
% LIGHTER THAN SP GR ____ (CRD-C 122)					
% FLAT AND ELONGATED (CRD-C 119, 120)					
WT AV % LOSS, 5 CYC $MgSO_4$ (CRD-C 115)					
L.A. ABRASION LOSS, % (CRD-C 117, 145) GRADING ____					
UNIT WT, LB/CU FT (CRD-C 106):					
FRIABLE PARTICLES, % (CRD-C 142)					
SPEC HEAT, BTU/LB/DEG F. (CRD-C 124)					
REACTIVITY WITH NaOH (CRD-C 128): Sc,mM/L:					
Rc,mM/L:					

MORTAR-MAKING PROPERTIES (CRD-C 116)
TYPE ____ CEMENT, RATIO: ____ DAYS, ____ %, ____ DAYS, ____ %

LINEAR THERMAL EXPANSION, MILLIONTHS/DEG F. (CRD-C 125, 126):

ROCK TYPE	PARALLEL	ACROSS	ON	AVERAGE

MORTAR:

MORTAR-BAR EXPANSION AT 100F, % (CRD-C 123):	FINE AGGREGATE 2 MO.	6 MO.	9 MO.	12 MO.	COARSE AGGREGATE 3 MO.	6 MO.	9 MO.	12 MO.
LOW-ALK. CEMENT: % Na_2O EQUIVALENT:								
HIGH-ALK. CEMENT: % Na_2O EQUIVALENT:								

SOUNDNESS IN CONCRETE (CRD-C 40, 114):			F&T	HW-CD	HD-CW
FINE AGG.	COARSE AGG.	DFE_{300}			
FINE AGG.	COARSE AGG.	DFE_{300}			

PETROGRAPHIC DATA (CRD-C 127):

REMARKS:

ENG FORM MAR 1968 6011-R

Plate 2

STATE:	INDEX NO.:	AGGREGATE DATA SHEET	TESTED BY: FC
LAT.:	LONG.:		DATE: 1-26-92

LAB SYMBOL NO.: TYPE OF MATERIAL: Natural chert gravel

LOCATION:

PRODUCER: MS Materials Co.
Vicksburg, MS

SAMPLED BY:

TESTED FOR:

USED AT:

PROCESSING BEFORE TESTING:

GEOLOGICAL FORMATION AND AGE:

GRADING (CRD-C 103) (CUM. % PASSING):

SIEVE	3-6"	1½-3"	¾-1½"	#4-¾"	FINE AGG.
6 IN.					
5 IN.					
4 IN.					
3 IN.					
2½ IN.					
2 IN.					
1½ IN.				100	
1 IN.				97	
¾ IN.				72	
½ IN.				40	
⅜ IN.				24	
NO. 4				2	
NO. 8				1	
NO. 16					
NO. 30					
NO. 50					
NO. 100					
NO. 200					
-200(a)					
F.M.(b)					

(a) CRD-C 105 (b) CRD-C 104

TEST RESULTS	3-6"	1½-3"	¾-1½"	#4-¾"	FINE AGG.
BULK SP GR, S.S.D. (CRD-C 107, 108)				2.55	
ABSORPTION, % (CRD-C 107, 108):				1.4	
ORGANIC IMPURITIES, FIG. NO. (CRD-C 121)	—	—	—	—	
SOFT PARTICLES, % (CRD-C 130)					—
% LIGHTER THAN SP GR ____ (CRD-C 122)					
% FLAT AND ELONGATED (CRD-C 119, 120)					
WT AV % LOSS, 5 CYC $MgSO_4$ (CRD-C 115)					
L.A. ABRASION LOSS, % (CRD-C 117, 145) GRADING ____					
UNIT WT, LB/CU FT (CRD-C 106):					
FRIABLE PARTICLES, % (CRD-C 142)					
SPEC HEAT, BTU/LB/DEG F. (CRD-C 124)					
REACTIVITY WITH NaOH (CRD-C 128): Sc, mM/L:					
Rc, mM/L:					

MORTAR-MAKING PROPERTIES (CRD-C 116)
TYPE ____ CEMENT, RATIO: ____ DAYS, ____ %, ____ DAYS, ____ %

LINEAR THERMAL EXPANSION, MILLIONTHS/DEG F. (CRD-C 125, 126):

ROCK TYPE	PARALLEL	ACROSS	ON	AVERAGE

MORTAR:

MORTAR-BAR EXPANSION AT 100F, % (CRD-C 123):	FINE AGGREGATE 2 MO.	6 MO.	9 MO.	12 MO.	COARSE AGGREGATE 3 MO.	6 MO.	9 MO.	12 MO.
LOW-ALK. CEMENT: % Na_2O EQUIVALENT:								
HIGH-ALK. CEMENT: % Na_2O EQUIVALENT:								

SOUNDNESS IN CONCRETE (CRD-C 40, 114):	F&T	HW-CD	HD-CW
FINE AGG. COARSE AGG. DFE_{300}			
FINE AGG. COARSE AGG. DFE_{300}			

PETROGRAPHIC DATA (CRD-C 127):

REMARKS:

ENG FORM 1 MAR 1968 6011-R

MATERIAL: ABC1
SOURCE: Southwestern Electric Power
LOCATION: Gentry, Arkansas
PREPARED FOR: Billy D. Neeley
SPECIFICATION: ASTM C 618
PROJECT: ABC Corp. Cement Test

REPORT NO.: WES 77C-94
DATE: 9 Sep 94
JOB NO.: VW8122S9960111A
DATE: 9 Aug 94

CHEMICAL ANALYSIS	RESULTS	ASTM C 618 SPEC LIMITS "CLASS C"
Moisture content, %	0.1	3.0 max
Loss on ignition, %	0.6	6.0 max
PHYSICAL TESTS		
Fineness (45 micrometre), % retained	13	34 max
Density, Mg/m^3	2.78	--

Plate 4. Test report of ABC1

MATERIAL: ABC2	REPORT NO.: WES 76C-94
SOURCE: Kansas Power & Light	DATE: 9 Sep 94
LOCATION: St. Marys, KS	JOB NO.: VW8122S9960111A
PREPARED FOR: Billy D. Neeley	
SPECIFICATION: ASTM C 618	
PROJECT: ABC Corp. Cement Test	

CHEMICAL ANALYSIS	RESULTS	ASTM C 618 SPEC LIMITS "CLASS C"
Moisture content, %	0.07	3.0 max
Loss on ignition, %	0.65	6.0 max
PHYSICAL TESTS		
Density, Mg/m^3	2.73	
Amount retained, 45 μm sieve, %	14	

Plate 5. Test report of ABC2

REPORT OF TESTS ON HYDRAULIC CEMENT

TO:

Husbands/Neeley
Structures Laboratory

FROM:
U. S. Army Corps of Engineers
Waterways Experiment Station
Engineering Materials Group
3909 Halls Ferry Road
Vicksburg, Mississippi 39180-6199

Company: Capitol Cement
Location: San Antonio, Texas
Specification: ASTM C 150, III
Contract No.:
Project: ABC Corp. Cement Test

Test Report No.: WES-51-94
Program: Single Sample
CTD No.: 920346
Job No.: VW8122S9960111A
Date Sampled: 28 June 94

_Partial test result

7/19/94 Tests complete, material X does, _does not meet specification

	Result	Retest	ASTM C 150 Spec Limits "Type III"
Chemical Analysis			
SiO_2, %	19.5		-
Al_2O_3, %	4.8		-
Fe_2O_3, %	2.0		-
CaO, %	64.0		-
MgO, %	1.3		6.0 max
SO_3, %	4.4		3.5,4.5 max[a]
Loss on ignition, %	2.6		3.0 max
Insoluble residue, %	0.03		0.75 max
Na_2O, %	0.13		-
K_2O, %	0.62		-
Alkalies-total as Na_2O,%	0.54		0.60 max
TiO_2, %	0.26		-
P_2O_5, %	0.14		-
C_3A, %	11		15 max
C_3S, %	62		-
C_2S, %	9		-
C_4AF, %	6		-
Physical Tests			
Heat of hydration, 7-day, cal/g	-		-
Surface area, m^2/kg, (air permeability)	617		-
Autoclave expansion, %	-0.05		0.80 max
Initial set, min. (Gillmore)	115		60 min
Final set, min. (Gillmore)	250		600 max
Air content, %	7		12 max
Compressive strength, 1-day, psi	4020		1800 min
Compressive strength, 3-day, psi	5950		3500 min
False set (final penetration), %	57		50 min

REMARKS:
[a]See ASTM C 150

Plate 6. Test report of Type III portland cement

REPORT DOCUMENTATION PAGE

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Billy D. Neeley

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report documents the preliminary investigation of a newly developed cementitious material from Ash Bonding Chemicals (ABC) Corporation. The ABC cementitious material is a new, high-early strength, blended-hydraulic cement composed primarily of subbituminous Class C fly ash. The Class C fly ash generally makes up 77 to 95 percent by weight of the total material. The remaining part can be slag and/or portland cement. Four readily available chemical compounds were used in small quantities to control the workability and setting time of the cementitious material, to enhance the strength, and to improve the durability. These admixtures are a set-suspending agent, an activator, a modifying retarder, and an accelerator. The objective of this research was to conduct a preliminary investigation of the ABC cementitious material to determine its viability for use in producing workable, durable, high-early strength concrete. Two ABC cements were used in the investigation, each being produced from a different source of Class C fly ash. Concrete mixtures produced with Type III portland cement, including a water-reducing admixture and a high-range water-reducing admixture, were tested for a comparison. The results indicated the ABC cementitious material as a possible alternative to Type III portland cement for producing high-early strength concrete.

14. SUBJECT TERMS

Concrete	High performance concrete
Fly ash	Subbituminous fly ash
High-early strength concrete	Type III Portland cement

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