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ELASTIC AND STRENGTH PROPERTIES OF HANFORD CONCRETE MIXES AT ROOM AND ELEVATED TEMPERATURES

MASTER

by

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HIGHLIGHTS

Tests were conducted on two Hanford concrete mixes to determine the modulus of elasticity, Poisson's ratio, compressive strength, and splitting tensile strength at room temperature and elevated temperatures. All tests were made on 6-in. diameter x 12-in. long cylinders. Modulus of elasticity and Poisson's ratio were determined by sonic (dynamic) and static test methods at room temperature and by a static test method at elevated temperatures. Variables of the program were the effect of (a) temperature and (b) length of exposure to elevated temperatures. Petrographic and fractographic analyses also were conducted.

Generally, sonic and static moduli of elasticity at 73F increased slightly with age for the 3K and 4.5K concrete mixes. Sonic values were about 20% higher than the static values. For both concrete mixes, the modulus of elasticity dropped sharply during the first 30 days of heating. From that point on, the drop of modulus was much more gradual. Effects of temperature on the concretes with regard to the modulus of elasticity were very pronounced. The lowest values were obtained at 450F.

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Poisson's ratio values determined by the sonic method for the 3K and 4.5K mixes are nearly the same, ranging from 0.20 and 0.23. Sonic Poisson's ratio is greater in all cases than the ratio determined by the static method. At elevated temperatures, Poisson's ratio data were very erratic for both mixes. However, notwithstanding these variations, the high temperature value for Poisson's ratio varied between 0.12 and 0.14. Length of exposure and temperature did not have a significant effect on the values obtained for Poisson's ratio.

For both mixes, splitting tensile strength of the concrete moist cured at 73F increased rapidly up to 200 days and decreased to about 350 days. Beyond that point, splitting tensile strength leveled off or increased. Splitting tensile strength of each mix generally decreased with both length of exposure and temperature. The greatest decrease in tensile splitting strength was obtained at 450F after about 900 days of exposure.

At room temperature, the moist-cured concrete's compressive strength increased with age. The greatest increase was between 30 and 200 days. Beyond this point, the increase was much smaller. The observed strength increase is representative for these concrete mixes. Compressive strength data for the 3K and 4.5K concretes heated at 250F, 350F, and 450F for over 900 days were very erratic. However, for most cases, strength decreased with increasing length of exposure. Also, strength decreased with increasing temperature. The lowest compressive strength values were obtained at 450F after 900 days exposure. However these reduced strengths were barely below the minimum specified levels of 3000 and 4500 psi.

Results of the petrographic examination show no clearly defined correlation with the temperature of storage or time of exposure. Information obtained suggests a possibility that real differences exist in the concrete due to these two variables. However, the necessity for additional data was demonstrated. Data obtained from fractographic examination suggest the possibility of major effects of both temperature and time on the type of fracture produced in compressive and splitting tensile tests. However, the examination was conducted after the cylinders had cooled to room temperature. The cooling probably produced a poorly understood relaxation effect on the paste aggregate bond which may have weakened the concrete. Consequently, the effects of temperature and time of exposure at elevated temperatures could not be evaluated conclusively.

INTRODUCTION

The purpose of this test program was to determine the effects of long-term exposure to elevated temperatures on the physical properties of concrete mixes used in Hanford radioactive waste storage tanks. Information gained from the program will be useful in several ways. It can be used to determine how much thermally induced degradation has occurred in the concrete used in existing waste tanks, thus helping to evaluate the adequacy of these tanks for continued waste storage. Property information for the Hanford materials can also be used to optimize and plan for maximum safety in the design of new waste tanks. Finally, at the present time, published literature on the long-term effects of elevated temperatures on Hanford concretes is not available. The program has provided data generally applicable to the use of concrete at elevated temperatures for prolonged periods of time. This information should be of value in several ongoing and planned programs at Hanford.

TEST PROGRAM

The experimental test program was conducted at the Construction Technology Laboratories of the Portland Cement Association in Skokie, Illinois. All tests were made on 6-in. diameter x 12-in. long cylinders of two concrete mixes designated 3K and 4.5K. Details of mix designs are given in Table 1. Materials for the mixes and mix design information were furnished by the sponsor. Raw materials used were from the same sources as for tank construction. Sand and gravel were obtained from the Hanford batch plant. Type II low alkaline portland cement was furnished by Lone Star Industries in Seattle. Test cylinders were fabricated following the procedures outlined in ASTM Designation: C192.[1]

(1) Numbers in raised parentheses refer to references on page 70.

TABLE 1 MIX DESIGNS

ITEM	QUANTITY (lb/cu/yd)	
	3000 Psi Mix (3K)	4500 Psi Mix (4.5K)
Portland Cement, Type II	493	653
Aggregate	2096	1880
Sand	1213	1240
Water	271	286
Darex, 2% Solution	3 oz	4.50 oz
Air (Percent by Volume)	5	5
Water/Cement Ratio	0.54	0.43

Details concerning the fabrication of the test cylinders are given in Appendix A.

Table 2 gives the schedule for the sonic test program. All tests were made on the same two specimens of the 3K and 4.5K mixes. Modulus of elasticity and Poisson's ratio were obtained at room temperature on moist-cured specimens at ages ranging from 32 to 1204 days.

Schedules for room temperature and elevated temperature tests using the static method are given in Table 3. Tests were made at room temperature on one or two specimens of the 3K and 4.5K mixes. Two specimens of each of the two mixes were tested at each of the elevated temperatures. Modulus of elasticity, Poisson's ratio, compressive strength, and splitting tensile strength were obtained at each of the test dates.

Information concerning petrographic and fractographic analyses is given in Appendix 2. Birefringence studies were made on specimens of 3K and 4.5K mixes that were exposed to temperatures of 250F, 350F, and 450F for periods ranging from 3 to 270 days. Air content estimated on broken surfaces and the tenacity of paste-aggregate bond were also determined on specimens heated at 250F, 350F, and 450F for periods ranging from 3 to 270 days. A fractographic analysis of broken surfaces was made on specimens of both mixes stored in the moist room at 73F for periods ranging from 30 to 679 days. Also, fractographic studies were made on specimens heated at 250F, 350F, and 450F for periods ranging from 3 to 487 days.

TABLE 2 SONIC METHOD TEST SCHEDULE

Test Date, Mo.-day-yr.	Age at Test, Days
6-23-75	32
7-21-75	60
8-20-75	90
12-3-75	193
1-19-76	240
5-16-76	360
10-5-76	502
3-30-77	678
11-11-77	873
5-9-78	1083
9-6-78	1204

TABLE 3 ELASTIC CONSTANTS (STATIC METHOD) AND STRENGTHS TEST SCHEDULES

Temperature at Test, F	Test Date, Mo.-day-yr.	Time in Fog Room, Days	Age at Test, Days	Time in Oven, Days: E, μ, Compressive Strength	Time in Oven, Days: Splitting Tensile Strength
73	6-21-75	30	30	0	0
73	12-2-75	194	194	0	0
73	1-19-76	240	240	0	0
73	5-17-76	361	361	0	0
73	3-31-77	679	679	0	0
73	11-18-77	880	880	0	0
73	9-6-78	1204	1204	0	0
250	12-4-75	193	196	3	3
250	12-11-75	193	203	10	10
250	12-31-75	193	223	30	30
250	2-19-76	193	273	80	80
250	4-29-76	193	343	150	150
250	8-27-76	193	463	270	270
250	4-1-77	283	679	396	396
250	9-29-77	283	861	578	578
250	9-1-78	270,276	1198	922,928	922,928
350	12-5-75	193	197	4	4
350	12-11-75	193	203	10	10
350	12-31-75	193	223	30	30
350	2-19-76	193	273	80	80
350	4-29-76	193	343	150	150

TABLE 3 ELASTIC CONSTANTS (STATIC METHOD) AND STRENGTHS TEST SCHEDULES (Continued)

Temperature at Test, F	Test Date, Mo.-day-yr.	Time in Fog Room, Days	Age at Test, Days	Time in Oven, Days: E, μ, Compressive Strength	Time in Oven, Days: Splitting Tensile Strength
350	8-27-76	193	463	270	270
350	4-1-77	276	679	403	403
350	9-30-77	276	851	585	585
350	9-1-78	276	1198	922	-
350	9-5-78	276	1202	-	926
450	12-11-75	197	203	6	6
450	12-15-75	197	207	10	10
450	12-23-75	197	215	18	18
450	1-7-76	197	230	33	33
450	2-3-76	197	257	60	60
450	3-15-76	197	297	100	100
450	5-24-76	197	367	170	170
450	9-30-76	197	497	300	300
450	3-31-77	270	679	409	409
450	9-29-77	270	861	591	591
450	9-1-78	283	1198	915	-
450	9-6-78	283	1203	-	920

TEST PROCEDURES

The height, diameter, and weight of cylinders were measured prior to being placed in the oven for heating. This information is listed in Table 4. Cylinder lengths and diameters are the average of two or three measurements as required by ASTM Designations C39,[2] C215,[3] C469,[4] C496.[5]

All specimens were transported from the oven to the test area in a well-insulated container. Tests were performed as quickly as possible to prevent heat loss. Specimens not tested to destruction were returned to the oven in the insulated container.

Specimens tested at elevated temperatures were heated to test temperatures at a rate of 70-75F per day. Five temperature changes over the 24-hr period were made to obtain the 70-75F temperature rise. Required temperature variation limits of ± 15F at 250F and 350F and ± 20F at 450F were easily maintained. A continuous record of oven-temperatures was maintained during the temperature rise and soak periods.

Modulus of Elasticity and Poisson's Ratio

Elastic constants of test cylinders were obtained using a dynamic and static method. A description of each method follows:

Sonic (Dynamic) Method

Modulus of elasticity and Poisson's ratio were obtained on

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
3K3-1	6.00	11.99	30.15
3K3-3	6.02	12.00	30.24
3K3-5	5.98	11.95	30.32
3K3-7	5.99	12.15	30.56
3K3-8	6.01	11.97	30.40
3K3-9	6.03	12.15	30.40
3K3-10	6.01	11.99	30.31
3K3-11	6.01	11.94	30.22
3K3-12	6.00	12.02	30.29
3K3-13	6.01	12.15	30.48
3K3-14	6.01	12.05	30.35
3K3-17	6.02	11.95	30.21
3K3-20	6.02	11.93	30.18
3K3-23	5.99	11.98	30.16
3K3-25	6.01	11.99	29.33
3K3-26	6.03	11.96	30.39
3K3-27	6.01	12.00	30.00
3K4-1	6.04	12.00	29.60
3K4-2	6.04	12.11	29.74
3K4-3	6.05	11.98	29.60
3K4-4	6.02	12.12	29.75
3K4-5	6.01	11.98	29.54
3K4-7	5.99	11.99	29.65
3K4-8	6.03	11.96	29.50
3K4-9	6.02	11.97	29.64
3K4-10	6.00	12.05	29.71
3K4-11	6.02	11.95	29.65
3K4-14	6.02	11.98	29.65
3K4-15	6.00	11.97	29.58
3K4-16	6.03	11.96	29.43
3K4-17	5.99	11.97	29.55
3K4-18	6.00	12.12	29.70
3K4-19	6.03	11.99	29.51
3K4-20	6.06	12.00	29.62
3K4-23	6.06	12.01	29.66
3K4-24	6.03	11.99	29.55
3K4-25	5.98	12.10	29.65
3K4-26	6.01	12.05	29.72
3K4-27	6.02	12.05	29.93
3K4-28	5.98	12.06	29.68
3K4-29	6.01	12.08	29.70
3K4-30	6.01	12.08	29.63

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE (Continued)

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
3K5-2	6.04	11.93	29.59
3K5-3	6.00	12.01	29.76
3K5-4	6.02	11.97	29.77
3K5-5	6.03	11.99	29.64
3K5-7	6.01	12.11	29.97
3K5-8	6.01	11.97	29.86
3K5-9	6.00	11.95	29.81
3K5-10			
3K5-11	5.98	11.93	29.82
3K5-12	6.01	12.11	29.88
3K5-13	6.02	12.13	30.16
3K5-14	6.01	11.97	29.87
3K5-17	6.01	12.00	29.94
3K5-20	5.99	11.97	29.84
3K5-23	5.99	11.96	29.76
3K5-25	6.01	12.00	29.70
3K5-27	6.00	12.00	29.74
3K5-28	6.01	12.00	29.69
3K6-1	6.03	11.99	29.59
3K6-3	6.03	11.98	29.50
3K6-4	6.03	12.12	29.58
3K6-5	6.01	12.00	29.61
3K6-6	6.01	12.15	29.62
3K6-8	6.01	11.99	29.57
3K6-10	6.00	12.13	29.95
3K6-11	6.02	11.94	29.51
3K6-14	6.00	11.98	29.55
3K6-16	6.00	12.10	29.77
3K6-17	6.00	11.99	29.53
3K6-19	6.03	11.98	29.66
3K6-23	6.04	12.00	29.53
3K6-24	6.01	12.15	29.64
3K6-25	6.01	11.97	29.55
3K6-26	6.00	12.10	29.74
3K6-27	5.98	12.01	29.64
3K6-28	5.99	11.99	29.63
3K6-30	6.02	11.98	29.62
3K7-1	6.00	12.01	29.13
3K7-2	6.01	11.95	28.94
3K7-3	6.08	12.01	29.11

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE (Continued)

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
3K7-4	6.00	12.07	29.16
3K7-5	6.03	11.97	28.95
3K7-6	6.00	12.09	29.21
3K7-7	6.02	12.12	29.41
3K7-8	6.03	11.97	28.84
3K7-9	6.07	12.12	29.14
3K7-10	6.02	11.98	28.99
3K7-11	6.02	11.96	29.09
3K7-14	6.00	11.97	28.90
3K7-17	6.01	11.98	29.07
3K7-19	6.01	11.95	29.27
3K7-20	6.02	12.00	28.97
3K7-21	6.00	11.98	29.12
3K7-22	5.98	12.11	29.04
3K7-23	6.02	11.99	29.28
3K7-24	6.04	12.13	29.40
3K7-25	6.03	11.99	29.10
3K7-27	6.03	11.97	29.04
3K7-28	6.02	12.13	28.35
3K8-1	6.01	11.98	29.49
3K8-3	6.02	11.99	29.56
3K8-4	6.01	12.10	29.48
3K8-5	6.06	11.98	29.45
3K8-6	6.00	12.17	29.67
3K8-8	6.02	11.98	29.55
3K8-11	6.01	11.99	29.59
3K8-13	6.05	12.17	29.59
3K8-14	6.03	11.98	29.43
3K8-15	-	-	-
3K8-17	6.03	11.98	29.57
3K8-18	-	-	-
3K8-21	5.96	11.97	29.38
3K8-22	6.00	12.01	29.61
3K8-23	-	-	-
3K8-24	6.00	11.98	29.62
3K8-25	6.03	12.00	29.51
3K8-26	6.00	12.17	29.69
3K8-28	6.01	12.03	29.67
3K8-29	-	-	-
3K8-30	6.00	11.97	29.57

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE (Continued)

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
3K9-1	6.01	11.96	29.51
3K9-2	5.98	12.10	29.84
3K9-3	6.05	11.94	29.37
3K9-5	6.01	11.99	29.56
3K9-8	5.99	11.99	29.61
3K9-9	6.04	12.13	29.72
3K9-10	5.99	12.11	29.72
3K9-11	6.03	11.97	29.62
3K9-12	5.99	12.09	29.76
3K9-14	6.01	11.97	29.63
3K9-17	6.01	11.99	29.64
3K9-20	6.00	11.96	29.46
3K9-23	6.03	11.98	29.62
3K9-25	6.00	11.97	29.54
3K9-28	6.03	11.98	29.54
3K9-29	5.99	12.10	29.64
4.5K3-1	6.01	12.01	29.45
4.5K3-2	6.02	12.06	29.63
4.5K3-3	6.00	12.02	29.46
4.5K3-5	6.00	12.01	29.37
4.5K3-7	6.02	12.11	29.75
4.5K3-8	5.99	11.97	29.37
4.5K3-11	6.01	12.01	29.42
4.5K3-14	5.98	11.98	29.36
4.5K3-15	6.03	12.11	29.57
4.5K3-17	6.01	12.01	29.43
4.5K3-18	6.01	12.08	29.57
4.5K3-19	6.03	11.99	29.40
4.5K3-21	6.01	11.99	29.32
4.5K3-22	6.00	11.95	29.36
4.5K3-23	6.02	11.99	29.45
4.5K3-25	6.05	11.98	29.44
4.5K3-27	5.98	12.01	29.31
4.5K4-1	6.00	11.97	29.45
4.5K4-3	6.02	11.92	29.41
4.5K4-4	5.98	12.01	29.58
4.5K4-6	6.05	12.11	29.64
4.5K4-7	6.03	11.99	29.63
4.5K4-8	6.02	11.95	29.43

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE (Continued)

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
4.5K4-10	6.01	12.15	29.48
4.5K4-11	6.07	11.97	29.44
4.5K4-12	6.00	12.00	29.52
4.5K4-13	5.99	12.04	29.60
4.5K4-14	6.00	11.97	29.72
4.5K4-15	6.02	12.02	29.82
4.5K4-17	6.03	12.00	29.73
4.5K4-19	6.05	12.13	29.70
4.5K4-20	6.02	11.96	29.58
4.5K4-21	6.01	11.95	29.64
4.5K4-23	6.04	11.93	29.57
4.5K4-24	6.02	12.02	29.74
4.5K4-26	6.00	12.08	29.66
4.5K4-28	6.01	12.06	29.50
4.5K4-29	5.95	12.09	29.62
4.5K4-30	5.99	12.09	29.73
4.5K5-1	5.99	11.92	29.47
4.5K5-2	5.99	11.96	29.60
4.5K5-3	6.01	11.98	29.60
4.5K5-5	5.99	12.00	29.66
4.5K5-6	6.00	12.14	29.80
4.5K5-7	6.00	11.96	29.47
4.5K5-8	5.98	12.02	29.62
4.5K5-9	5.98	11.99	29.41
4.5K5-10	5.96	12.12	29.65
4.5K5-11	6.00	11.99	29.43
4.5K5-13	6.02	12.06	29.69
4.5K5-14	6.03	11.97	29.46
4.5K5-16	6.03	11.93	29.45
4.5K5-20	5.98	12.01	29.30
4.5K5-23	5.99	11.95	29.25
4.5K5-25	6.04	12.00	29.53
4.5K5-27	6.02	12.14	29.67
4.5K5-28	6.00	12.14	29.80
4.5K6-2	6.01	12.09	29.35
4.5K6-3	6.01	11.96	29.12
4.5K6-6	6.00	11.97	29.14
4.5K6-7	6.03	12.11	29.21
4.5K6-8	6.02	11.99	29.09

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE (Continued)

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
4.5K6-11	6.03	12.02	29.23
4.5K6-12	6.01	11.95	29.28
4.5K6-14	6.01	11.99	29.17
4.5K6-17	6.03	12.02	29.30
4.5K6-18	6.02	11.97	29.23
4.5K6-19	6.02	12.14	29.43
4.5K6-20	6.00	12.00	29.30
4.5K6-23	6.03	11.98	29.25
4.5K6-24	6.04	12.07	29.48
4.5K6-25	6.03	11.94	29.12
4.5K6-26	6.00	12.00	29.25
4.5K6-27	6.04	11.97	29.16
4.5K6-28	6.02	11.99	29.29
4.5K6-29	6.01	12.12	29.39
4.5K7-1	5.94	11.97	29.01
4.5K7-2	6.01	12.09	29.37
4.5K7-3	5.96	11.98	29.11
4.5K7-4	6.01	12.01	29.05
4.5K7-5	5.99	12.09	29.24
4.5K7-8	5.98	11.97	28.97
4.5K7-9	6.05	12.13	29.35
4.5K7-10	6.03	11.98	29.16
4.5K7-12	6.02	12.12	29.25
4.5K7-15	6.01	12.00	29.06
4.5K7-17	6.02	11.95	29.07
4.5K7-18	5.99	11.97	29.05
4.5K7-19	6.01	12.12	29.21
4.5K7-20	6.02	11.96	28.98
4.5K7-21	5.99	11.96	28.99
4.5K7-22	5.98	11.99	28.95
4.5K7-23	6.02	11.98	29.10
4.5K7-24	6.03	11.97	29.09
4.5K7-25	6.02	11.98	29.19
4.5K7-27	5.98	11.99	29.01
4.5K7-28	6.01	12.13	29.36
4.5K7-29	6.02	12.13	29.19

TABLE 4 DIMENSIONS AND WEIGHTS OF CYLINDERS AT AMBIENT TEMPERATURE (Continued)

Specimen No.	Diameter, in.	Height, in.	Weight, lb.
4.5K8-1	6.07	11.98	29.50
4.5K8-2	-	-	-
4.5K8-3	-	12.01	29.55
4.5K8-5	-	-	-
4.5K8-6	6.01	11.97	29.42
4.5K8-8	5.99	11.97	29.53
4.5K8-10	6.02	11.93	29.43
4.5K8-11	6.02	11.96	29.46
4.5K8-12	6.02	12.16	29.72
4.5K8-13			
4.5K8-14	6.03	12.00	29.66
4.5K8-15	6.02	12.12	29.60
4.5K8-16	6.01	11.95	29.41
4.5K8-17	6.03	11.96	29.70
4.5K8-18	6.03	12.13	29.75
4.5K8-20	-	-	-
4.5K8-22	6.02	11.96	29.46
4.5K8-23	5.96	11.97	29.48
4.5K8-24	-	-	-
4.5K8-25	6.00	12.00	29.51
4.5K8-26	6.02	12.16	29.71
4.5K8-27	6.00	11.98	29.50
4.5K8-28	6.00	11.97	29.43
4.5K8-29	6.01	11.99	29.54
4.5K8-30	6.01	12.00	29.66
4.5K9-1	6.01	11.94	29.29
4.5K9-2	6.02	12.14	29.46
4.5K9-3	6.05	11.97	29.40
4.5K9-5	5.99	11.98	29.46
4.5K9-8	6.03	12.03	29.54
4.5K9-11	5.98	11.99	29.38
4.5K9-14	6.05	11.94	29.34
4.5K9-15	6.02	12.15	29.60
4.5K9-17	6.00	11.99	29.49
4.5K9-24	6.01	12.17	29.68
4.5K9-25	6.04	11.98	29.31
4.5K9-29	6.03	12.13	29.65

specimens cured in the moist room at 70F by following the general provisions given in ASTM Designation C215.[3] The equipment consisted of a variable frequency audio-oscillator, amplifiers, a driver unit, a pick-up unit, and meter type and cathode ray oscilloscope indicators. Specimens were supported at the quarter points. The driving force was applied normal to the specimen surface near one end. Fundamental, transverse, and torsional frequencies were obtained. The driving force also was applied normal to the surface midway between the ends of the specimen. The fundamental transfer frequency can be obtained in this manner and was used to check the value obtained by driving the specimen by one end. Frequency determination required about 1 min. The test equipment with test cylinder in place is shown in Fig. 1.

<u>Static Method</u>

The provisions of ASTM Designation: C469[4] were following in determining the elastic constants by this method. A compressometer fitted with differential transformers were used to measure longitudinal and lateral strains. During elevated temperature tests, the transformers were protected with asbestos heat shields. A differential transformer was also used to indicate load. Outputs from the differential transformers were recorded on an XYY recorder. Thus, the stress-longitudinal strain and stress-lateral strain curves were obtained simultaneously during each loading of the specimens. Surfaces of the specimens used for determining the elastic constants were lapped.

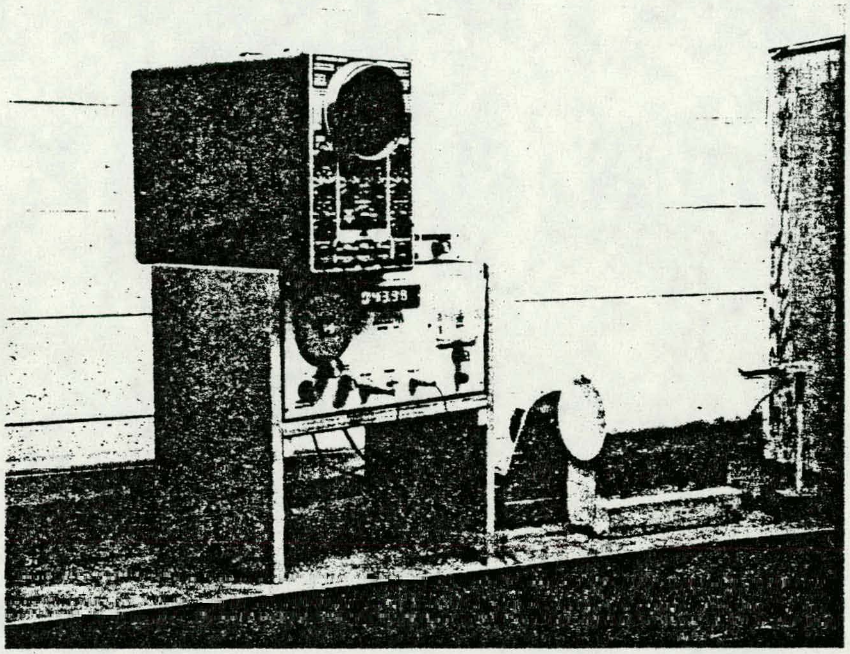

Fig.1 Sonic Test Method For Determining Elastic Constants

Specimens were loaded three or four times for determination of elastic constants. The first loading was a seating loading, and the information obtained from it was not used. Elastic constants were calculated for subsequent loadings and averaged. Specimens were usually loaded to 40 to 50 percent of ultimate for obtaining elastic constants data. Typical stress-strain curves obtained during a loading are shown in Fig. 2. Fitting the specimen with the compressometer, balancing the electrical circuits, and loading the specimen required from 10 to 15 min. Figure 3 shows a test cylinder subjected to the static load test for elastic constants determination.

Compressive Strength

Compressive strength at room and elevated temperatures was obtained by following the general guideline of ASTM Designation: C39.[2] Surfaces of cylinders used to obtain cylinder strength were lapped. Elevated temperature strength determinations were made on cylinders used for obtaining elastic constants by the static method. After the elastic constants were obtained, the cylinders were returned to the oven for at least 2 hr before being tested. The compressive strength test took about 5 min.

Splitting Tensile Strength

To determine splitting tensile strength, the provisions of ASTM Designation C496[5] were followed. At each test date, one of the two specimens of each mix design tested at elevated temperatures was used for determining elastic constants. Test

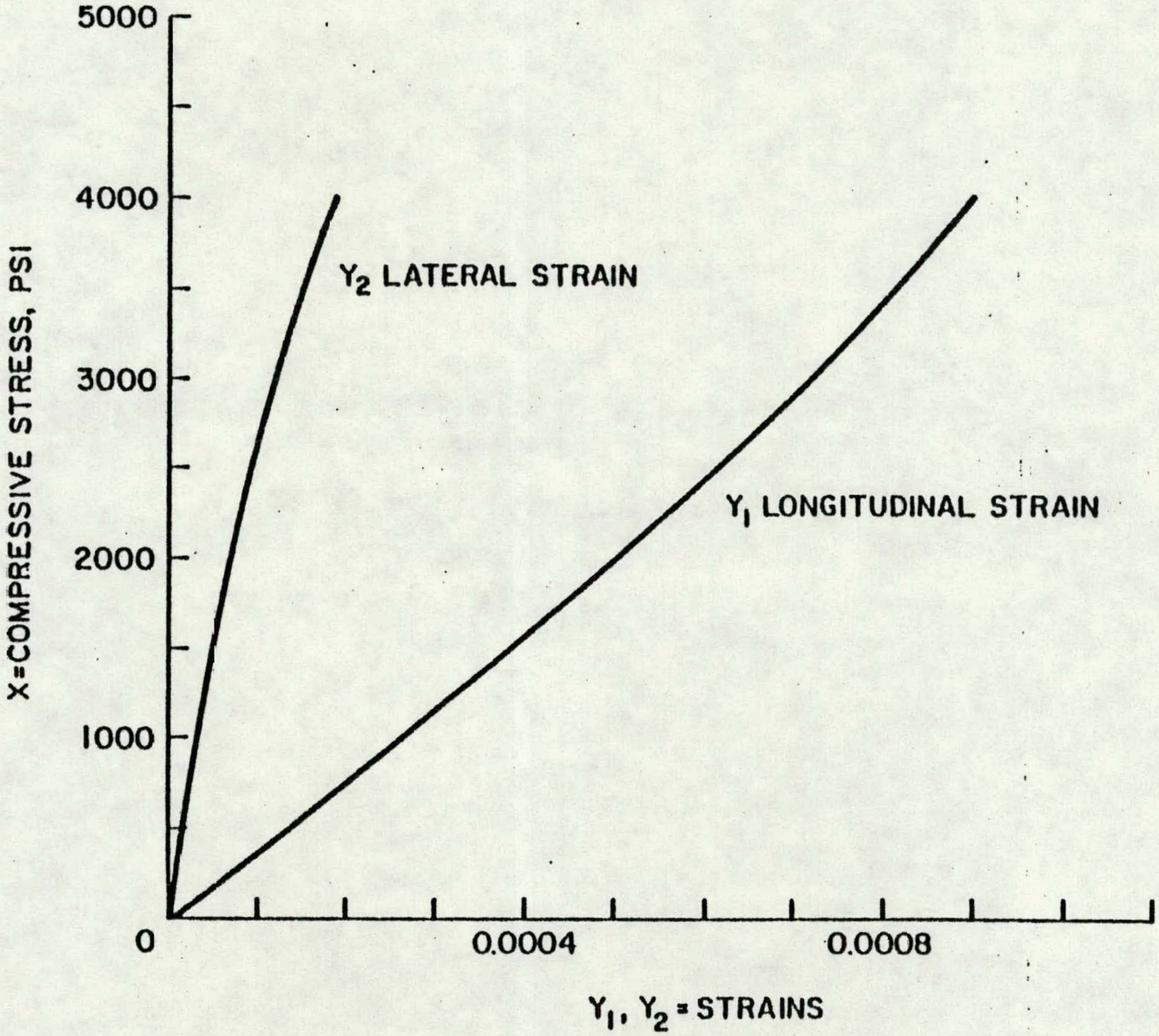

FIG. 2 – STRESS-STRAIN CURVES USING X-Y-Y PLOTTER FOR STATIC TEST

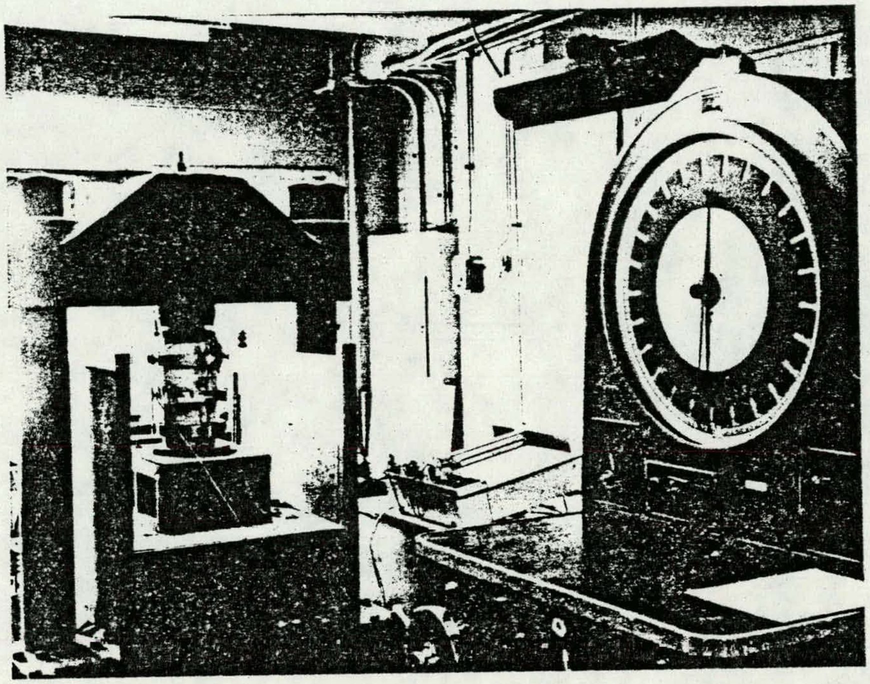

Fig.3 Static Test Method For Determining Elastic Constants and Compressive Strength

specimens were removed from the fog room or oven, marked with diametral lines, positioned in the testing machine, and loaded to failure. The 1/8-in. thick plywood bearing strips were not affected by the heat from the test specimens. The time required for this test procedure did not exceed 10 min.

Petrographic Analysis

Cylinders representing specified time and temperature combinations were removed from the ovens. After a few hours of cooling at room temperature, a 1-in. thick slice was cut transversely using a water-cooled saw. A small block cut from the interior of the slice with an air-cooled saw was lapped, dried at 122F, and mounted on a standard petrographic slide with epoxy adhesive. Thin sections were ground to approximately 10 to 20 microns thickness and protected with cover glass loose-mounted in epoxy. The thin sections were labeled and were numerically coded so that they could be described without prior bias as to duration of storage and temperature.

Birefringence is the numerical difference between the maximum and minimum indices of refraction of an anisotropic crystalline solid and is related to the crystal thickness (thin section thickness) by the following equation:

$$t = \frac{\lambda \theta}{180} / B$$

where

λ = wavelength of transmitted light, in millimicrons (540)

θ = analyzer rotation on the microscope, in degrees

B = birefringence of the crystal solid

t = thickness, in microns

Assuming a quartz birefringence of 0.009, thickness of the concrete thin section was determined by averaging several measurements of θ on 6 to 8 grains of quartz. Using this calculated value of thickness, the average birefringence of calcium hydroxide in the same thin section was determined by examination of 8 to 10 crystals in the portland cement paste of the concrete. More information on the petrographic and fractographic analyses is given in Appendix 2.

TEST RESULTS

Test results for all room and elevated temperature tests are given in Tables 5 to 7 and Figs. 4 to 22.

Modulus of Elasticity

Modulus of elasticity data at room temperature determined by the sonic and static methods for the 3K and 4.5K mixes are given in Tables 5 and 6 and shown in Figs. 4 and 5. For both mixes, sonic modulus increased with increasing moisture period. The largest increases occurred between 30 and 200 days. Over the next 1000 days, the increase in modulus was quite small. Higher values of the sonic modulus were obtained for the 4.5K mix at room temperature. The increase in modulus at room temperature did not differ appreciably for either mix.

TABLE 5 ELASTIC CONSTANTS AT ROOM TEMPERATURE - SONIC METHOD

Specimen No.	Date of Test, Mo.-day-yr.	Age at Test, Days[1]	Weight at Test, lb	Modulus of Elasticity, psi, Millions	Poisson's Ratio
3K4-25	6-23-75	32	29.66	5.16	0.22
3K4-27	6-23-75	32	29.94	5.45	0.22
4.5K4-25	6-23-75	32	29.60	5.38	0.20
4.5K4-27	6-23-75	32	29.80	5.66	0.23
3K4-25	7-21-75	60	29.67	5.29	0.22
3K4-27	7-21-75	60	29.95	5.51	0.21
4.5K4-25	7-21-75	60	29.61	5.54	0.21
4.5K4-27	7-21-75	60	29.80	5.64	0.19
3K4-25	8-20-75	90	29.69	5.38	0.19
3K4-27	8-20-75	90	29.96	5.65	0.22
4.5K4-25	8-20-75	90	29.63	5.65	0.21
4.5K4-27	8-20-75	90	29.70	5.93	0.23
3K4-25	12-3-75	193	29.69	5.50	0.21
3K4-27	12-3-75	193	29.96	5.76	0.22
4.5K4-25	12-3-75	193	29.64	5.81	0.21
4.5K4-27	12-3-75	193	29.72	6.11	0.25
3K4-25	1-19-76	240	29.69	5.50	0.30
3K4-27	1-19-76	240	29.97	5.70	0.20
4.5K4-25	1-19-76	240	29.65	5.82	0.22
4.5K4-27	1-19-76	240	29.72	6.11	0.31
3K4-25	5-15-76	360	29.72	5.63	0.23
3K4-27	5-15-76	360	29.99	5.86	0.23
4.5K4-25	5-15-76	360	29.67	5.86	0.22
4.5K4-27	5-15-76	360	29.75	6.18	0.24

[1]Specimens in fog room at 100% relative humidity and 73F

TABLE 5 ELASTIC CONSTANTS AT ROOM TEMPERATURE - SONIC METHOD (con'd)

Specimen No.	Date of Test, Mo.-day-yr.	Age at Test, Days[1]	Weight at Test, lb	Modulus of Elasticity, psi, Millions	Poisson's Ratio
3K4-25	10-5-76	502	29.73	5.64	0.22
3K4-27	10-5-76	502	29.99	5.87	0.23
4.5K4-25	10-5-76	502	29.70	5.89	0.21
4.5K4-27	10-5-76	502	29.76	6.23	0.25
3K4-25	3-30-77	678	29.74	5.74	0.23
3K4-27	3-30-77	678	30.00	5.92	0.22
4.5K4-25	3-30-77	678	29.72	5.99	0.22
4.5K4-27	3-30-77	678	29.78	6.30	0.25
3K4-25	11-11-77	873	29.73	5.66	0.20
3K4-27	11-11-77	873	29.99	5.91	0.22
4.5K4-25	11-11-77	873	29.71	5.99	0.22
4.5K4-27	11-11-77	873	29.77	6.30	0.24
3K4-25	5-9-78	1083	29.75	5.71	0.20
3K4-27	5-9-78	1083	30.03	5.97	0.22
4.5K4-25	5-9-78	1083	29.73	6.11	0.23
4.5K4-27	5-9-78	1083	29.82	6.33	0.22
3K4-25	9-6-78	1204	29.73	5.69	0.21
3K4-27	9-6-78	1204	30.00	5.93	0.20
4.5K4-25	9-6-78	1204	29.71	6.02	0.20
4.5K4-27	9-6-78	1204	29.79	6.33	0.24

[1] Specimens in fog room at 100% relative humidity and 73F

TABLE 6 - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
3K4-28	6-21-75	30	30	0	73	29.62	4430	4.48	0.15
3K4-30	6-21-75	30	30	0	73	29.49	4250	4.05	0.15
4.5K4-28	6-21-75	30	30	0	73	29.37	5160	4.32	0.15
4.5K4-30	6-21-75	30	30	0	73	29.68	5510	4.58	0.16
3K9-1	12-2-75	194	194	0	73	29.51	5570	4.65	0.16
3K9-3	12-2-75	194	194	0	73	29.37	5480	4.76	0.16
4.5K9-1	12-2-75	194	194	0	73	29.29	6450	5.00	0.16
4.5K9-3	12-2-75	194	194	0	73	29.40	6320	5.02	0.18
3K6-25	1-19-76	240	240	0	73	29.55	5680	4.87	0.17
4.5K6-25	1-19-76	240	240	0	73	29.12	6530	5.03	0.16
3K6-28	5-17-76	361	361	0	73	29.64	5410	4.38	0.17
4.5K6-28	5-17-76	361	361	0	73	29.31	6790	4.46	0.17
3K5-28	3-31-77	679	679	0	73	29.71	5860	5.06	0.15
3K8-28	3-31-77	679	679	0	73	29.68	-[3]	4.92	0.16
4.5K5-9	3-31-77	679	679	0	73	29.43	6640	5.64	0.18
4.5K8-29	3-31-77	679	679	0	73	29.56	-	5.44	0.18
3K4-9	11-18-77	880	880	0	73	29.64	5750	4.61	0.15
3K4-15	11-18-77	880	880	0	73	29.58	-	4.83	0.17
4.5K4-7	11-18-77	880	880	0	73	29.63	5950	5.71	0.18
4.5K4-12	11-18-77	880	880	0	73	29.53	-	5.39	0.17
3K8-15	9-6-78	1204	1204	0	73		6070	4.98	0.16
3K8-18	9-6-78	1204	1204	0	73		-	5.21	0.18
3K8-29	9-6-78	1204	1204	0	73		6150	5.06	0.16
4.5K8-5	9-6-78	1204	1204	0	73		-	5.65	0.19
4.5K8-20	9-6-78	1204	1204	0	73		7725	5.48	0.20
4.5K8-24	9-6-78	1204	1204	0	73		8120	5.79	0.19

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3]Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
3K3-1	12-4-75	196	193	3	250	29.15	5600	3.82	0.14
3K3-5	12-4-75	196	193	3	250	29.34	5590	4.03	0.13
3K3-3	12-4-75	196	193	3	250	29.23	-[3]	3.80	0.13
4.5K3-3	12-4-75	196	193	3	250	28.58	5320	3.82	0.12
4.5K3-5	12-4-75	196	193	3	250	28.54	5230	4.04	0.14
4.5K3-1	12-4-75	196	193	3	250	28.70	-	3.91	0.12
3K8-3	12-11-75	203	193	10	250	27.81	5665	3.66	0.15
3K8-5	12-11-75	203	193	10	250	27.74	5420	3.71	0.14
3K8-1	12-11-75	203	193	10	250	27.74	-	3.71	0.11
4.5K8-1	12-11-75	203	193	10	250	27.79	6920	4.36	0.14
4.5K8-6	12-11-75	203	193	10	250	27.72	6780	4.04	0.14
4.5K8-3	12-11-75	203	193	10	250	27.94	-[3]	4.11	0.14
3K7-1	12-31-75	223	193	30	250	27.33	5295	3.02	0.12
3K7-5	12-31-75	223	193	30	250	27.16	5250	3.04	0.13
3K7-3	12-31-75	223	193	30	250	27.29	-	3.14	0.15
4.5K7-3	12-31-75	223	193	30	250	27.32	6055	3.31	0.15
4.5K7-4	12-31-75	223	193	30	250	27.24	5930	3.42	0.14
4.5K7-1	12-31-75	223	193	30	250	27.22	-	4.06	0.19
3K4-1	2-19-76	273	193	80	250	27.72	5170	3.13	0.15
3K4-3	2-19-76	273	193	80	250	27.75	5160	3.05	0.13
3K4-5	2-19-76	273	193	80	250	27.67	-	3.24	0.13
4.5K4-3	2-19-76	273	193	80	250	27.61	6290	3.40	0.12
4.5K4-4	2-19-76	273	193	80	250	27.80	6020	3.42	0.15
4.5K4-1	2-19-76	273	193	80	250	27.59	-	3.34	0.12
3K5-3	4-29-76	343	193	150	250	27.95	5710	3.15	0.11
3K5-5	4-29-76	343	193	150	250	27.82	5510	3.09	0.12

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3]Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
3K5-2	4-29-76	343	193	150	250	27.84	-[3]	3.13	0.12
4.5K5-3	4-29-76	343	193	150	250	27.72	6160	3.41	0.14
4.5K5-5	4-29-76	343	193	150	250	27.76	6180	3.18	0.11
4.5K5-1	4-29-76	343	193	150	250	27.64	-	3.12	0.12
3K6-3	8-27-76	463	193	270	250	27.71	5250	3.09	0.14
3K6-5	8-27-76	463	193	270	250	27.84	5080	3.00	0.12
3K6-1	8-27-76	463	193	270	250	27.80	-	2.84	0.14
4.5K6-3	8-27-76	463	193	270	250	27.11	6020	3.16	0.12
4.5K6-6	8-27-76	463	193	270	250	27.14	5990	3.07	0.13
4.5K6-8	8-27-76	463	193	270	250	27.04	-	3.68	0.14
3K9-14	4-1-77	679	283	396	250	27.77	5190	3.17	0.13
3K9-20	4-1-77	679	283	396	250	27.59	4990	3.08	0.13
3K9-17	4-1-77	679	283	396	250	27.78	-	3.15	0.13
4.5K8-25	4-1-77	679	283	396	250	27.64	6470	3.36	0.13
4.5K8-28	4-1-77	679	283	396	250	27.49	7020	3.48	0.12
4.5K8-16	4-1-77	679	283	396	250	27.50	-	3.41	0.11
3K9-25	9-29-77	861	283	578	250	27.69	5300	3.07	0.14
3K9-28	9-29-77	861	283	578	250	27.68	5080	3.03	0.14
3K9-23	9-29-77	861	283	578	250	27.76	-	2.99	0.18
4.5K8-10	9-29-77	861	283	578	250	27.54	6620	3.32	0.12
4.5K8-27	9-29-77	861	283	578	250	27.64	6425	3.21	0.12
4.5K8-22	9-29-77	861	283	578	250	27.57	-	3.21	0.12
3K8-21	9-1-78	1198	276	922	250		4530	2.43	0.11
3K8-25	9-1-78	1198	276	922	250		4625	2.60	0.13
3K8-30	9-1-78	1198	276	922	250		-	2.71	0.14

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3]Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
4.5K9-5	9-1-78	1198	270	928	250		-[3]	4.01	0.14
4.5K9-8	9-1-78	1198	270	928	250		5855	3.29	0.13
4.5K9-25	9-1-78	1198	270	928	250		5890	3.37	0.13
3K3-8	12-5-75	197	193	4	350	28.64	6100	3.47	0.12
3K3-14	12-5-75	197	193	4	350	28.53	5780	3.38	0.09
3K3-11	12-5-75	197	193	4	350	28.37	-	3.53	0.10
4.5K3-8	12-5-75	197	193	4	350	27.63	5600	4.04	0.17
4.5K3-14	12-5-75	197	193	4	350	27.65	5430	3.33	0.14
4.5K3-11	12-5-75	197	193	4	350	27.55	-	3.46	0.12
3K4-8	12-11-75	203	193	10	350	27.53	5150	2.69	0.10
3K4-11	12-11-75	203	193	10	350	27.58	4740	2.62	0.12
3K4-14	12-11-75	203	193	10	350	27.71	-	2.73	0.14
4.5K4-8	12-11-75	203	193	10	350	27.50	6520	3.09	0.11
4.5K4-11	12-11-75	203	193	10	350	27.50	6330	3.40	0.10
4.5K4-14	12-11-75	203	193	10	350	27.80	-	3.04	0.09
3K5-11	12-31-75	223	193	30	350	27.90	5480	2.72	0.14
3K5-14	12-31-75	223	193	30	350	27.93	5540	2.59	0.11
3K5-8	12-31-75	223	193	30	350	27.94	-	2.74	0.12
4.5K5-8	12-31-75	223	193	30	350	27.65	5280	2.75	0.13
4.5K5-11	12-31-75	223	193	30	350	27.45	5675	2.77	0.13
4.5K5-14	12-31-75	223	193	30	350	27.43	-	2.94	0.13
3K6-11	2-19-76	273	193	80	350	27.54	4780	2.56	0.10
3K6-14	2-19-76	273	193	80	350	27.56	4810	2.38	0.11
3K6-8	2-19-76	273	193	80	350	27.61	-	2.51	0.13
4.5K6-11	2-19-76	273	193	80	350	27.19	5430	2.74	0.14

[1] Specimens in fog room at 100% relative humidity and 73F

[2] Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3] Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
4.5K6-14	2-19-76	273	193	80	350	27.13	5275	2.72	0.14
4.5K6-12	2-19-76	273	193	80	350	27.24	-	2.66	0.14
3K7-8	4-29-76	343	193	150	350	26.87	4410	2.11	0.15
3K7-11	4-29-76	343	193	150	350	27.11	4675	2.29	0.14
3K7-14	4-29-76	343	193	150	350	26.93	-	2.17	0.14
4.5K7-8	4-29-76	343	193	150	350	26.92	5490	2.34	0.12
4.5K7-10	4-29-76	343	193	150	350	27.11	4890	2.29	0.15
4.5K7-15	4-29-76	343	193	150	350	26.99	-	2.32	0.14
3K8-8	8-27-76	463	193	270	350	27.55	4910	2.52	0.13
3K8-11	8-27-76	463	193	270	350	27.66	4960	2.51	0.14
3K8-14	8-27-76	463	193	270	350	27.39	-	2.52	0.14
4.5K8-8	8-27-76	463	193	270	350	27.46	6190	2.78	0.11
4.5K8-11	8-27-76	463	193	270	350	27.37	6300	3.14	0.11
4.5K8-14	8-27-76	463	193	270	350	27.61	-	2.78	0.11
3K6-24	4-1-77	679	276	403	350	27.65	4650	2.37	0.13
3K6-30	4-1-77	679	276	403	350	27.65	4430	2.17	0.15
3K6-27	4-1-77	679	276	403	350	27.65	-	2.20	0.12
4.5K6-18	4-1-77	679	276	403	350	27.12	5450	2.43	0.12
4.5K6-26	4-1-77	679	276	403	350	27.18	5160	2.46	0.12
4.5K6-27	4-1-77	679	276	403	350	27.07	-	2.37	0.16
3K7-19	9-30-77	861	276	585	350	27.31	4390	2.33	0.16
3K7-25	9-30-77	861	276	585	350	27.10	4320	2.32	0.15
3K7-10	9-30-77	861	276	585	350	26.97	-	2.16	0.14
4.5K7-24	9-30-77	861	276	585	350	28.01	5100	2.32	0.14
4.5K7-25	9-30-77	861	276	585	350	28.12	5500	2.34	0.14

[1] Specimens in fog room at 100% relative humidity and 73F

[2] Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3] Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
3K7-17	1-7-76	230	197	33	450	27.01	4280	2.08	0.18
3K7-23	1-7-76	230	197	33	450	27.22	4455	2.06	0.17
3K7-20	1-7-76	230	197	33	450	26.80	-[3]	2.06	0.16
4.5K7-18	1-7-76	230	197	33	450	26.89	5165	2.18	0.14
4.5K7-20	1-7-76	230	197	33	450	26.84	5110	2.20	0.14
4.5K7-23	1-7-76	230	197	33	450	26.73	-	2.28	0.09
3K8-17	2-3-76	257	197	60	450	27.44	4780	2.29	0.15
3K8-22	2-3-76	257	197	60	450	27.35	4630	2.34	0.16
3K8-24	2-3-76	257	197	60	450	27.37	-	2.17	0.14
4.5K8-17	2-3-76	257	197	60	450	27.51	5560	2.37	0.13
4.5K8-30	2-3-76	257	197	60	450	27.50	5130	2.27	0.09
4.5K8-23	2-3-76	257	197	60	450	27.30	-	2.28	0.14
3K9-5	3-15-76	297	197	100	450	27.54	4350	1.93	0.16
3K9-8	3-15-76	297	197	100	450	27.47	4415	2.08	0.15
3K9-11	3-15-76	297	197	100	450	27.53	-	2.04	0.21
4.5K9-11	3-15-76	297	197	100	450	27.26	5270	2.14	0.10
4.5K9-17	3-15-76	297	197	100	450	27.41	5210	2.08	0.10
4.5K9-14	3-15-76	297	197	100	450	27.28	-	2.12	0.15
3K3-25	5-24-76	367	197	170	450	27.25	5140	2.06	0.09
3K5-25	5-24-76	367	197	170	450	27.52	4560	1.91	0.14
3K4-24	5-24-76	367	197	170	450	27.52	-	1.84	0.16
4.5K3-25	5-24-76	367	197	170	450	27.43	4880	1.73	0.12
4.5K4-24	5-24-76	367	197	170	450	27.60	5340	1.70	0.13
4.5K5-25	5-24-76	367	197	170	450	27.40	-	1.84	0.12
3K3-20	9-30-76	497	197	300	450	28.09	5920	1.94	0.10

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3]Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
4.5K7-17	9-30-77	861	276	585	350	27.01	-[3]	2.41	0.09
3K7-2	9-1-78	1198	276	922	350		4525	2.46	0.12
3K7-21	9-1-78	1198	276	922	350		4350	2.47	0.13
3K7-27	9-1-78	1198	276	922	350		-	2.53	0.13
4.5K7-21	9-1-78	1198	276	922	350		4680	2.58	0.13
4.5K7-22	9-1-78	1198	276	922	350		4770	2.62	0.11
4.5K7-27	9-1-78	1198	276	922	350		-	2.56	0.10
3K4-20	12-11-75	203	197	6	450	27.59	4540	2.39	0.15
3K4-23	12-11-75	203	197	6	450	27.60	4930	2.26	0.14
3K4-17	12-11-75	203	197	6	450	27.52	-	2.41	0.14
4.5K4-17	12-11-75	203	197	6	450	27.70	5760	2.75	0.12
4.5K4-20	12-11-75	203	197	6	450	27.57	5820	2.69	0.08
4.5K4-23	12-11-75	203	197	6	450	27.56	-	2.82	0.13
3K5-20	12-15-75	207	197	10	450	27.85	4995	2.26	0.13
3K5-23	12-15-75	207	197	10	450	27.74	4830	2.33	0.13
3K5-17	12-15-75	207	197	10	450	27.86	-	2.16	0.09
4.5K5-16	12-15-75	207	197	10	450	27.29	5990	2.60	0.12
4.5K5-20	12-15-75	207	197	10	450	27.38	5150	2.26	0.13
4.5K5-23	12-15-75	207	197	10	450	27.37	-	2.67	0.13
3K6-17	12-23-75	215	197	18	450	27.47	4540	2.13	0.13
3K6-23	12-23-75	215	197	18	450	27.43	4320	2.23	0.14
3K6-19	12-23-75	215	197	18	450	27.65	-	2.09	0.12
4.5K6-17	12-23-75	215	197	18	450	27.06	5255	2.13	0.10
4.5K6-23	12-23-75	215	197	18	450	27.00	5430	2.24	0.11
4.5K6-20	12-23-75	215	197	18	450	27.15	-	2.35	0.14

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3]Designates that specimen was used for splitting tensile test after elastic constants were determined

TABLE 6 (con'd) - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES (STATIC METHOD) AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven Days[2]	Temperature at Test, F	Weight at Test, lb	Compressive Strength, psi	Modulus of Elasticity, million psi	Poisson's Ratio
3K3-23	9-30-76	497	197	300	450	28.04	5150	2.14	0.12
3K3-17	9-30-76	497	197	300	450	28.11	-[3]	2.62	0.10
4.5K3-19	9-30-76	497	197	300	450	27.36	4620	1.75	0.17
4.5K3-23	9-30-76	497	197	300	450	27.40	4940	1.67	0.16
4.5K3-17	9-30-76	497	197	300	450	27.39	-	1.74	0.09
3K3-10	3-31-77	679	270	409	450	28.20	4720	1.91	0.15
3K3-12	3-31-77	679	270	409	450	28.17	4590	1.84	0.18
3K3-27	3-31-77	679	270	409	450	27.91	-	1.90	0.14
4.5K3-27	3-31-77	679	270	409	450	27.25	4850	1.78	0.16
4.5K3-21	3-31-77	679	270	409	450	28.29	4950	1.77	0.15
4.5K3-22	3-31-77	679	270	409	450	27.32	-	1.96	0.15
3K4-16	9-29-77	861	270	591	450	27.20	3540	1.28	0.16
3K4-19	9-29-77	861	270	591	450	27.32	3630	1.29	0.18
3K4-7	9-29-77	861	270	591	450	27.44	-	1.51	0.20
4.5K4-15	9-29-77	861	270	591	450	27.50	4240	1.50	0.12
4.5K4-21	9-29-77	861	270	591	450	27.37	4580	1.54	0.09
4.5K4-19	9-29-77	861	270	591	450	27.36	-	1.46	0.13
3K5-4	9-1-78	1198	283	915	450	27.60	-	1.55	0.14
3K5-9	9-1-78	1198	283	915	450		3850	1.52	0.12
3K5-27	9-1-78	1198	283	915	450		3605	1.42	0.15
4.5K5-2	9-1-78	1198	283	915	450	27.39	-	1.55	0.11
4.5K5-7	9-1-78	1198	283	915	450		4100	1.40	0.11
4.5K5-28	9-1-78	1198	283	915	450		4165	1.46	0.10

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

[3]Designates that specimen was used for splitting tensile test after elastic constants were determined

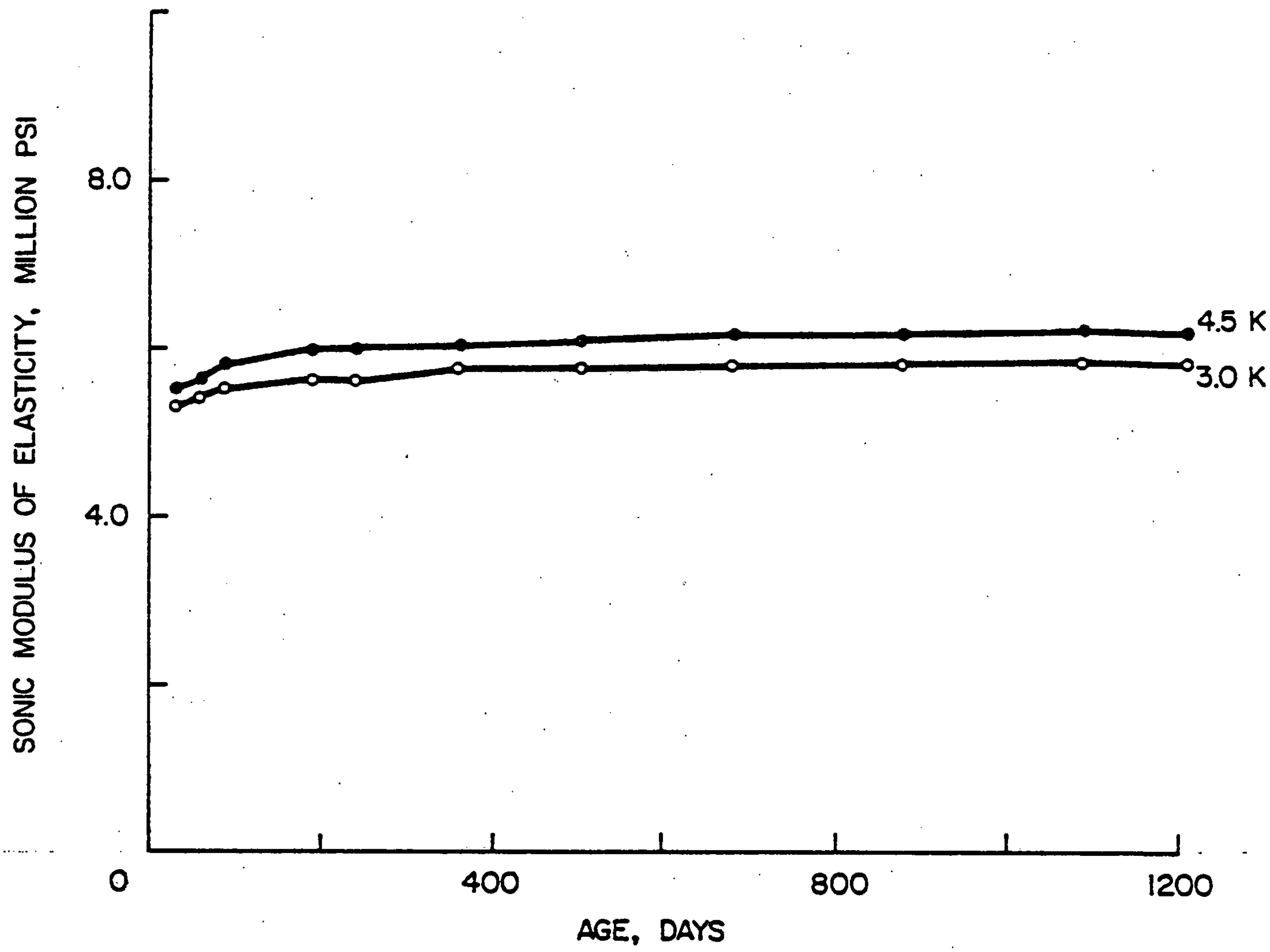

FIG. 4 MODULUS OF ELASTICITY OF MOIST-CURED CYLINDERS - SONIC METHOD

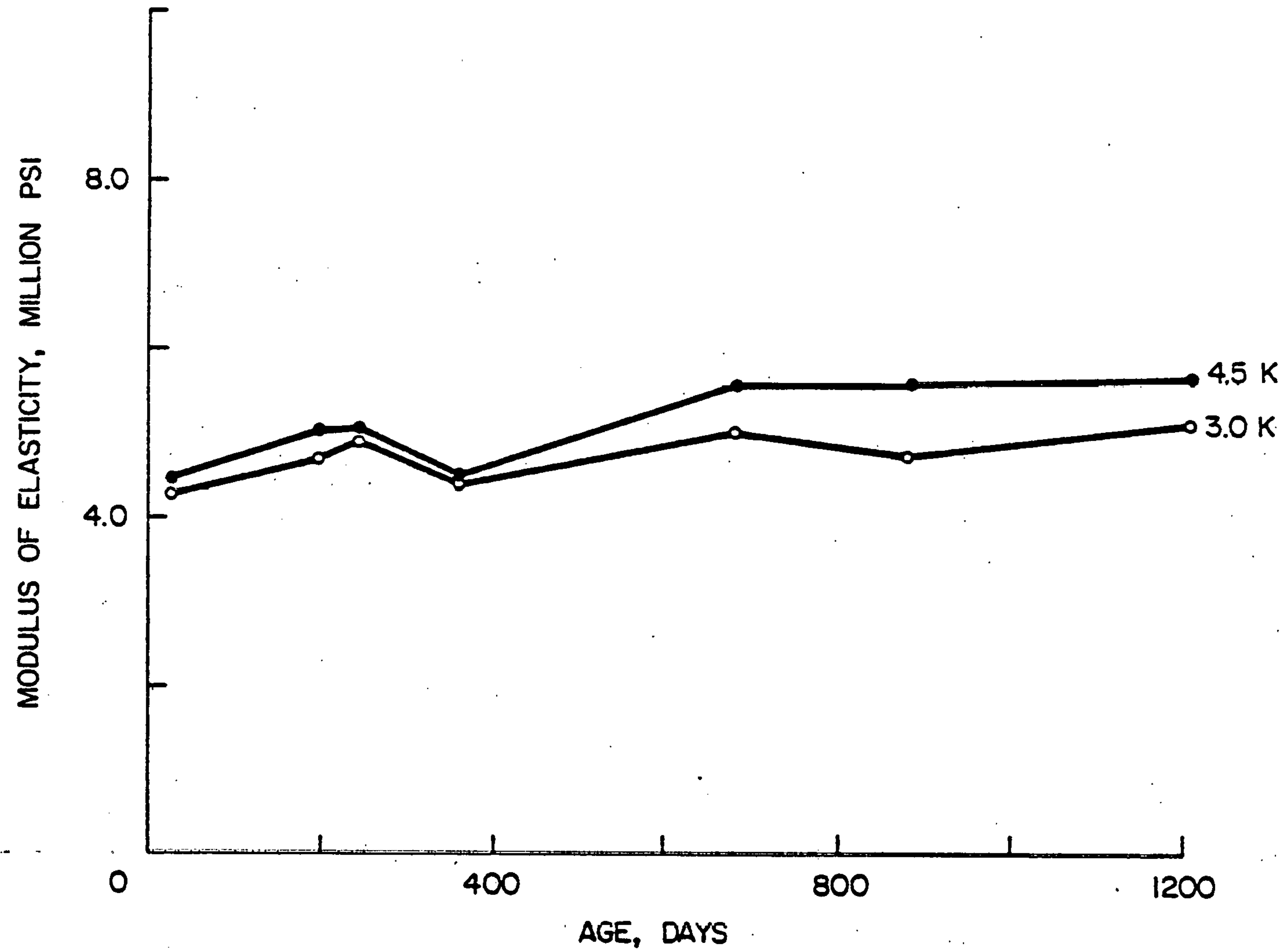

FIG. 5 MODULUS OF ELASTICITY OF MOIST-CURED CYLINDERS

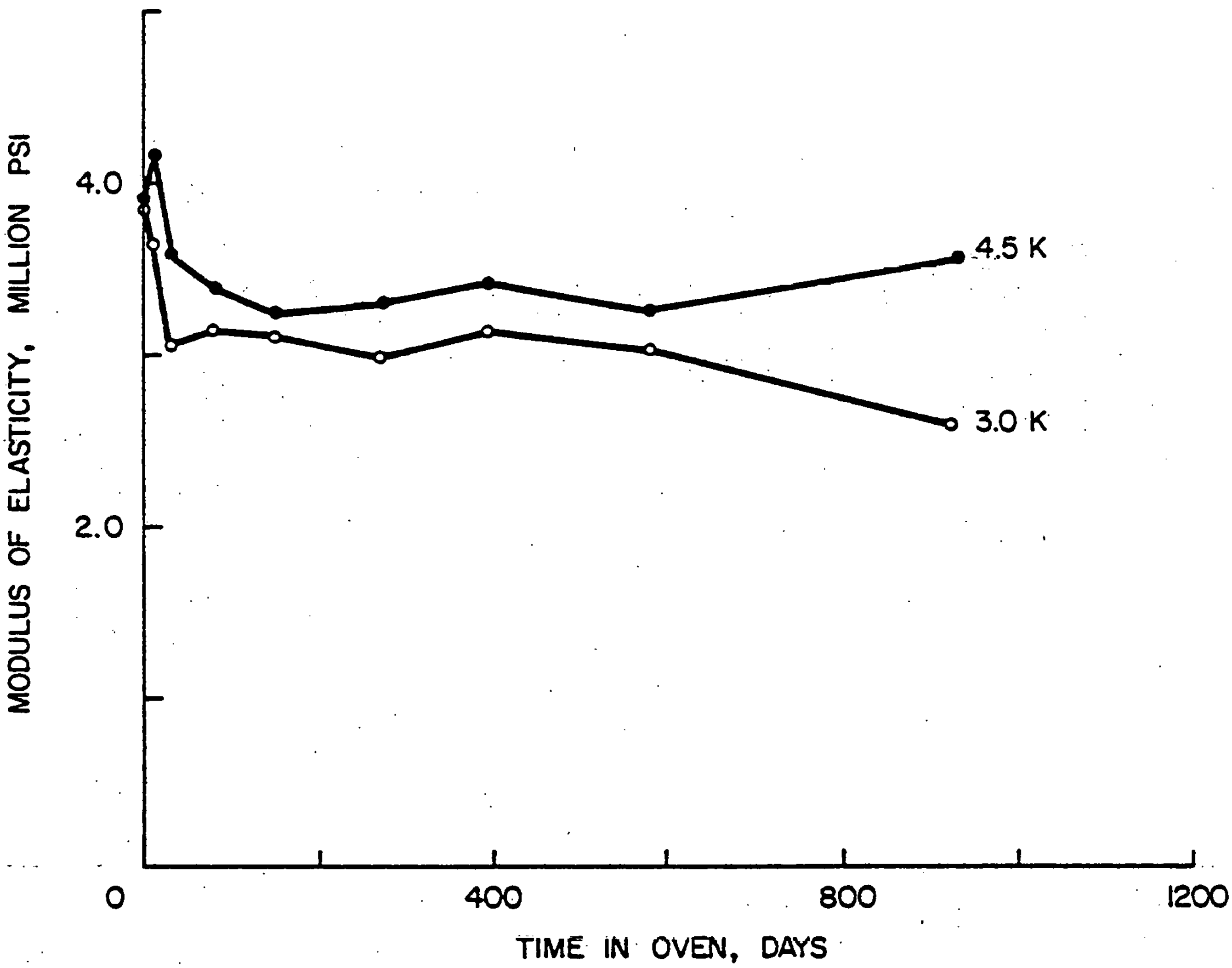

FIG. 6 MODULUS OF ELASTICITY OF CYLINDERS AT 250 F

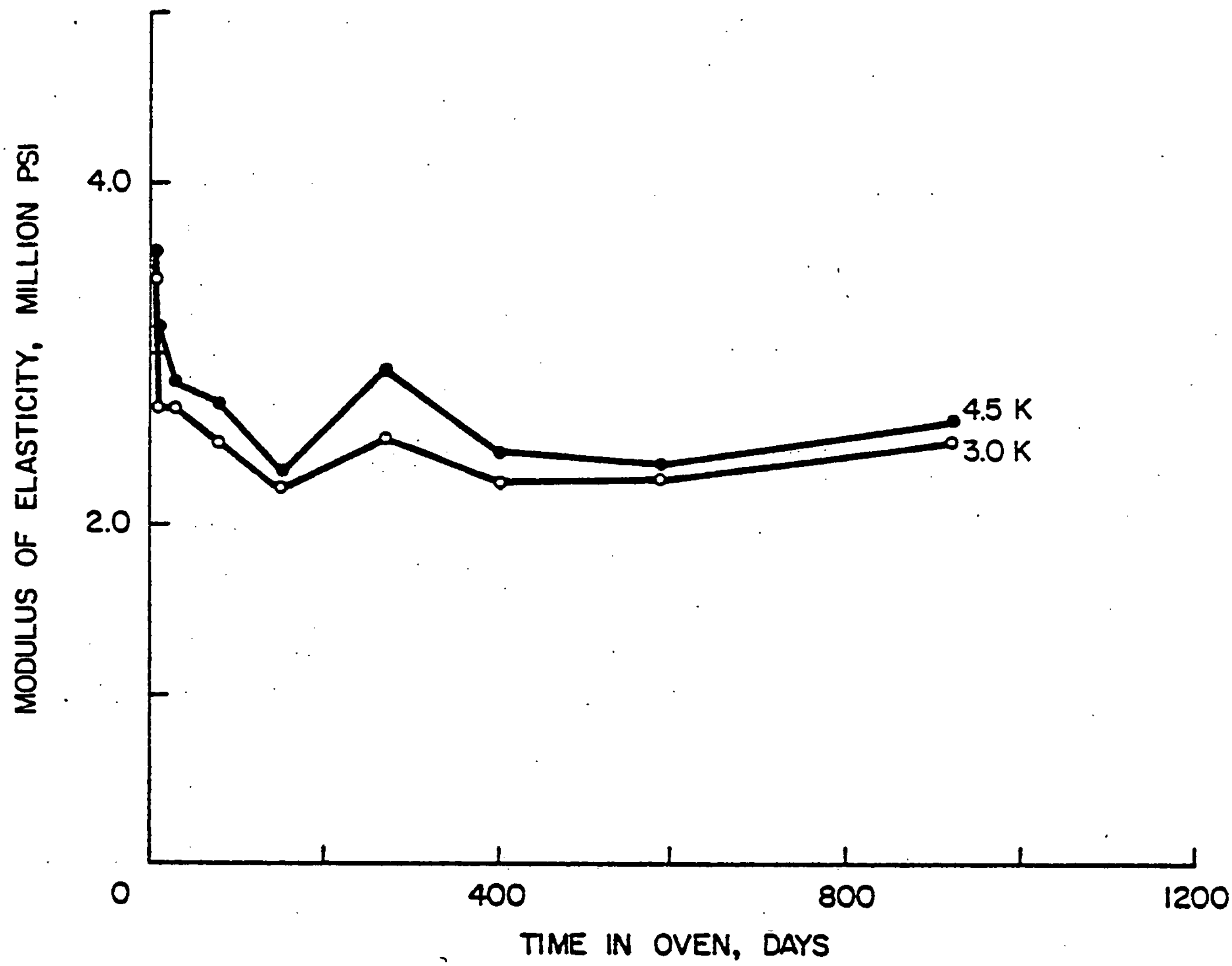

FIG. 7 MODULUS OF ELASTICITY OF CYLINDERS AT 350 F

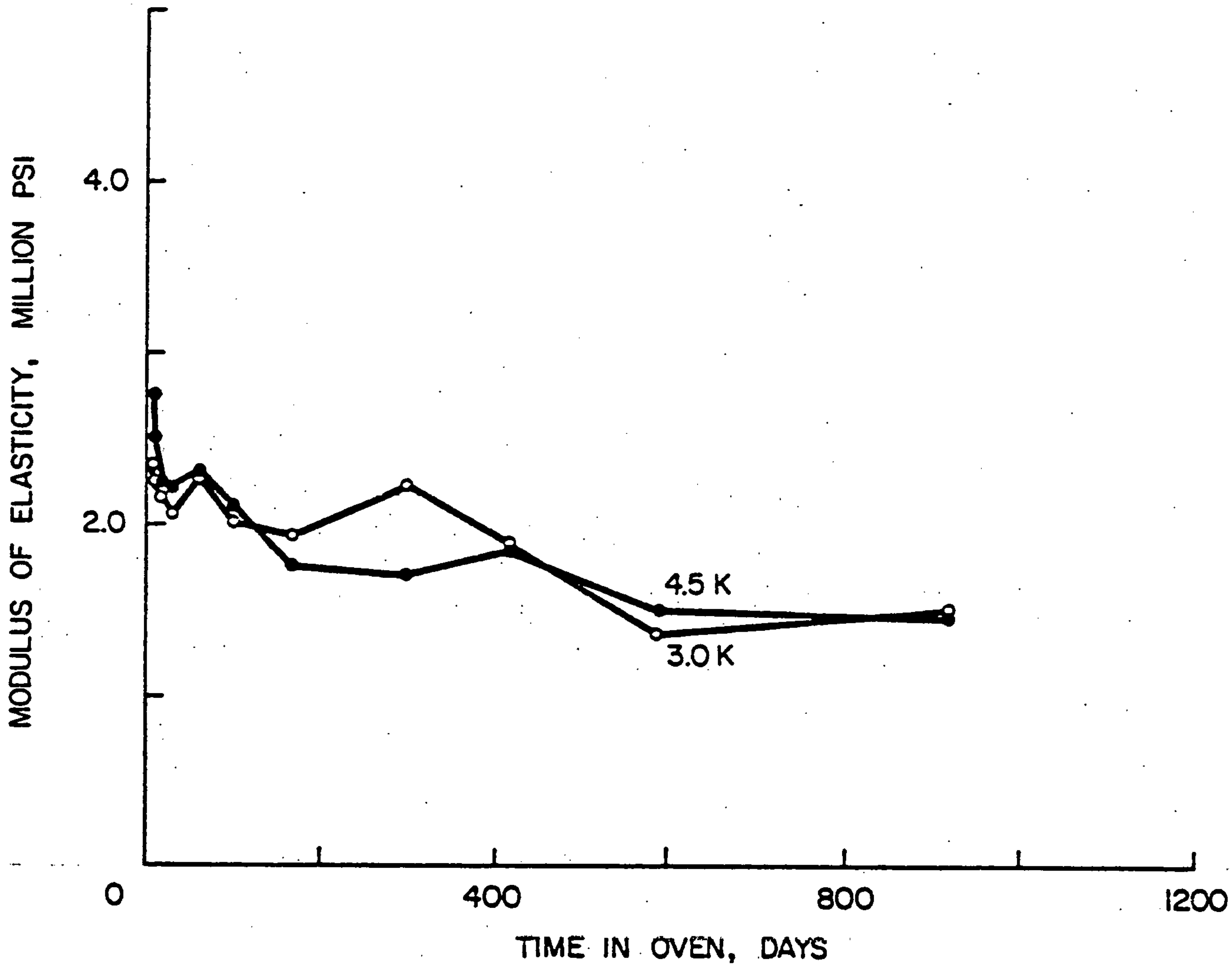

FIG. 8 MODULUS OF ELASTICITY OF CYLINDERS AT 450 F

All of the sonic modulus values were determined from tests of the same cylinders for each mix. Consequently, in-batch and batch-to-batch variations of the test specimens did not affect the sonic modulus-age relationships of the two concrete mixes.

Static modulus of elasticity of the moist-cured concretes also generally increased with age. Higher values of static modulus were obtained for the 4.5K mix at room temperature. The increase in modulus of elasticity did not differ appreciably for either mix. Static values at all ages were lower than corresponding values obtained by the sonic method.

Modulus of elasticity values obtained from tests of cylinders heated at 250F, 350F, and 450F for periods ranging from 3 to 926 days are given in Tables 6 and shown in Figs. 6, 7, and 8. Generally, the modulus of elasticity for both concrete mixes decreased as the heating time increased. At all temperatures, the rate of decrease in modulus was greatest between 3 and about 150 days. Lower values of the modulus of elasticity were generally obtained for the 3K mix than for the 4.5K mix at all three temperatures. However, the data are not as clearly defined at 450F.

Temperature had a very significant effect on the elastic modulus of the concretes. At 250F, values of the elastic modulus dropped from an average initial value of 4.3 million psi to about 3.8 million psi. After 926 days, the average modulus for both mixes was about 3 million psi. At 350F, the initial modulus value of 4.3 million psi was reduced to 3.5 million psi, after three days of heating. After 926 days of heating, the modulus values were about 2.5 million psi. The decrease in modulus at 450F after only three days of heating was very significant. After three days of heating, the modulus of elasticity was about 2.5 million psi as compared with an original value of 4.3 million psi. At the end of about 922 days of heating, modulus values for the 3K and 4.5K mixes were about 1.5 million psi.

Poisson's Ratio

Information on Poisson's ratio obtained by the sonic and static methods at 73F for both mixes over a period of 1204 days is shown in Figs. 9 and 10 and Tables 5 and 6.

Poisson's ratio determined by the sonic method remained relatively constant for both mixes. With the exception of the data obtained at 240 days, Poisson's ratio for the 3K mix varied from 0.21 to 0.25. For the 4.5K mix, values of Poisson's ratio determined sonically ranged from 0.20 to 0.27. Generally, higher values were obtained for the 4.5K mix.

Figure 10 shows the information on Poisson's ratio at 73F determined by the static method. Poisson's ratio appears to increase somewhat with age. Generally, higher values were obtained for the 4.5K mix than for the 3K mix.

At all test dates, the static Poisson's ratio is smaller than the ratio determined by the sonic method. For the 3K mix, static values ranged from 0.15 to 0.17. The range of values for the 4.5K mix was 0.16 to 0.19.

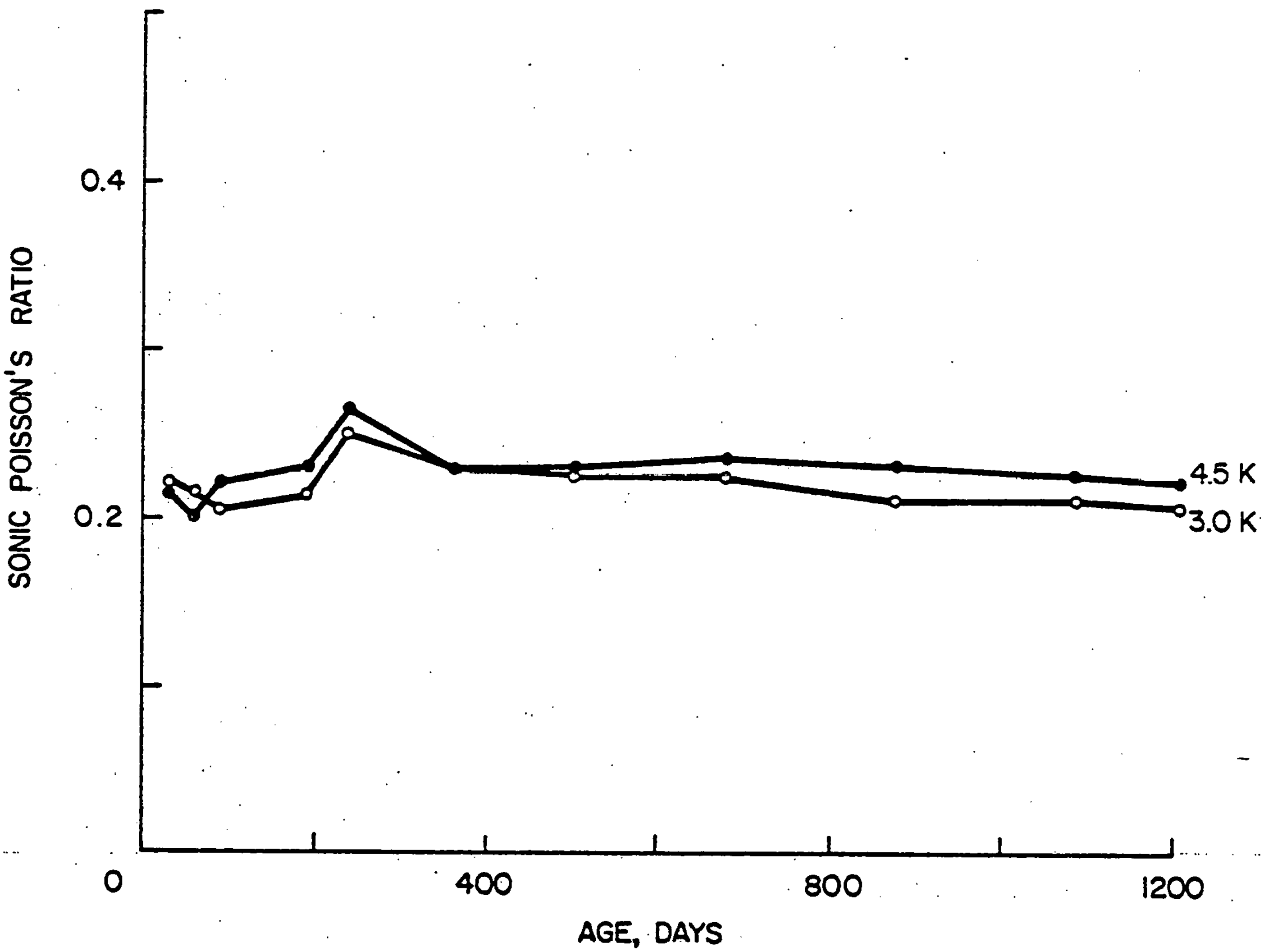

FIG. 9 POISSON'S RATIO OF MOIST-CURED CYLINDERS - SONIC METHOD

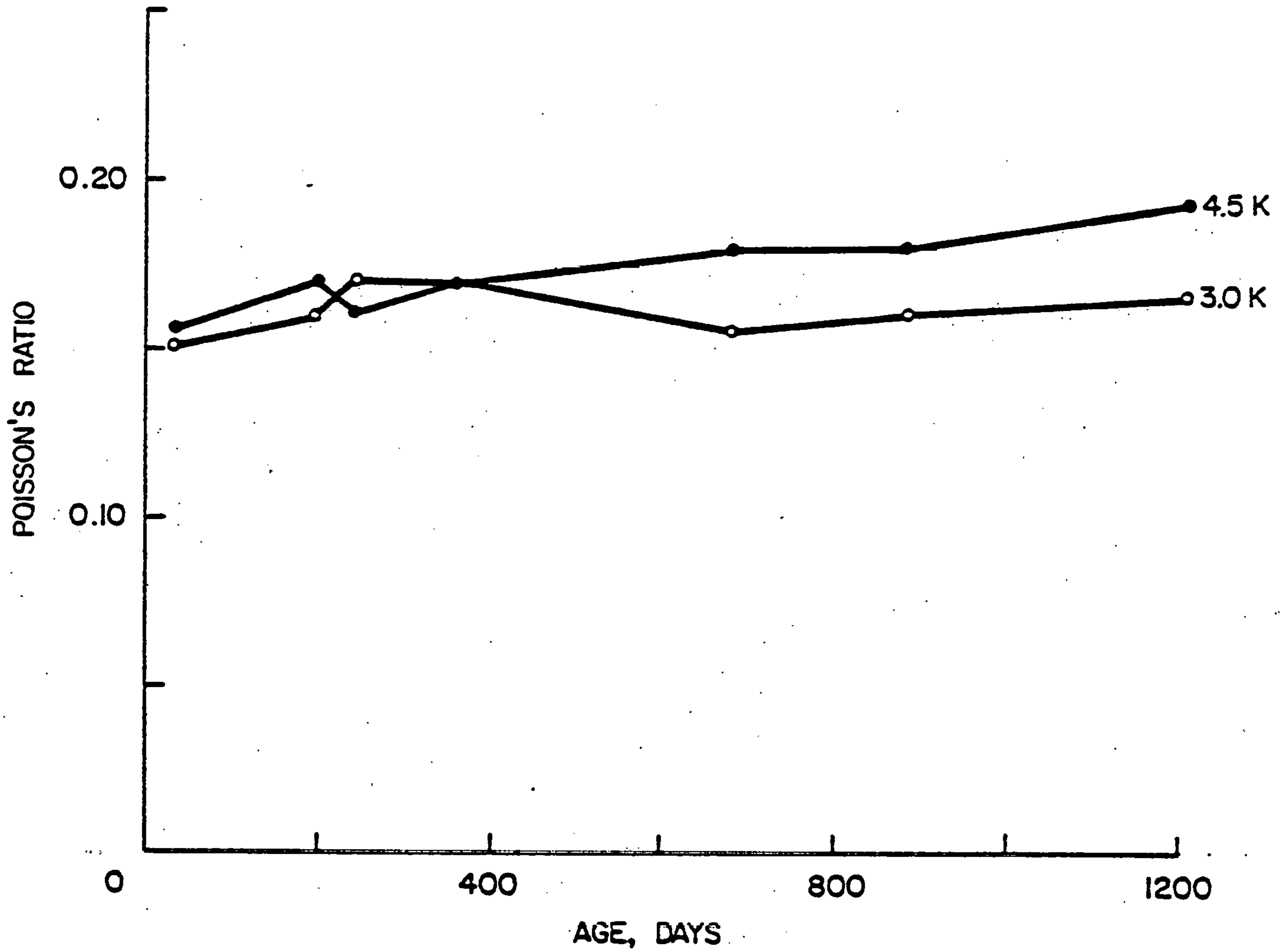

FIG. 10 POISSON'S RATIO OF MOIST-CURED CYLINDERS

Figures 11, 12, and 13 and Table 6 show data for Poisson's ratio determined by the static method at temperatures of 250, 350, and 450F, respectively. Poisson's ratio data were very erratic. The largest fluctuation in the data occurred at 450F. There are numerous cross-overs in the Poisson's ratio curves for the 3K and 4.5K mixes at all three temperatures. However, notwithstanding these variations, the high temperature values for Poisson's ratio varied between 0.10 and 0.14. In general, age and temperature did not have a large effect on the values of Poisson's ratio obtained at the various test dates.

Splitting Tensile Strength

Splitting tensile strength information of moist-cured cylinders of both mixes, over a period of 1204 days, is shown in Fig. 14 and Table 7. For both mixes, the splitting tensile strength increased rapidly up to about 190 days of age. Beyond that point, strength decreased to about 350 days, and either leveled off or increased from that point on. The rapid increase followed by a decrease during the first 400 days of moisture cure at room temperature is not easily explained. Generally, it would be expected that the splitting tensile strength would increase with age during the moist-curing period. It is possible that the in-batch and batch-to-batch variations of the test cylinders affected the test results. Notwithstanding the irregularities in the data, the 1204 day strength values are higher by over 100 psi than the values obtained at 30 days.

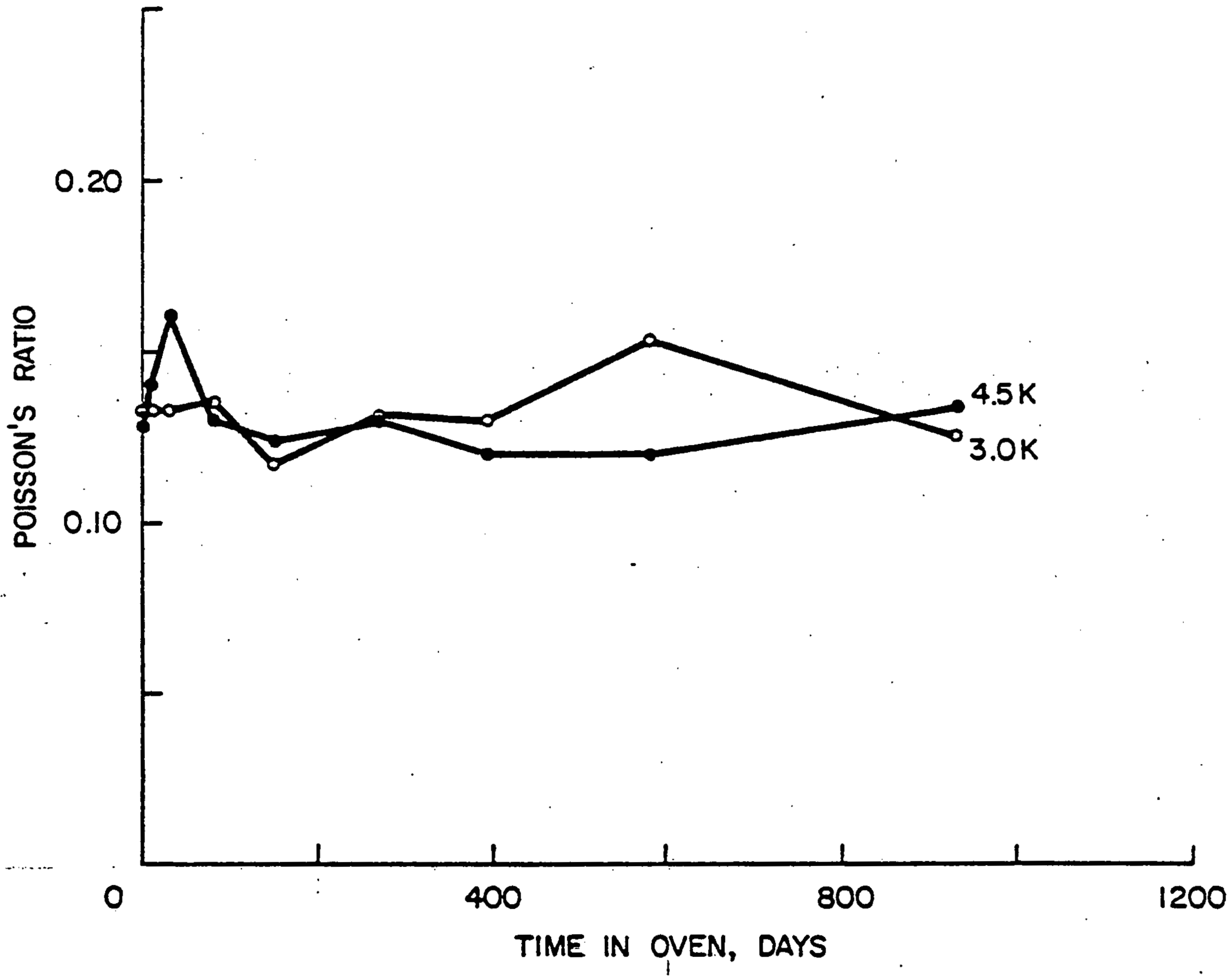

FIG. 11 POISSON'S RATIO OF CYLINDERS AT 250 F

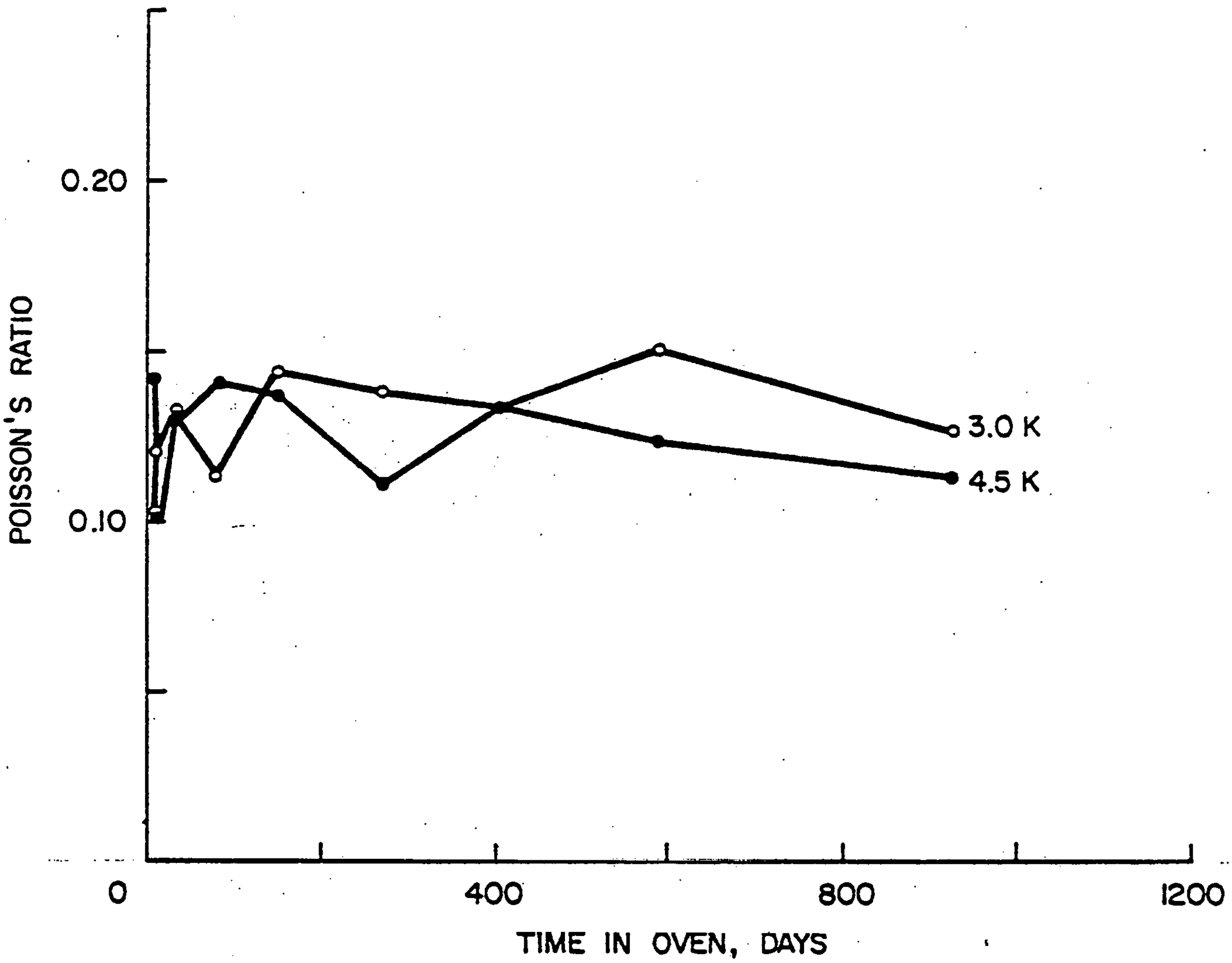

FIG. 12 POISSON'S RATIO OF CYLINDERS AT 350 F

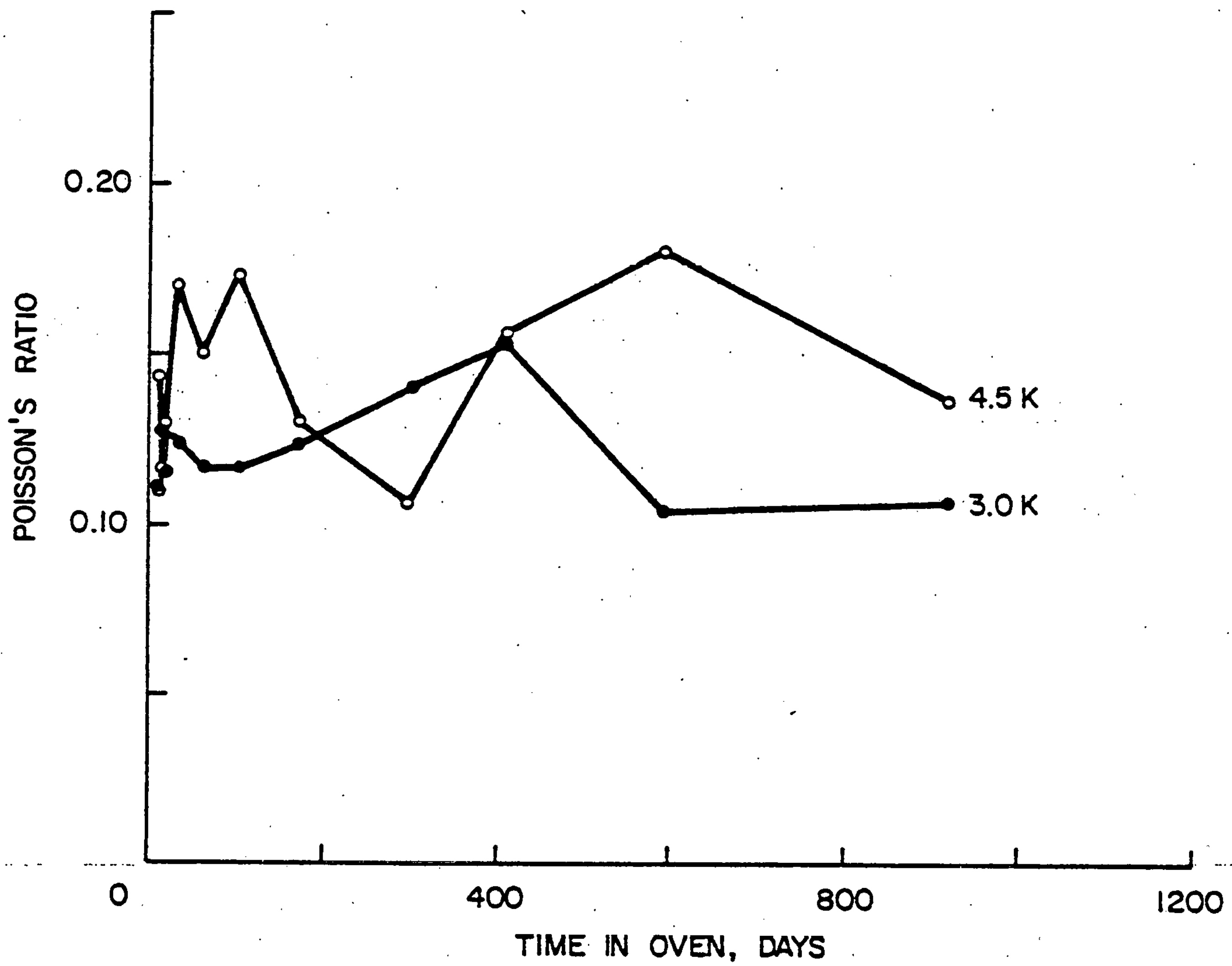

FIG. 13 POISSON'S RATIO OF CYLINDERS AT 450 F

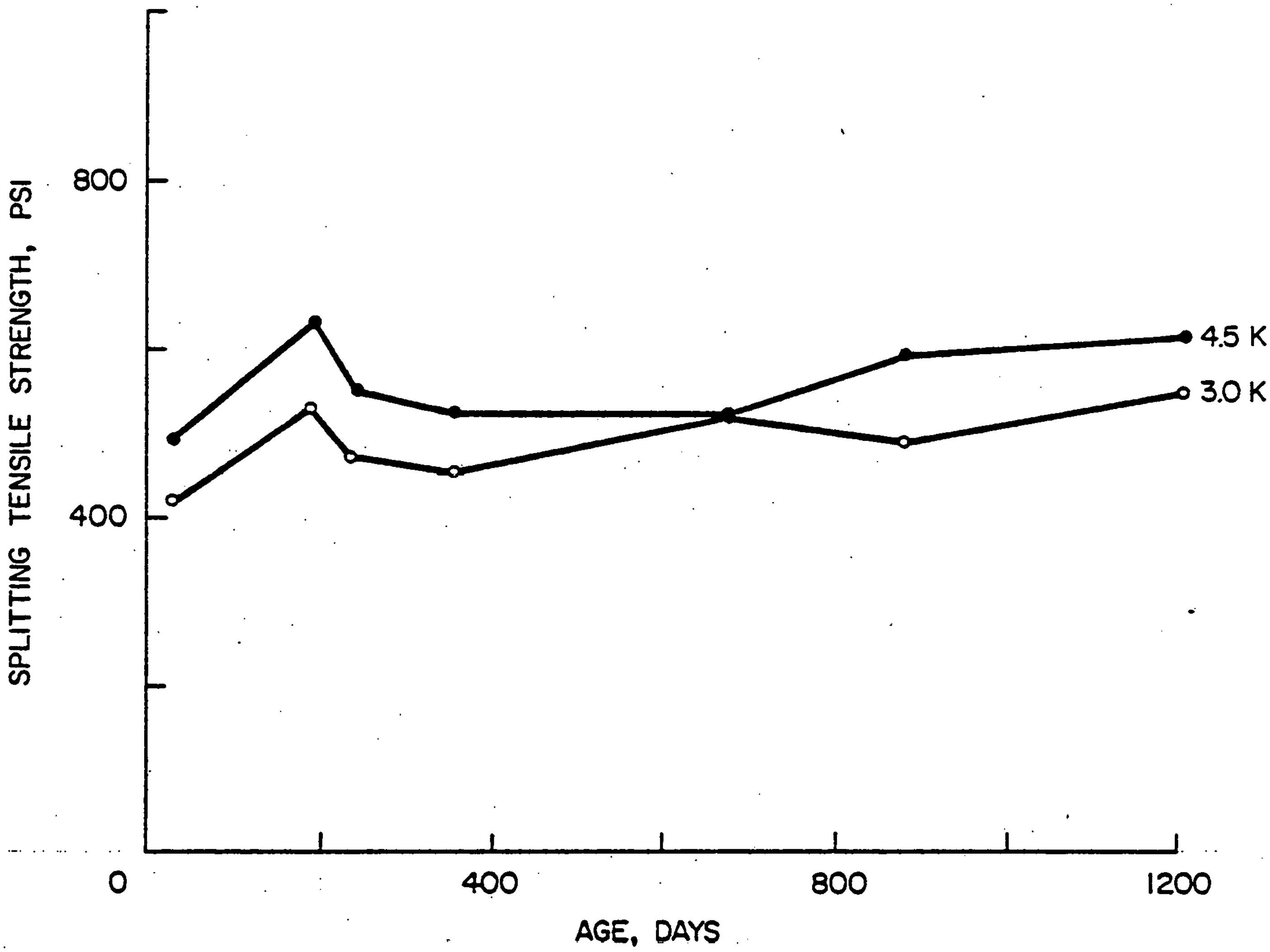

FIG. 14 SPLITTING TENSILE STRENGTH OF MOIST-CURED CYLINDERS

TABLE 7 - SPLITTING TENSILE STRENGTH AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven, Days[2]	Temperature at Test, F	Weight at Test, lb	Splitting Tensile Strength, psi
3K4-26	6-21-75	30	30	0	73	29.73	412
3K4-29	6-21-75	30	30	0	73	29.69	418
4.5K4-26	6-21-75	30	30	0	73	29.67	457
4.5K4-29	6-21-75	30	30	0	73	29.63	522
3K9-2	12-2-75	194	194	0	73	29.84	548
3K9-10	12-2-75	194	194	0	73	29.72	513
4.5K9-2	12-2-75	194	194	0	73	29.46	622
4.5K9-15	12-2-75	194	194	0	73	29.62	644
3K7-28	1-19-76	240	240	0	73	28.35	470
4.5K7-29	1-19-76	240	240	0	73	28.19	550
3K7-7	5-17-76	361	361	0	73	29.41	451
4.5K7-28	5-17-76	361	361	0	73	29.36	525
3K8-28	3-31-77	679	679	0	73	29.68	519
4.5K8-29	3-31-77	679	679	0	73	29.56	525
3K4-15	11-18-77	880	880	0	73	29.58	491
4.5K4-12	11-18-77	880	880	0	73	29.53	592
3K8-18	9-7-78	1204	1204	0	73		512
3K8-23	9-7-78	1204	1204	0	73		561
4.5K8-5	9-7-78	1204	1204	0	73		591
4.5K8-13	9-7-78	1204	1204	0	73		642
3K3-3	12-4-75	196	193	3	250	29.23	502
3K3-7	12-4-75	196	193	3	250	29.51	550
4.5K3-1	12-4-75	196	193	3	250	28.70	547
4.5K3-7	12-4-75	196	193	3	250	28.71	529
3K8-1	12-11-75	203	193	10	250	27.74	476
3K8-4	12-11-75	203	193	10	250	27.68	476
4.5K8-2	12-11-75	203	193	10	250	27.94	568
4.5K8-3	12-11-75	203	193	10	250	27.83	499
3K7-3	12-31-75	223	193	30	250	27.29	434

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven at 75F/day to test temperature

TABLE 7 (con'd) - SPLITTING TENSILE STRENGTH AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven, Days[2]	Temperature at Test, F	Weight at Test, lb	Splitting Tensile Strength, psi
3K7-4	12-31-75	223	193	30	250	27.37	453
4.5K7-1	12-31-75	223	193	30	250	27.22	496
4.5K7-9	12-31-75	223	193	30	250	27.55	478
3K4-2	2-19-76	273	193	80	250	27.84	441
3K4-5	2-19-76	273	193	80	250	27.67	423
4.5K4-1	2-19-76	273	193	80	250	27.59	497
4.5K4-6	2-19-76	273	193	80	250	27.82	498
3K5-2	4-29-76	343	193	150	250	27.84	441
3K5-7	4-29-76	343	193	150	250	28.17	498
4.5K5-1	4-29-76	343	193	150	250	27.64	497
4.5K5-6	4-29-76	343	193	150	250	27.93	506
3K6-1	8-27-76	463	193	270	250	27.80	412
3K6-4	8-27-76	463	193	270	250	27.77	395
4.5K6-2	8-27-76	463	193	270	250	27.31	471
4.5K6-8	8-27-76	463	193	270	250	27.04	430
3K9-17	4-1-77	679	283	396	250	27.78	451
3K9-29	4-1-77	679	283	396	250	27.73	417
4.5K3-16	4-1-77	679	283	396	250	27.50	460
4.5K8-26	4-1-77	679	283	396	250	27.80	477
3K9-9	9-29-77	861	283	578	250	27.87	484
3K9-23	9-29-77	861	283	578	250	27.76	396
4.5K3-12	9-29-77	861	283	578	250	27.82	504
4.5K3-22	9-29-77	861	283	578	250	27.57	464
3K8-26	9-1-78	1198	276	922	250		408
3K8-30	9-1-78	1198	276	922	250		400
4.5K9-5	9-1-78	1198	270	928	250		373
4.5K9-29	9-1-78	1198	270	928	250		491
3K3-9	12-5-75	197	193	4	350	28.58	495
3K3-11	12-5-75	197	193	4	350	28.37	546

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven ay 75F/day to test temperature

TABLE 7 (con'd) - SPLITTING TENSILE STRENGTH AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven, Days[2]	Temperature at Test, F	Weight at Test, lb	Splitting Tensile Strength, psi
4.5K3-11	12-5-75	197	193	4	350	27.55	498
4.5K3-15	12-5-75	197	193	4	350	27.65	576
3K4-4	12-11-75	203	193	10	350	27.75	450
3K4-14	12-11-75	203	193	10	350	27.71	392
4.5K4-10	12-11-75	203	193	10	350	27.74	515
4.5K4-14	12-11-75	203	193	10	350	27.80	511
3K5-8	12-31-75	223	193	30	350	27.94	478
3K5-12	12-31-75	223	193	30	350	27.94	496
4.5K5-10	12-31-75	223	193	30	350	27.65	470
4.5K5-14	12-31-75	223	193	30	350	27.43	499
3K6-6	2-19-76	273	193	80	350	27.54	390
3K6-8	2-19-76	273	193	80	350	27.61	389
4.5K6-7	2-19-76	273	193	80	350	27.06	427
4.5K6-12	2-19-76	273	193	80	350	27.24	408
3K7-9	4-29-76	343	193	150	350	27.11	375
3K7-14	4-29-76	343	193	150	350	26.93	381
4.5K7-12	4-29-76	343	193	150	350	27.17	393
4.5K7-15	4-29-76	343	193	150	350	26.99	412
3K8-6	8-27-76	463	193	270	350	27.66	409
3K8-14	8-27-76	463	193	270	350	27.39	395
4.5K8-14	8-27-76	463	193	270	350	27.61	424
4.5K8-15	8-27-76	463	193	270	350	27.54	435
3K6-26	4-1-77	679	276	403	350	27.75	435
3K6-27	4-1-77	679	276	403	350	27.65	393
4.5K6-24	4-1-77	679	276	403	350	27.35	433
4.5K6-27	4-1-77	679	276	403	350	27.07	380
3K7-10	9-30-77	861	276	585	350	26.97	343
3K7-24	9-30-77	861	276	585	350	27.42	380
4.5K7-5	9-30-77	861	276	585	350	27.17	459

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven ay 75F/day to test temperature

TABLE 7 (con'd) - SPLITTING TENSILE STRENGTH AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven, Days[2]	Temperature at Test, F	Weight at Test, lb	Splitting Tensile Strength, psi
4.5K7-17	9-30-77	861	276	585	350	27.01	441
3K7-6	9-5-78	1202	276	926	350	27.19	424
3K7-27	9-5-78	1202	276	926	350		424
4.5K7-2	9-5-78	1202	276	926	350	27.31	394
4.5K7-27	9-5-78	1202	276	926	350		378
3K4-17	12-11-75	203	197	6	450	27.52	393
3K4-18	12-11-75	203	197	6	450	27.64	392
4.5K4-19	12-11-75	203	197	6	450	27.69	469
4.5K4-23	12-11-75	203	197	6	450	27.56	477
3K5-13	12-15-75	207	197	10	450	28.14	425
3K5-17	12-15-75	207	197	10	450	27.86	387
4.5K5-23	12-15-75	207	197	10	450	27.37	424
4.5K5-27	12-15-75	207	197	10	450	27.53	463
3K6-10	12-23-75	215	197	18	450	27.92	392
3K6-19	12-23-75	215	197	18	450	27.47	399
4.5K6-19	12-23-75	215	197	18	450	27.29	440
4.5K6-20	12-23-75	215	197	18	450	27.15	407
3K7-20	1-7-76	230	197	33	450	26.80	387
3K7-22	1-7-76	230	197	33	450	27.03	407
4.5K7-19	1-7-76	230	197	33	450	26.92	436
4.5K7-23	1-7-76	230	197	33	450	26.73	425
3K8-13	2-3-76	257	197	60	450	27.44	396
3K8-24	2-3-76	257	197	60	450	27.37	355
4.5K8-18	2-3-76	257	197	60	450	27.64	426
4.5K8-23	2-3-76	257	197	60	450	27.30	416
3K9-11	3-15-76	297	197	100	450	27.53	393
3K9-12	3-15-76	297	197	100	450	27.62	396
4.5K9-14	3-15-76	297	197	100	450	27.28	396
4.5K9-24	3-15-76	297	197	100	450	27.54	409

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven ay 75F/day to test temperature

TABLE 7 (con'd) - SPLITTING TENSILE STRENGTH AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test, Mo.-day-yr.	Age at Test, Days	Time in Fog Room, Days[1]	Time in Oven, Days[2]	Temperature at Test, F	Weight at Test, lb	Splitting Tensile Strength, psi
3K4-24	5-24-76	367	197	170	450	27.60	349
3K6-16	5-24-76	367	197	170	450	27.61	391
4.5K5-25	5-24-76	367	197	170	450	27.40	410
4.5K6-29	5-24-76	367	197	170	450	27.18	390
3K3-13	9-30-76	497	197	300	450	28.41	433
3K3-17	9-30-76	497	197	300	450	28.11	424
4.5K3-17	9-30-76	497	197	300	450	27.39	425
4.5K3-18	9-30-76	497	197	300	450	27.54	451
3K3-26	3-31-77	679	270	409	450	28.27	357
3K3-27	3-31-77	679	270	409	450	27.25	391
4.5K3-2	3-31-77	679	270	409	450	27.59	424
4.5K3-22	3-31-77	679	270	409	450	27.91	407
3K4-7	9-29-77	861	270	591	450	27.44	285
3K4-10	9-29-77	861	270	591	450	27.51	264
4.5K4-13	9-29-77	861	270	591	450	27.40	355
4.5K4-19	9-29-77	861	270	591	450	27.36	347
3K5-4	9-6-78	1203	283	920	450	27.60	261
3K5-10	9-6-78	1203	283	920	450	27.73	324
4.5K5-2	9-6-78	1203	283	920	450	27.39	341
4.5K5-13	9-6-78	1203	283	920	450	27.44	366

[1]Specimens in fog room at 100% relative humidity and 73F

[2]Specimens tested at 250, 350, and 450F heated in oven ay 75F/day to test temperature

Figures 15, 16, and 17 show the effect of heat soaking the specimens at temperatures of 250F, 350F, and 450F for over 900 days. Although there were some crossovers in the data, generally the tensile splitting strength of the mixes decreased with increased time at elevated temperatures. Generally, the splitting tensile strength decreased with temperature. The greatest decrease was obtained at the 450F level. For the 3K mix, the splitting tensile strength was 295 psi after 920 days in the oven. This compares with an initial value prior to heating of about 460 psi. Splitting tensile strength of the 4.5K mix dropped from an initial value of 540 psi to a final value of 352 psi.

Compressive Strength

Compressive strengths of the two concrete mixes determined at 73F on moist-cure cylinders are shown in Fig. 18 and given in Table 6. Generally, compressive strength increased with age. The greatest increase was between 30 and 200 days. Beyond this point, the increase was much smaller. This type of strength increase is normal for these concrete mixes. Figure 19 shows a representative age-strength relationship for moist-cured concrete expressed as percentages of that obtained at 28 days. This curve represents results of many tests obtained over a period of years at the Portland Cement Association. It can be seen that the most rapid increase in strength occurs during the first 180 days of the period. Beyond that point, strength increases at a much slower rate.

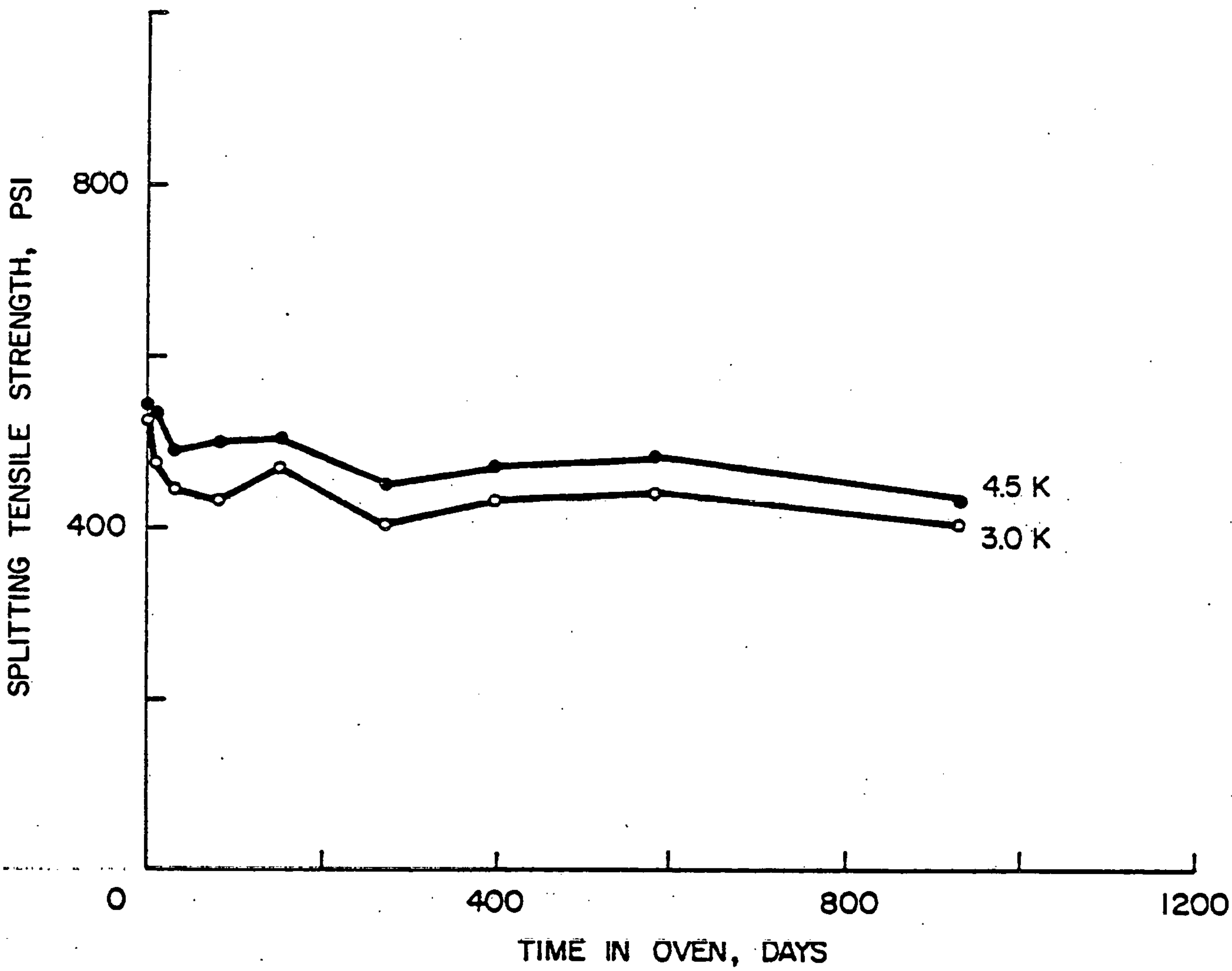

FIG. 15 SPLITTING TENSILE STRENGTH OF CYLINDERS AT 250 F

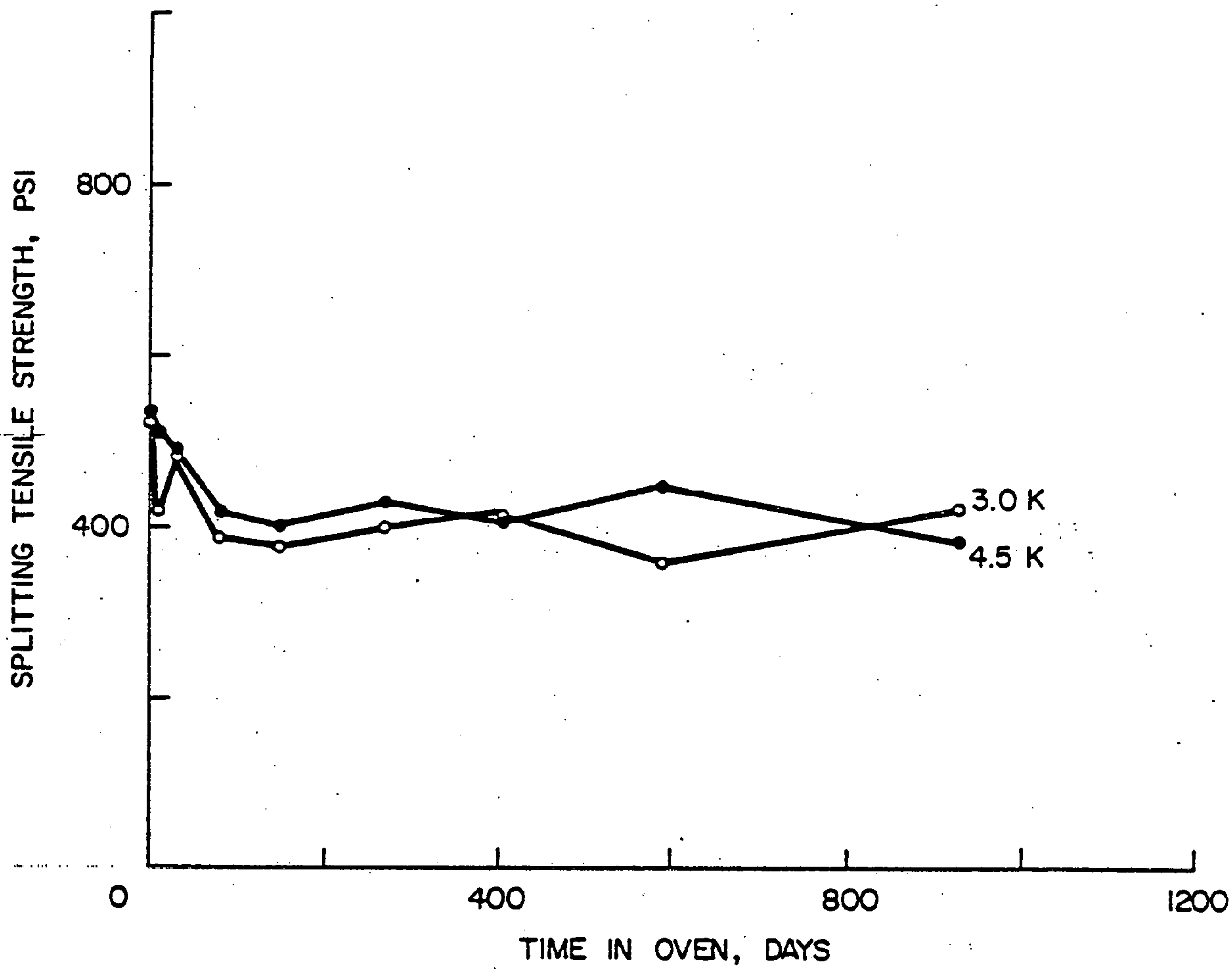

FIG. 16 SPLITTING TENSILE STRENGTH OF CYLINDERS AT 350 F

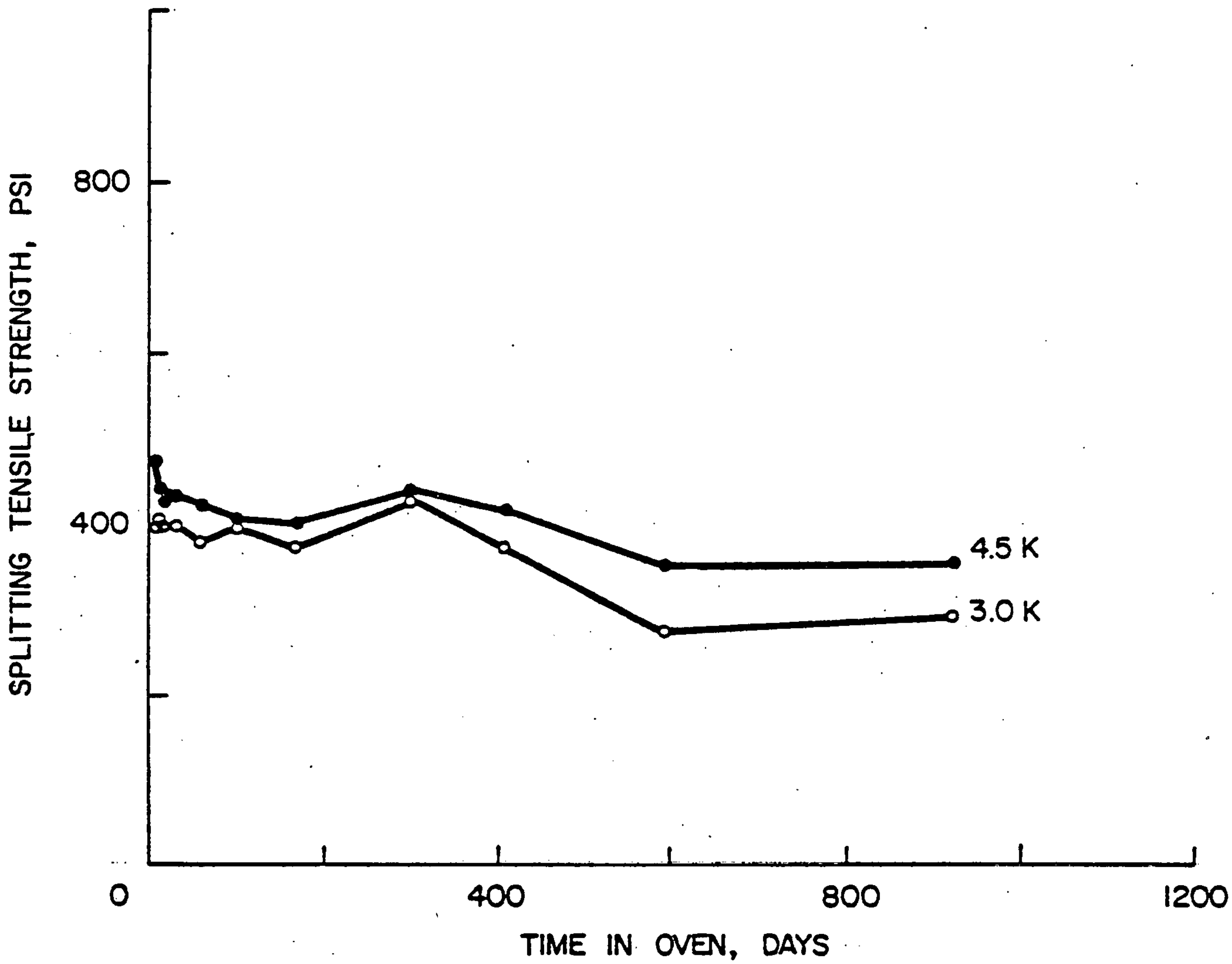

FIG. 17 SPLITTING TENSILE STRENGTH OF CYLINDERS AT 450 F

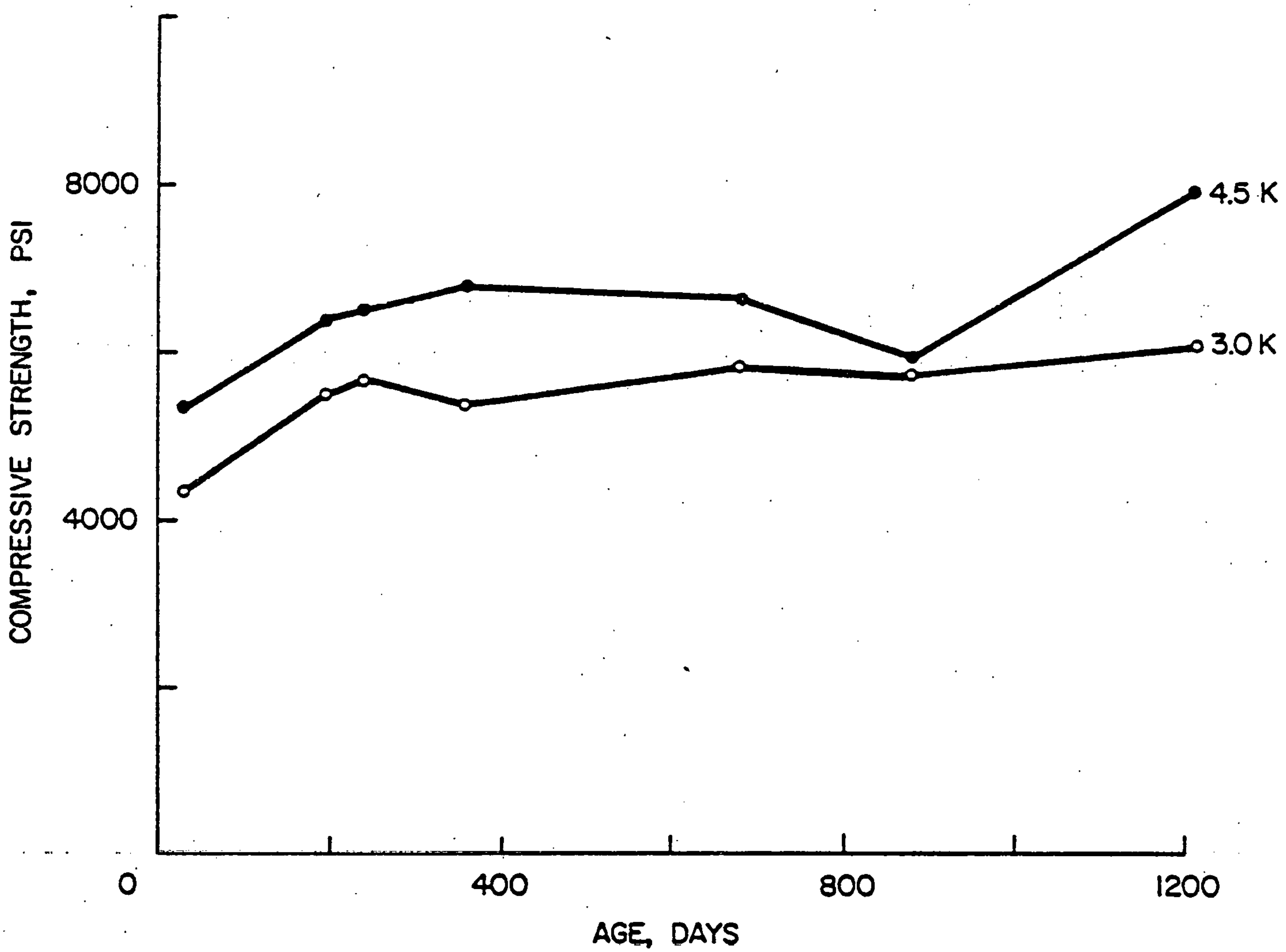

FIG. 18 COMPRESSIVE STRENGTH OF MOIST-CURED CYLINDERS

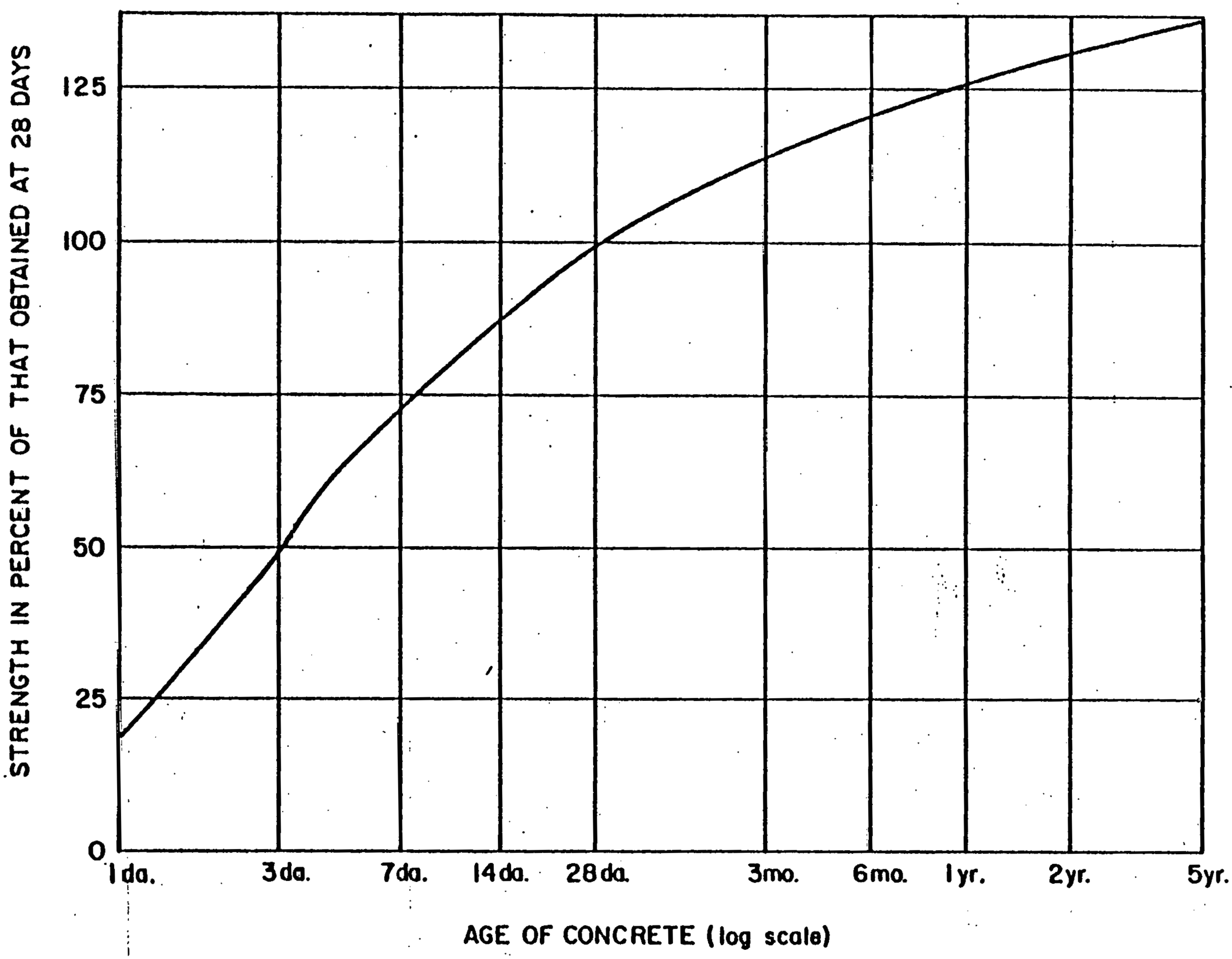

FIG. 19 AGE—STRENGTH RELATIONSHIPS FOR MOIST—CURED CONCRETE

Figures 20, 21, and 22 show compressive strength test data for the 3K and 4.5K mixes heated at 250, 250, and 450F for about 920 days. These data are also given in Table 6. For the most part, the compressive strength data is very erratic. For the 3K mix, strength decreased with increasing age at all three temperatures with the exception of the data at 450F between 100 and 400 days of exposure to heat. Generally, the compressive strength of the 4.5K concrete decreased with increasing time at elevated temperatures. This trend is most pronounced at the 450F temperature.

Strength decreased also with increasing temperature. The decrease was most pronounced at 450F. The lowest strength values obtained were those after about 920 days at 450F. It is interesting to note that even after over 900 days exposure at a temperature of 450F, the compressive strengths of both mixes barely decreased below the specification levels of 3000 and 4500 psi.

Reasons for the fluctuations in some of the test data, particularly the compressive strength data, are not clearly defined. Some variations in test results are probably due to testing at elevated temperatures. Usually, test results obtained at elevated temperatures show more scatter than those obtained at room temperature.

The greatest difficulty in analyzing the data probably results from batch-to-batch and in-batch variations in the

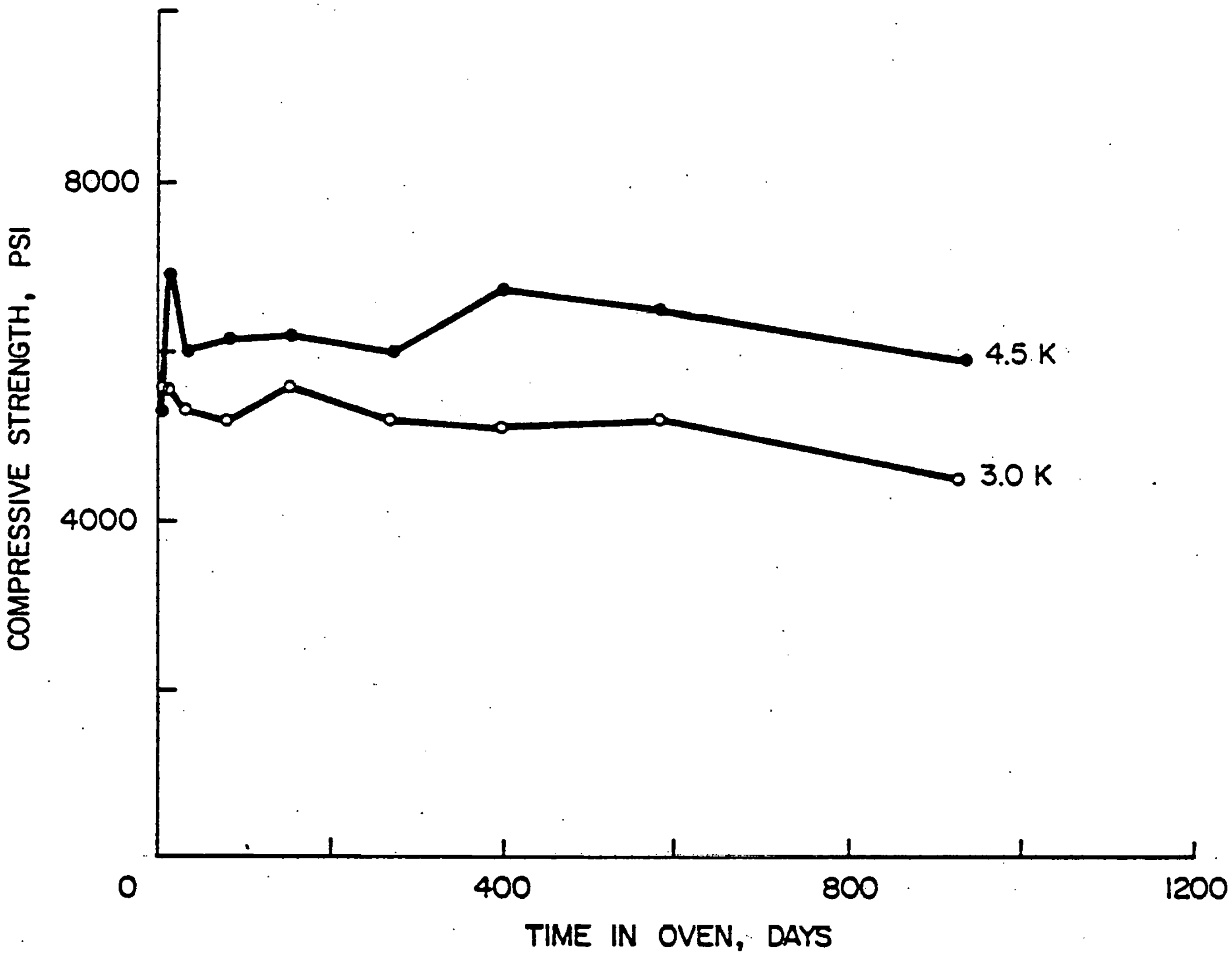

FIG. 20 COMPRESSIVE STRENGTH OF CYLINDERS AT 250 F

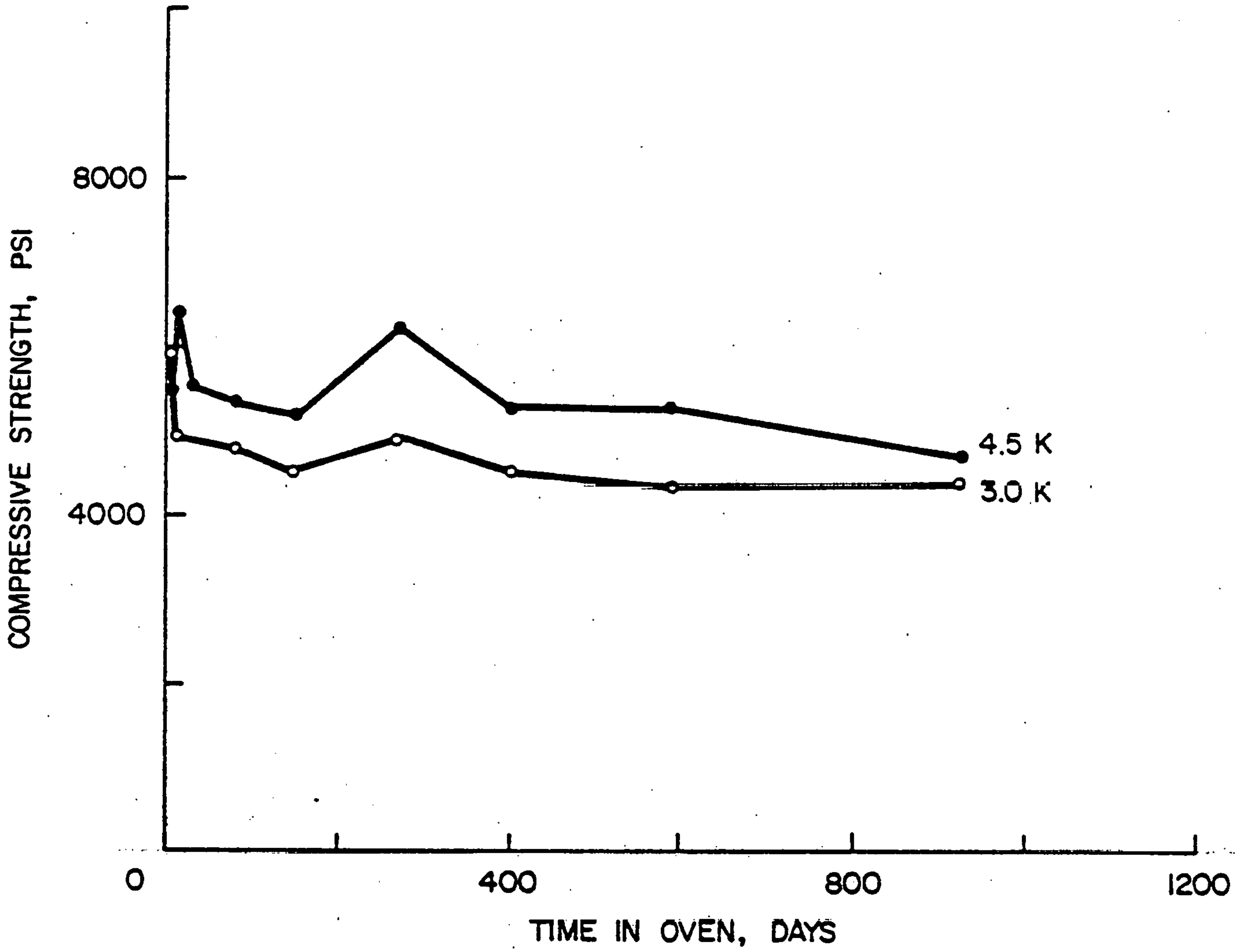

FIG. 21 COMPRESSIVE STRENGTH OF CYLINDERS AT 350 F

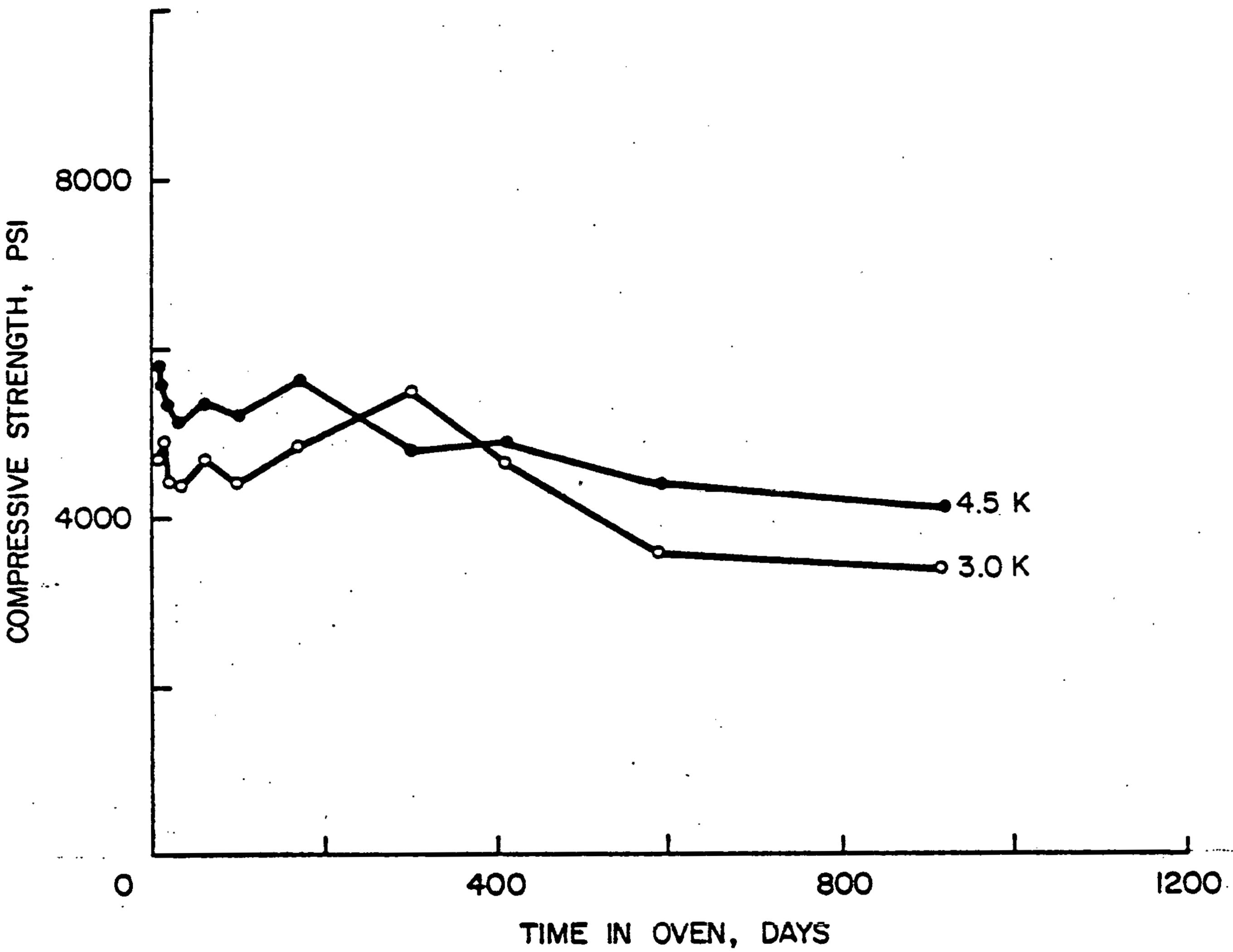

FIG. 22 COMPRESSIVE STRENGTH OF CYLINDERS AT 450 F

original strength of the specimens. Tests were made on two cylinders of each of the batches of the 3K and 4.5K mixes after 879 days of moist-curing to determine the room temperature strengths.

For the 3K mix, strengths varied from about 4200 to 6200 psi; for the 4.5K mix, variations in strength were from about 5100 psi to around 7200 psi. In-batch variations ranged from about 200 psi to 1300 psi. Undoubtedly, these variations in strength affected the test results. It is possible that these variations in strength are masking the indicated downward trend of compressive strength with increasing time of exposure to elevated temperatures. For example, if the 3-day strengths were determined on cylinders having compressive strength at the lower range of initial strengths, and the 900-day strengths were determined on cylinders having initially high compressive strengths, the effect of exposure time and temperature on the compressive strength would be difficult to evaluate.

Petrographic and Fractographic Analyses

Detailed information concerning the petrographic and fractographic work is given in Appendix 2. A summary of the major findings of these analyses follows.

Petrographic Analysis

Samples of 28 cylinders of laboratory-prepared concrete, stored at various temperatures for different lengths of time, were examined with a polarized light microscope and stereomicroscope to determine the microstructural effects on the paste and the paste-aggregate bond. An attempt was made to discern the progressive changes in microcrystalline texture of the paste as functions of duration and temperature of storage. The duration of storage ranged from 3 to 270 days. Temperatures were 250F, 350F, and 450F.

From the test, it was concluded that calcium hydroxide birefringencies showed no clearly defined correlation with temperature of storage. A "t" test for significant difference between the 250F and 350F data when compared with the 450F data gives a value of 1.28. This suggests the possibility that a real difference exists, but implies the necessity for additional data. In terms of storage time, samples stored at 270 days revealed relatively high birefringencies. A "t" test for significant difference in the birefringencies of the 1 to 100-day samples as compared with 150 to 270-day samples results in a value of 1.37. This again suggests a defined relationship and need for additional data.

Both "t" tests show correlations at a 90% probability level, but better relationships are required.

The fractured surfaces of the petrographic samples were broken with a hammer and revealed an obvious weakening of the paste-aggregate bond. It appeared that a significant reduction of the strength of the paste-aggregate bond occurred after cooling and returning to room temperature conditions.

Fractographic Analysis

Fractured surfaces of 202 cylinders broken by compression and by splitting tensile methods were examined. The cylinders represented concrete stored at various lengths of time at temperatures of 73, 250, 350, 450F.

Data obtained from this examination suggests the possibility of major effects of both temperature and time on the type of fracture produced in compression and splitting tensile tests. However, the fractographic examination was conducted after the cylinders had cooled to room temperature. Cooling probably produced a poorly understood relaxation effect on the paste-aggregate bond. This may have weakened the concrete. Results are inconclusive at this time.

SUMMARY

The following observations are based on results of tests on 6-in. diameter x 12-in. long cylinders of 3K and 4.5K Hanford concrete mixes.

Tests were made to determine modulus of elasticity and Poisson's ratio. These constants were determined at room temperature using sonic (dynamic) and static test methods. Elevated temperature tests were made using the static method. Compressive strength and splitting tensile strenth were also determined by the static test method at room and elevated temperatures. Petrographic and fractographic analyses were made on cylinders that were tested at room and elevated temperatures. These analyses were made after the concrete had cooled to room temperature.

1. The modulus of elasticity of moist-cured specimens increased with age. Higher values were obtained for the 4.5K mix. Also, higher values were obtained by the sonic method.

2. The modulus of elasticity of each concrete mix decreased with increasing exposure time to elevated temperatures. The largest decrease occurred during the first 30 days of exposure.

3. The modulus of elasticity decreased with increasing temperature. At 250F, after over 900 days of exposure, modulus values averaged only about 50% of the initial values. At 350F, final average modulus values were 45% of the initial values. After over 900 days exposure at 450F, modulus values for the two concrete mixes were only 30% of the initial values.

4. With the exception of the data at 240 days, values of Poisson's ratio obtained for both concretes by the sonic method remained relatively constant over the 1204 day moist-cure exposure period at 73F. Values obtained were slightly higher for the 4.5K mix than for the 3K mix.

5. Poisson's ratio obtained by the static method on room temperature specimens moist-cured for 1204 days increased slightly with increasing age. Higher values were obtained for the 4.5K mix than for the 3K mix. Values

ranged from about 0.15 to 0.19. Values obtained by the static method were smaller than those obtained by the sonic method.

6. Elevated temperature Poisson's ratio data were very erratic with numerous crossovers in the curves for the 3K and 4.5K mixes. High temperature values for Poisson's ratio varied between 0.10 and 0.14. In general, age and temperature did not have a large effect on the values obtained for Poisson's ratio.

7. For both mixes, splitting tensile strength at room temperature increased rapidly up to 200 days and then decreased to about 350 days. Beyond this point, strengths either leveled off or increased.

8. Although there was some fluctuation in the data at the three elevated test temperatures, generally the tensile splitting strength of both mixes decreased with increasing age and higher temperature. The largest decrease in splitting tensile strength was obtained at the 450F temperature, after over 900 days of exposure.

9. Compressive strength obtained from both concretes moist-cured at 73F for 1204 days increased with increasing age. The most rapid strength increase occurred during the first 200 days.

10. Compressive strength test data for the two concretes heated at 250F, 350F, and 450F were very erratic. For most cases, strength decreased with increasing time of

exposure and also decreased with increasing temperatures. The lowest values obtained were at 450F after over 900 days exposure. It is significant to note that after this extended period of exposure to these elevated temperatures, compressive strengths of both mixes were barely below the specified minimum levels of 3000 and 4500 psi.

11. Samples of both concretes stored from 3 to 270 days at 250, 350, 450F were examined to determine the micro-structural effects of temperature and duration of exposure on the paste and paste-aggregate bond. From these studies it was concluded that calcium hydroxide birefringencies showed no clearly defined correlation with temperature of storage or with length of storage.

12. Data were obtained from the fractographic examination of over 200 cylinders broken in compression or by the split tensile method. These results suggest the possibility of major effects of both temperature and time of storage at these temperatures on the type of fracture produced. These tests were performed on cylinders exposed for various lengths of time to temperatures of 73F, 250F, 350F, and 450F. Since the fractographic examination was conducted after the cylinders had cooled to room temperature, it appears that a poorly understood relaxation effect on the paste-aggregate bond due to cooling may have weakened the concrete. Thus, it was difficult to interpret the results of the fractographic examination.

REFERENCES

1. ASTM Designation: C192, "Standard Method of Making and Curing Concrete Test Specimens in the Laboratory", American Society for Testing and Materials, Philadelphia, Pa.

2. ASTM Designation: C39, "Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens", American Society for Testing and Materials, Philadelphia, Pa.

3. ASTM Designation: C215, "Standard Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens", American Society for Testing and Materials, Philadelphia, Pa.

4. ASTM Designation: C469, "Standard Method of Test for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression", American Society for Testing and Materials, Philadelphia, Pa.

5. ASTM Designation: C496, "Standard Method of Test for Splitting Tensile Strength of Cylindrical Concrete Specimens", American Society for Testing and Materials, Philadelphia, Pa.

A P P E N D I X 1

PETROGRAPHIC AND FRACTOGRAPHIC ANALYSES

PETROGRAPHIC ANALYSIS OF HEATED TEST SPECIMENS

Samples of 28 cylinders of lab-prepared concrete, stored at various temperatures for different lengths of time, have been studied with a polarized-light microscope and stereomicroscope to determine the microstructural effects on the paste and the paste-aggregate bond. An attempt was made to discern the progressive changes in microcrystalline texture of the pastes as functions of duration and temperature of storage. Duration of storage ranged from 3 to 270 days (after a 193-day initial cure at 73F and 100% RH). Temperatures were 250, 350 and 450F.

METHODS

Cylinders representing specified time and temperature combinations were withdrawn from storage ovens and, after a few hours of cooling in the lab atmosphere, a 2.5 cm-thick slice was cut transversly on a water-cooled saw. A small block cut from the interior of the slice with an oil-cooled saw, was lapped dried at 50°C, and mounted on standard petrographic glass slides with epoxy. Thin sections were ground to approximately 10-20 microns thickness and protected with cover glass loose-mounted in epoxy. The thin sections were labeled and most were numerically coded so that they could be described without prior bias as to duration of storage and temperature.

Optical properties of any solid material are functions of chemical composition and conditions of formation (temperature and pressure). After genesis, some phases are thermodynamically sensitive to changes in these conditions, with consequent changes in some optical properties. Calcium hydroxide, one of the principal hydration products of portland cement, normally occurs in crystal sizes large enough for optical examination in polarized light and determination of birefringence.

Birefringence is the numerical difference between the maximum and minimum indices of refraction of an anisotropic crystalline solid and can be related to the crystal thickness (thin-section thickness) in the following equation:

$$t = \frac{\lambda\theta}{180} / B$$

where

λ = wavelength of transmitted light in millimicrons (540)

θ = degrees of analyzer rotation on the microscope

B = birefringence of the crystalline solid

t = thickness

Assuming a quartz birefringence of .009, thickness of the concrete thin section was determined by averaging several measurements of θ on 6 to 8 grains of quartz. Using this calculated value of thickness, the average birefringence of calcium hydroxide in the same thin section was determined by examination of 8 to 10 crystals in the portland cement paste of the concrete. Birefringence data are given in Table 1.

Data groups in terms of temperature and duration of storage are presented in Table 2.

DESCRIPTION OF THE CONCRETE

Coarse aggregates in the concrete are principally basalt, dolerite, and gabbro, with lesser amounts of quartz, plagioclose, and biotite gueiss. Fine aggregates are fragments of the above-mentioned rocks; and in addition, metasandstones of various types, metaquartzite, quartz diorite, and argillite. No reaction products of potentially reactive aggregates were noted.

The paste, which is formed by the combination of water and cement contains, in addition to hydration products, unhydrated portland cement grains (UPC's) and air voids. Hydration products are primarily calcium silicate hydrates and calcium hydroxide, the latter having crystals large enough in normal concrete for determination of optical properties.

Calcium hydroxide occurs in pastes as 1) aggregate fringes, 2) concentrations in the paste, 3) finely dispersed amidst other hydration products, and 4) air-void fillings. Only the first two occurrences are considered in this report. Calcium hydroxide, in pure form, is assumed to have the properties listed in Taylor (1964) p. 352:

Hexazonal system

Refractive indices of 1.573 and 1.545

Birefringence = 0.028

It is clear that the birefringence determined for calcium hydroxide in the present report does not equal that stated by Taylor,* even for the "control" specimen (thin section No. 2).

The products of hydration are aggregated in paste to form a microcrystalline mosaic-an intimate intergrowth of principally calcium silicate hydrate and calcium hydroxide - the amounts of which are determined largely by the quantities of cement and water. Individual crystals comprising the microscrystalline mosaic are normally in the range of 0.1-10.0 microns, with a submicron average. The average size is beyond resolution in a polarized-light microscope, thus all of the calcium hydroxide birefringence measurements in the present study were made on relatively large, probably impure crystals or groups of crystals.

It is thought that the nodal crystal sizes of calcium silicate hydrate and calcium hydroxide would show progressive changes with temperature and duration of storage. However, because of the small crystal size and optically indefinite crystal boundaries, measurements could not be reliably made. Perhaps, examination of a polished and etched surface with a scanning electron microscope (SEM) would show progressive changes in crystal size. The SEM allows only observation of size and morphology (form) to the exclusion of other optical properties, thus the method has some limitations.

During sample preparation for thin sectioning, slight differences in tenacity of paste-aggregate bond were

*Taylor, H.F.W., Chemistry of Cements, Academic Press, New York, 1976 noted. Thus, using the categories given below on hand specimens (slices 2.5-3.0 in. thick) broken with a small hammer, the relative differences of paste-aggregate tenacity were determined.

Rank

1.0 all coarse aggregates sheared

2.0 most sheared, a few not broken

3.0 approximately equal proportions of sheared and non-broken aggregates

4.0 most aggregates not sheared (pullouts common), but a few aggregates broken

5.0 All coarse aggregates remain unbroken (pullouts abundant)

Of 40 samples examined (Table 3), tenacity of the paste-aggregate bond averages 4.6 (std. dev. = 0.52), thus in almost all of the samples pullouts and unbroken aggregates characterize the hammer-fractured surface. Samples giving relatively low values are:

4.5K/350°/4 days- 3.0

3K Control - 3.2 (no heat treatment)

3K/450°/6 days - 3.5

Thus, it appears that significant reduction of the strength of the paste-aggregate bond occurs after cooling and returning to room temperature conditions.

Air contents, estimated on broken surfaces of 40 cylinder samples have an average of 2.8% (std. dev.= 0.86%).

Comparatively high tenacity values generally correlate with relatively high air contents.

CONCLUSIONS

Calcium hydroxide birefringences show no clearly defined correlation with temperature of storage, judging from the averages given in Table 2. A "t" test for a significant difference between the 250 + 350F vs. 450F data gives a value of 1.28 which suggests the possibility that a real difference exists, but implies the necessity for additional data. In terms of storage times, samples stored for 270 days revealed relatively high birefringence. A "t" test for significant difference in the birefringences of the 1-100 days vs. 150-270 day samples results in a value of 1.37 which, again, suggests a poorly defined relationship and the need for additional data. Both "t" tests show correlation at 90% probability level, but better relationships are usually required.

Examination of the fracture surfaces of samples broken with a hammer reveal an obvious weakening of the paste aggregate bond. Apparently, desiccation of the concrete during storage for appreciable lengths of time at moderately high temperatures dehydrates the cement hydration products, resulting in submicroscopic contraction of the paste, and consequently weakening its bond with aggregate after cooling. An additional factor contributing to rupture of the bond may be related to relaxation of thermally induced stresses arising from differential expansion of various aggregate minerals at the paste contact.

TABLE 1

THIN SECTION LIST AND BIREFRINGENCE OF CALCIUM HYDROXIDE

Code No.	Concrete	Temperature F	Time Days	Average Birefringence
1	4.5K	450	100	.0125
2	3K	Control Specimen		.0202
3	3K	450	100	.0108
4	4.5K	450	6	.0208
5	3K	450	6	.0159
6	3K	350	4	.0120
7	4.5K	350	4	.0197
8	3K	350	150	.0113
9	3K	250	150	.0142
10	4.5K	250	3	.0173
11	3K	450	10	.0091
12	3K	250	3	.0178
13	3K	450	170	.0179
14	4.5K	450	10	.0117
15	4.5K	350	150	.0203
16	3K	250	100	.0187
17	4.5K	450	170	.0187
18	4.5K	450	60	.0117
19	3K	450	60	.0090
20	4.5K	250	150	.0087
21	3K	250	3	.0186
22	4.5K	250	100	.0123
23	3K	350	270	.0160
24	4.5K	250	270	.0182
25	3K	250	270	.0176
26	4.5K	350	270	.0198
27	4.5K	450	270	.0202
28	3K	450	270	.0123

TABLE 2

BIREFRINGENCE VS. TEMPERATURE AND DURATION OF STORAGE

250F	350F	450F
.0142	.0120	.0125
.0173	.0197	.0108
.0178	.0113	.0208
.0187	.0203	.0159
.0087	.0160	.0091
.0186	.0198	.0179
.0123	n = 6	.0117
.0182	σ = .0041	.0187
.0176	$\bar{x}$ = .0165	.0117
n = 9		.0090
σ = .0035		.0202
$\bar{x}$ = .0159		.0123
		n = 12
		σ = .0043
		$\bar{x}$ = .0142

1-10 days	60-100 days	150-170 days	270 days
.0208	.0125	.0113	.0160
.0159	.0108	.0142	.0182
.0120	.0187	.0179	.0176
.0197	.0117	.0203	.0198
.0173	.0090	.0187	.0202
.0091	.0123	.0087	.0123
.0178	n = 6	n = 6	n = 6
.0117	σ = .0032	σ = .0046	σ = .0029
.0186	$\bar{x}$ = .0125	$\bar{x}$ = .0152	$\bar{x}$ = .0174
n = 9			
σ = .0040			
$\bar{x}$ = .0159			

TABLE 3

AIR CONTENT AND TENACITY

Specimen No.	Estimated Air Content-%	Fracture Surface
4.5K 350/4d	2	3
3K Control	1	3.2
3K 450/6d	3	3.5
4.5K 350/80d	3	5
4.5K 250/3d	3	4.5
3K 350/4d	3	4.5
4.5K 450/6d	2.5	4.5
3K 250/150d	1	5
4.5K 250/6	3.5	5 (bubbles around aggregates)
3K 450/18d	3.5	5
4.5 450/18d	3	5
3K 350/10d	3	4.75
4.5K 450/10d	3	5
4.5K 450/100d	2.5	4.75
3K 450/101d	2	4.75 (bubble clusters)
4.5K 250/150d	2.5	4.75 (bubbles around aggregates)
4.5K 350/150d	2	4.75
3K 450/33d	2	4
3K 450/ -	3.5	5
4.5K 450/60d	2.5	4.75
4.5K 350/30d	2.5	5
3K 250/6d	2	4
3K 250/80d	2	5
4.5K 350/10d	3.5	5
3K 350/30d	3	5
4.5K 250/30d	3.5	4.5 (lapped)
3K 250/30d	3	4.5 (lapped)
3K 350/150d	4	5
4.5K 450/170d	4	5
3K 450/60d	4.5	5
4.5K 250/80d	4	5 (bubbles around aggregates)
3K 350/80d	3.0	5
4.5K 450/33d	3.5	4.75
3K 450/10d	3.0	5
4.5K 250/270d	2.5	3.8
4.5K 350/270d	2.5	4.0
3K 250/270d	1.5	4.5
3K 350/270d	3.0	4.5
4.5K 450/270d	3.2	4.75
3K 450/270d	2.8	4.75
	$\sigma = 0.86$	$\sigma = .52$
	$\bar{x} = 2.8$	$\bar{x} = 4.6$

FRACTOGRAPHIC ANALYSIS OF BROKEN TEST SPECIMENS

Fracture surfaces on 202 concrete cylinders broken by compressive or split tensile methods have been examined. The cylinders represent concrete stored for various lengths of time at temperatures of 70, 250, 350, and 450F. Each fracture surface was categorized with the following numerical scale:

1. Aggregates sheared, very few pullouts
2. Most aggregates broken, some not
3. Sheared and unbroken aggregates about equal
4. Some aggregates broken, pullouts abundant
5. Very few aggregates broken, pullouts very abundant. See photos.

Observational data are given in Table I.

Relationship of Fracture Surface to Temperature

Comparison of types of fracture surfaces produced in compression and split tensile tests, using a t-test on average values, indicate significant differences between compressive test surfaces at 70F and those at 450F (95% level).

Insignificant differences, determined in the same way, are indicated for surfaces produced by split tensile test (70F and 450F).

Inspection of the data in Table I suggests obvious differences in compressive vs. split tensile surfaces. The typical surface produced in compressive shows a relatively large number of pullouts and few broken aggregates (Ave = 4.60). In contrast, the surface produced by the split-tensile test reveals comparatively fewer pullouts and more broken aggregates (Ave = 3.63). Average standard deviations for compressive and tensile test data are 0.17 and 0.05, respectively, indicating relative uniformity in the tensile test data.

Relationship of Fracture Surface to Duration of Storage

Date presented in Table 1 were grouped into two storage categories: 4 to 101 days of storage and 150 to 679 days of storage. Fracture surfaces produced by compression tests are not significantly different at the 95% probability level, using a t-test, for concrete in both storage categories.

Average compression test values are 4.58 and 4.63 for the 4 to 101 day and 150 to 679 day categories, respectively.

Fracture surfaces formed in the split tensile test are significantly different at the 95% level, using the same categories and statistical test. Average values are 3.57 and 3.76 for the 4 to 101 day and 150 to 679 day categories, respectively.

CONCLUSIONS

These data suggest the possibility of major effects of both temperature and time on the type of fracture produced in compression and split tensile tests. However, all the tests were conducted after the cylinder had cooled to room temperature, thus, possibly producing a poorly understood "relaxation" effect in the paste-aggregate bond, and weakening the concrete. Partial elimination of cement water of hydration and subsequent paste recrystallization may account for strength decrease with time and temperature. Recrystallization normally involves an increase in crystal size but this was not observed by thin-section microscopy. Use of a scanning electron microscope may yield conclusive data.

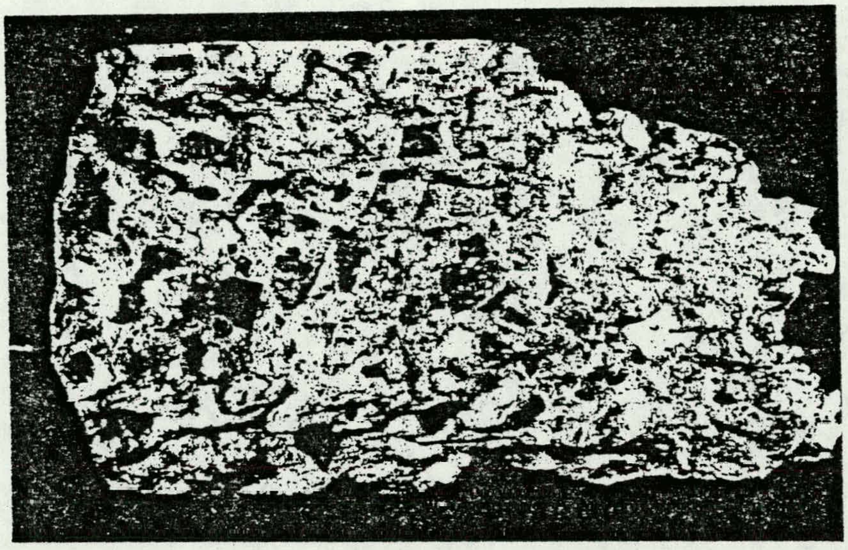

Photo 1 - Compression Test Cylinder 45K 4-28, stored at 70F for 30 days, with a fracture surface rating of 4.6. Note numerous sockets (pullouts) and relatively few broken aggregates.

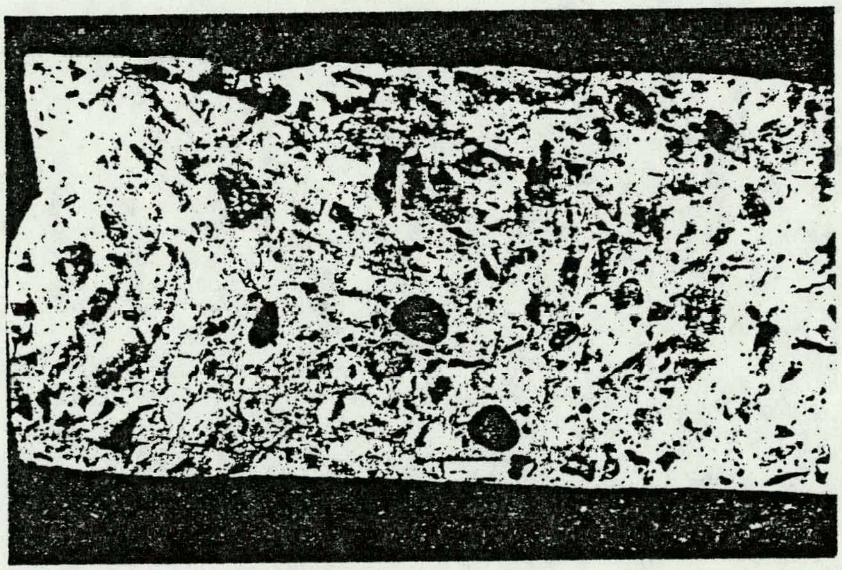

Photo 2 - Split Tensile Test Cylinder 45K 4-29, stored at 70F for 30 days, with a fracture surface rating of 3.5 Two centimeter scale.

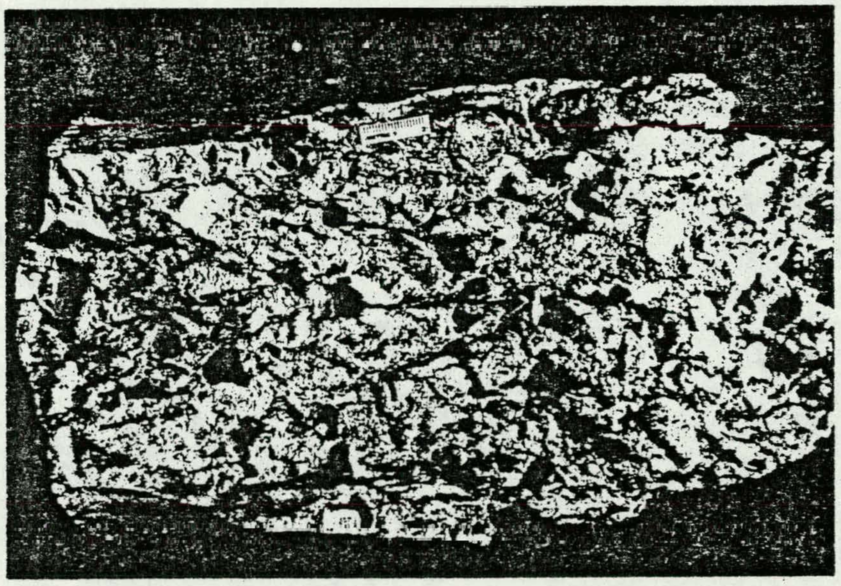

Photo 3 - Compression Test Cylinder 45K 3-21, stored at 450F for 487 days, ranking 4.7 on the relative scale and showing mostly pullouts and very few broken aggregates. Two centimeter scale.

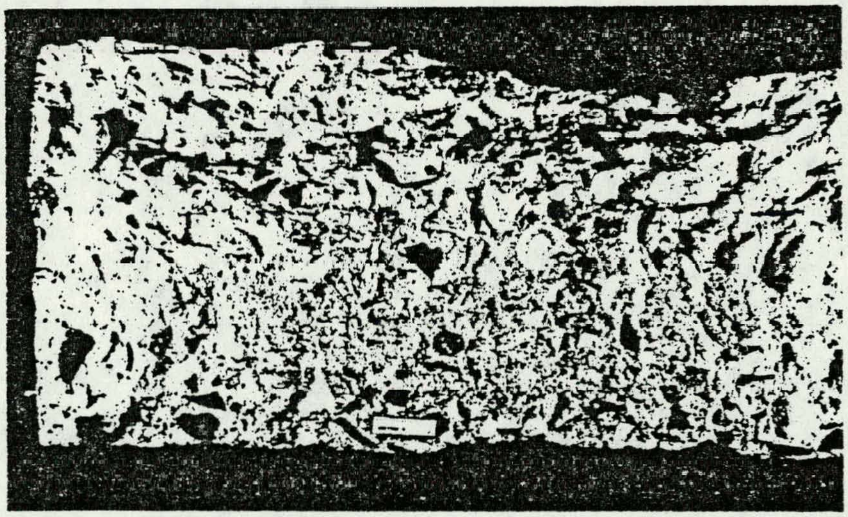

Photo 4 - Split Tensile Test Cylinder 45K 3-22, stored at 450F for 487 days, which ranks 3.7 on the fracture surface scale and shows abundant pullouts.

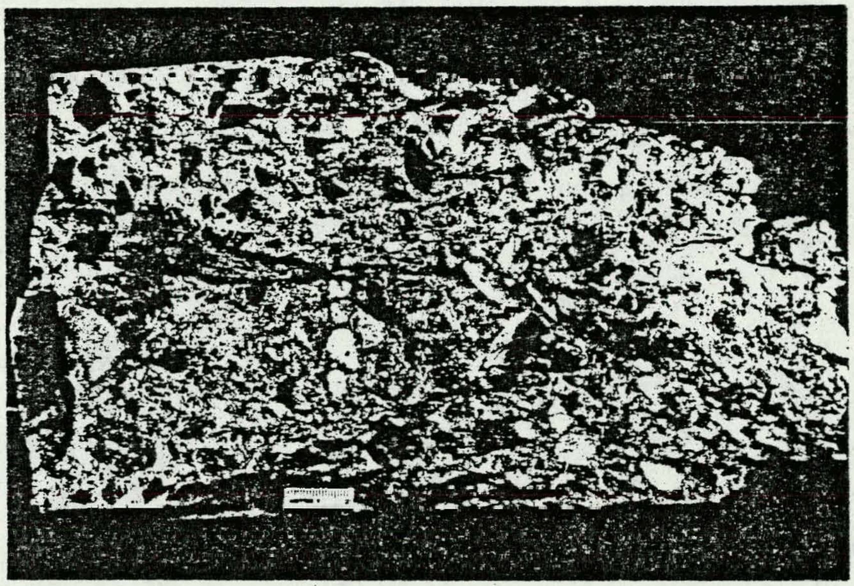

Photo 5 - Compression Test Cylinder, 4.5K 5-9, moist cured for 679 days, with a fracture surface ranking of 3.6. Note relatively numerous broken aggregates.

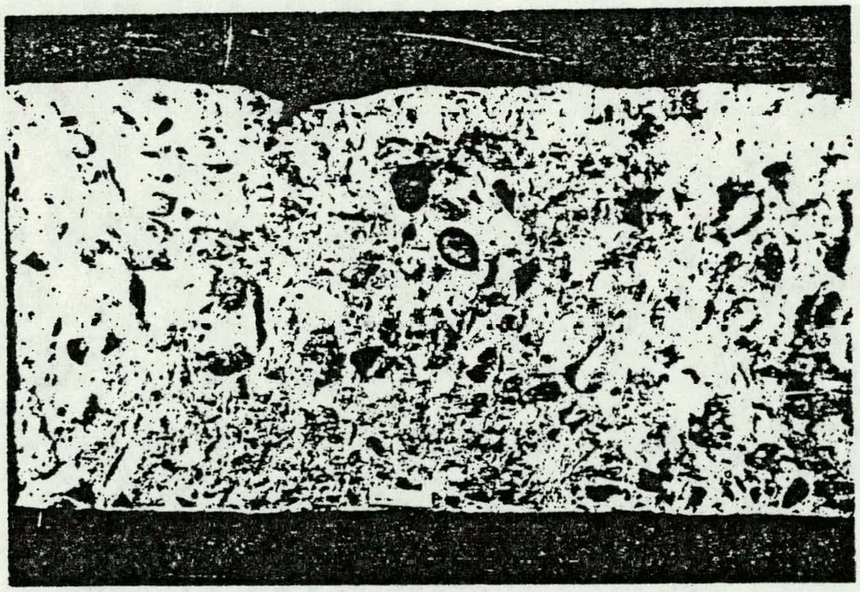

Photo 6 - Split Tensile-Test Cylinder, 4.5K 8-29, moist-cured for 679 days. Fracture surface has relatively few pullouts and many broken aggregates, with a ranking of 3.5 on the relative scale.

TABLE I

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
4.5K 4-29	70/30	-	3.5
4.5K 4-26	70/30	-	3.5
3K 4-28	70/30	4.6	-
3K 1-4	70/71	4.0	-
3K 4-26	70/30	-	3.5
3K 4-30	70/30	4.8	-
4.5K 6-28	70/361	4.7	-
4.5K 4-29	70/30	-	3.7
4.5K 1-11	70/71	-	3.5
4.5K 2-15	70/71	-	3.7
3K 6-28	70/361	4.5	-
3K 7-7	70/361	-	3.7
4.5K 9-1	70/194	4.5	-
3K 9-1	70/194	4.0	-
3K 9-3	70/194	4.8	-
4.5K 9-3	70/194	4.8	-
4.5K 9-15	70/194	-	3.3
4.5K 9-2	70/194	-	3.5
3K 9-2	70/194	-	4.2
3K 9-10	70/194	-	4.5
3K 1-5	70/34	4.5	-
4.5K 2-7	70/34	4.0	-
3K 1-7	70/34	4.0	-
3K 6-25	70/240	4.6	-
3K 7-28	70/240	-	4.0
4.5K 6-25	70/240	4.0	-
4.5K 7-29	70/240	-	3.4
3K 5-5	250/150	4.7	-
3K 5-2	250/150	-	4.0

TABLE 1 (CONTINUED)

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
3K 5-3	250/150	4.8	-
3K 5-7	250/150	-	4.0
45K 5-5	250/150	4.7	-
45K 5-1	250/150	-	3.8
45K 5-6	250/150	-	3.8
45K 5-3	250/150	4.8	-
45K 8-1	250/10	4.5	-
45K 8-6	250/10	4.5	-
45K 8-3	250/10	-	3.5
45K 8-2	250/10	-	3.3
3K 8-3	250/10	4.7	-
3K 8-4	250/10	-	3.5
3K 8-1	250/10	-	3.7
3K 8-5	250/10	4.5	-
3K 4-3	250/80	4.5	-
3K 4-2	250/80	-	3.8
3K 4-1	250/80	4.7	-
3K 4-5	250/80	-	3.6
3K 6-4	250/270	-	3.8
3K 6-1	250/270	-	4.0
3K 6-3	250/270	4.5	-
3K 6-5	250/270	4.3	-
45K 6-6	250/270	4.7	-
45K 6-3	250/270	4.7	-
45K 6-2	250/270	-	3.5
45K 6-8	250/270	-	3.5
45K 7-4	250/30	4.6	-
45K 7-1	250/30	-	3.5
3K 7-3	250/30	-	3.6
45K 7-3	250/30	4.8	-
45K 7-9	250/30	-	3.6

TABLE 1 (CONTINUED)

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
3K 7-4	250/3	-	3.5
4.5K 3-5	250/3	4.6	-
4.5K 3-3	250/3	4.7	-
4.5K 3-1	250/3	-	3.6
4.5K 3-7	250/3	-	3.5
3K 3-3	250/3	-	3.4
3K 3-5	250/3	4.6	-
3K 3-7	250/3	-	3.5
3K 3-1	250/3	4.6	-
3K 4-8	350/10	4.5	-
3K 7-14	350/10	-	3.6
3K 4-11	350/10	4.7	-
3K 4-4	350/10	-	3.5
4.5K 4-11	350/10	4.3	-
4.5K 4-10	350/10	-	3.3
4.5K 4-14	350/10	-	3.0
4.5K 4-8	350/10	4.3	-
3K 3-11	350/4	-	3.5
3K 3-14	350/4	4.7	-
3K 3-8	350/4	4.7	-
3K 3-9	350/4	-	3.5
4.5K 3-11	350/4	-	3.4
4.5K 3-8	350/4	4.7	-
4.5K 3-14	350/4	4.7	-
4.5K 3-15	350/4	-	3.4
3K 6-6	350/80	-	3.6
3K 6-8	350/80	-	3.6
3K 6-11	350/80	4.7	-
3K 6-14	350/80	4.8	-
4.5K 6-7	350/80	-	3.5

TABLE 1 (CONTINUED)

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
45K 6-12	350/80	-	3.5
45K 6-11	350/80	4.6	-
45K 6-14	350/80	4.8	-
45K 5-10	350/30	-	3.6
45K 5-8	350/30	4.5	-
45K 5-14	350/30	-	3.6
45K 5-11	350/30	4.6	-
3K 5-8	350/30	-	3.6
3K 5-11	350/30	4.4	-
3K 5-14	350/30	4.2	-
3K 5-12	350/30	-	3.5
3K 7-14	350/150	-	3.7
3K 7-8	350/150	4.6	-
3K 7-9	350/150	-	3.7
3K 7-11	350/150	4.8	-
45K 7-8	350/150	4.5	-
45K 7-12	350/150	-	3.7
45K 7-15	350/150	-	3.5
45K 7-10	350/150	4.7	-
45K 8-15	350/270	-	3.5
45K 8-11	350/270	4.7	-
45K 8-8	350/270	4.7	-
45K 8-14	350/270	-	3.7
3K 8-14	350/270	-	3.7
3K 8-11	350/270	4.7	-
3K 8-8	350/270	4.8	-
3K 8-6	350/270	-	4.0
45K 6-23	450/18	4.8	-
45K 6-19	450/18	-	3.7
45K 6-17	450/18	4.5	-

TABLE 1 (CONTINUED)

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
45K 6-20	450/18	-	3.7
3K 6-19	450/18	-	3.6
3K 6-23	450/18	4.7	-
3K 6-10	450/18	-	4.0
3K 6-17	450/18	4.7	-
3K 7-23	450/33	4.7	-
3K 7-20	450/33	-	3.6
3K 7-17	450/33	4.5	-
45K 7-20	450/33	4.5	-
45K 7-23	450/33	-	3.5
45K 7-18	450/33	4.5	-
45K 7-19	450/33	-	3.6
45K 6-29	450/170	-	3.7
45K 5-25	450/170	-	3.8
45K 4-24	450/170	4.7	-
45K 3-25	450/170	4.7	-
3K 3-25	450/170	4.8	-
3K 5-25	450/170	4.8	-
3K 4-24	450/170	-	3.8
3K 6-16	450/170	-	3.6
45K 4-19	450/6	-	3.5
45K 4-20	450/6	4.8	-
45K 4-23	450/6	-	3.5
45K 4-17	450/6	4.8	-
3K 4-20	450/6	4.6	-
3K 4-17	450/6	-	3.6
3K 4-23	450/6	4.8	-
3K 4-18	450/6	-	3.6
3K 8-17	450/60	4.8	-
3K 8-13	450/60	-	3.6
3K 8-22	450/60	4.8	-

TABLE 1 (CONTINUED)

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
3K 8-24	450/60	-	3.7
45K 8-23	450/60	-	3.5
45K 8-30	450/60	4.6	-
45K 8-18	450/60	-	3.5
45K 8-17	450/60	4.7	-
45K 9-14	450/100	-	3.4
45K 9-24	450/100	-	3.6
3K 9-11	450/100	-	3.8
3K 9-12	450/100	-	3.8
3K 5-20	450/10	4.6	-
3K 5-13	450/10	-	3.7
3K 5-17	450/10	-	3.7
45K 5-16	450/10	4.6	-
45K 5-27	450/10	-	3.5
45K 5-23	450/10	-	3.6
45K 5-20	450/10	4.6	-
45K 3-23	450/300	4.8	-
45K 3-19	450/300	4.8	-
45K 3-28	450/300	-	3.6
45K 3-17	450/300	-	3.7
3K 3-20	450/300	4.5	-
3K 3-23	450/300	4.7	-
3K 3-17	450/300	-	3.6
3K 3-13	450/300	-	3.5
45K 6-20	350/487	4.8	-
3K 6-24	350/487	4.8	-
3K 6-30	350/487	4.9	-
45K 6-26	350/487	4.8	-
45K 8-28	250/487	4.7	-
45K 8-25	250/487	4.7	-
3K 9-20	250/487	4.8	-

TABLE 1 (CONTINUED)

FRACTURE SURFACES ON TESTED CYLINDERS

Cylinder No.	Temp/Days	Compression	Split Tensile
3K 9-14	250/487	4.7	-
4.5K 8-29	70/679	-	3.5
3K 8-28	70/679	-	3.6
4.5K 5-9	70/679	3.6	-
3K 5-28	70/679	4.0	-
4.5K 3-21	450/487	4.7	-
4.5K 3-27	450/487	4.8	-
3K 3-12	450/487	4.8	-
3K 3-10	450/487	4.8	-
4.5K 3-22	450/487	-	3.7
3K 3-26	450/487	-	3.9
4.5K 3-2	450/487	-	4.0
3K 3-27	450/487	-	4.0
4.5K 8-26	250/487	-	3.8
3K 9-29	250/487	-	3.6
3K 9-17	250/487	-	4.0
4.5K 8-16	250/487	-	3.7
4.5K 6-27	350/487	-	3.9
3K 6-27	350/487	-	4.0
4.5K 6-24	350/487	-	4.0
3K 6-26	350/487	-	3.8

A P P E N D I X 2

MIX DESIGN INFORMATION

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 5 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO SK 3 DATE 22 MAY 75 TIME 0930

MATERIALS

CEMENT	LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S
	2-NONE
COARSE AGGREGATE .	1-R
	2-NONE
ADMIXTURE.	1-DAREX AEA
	2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	498.	BGS/CU YD	5.30
FINE AGGREGATE . . 1 . .		1217.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		2102.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.20		
2 . .		0.00		
WATER.		277.	GALS/CU YD	33.28

TOTAL WEIGHT . . . . . . LBS/CU YD 4096.21

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . . 3.0
AIR CONTENT,PERCENT . . 3.8
UNIT WEIGHT,LBS/CU FT . 151.7

BATCH ANALYSIS

WATER CEMENT RATIO	0.55	BY WT	6.27	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.6	BY WT	37.0	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.14	PRESS	2.02	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 27 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 6 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO SK 4 DATE 22 MAY 75 TIME 1030

MATERIALS

CEMENT		LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S	
	2-NONE	
COARSE AGGREGATE .	1-R	
	2-NONE	
ADMIXTURE.	1-DAREX AEA	
	2-NONE	

BATCH INGREDIENTS

CEMENT		LBS/CU YD	490.	BGS/CU YD	5.22
FINE AGGREGATE . .	1 . .		1198.		
	2 . .		0.		
COARSE AGGREGATE .	1 . .		2063.		
	2 . .		0.00		
ADMIXTURE.	1 . .		0.29		
	2 . .		0.00		
WATER.			247.	GALS/CU YD	29.73
TOTAL WEIGHT		LBS/CU YD	4005.46		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . .	3.25
AIR CONTENT, PERCENT . .	4.9
UNIT WEIGHT, LBS/CU FT .	148.3

BATCH ANALYSIS

WATER CEMENT RATIO	0.50	BY WT	5.69	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.6	BY WT	37.0	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.08	PRESS	2.19	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 7 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 5 DATE 22 MAY 75 TIME 1100

MATERIALS

CEMENT	LONE STAR P C CO TYPE II	
FINE AGGREGATE . .	1-S	
	2-NONE	
COARSE AGGREGATE .	1-R	
	2-NONE	
ADMIXTURE.	1-DAREX AEA	
	2-NONE	

BATCH INGREDIENTS

CEMENT		LBS/CU YD 494.	BGS/CU YD	5.26
FINE AGGREGATE . .	1 . .	1202.		
	2 . .	0.		
COARSE AGGREGATE .	1 . .	2083.		
	2 . .	0.00		
ADMIXTURE.	1 . .	0.34		
	2 . .	0.00		
WATER.		255.	GALS/CU YD	30.72
TOTAL WEIGHT		LBS/CU YD 4037.08		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . . 3.0
AIR CONTENT,PERCENT . . 4.5
UNIT WEIGHT,LBS/CU FT . 149.5

BATCH ANALYSIS

WATER CEMENT RATIO	0.51	BY WT	5.84	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.5	BY WT	36.9	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.09	PRESS	2.12	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 8 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 6 DATE 22 MAY 75 TIME 1120

MATERIALS

CEMENT	LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S
	2-NONE
COARSE AGGREGATE .	1-R
	2-NONE
ADMIXTURE.	1-DAREX AEA
	2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	489.	BGS/CU YD 5.21
FINE AGGREGATE . . 1 . .		1179.	
2 . .		0.	
COARSE AGGREGATE . 1 . .		2071.	
2 . .		0.00	
ADMIXTURE. . . . . 1 . .		0.39	
2 . .		0.00	
WATER.		260.	GALS/CU YD 31.24
TOTAL WEIGHT	LBS/CU YD	4001.33	

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . .	3.50
AIR CONTENT, PERCENT . .	5.0
UNIT WEIGHT, LBS/CU FT .	148.1

BATCH ANALYSIS

WATER CEMENT RATIO	0.53	BY WT	5.99	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.2	BY WT	36.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.18	PRESS	2.24	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI
---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 9 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 7 DATE 23 MAY 75 TIME 0850

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT		LBS/CU YD	484.	BGS/CU YD	5.15
FINE AGGREGATE . .	1 . .		1169.		
	2 . .		0.		
COARSE AGGREGATE .	1 . .		2047.		
	2 . .		0.00		
ADMIXTURE.	1 . .		0.38		
	2 . .		0.00		
WATER.			261.	GALS/CU YD	31.42
TOTAL WEIGHT		LBS/CU YD	3962.83		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 3.0
AIR CONTENT,PERCENT . . 6.3
UNIT WEIGHT,LBS/CU FT . 146.7

BATCH ANALYSIS

WATER CEMENT RATIO	0.53	BY WT	6.09	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.3	BY WT	36.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.34	PRESS	2.35	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 29 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1430 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 10 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 8 DATE 23 MAY 75 TIME 0910

MATERIALS

CEMENT	LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S
	2-NONE
COARSE AGGREGATE .	1-R
	2-NONE
ADMIXTURE.	1-DAREX AEA
	2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	491.	BGS/CU YD	5.22
FINE AGGREGATE . . 1 . .		1133.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		2072.		
2 . .		0.00		
ADMIXTURE. . . . . . 1 . .		0.34		
2 . .		0.00		
WATER.		267.	GALS/CU YD	32.13
TOTAL WEIGHT	LBS/CU YD	4015.08		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . . 3.25
AIR CONTENT,PERCENT . . 4.9
UNIT WEIGHT,LBS/CU FT . 148.7

BATCH ANALYSIS

WATER CEMENT RATIO	0.54	BY WT	6.14	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.3	BY WT	36.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.21	PRESS	2.22	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE II - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 9 DATE 23 MAY 75 TIME 0930

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	489.	BGS/CU YD	5.21
FINE AGGREGATE . . 1 . .		1179.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		2068.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.36		
2 . .		0.00		
WATER.		263.	GALS/CU YD	31.65
TOTAL WEIGHT	LBS/CU YD	4001.33		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 3.00
AIR CONTENT,PERCENT . . 5.0
UNIT WEIGHT,LBS/CU FT . . 148.1

BATCH ANALYSIS

WATER CEMENT RATIO	0.53	BY WT	6.07	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.3	BY WT	36.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.20	PRESS	2.24	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 29 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 12 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5 K 3   DATE 22 MAY 75   TIME 1315

MATERIALS

CEMENT	LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S
	2-NONE
COARSE AGGREGATE .	1-R
	2-NONE
ADMIXTURE.	1-DAREX AEA
	2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	652.	BGS/CU YD	6.94
FINE AGGREGATE . . 1 . .		1215.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		1864.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.59		
2 . .		0.00		
WATER.		278.	GALS/CU YD	33.38

TOTAL WEIGHT . . . . . . LBS/CU YD 4010.96

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES 3.00
AIR CONTENT,PERCENT . . 5.0
UNIT WEIGHT,LBS/CU FT . 148.5

BATCH ANALYSIS

WATER CEMENT RATIO	0.42	BY WT	4.80	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.4	BY WT	39.3	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.72	PRESS	1.72	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 28 IN SUMM
CURE   MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 13 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5K 4 DATE 22 MAY 75 TIME 1335

MATERIALS

CEMENT	LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S
	2-NONE
COARSE AGGREGATE .	1-R
	2-NONE
ADMIXTURE.	1-DAREX AEA
	2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	652.	BGS/CU YD	6.94
FINE AGGREGATE . . 1 . .		1209.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		1860.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.63		
2 . .		0.00		
WATER.		289.	GALS/CU YD	34.72
TOTAL WEIGHT	LBS/CU YD	4012.33		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . .	3.00
AIR CONTENT,PERCENT . .	4.6
UNIT WEIGHT,LBS/CU FT .	148.6

BATCH ANALYSIS

WATER CEMENT RATIO	0.44	BY WT	5.00	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.3	BY WT	39.7	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.75	PRESS	1.74	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 14 BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5K 5 DATE 22 MAY 75 TIME 1400

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	651.	BGS/CU YD	6.93
FINE AGGREGATE . . 1 . .		1192.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		1855.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.63		
2 . .		0.00		
WATER.		309.	GALS/CU YD	37.20
TOTAL WEIGHT	LBS/CU YD	4009.58		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 4.00
AIR CONTENT,PERCENT . . 4.5
UNIT WEIGHT,LBS/CU FT . 148.5

BATCH ANALYSIS

WATER CEMENT RATIO	0.47	BY WT	5.36	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.1	BY WT	39.4	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.85	PRESS	1.78	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 28 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1430 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 15- BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5K 6 DATE 22 MAY 75 TIME 1430

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	640.	BGS/CU YD	6.81
FINE AGGREGATE . . 1 . .		1190.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		1830.		
2 . .		0.00		
ADMIXTURE. . . . . . 1 . .		0.67		
2 . .		0.00		
WATER.		280.	GALS/CU YD	33.63

TOTAL WEIGHT . . . . LBS/CU YD 3942.21

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 4.50
AIR CONTENT,PERCENT . . 5.4
UNIT WEIGHT,LBS/CU FT . 146.0

BATCH ANALYSIS

WATER CEMENT RATIO	0.43	BY WT	4.93	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.4	BY WT	39.7	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.79	PRESS	1.88	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6 X 12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 16 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5K 7 DATE 22 MAY 75 TIME 1445

MATERIALS

CEMENT	LONE STAR P C CO TYPE II	
FINE AGGREGATE . .	1-S	
	2-NONE	
COARSE AGGREGATE .	1-R	
	2-NONE	
ADMIXTURE.	1-DAREX AEA	
	2-NONE	

BATCH INGREDIENTS

CEMENT	LBS/CU YD	643.	BGS/CU YD 6.84
FINE AGGREGATE . . 1 . .		1186.	
2 . .		0.	
COARSE AGGREGATE . 1 . .		1832.	
2 . .		0.00	
ADMIXTURE. . . . . 1 . .		0.67	
2 . .		0.00	
WATER.		294.	GALS/CU YD 35.34
TOTAL WEIGHT	LBS/CU YD	3957.33	

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . .	4.50
AIR CONTENT,PERCENT . .	5.7
UNIT WEIGHT,LBS/CU FT .	146.5

BATCH ANALYSIS

WATER CEMENT RATIO	0.45	BY WT	5.16	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.2	BY WT	39.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.88	PRESS	1.87	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 29 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 17 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5K 8 DATE 22 MAY 75 TIME 1515

MATERIALS

CEMENT	LONE STAR P C CO TYPE II
FINE AGGREGATE . .	1-S
	2-NONE
COARSE AGGREGATE .	1-R
	2-NONE
ADMIXTURE.	1-DAREX AEA
	2-NONE

BATCH INGREDIENTS

CEMENT		LBS/CU YD	652.	BGS/CU YD 6.93
FINE AGGREGATE . .	1 . .		1207.	
	2 . .		0.	
COARSE AGGREGATE .	1 . .		1856.	
	2 . .		0.00	
ADMIXTURE.	1 . .		0.68	
	2 . .		0.00	
WATER.			294.	GALS/CU YD 35.33
TOTAL WEIGHT		LBS/CU YD	4010.96	

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . .	3.0
AIR CONTENT,PERCENT . .	4.6
UNIT WEIGHT,LBS/CU FT .	148.5

BATCH ANALYSIS

WATER CEMENT RATIO	0.45	BY WT	5.09	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.4	BY WT	39.7	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.78	PRESS	1.75	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 18 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 4.5K 9 DATE 23 MAY 75 TIME 0950

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	650.	BGS/CU YD	6.92
FINE AGGREGATE . . 1 . .		1240.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		1862.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.68		
2 . .		0.00		
WATER.		239.	GALS/CU YD	28.75
TOTAL WEIGHT	LBS/CU YD	3993.08		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 3.50
AIR CONTENT,PERCENT . . 5.2
UNIT WEIGHT,LBS/CU FT . 147.8

BATCH ANALYSIS

WATER CEMENT RATIO	0.36	BY WT	4.15	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	39.9	BY WT	40.3	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	1.55	PRESS	1.69	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 29 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

Portland Cement Association
Construction Technology Laboratories

Project CR-1480 - Concrete Test Cylinder Fabrication
Battelle Pacific Northwest Laboratories

TABLE 19 - CONCRETE MIX INFORMATION

Mix No.	Water Cement Ratio	Portland Cement	Water	Air	Sand	Aggregate	Darex
3K Concrete Mixture							
3K3	0.55	498	277	3.8	1217	2102	0.20
3K4	0.50	490	247	4.9	1198	2068	0.29
3K5	0.51	494	255	4.5	1202	2083	0.34
3K6	0.53	489	260	5.0	1179	2071	0.39
3K7	0.53	484	261	6.3	1169	2047	0.38
3K8	0.54	491	267	4.9	1183	2072	0.34
3K9	0.53	489	263	5.0	1179	2068	0.36
Ave.	0.53	491	261	4.9	1190	2073	0.33
Target	0.54	498	271	5.0	1213	2096	0.20
4.5K Concrete Mixture							
4.5K3	0.42	652	278	5.0	1215	1864	0.59
4.5K4	0.44	652	289	4.6	1209	1860	0.63
4.5K5	0.47	651	309	4.5	1192	1855	0.63
4.5K6	0.43	640	280	5.4	1190	1830	0.67
4.5K7	0.45	643	294	5.7	1186	1832	0.67
4.5K8	0.45	652	294	4.6	1207	1856	0.68
4.5K9	0.36	650	239	5.2	1240	1862	0.68
Ave.	0.43	649	283	5.0	1206	1851	0.65
Target	0.43	658	286	5.0	1240	1880	0.30

Portland Cement Association
Construction Technology Laboratories

Project CR-1480 - Concrete Test Cylinder Fabrication
Battelle Pacific Northwest Laboratories

TABLE 20 - MATERIAL CONSUMPTION

Mix No.	Lone Star Cement	S Aggregate	R Aggregate	6x12 in. Spec	Cast Order
		3K Concrete Mixtures			
1	64.6	164.94	271.70	15	1
2	64.6	164.94	271.70	17	2
3	110.6	270.04	472.0	27	5
4	110.6	271.50	462.7	30	6
5	110.6	271.00	467.3	30	7
6	110.6	271.00	467.3	30	8
7	110.6	271.00	467.3	29	15
8	110.6	271.00	467.3	30	16
9	110.6	271.00	467.3	29	17
SUB TOTAL TO DATE	903.4	2497.42	3814.6	237	-
		4.5K Concrete Mixures			
1	85.30	168.61	243.70	16	3
2	85.30	168.61	243.70	16	4
3	146.2	275.6	417.8	28	9
4	146.2	275.6	417.8	30	10
5	146.2	275.6	417.8	28	11
6	146.2	275.6	417.8	30	12
7	146.2	275.6	417.8	29	13
8	146.2	275.6	417.8	30	14
9	146.2	275.6	417.8	29	18
SUB TOTAL TO DATE	1194.0	2266.42	3412.00	236	-
TOTAL TO DATE	2097.4	4763.84	7226.60	473	18

AWI 5/27/75

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