MISCELLANEOUS PAPER C-71-5

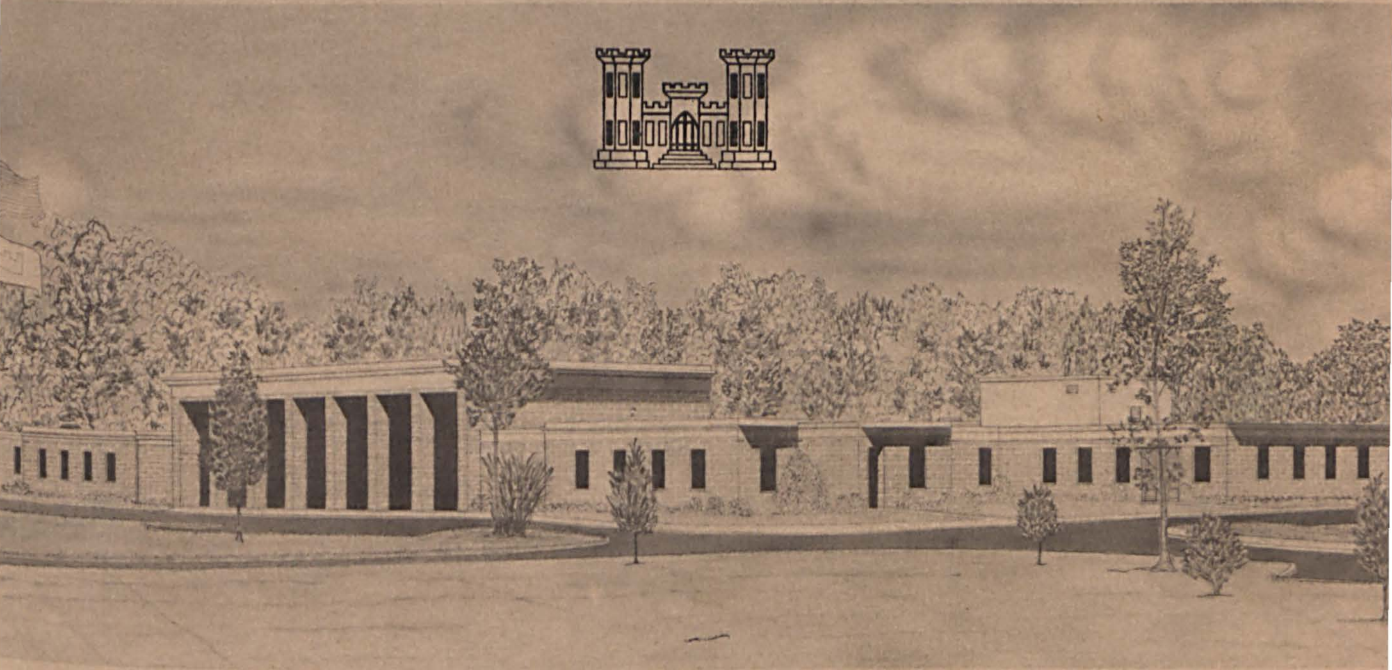
INVESTIGATION OF EXPANDING GROUT AND CONCRETE

Report 1

SUMMARY OF FIELD MIXTURE TEST RESULTS, JULY 1969 THROUGH JUNE 1970

by

G. C. Hoff



June 1971

Sponsored by **U. S. Atomic Energy Commission - Sandia Laboratories**

and

Test Command, Defense Atomic Support Agency

Conducted by **U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi**

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ARMY-MRC VICKSBURG, MISS.

ABSTRACT

Laboratory evaluations were made of 14 grout mixtures and seven concrete mixtures, all of which contained type K expansive cement wholly or in part. The mixtures were developed for field use on a number of different projects. The mixtures varied widely in ingredients, proportions, curing, and the type of evaluations made. Very few direct comparisons of behavior among mixtures could be made. Three special control study mixtures were also evaluated as a pilot study.

Both shrinkage-compensating and self-stressing type K expansive cements were used. The self-stressing cement was used as a portion of the total cement, while the shrinkage-compensating cement was used as the only cement in the mixture. Each mixture was evaluated for some, but not all, of the following physical characteristics: expansion, strength, modulus of elasticity, compressional wave velocity, constrained pressure, temperature rise, slump loss, and efflux time. Comparisons were made as appropriate. Temperature rise values as high as 178 F were recorded. The various mixtures developed 3-day compressive strengths ranging from less than 1300 psi to more than 4700 psi. The maximum compressive strength noted was 7155 psi on one mixture at 28 days age; other 28-day strengths on other mixtures were as low as 2115 psi. Static modulus of elasticity values were between 1.0 and 3.5 million psi with corresponding dynamic moduli being 20 to 30 percent greater. The greatest unrestrained expansion observed was 0.158 percent; this included both thermal and chemical expansions. Most expansions were considerably less, however. Restrained expansions were always less than unrestrained expansions. Compressional

wave velocities from 10,800 to 14,395 fps were observed. A constrained stress of 52 psi was measured for one grout mixture. Slump loss evaluations indicated that the amount of loss was a function of the mixture ingredients and proportions as well as the mixing cycle.

Recommendations as to expansion determinations, curing conditions, and constrained stress measurements are included in the appendix.

PREFACE

The investigation reported herein was authorized jointly by the Test Command, Defense Atomic Support Agency, and U. S. Atomic Energy Commission - Sandia Laboratories.

The work was conducted during fiscal year 1970 by personnel of the Concrete Division of the U. S. Army Engineer Waterways Experiment Station (WES) under the supervision of Messrs. Bryant Mather, J. M. Polatty, R. V. Tye, Jr., B. R. Sullivan, and R. A. Bendinelli. This report was prepared by Mr. George C. Hoff. The investigation was coordinated with Mr. C. W. Gulick, Jr., of Sandia Laboratories and Mr. Joseph LaComb and Major M. J. Jones, Jr., CE, of Test Command, Defense Atomic Support Agency. Subsequent reports will be issued in this series.

COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of WES during the conduct of this investigation and the preparation and publication of this report. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
cubic feet	0.0283168	cubic meters
cubic yards	0.764555	cubic meters
cubic feet per second	0.0283168	cubic meters per second
~~ounces~~	~~28.3495~~	~~grams~~
pounds	0.45359237	kilograms
pounds per square inch	0.00689476	meganewtons per square meter
Fahrenheit degrees	5/9	Celsius or Kelvin degrees[a]

---

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

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The "Investigation of Expanding Grouts and Concretes" was authorized jointly by the Test Command, Defense Atomic Support Agency, and U. S. Atomic Energy Commission - Sandia Laboratories to study the behavior of expansive cements when used in grouts and concretes and also to provide expansive cement mixture design support for field tests conducted at the Nevada Test Site (NTS) and other testing areas. The first report of this study (Reference 1) developed information as to the basic behavioral trends that expansive cement grouts and concretes might follow when adapted and modified to the job requirements of actual field tests.

The information contained in this report describes the results of laboratory evaluations of actual grout and concrete mixtures used at the NTS during Projects DIAMOND DUST, DIESEL TRAIN, HUDSON MOON, DIANA MIST, MING VASE, MINT LEAF, and CAMPHOR and also during MINERAL LODE conducted at Cedar City, Utah, plus the results of basic mixtures to be used at NTS that involve naturalite sand and rock. Appendix A describes some special control study (SCS) mixture evaluations that were made as a prelude to a more comprehensive laboratory study of expansive cement behavior. All of the work was done between 1 July 1969 and 30 June 1970.

Because of the differences in performance requirements for each project, the grouts and concretes described in this report vary widely in type and proportion of ingredients, curing environment, specimen size, age of test, and type of evaluation made. Since there were no requirements for control mixtures (without expansive cement), none were made. Hence, the advantages of using expansive cement are not immediately obvious. Because of the many differences between each mixture, very few direct comparisons of behavior can be made. The data are presented solely for informational purposes and to supplement the very limited amount of information that is available on expansive cement grouts and concretes.

1.2 SCOPE

Fourteen grout mixtures and seven concrete mixtures were studied. Each mixture was evaluated for some but not all of the following physical properties and characteristics:

1. Expansion:
    a. Restrained.
    b. Unrestrained.
2. Strength:
    a. Compressive.
    b. Flexural.
    c. Tensile splitting (diametral compression).
    d. Shear.
    e. Bond.
3. Modulus of elasticity:
    a. Static.
    b. Dynamic.

4. Ultrasonic pulse velocity.
5. Constrained stress.
6. Temperature rise.
7. Slump loss.
8. Flow determination.

A schedule of the physical test program is shown in Table 1.1.

Each mixture contained some expansive cement. Both shrinkage-compensating and self-stressing type K cements were used. The shrinkage-compensating cement was used as the only cement in a mixture, while the self-stressing cement was used in combination with either types II or III or class G portland cements. The type and proportion of other ingredients varied widely between mixtures so as to meet job criteria.

The mixture designations under the projects that they were originally developed for and some general supporting information regarding the use of each mixture are as follows.

Mixture	Type of Mixture	Expansive Cement Content, pcf of Mixture	Remarks
1. DIAMOND DUST			
a. DDCPPII	Grout	0.99*	Developed for DIAMOND DUST but used in MINT LEAF
b. DDCPPIIA	Grout	1.00*	Laboratory development only
c. DDCPPIIB	Grout	2.00*	Used in DIAMOND DUST
d. DDCPPIII	Grout	1.00*	Laboratory development only
e. DDCCG-1	Grout	31.64**	Laboratory development only
f. DD-1	Grout	1.39*	Instrument-hole grouting
g. DDC-1	Concrete	14.61**	Laboratory development only

(continued)

(Continued)

Mixture	Type of Mixture	Expansive Cement Content pcf of Mixture	Remarks
2. DIESEL TRAIN			
a. DTCS-1	Grout	0.32*	Used in button-up operations on DIESEL TRAIN, DIAMOND MINE, and HUDSON MOON
b. DTCS-1A	Grout	0.31*	Used in prestemming and button-up operations on MING VASE, around the LOS pipe and in an experimental alcove on DIESEL TRAIN, in the cable trenches of HUDSON MOON and DIANA MIST, and in other locations in DIAMOND DUST and MINT LEAF
c. DTCS-2	Grout	0.53*	Laboratory development only
d. DTCS-3	Grout	0.68*	Laboratory development only
e. DTCS-CP-1	Grout	0.29*	Laboratory development only
3. HUDSON MOON			
HMHS-1	Grout	0.33*	Laboratory development only, similar to DTCS-1
4. CAMPHOR			
CAM4	Concrete	3.48*	Developed for use in overburden plug
5. MINERAL LODE			
MLEH-1	Concrete	11.20*	Placed around experimental silos
6. Naturalite aggregate mixtures			
a. NSG-1	Grout	0.31*	Laboratory development only
b. NSG-1A	Grout	0.34*	Laboratory development only
c. C1	Concrete	3.50*	Laboratory development only

(Continued)

(Continued)

Mixture	Type of Mixture	Expansive Cement Content pcf of Mixture	Remarks
d. C2	Concrete	4.03*	Laboratory development only
e. CCC4	Concrete	17.39**	Laboratory development only
f. CCC5	Concrete	20.87**	Laboratory development only

* Amount of total batch cement that was a self-stressing expansive cement.

** Shrinkage-compensating expansive cement--the only cement in the batch.

Table 1.1

Physical Testing Program

Mixture Designation	Expansion		Strength					Modulus of Elasticity		Ultrasonic Pulse Velocity	Can Stress	Temperature Rise	Slump Loss	Flow Determination
	Restrained	Unrestrained	Compressive	Flexural	Tensile Splitting	Shear	Bond	Static	Dynamic					
Grouts														
DDCPPII	X	X	X	X		X		X	X	X	X	X		
DDCPPIIA			X				X	X	X	X		X		
DDCPPIIB			X	X				X	X	X		X	X	
DDCPPIII	X	X	X	X		X		X	X	X		X		
DDCCG 1			X									X		
DTCS-1		X	X					X						
DTCS-1A		X	X					X				X		X
DTCS-2		X	X					X						
DTCS-3		X	X					X						
DTCS-CP-1		X	X											
HMHS-1			X		X	X								X
DD-1		X												
NSG-1			X					X	X					X
NSG-1A			X					X	X					X
Concretes														
C1	X	X	X					X	X				X	
C2			X											
CCC4													X	
CCC5													X	
DDC-1			X										X	
CAM4			X										X	
MLEH-1		X	X				X			X				

CHAPTER 2

MATERIALS AND MIXTURE PROPORTIONS

The specific materials used in the formulation of the grouts and concretes described in this report were dictated by the particular job requirements for which the grouts and concretes were used. This resulted in a large variety of different materials and considerable latitude in mixture proportioning, both of which make direct comparison of the physical properties obtained from different mixtures quite difficult.

Summaries of the mixture ingredients and proportioning for the grouts and concretes are shown in Tables 2.1 and 2.2, respectively. Descriptions, where available, of the various materials are contained in the following paragraphs.

2.1 CEMENTITIOUS MATERIAL

2.1.1 Portland Cements. Three portland cements were used: a type II, type III, and a class G oil-well cement. These cements were given Waterways Experiment Station (WES) designations RC-626, 47-C-1, and RC-616, respectively. No chemical or physical testing was done for the types II and III cements. However, the test results for the class G cement (RC-616) are contained in Table 2.3.

2.1.2 Expansive Cements. Two expansive cements were used. Both were type K, one being a self-stressing cement (RC-610(2)) and the other a shrinkage-compensating cement (RC-623). Both consist of portland cement compounds, anhydrous calcium aluminate sulfate ($C_4A_3\overline{S}$), calcium sulfate ($CaSO_4$), and lime (CaO). The $C_4A_3\overline{S}$ is a component of a separately burned clinker that is interground with portland clinker or blended with portland cement, or it may be formed simultaneously with the portland clinker compounds during the burning process. The shrinkage-compensating cement is the same as the self-stressing cement except that it contains less of the expansive component. The results of a chemical analysis and some limited physical testing for these cements are included in Table 2.3.

2.1.3 Fly Ash. Fly ash (AD-239) is a pozzolanic material that is added to grouts and concretes, usually on a partial cement replacement basis, as a means for reducing the amount of heat developed during hydration and also to reduce the cost of the grout and concrete. It contributes to cementing behavior over extended time periods. The fly ash used had a specific gravity of 2.45.

2.2 SAND

Five different sands were used. The detail in which each sand was examined was dictated by the requirements of its ultimate use in the field; hence some sand descriptions are more detailed than others.

2.2.1 NTS Concrete Sand. This was a naturally occurring angular sand that had a specific gravity of 2.61 and an absorption of 2.5 percent.

2.2.2 Monterey Sand. This sand had a specific gravity of 2.65 and an absorption of 0.8 percent. The grading showed 97.8 percent passing a No. 20 sieve, with 95 percent being retained on a No. 40 sieve.

2.2.3 Oceanside Sand. This sand had a specific gravity of 2.65 and an absorption of 0.3 percent, and is very similar to Monterey sand.

2.2.4 Harris Pit Sand, Cedar City, Utah.

This sand had a specific gravity of 2.61 and an absorption of 2.4 percent. The grading was as follows.

Sieve Number	Cumulative Percent Passing
4	99.6
8	83.7
16	66.2
30	51.4
50	32.8
100	7.9

2.2.5 Naturalite Sand.

This sand was a crushed fines and had a specific gravity of 2.12 and an absorption of 6.1 percent. The grading was as follows.

Sieve Number	Cumulative Percent Passing
8	100
16	52.4
30	33.0
50	22.1
100	13.2

2.3 COARSE AGGREGATE

2.3.1 NTS Concrete Aggregate.

This aggregate had a specific gravity of 2.63 and an absorption of 2.1 percent. The grading was as follows.

Sieve Size	Cumulative Percent Passing
1 in.	100
3/4 in.	67
1/2 in.	14
3/8 in.	2
No. 4	0

2.3.2 Naturalite Aggregate. This aggregate had a specific gravity of 1.88 and an absorption of 6.1 percent. The grading was as follows.

Sieve Size	Cumulative Percent Passing
1 in.	100
3/4 in.	70
1/2 in.	51
3/8 in.	15
No. 4	3

2.3.3 Cedar City Aggregate. This aggregate had a specific gravity of 2.63 and an absorption of 2.5 percent. The grading was as follows.

Sieve Size	Cumulative Percent Passing
1 in.	100
3/4 in.	58.4
1/2 in.	24.4
3/8 in.	12.0
No. 4	2.7

2.4 BARITE

Barite (AD-426) is a barium sulfate and is an inert material added to grout mixtures to increase density, reduce strength, and reduce temperatures. It has a specific gravity of 4.25 and is very fine with most of the material passing a No. 200 sieve. This fineness results in a higher water demand, which, in turn, reduces the strength of the grout containing the material.

2.5 GEL

The term gel usually refers to sodium bentonites belonging to the general class of montmorillonite clays. It is used as a suspending medium for sands and also for its ability to retain water. Both of these aspects aid in the pumping of grouts. The specific gravity of the gel (AD-369) used was 2.39.

2.6 TERRA ALBA

Terra Alba (AD-403) is a finely divided gypsum with 99.1 percent passing the No. 325 sieve. The material had a specific gravity of 2.50 and an SO_3 content of 46.5 percent. It was used to aid the expansive component in the cement by supplying some SO_3 to combine with the CaO in the formation of calcium sulfate.

2.7 ADMIXTURES

2.7.1 Pozz 8. Pozz 8 (AD-247) is a lignin-based, type A[1] water-reducing admixture which reduces the quantity of mixing water required to produce grouts or concretes of a given consistency.

2.7.2 CFR-2. CFR-2 (AD-420) is a sodium salt of polymerized alkylnapthalene-sulfonic acids which is used as a friction-reducing admixture to aid in the pumpability of grouts.

2.7.3 100 XR. 100 XR is a glucose-based admixture that retards the setting of grouts and concretes for extended periods of time.

2.7.4 Plastiment. Plastiment (AD-380) is a type D[1] chemical admixture that both reduces the quantity of mixing water required to produce concrete of a given consistency and retards the setting of the concrete.

---

1. CRD-C 87, "Standard Specification for Chemical Admixtures for Concrete" (Reference 2).

Table 2.1

Grouts - Materials and Mixture Proportions

Mixture Designation	Mixture Proportions for a One Cubic Foot Batch, lb													
	DDCPPII	DDCPPIIA	DDCPPIIB	DDCPPIII	DDCCG-1	DTCS-1	DTCS-1A	DTCS-2	DTCS-3	DTCS-CP-1	HMHS-1	DD-1	NSG-1	NSG-1A
Cement, Type II (RC-626)	27.78	20.83	17.39	-	-	-	-	-	-	-	-	-	-	-
Type III (47-C-1)	-	-	-	21.49	-	-	-	-	-	37.39	-	-	-	-
Type G (RC-616)	-	-	-	-	-	33.30	24.77	33.26	33.10	-	38.37	26.85	33.89	25.15
Type K														
ChemComp (RC-623)	-	-	-	-	31.64	-	-	-	-	-	-	-	-	-
ChemStress (RC-610(2))	0.99	1.00	2.00	1.00	-	0.32	0.31	0.53	0.68	0.29	0.33	1.39	0.31	0.34
Fly Ash	14.46	16.20	13.53	16.79	-	12.74	12.89	12.72	12.66	14.30	9.76	-	12.97	13.09
Sand														
NTS Concrete Sand	46.86	53.08	80.18	50.41	-	-	-	-	-	44.51	40.65	-	-	-
Monterey Sand	-	-	-	-	-	39.64	33.00	39.60	39.41	-	-	-	-	-
Oceanside Sand	-	-	-	-	50.49	-	-	-	-	-	-	-	-	-
Naturalite Sand	-	-	-	-	-	-	-	-	-	-	-	-	28.15	23.37
Barite (AD-426)	14.80	22.12	10.99	16.04	-	13.21	24.20	13.20	13.14	14.84	10.84	37.59	8.61	20.54
Gel	1.69	1.85	-	1.53	3.48	0.95	1.14	0.95	0.95	1.07	-	3.39	0.96	1.16
Water	25.34	22.72	17.00	24.88	31.64	27.80	30.36	27.93	27.85	23.78	28.08	33.88	28.30	30.87
Pozz 8 (AD-247)	0.12	0.04	0.05	0.11	-	-	-	-	-	0.15	-	-	-	-
CFR-2 (AD-420)	-	-	-	-	-	0.23	0.08	0.23	0.23	-	-	0.11	0.24	0.08
100 x R	-	-	-	-	1.01[1]	-	-	-	-	-	-	-	-	-

---

[1] Fluid ounces

(Continued)

(Sheet 1 of 2)

Table 2.1 (Concluded)

Mixture Designation	DDCPPII	DDCPPIIA	DDCPPIIB	DDCPPIII	DDCCG 1	DTCS-1	DTCS-1A	DTCS-2	DTCS-3	DTCS-CP-1	HMHS-1	DD-1	NSG-1	NSG-1A
Theoretical Unit Weight, pcf	131.9	132.3	141.3	132.3	117.3	127.2	126.8	128.1	128.0	136.3	128.1	127.3	113.4	114.6
Theoretical Cement Factor,[2] Bags Per Cubic Yard	8.0	6.0	5.0	6.2	9.1	9.7	7.2	9.7	9.7	10.8	11.1	8.1	9.8	7.3
Water/Cementitious Ratio[3]	0.59	0.60	0.52	0.63	1.00	0.60	0.80	0.60	0.60	0.47	0.58	1.20	0.60	0.8

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[2] This is the amount of all cements in the mixture.
[3] The cementitious fraction includes all cements plus the fly ash.

(Sheet 2 of 2)

Table 2.2

Concretes - Materials and Mixture Proportions

	Mixture Proportions for a One Cubic Foot Batch, lb						
Mixture Designation	C1	C2	CCC4	CCC5	DDC-1	CAM4	MLEH-1
Cement, Type II (RC-626)	32.18	24.20	-	-	-	16.52	16.70
Type K							
ChemComp (RC-623)	-	-	17.39	20.87	14.61	-	-
ChemStress (RC-610(2))	3.50	4.03	-	-	-	3.48	11.20
Fly Ash	-	8.09	18.09	-	4.92	5.51	-
Sand							
NTS Concrete Sand	42.62	41.24	44.61	62.26	54.23	52.33	-
Harris Pit Sand	-	-	-	-	-	-	42.09
Coarse Aggregate							
NTS Concrete Aggregate	-	-	-	-	56.12	53.73	-
Naturalite Aggregate	38.05[1]	36.82[1]	30.84[2]	29.81[2]	-	-	-
Cedar City Aggregate	-	-	-	-	-	-	66.41
Terra Alba (AD-403)	-	-	-	-	-	-	1.70
Water	13.92	14.17	15.65	15.65	13.67	13.52	11.30
Pozz 8 (AD-247)	0.10	0.09	-	-	-	-	-
100 x R[3]	1.43	1.47	1.11	1.33	1.11	-	-
Plastiment[3] (AD-300)	-	-	-	-	-	1.08	1.29

---

1. 1/2 inch maximum size
2. 3/4 inch maximum size
3. Units are fluid ounces.

(Continued)

(Sheet 1 of 2)

Table 2.2 (Concluded)

Mixture Designation	C1	C2	CCC4	CCC5	DDC-1	CAM4	MLEH-1
Theoretical Unit Weight, pcf	130.3	128.5	126.7	128.7	143.7	145.2	149.4
Theoretical Cement Factor[4] Bags Per Cubic Yard	10.2	8.1	5.0	6.0	4.2	5.7	8.5
Water/Cementitious Ratio[5]	0.39	0.39	0.44	0.75	0.70	0.53	0.38

---

[4] This is the amount of all cements in the mixture.

[5] The cementitious fraction includes all cements, the fly ash, and terra alba.

(Sheet 2 of 2)

Table 2.3
Chemical and Physical Test Results for Cements

Chemical Analysis

Cement Designation	RC-616	RC-623	RC-610(2)
Constituents		Percent	
SiO_2	23.0	18.2	18.5
Al_2O_3	3.9	6.3	6.2
Fe_2O_3	3.0	1.8	1.8
MgO	4.0	4.3	2.8
SO_3	1.7	5.9	6.7
CaO	63.8	60.6	61.9
Na_2O	--	0.28	0.25
K_2O	--	0.38	0.43
Loss on ignition	0.9	2.3	1.3
Alkalies-total as Na_2O	0.42	0.53	0.53
Insoluble residue	1.29	0.65	0.55
C_3S	49.6	--	--
C_3A	5.2	13.5	13.5
C_2S	28.7	--	--
C_4AF	9.0	--	--

Physical Properties

	RC-616	RC-623	RC-610(2)
Setting time, Gillmore hours:minutes			
Initial	3:20	--	--
Final	5:20	--	--
Autoclave expansion, pcf	0.14	--	--
Air content of mortar, pcf	5.8	--	--
Compressive strength of mortar, psi			
3 Days	1900	--	--
7 Days	2760	--	--
Surface area, Blaine fineness, cm^2/g	3190	4485	--
Heat of hydration cal/g			
1 Day	--	53	--
2 Days	--	57	--
3 Days	--	63	--
7 Days	--	74	--
28 Days	--	77	--
Specific gravity	3.15	3.08	3.06

CHAPTER 3

TEST PROCEDURES

3.1 TEMPERATURE RISE TESTS AND CURING TEMPERATURE HISTORIES

Of the 14 grout mixtures studied, only one, mixture DD-1, did not have its test specimens cured at elevated temperatures with respect to the normal laboratory curing temperature of 73 F. Of the seven concrete mixtures studied, all except mixtures CCC4 and CCC5, which were not represented by any hardened test specimens, had their test specimens cured at elevated temperatures. The curing temperature history for each mixture was determined using the measurements made in the field in connection with large mass placements of similar grouts or agreed to by the sponsoring agencies and WES personnel. In a few instances, more than one curing temperature history was utilized for a given mixture. The moisture condition of the test specimens varied and is described for each test later in the report.

Most of the elevated temperature curing was done in a circulating-air electric oven. The temperature in the oven was programmed to fit the desired curing history curve. In a few instances, where a constant elevated temperature was required, the specimens were placed in constant elevated temperature rooms for the duration of curing. The following paragraphs describe the temperature rise testing and the curing temperature histories for the mixtures.

3.1.1 Grouts.

DIAMOND DUST Mixtures. Five of the six DIAMOND DUST mixtures (DDCPPII, IIA, IIB, III, and DDCGG-1) were evaluated to determine their temperature development behavior. This was done by casting a 2-ft cube of each mixture and instrumenting the center of each cube with thermocouples. The cube was allowed to remain in the formwork for the entire period of observation. Ambient curing temperature was 73 F. An insulation material was placed on the exposed top surface of the cube to minimize heat loss through that surface. The output from the thermocouples was continuously plotted on strip-chart recorders and can be seen in Fig. 3.1 for these mixtures. The curing temperature history of the test specimens from each of these mixtures was done in the oven in accordance with the curve shown in Fig. 3.1 for that mixture. Test specimens from mixture DD-1 were cured at a constant temperature of 68 F.

DIESEL TRAIN Mixtures. Temperature development was evaluated only for mixture DTCS-1A. The test specimen was a 60-in.-high, 30-in.-diameter cylinder and was instrumented with thermocouples. The average output from these sensing devices is shown in Fig. 3.2a. The specimen was allowed to remain in its form for the entire period of observation. Other test specimens for this mixture were cured at elevated temperatures in accordance with the curve shown in fig. 3.2b and c except where noted differently.

The curing temperature history of test specimens from mixtures DTCS-1, DTCS-2, DTCS-3, and DTCS-CP-1 followed the curves shown in Fig. 3.2 for those mixtures. These temperature curves were in accordance with the project sponsor's instructions. Some exceptions did occur and are noted in the text.

HUDSON MOON, High-Strength Mixture. The test specimens from mixture HMHS-1 were cured in accordance with a temperature history agreed to by sponsor and WES personnel. This curve is shown in Fig. 3.3.

Naturalite Sand Grout Mixtures. The test specimens from mixtures NSG-1 and NSG-1A were cured in accordance with a temperature history agreed to by sponsor and WES personnel. This curve is shown in Fig. 3.2.

3.1.2 Concretes.

Naturalite Coarse Aggregate Concrete Mixtures. The test specimens from mixtures C1 and C2 were tested in accordance with a temperature history agreed to by sponsor and WES personnel. This curve is shown in Fig. 3.2. Mixtures CCC4 and CCC5 had no hardened test specimens; hence no curing was required.

DIAMOND DUST Concrete Mixture. Two sets of test specimens were made for mixture DDC-1 and each set was cured differently. One set was cured at 150 F for 2 days, 100 F for the next 12 days, and then at 75 F for the last 14 days. The second set was cured at 100 F for the first 12 days and at 75 F for the remaining 16 days.

CAMPHOR Concrete Mixture. The majority of the test specimens made from mixture CAM4 were cured in accordance with a temperature history agreed to by sponsor and WES personnel. This curve is shown in Fig. 3.4. Some exceptions did occur and are noted in the text.

MINERAL LODE Concrete Mixture. The test specimens made from mixture MLEH-1 were cured in accordance with a temperature history agreed to by sponsor and WES personnel. This curve is shown in Fig. 3.5.

3.2 EXPANSION TESTS

3.2.1 Equipment and Procedures. Length-change specimens, both for unrestrained and restrained tests, were made in molds conforming to those described in ASTM C 490, "Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete," with the exception that for restrained bars the molds were blocked on the ends to provide a 10-in. gage length between end plates. All grout mixtures used 2- by 2-in. bars with a 10-in. gage length, while the concrete bars were 3 by 3 in. with a 10-in. gage length. Both sizes of restrained bars had 3/8-in. plates on each end which were connected by a centrally located, 3/16-in.-diameter, continuously threaded mild steel rod. Length changes were measured using a length comparator. Stainless steel cap nuts, which fit into the comparator, were placed on the ends of the threaded rod which extended through the end plates of the restrained bar specimens. The demolding times of the bars varied, depending on the hardening characteristics of the mixture, but generally most bars were demolded and the initial length determined at 24 hours age. Unless otherwise noted, all bar measurements were made while the bars were at the temperature at which they were being cured.

3.2.2 Grouts. Unrestrained expansion was measured for all grout mixtures except DDCPPIIA, DDCPPIIB, DDCCG1, HMHS-1, NSG-1, and NSG-1A. Restrained expansion was measured only for mixtures DDCPPII and DDCPPIII. All grout mixture expansion bars were cured underwater except for a few bars each from mixtures DTCS-1, DTCS-2, and DTCS-3, which were cured over water in either plastic bags or jars. The curing temperature history of the bars varied widely both within and between mixtures. The curing temperature history for each set of expansion data is described in Figs. 3.1 to 3.3.

3.2.3 Concrete. Only mixtures C1 and CAM4 were studied for restrained expansion, while mixtures C1 and MLEH-1 were studied for unrestrained expansion. All specimens were cured underwater except for a few bars from the CAM4 mixture which were cured in plastic bags. The curing temperature histories for the bars are described in Figs. 3.2, 3.4, and 3.5.

3.3 COMPRESSIVE STRENGTH TESTS

Compressive strength determinations were made on a number of different sized cylinders and cores and also on 2-in. cubes. The age of the materials at test varied from 3 to 84 days. The moisture condition and curing temperature histories of the test specimens also varied. All cubes were tested while the material was at the same temperature it was curing at just prior to testing. All cores and cylinders were capped immediately upon their removal from their curing environment, stored for 30 minutes at 73 F, and then tested. With these exceptions, all tests were conducted in accordance with one of the following test methods (Reference 2): CRD-C 14, "Standard Method of Test for Compressive Strength of Molded Cylinders"; CRD-C 27, "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"; and CRD-C 227, "Compressive Strength, Two-Inch Cubes."

3.3.1 Grouts. All the grout mixtures except DD-1 were evaluated for compressive strength. The test specimens were primarily 2-in. cubes that were kept underwater during their entire curing period. There were some exceptions. Mixture DTCS-1A had some 2-in. cubes that were sealed in plastic bags during curing. Mixture DTCS-3 had some cubes that were cured at 20 percent relative humidity from the time of demolding. Cores were drilled from the 2-ft cubes cast for the temperature-rise studies (Section 3.1.1) of mixtures DDCPPIIB and DDCCG-1 and evaluated for compressive strength. The cores of DDCPPIIB were drilled at 9 days age and tested at 10 days age. The cores of DDCCG-1 were both drilled and tested at 7 days age. In both cases, ~~the cores received only ambient-condition~~ curing after drilling.

3.3.2 Concretes. All of the concrete mixtures except CCC4 and CCC5 were evaluated for compressive strength. All specimens were 3- by 6-in. cylinders except for mixture MLEH-1 which had 6- by 12-in. cylinders. All cylinders were cured underwater. Mixture CAM4 also had some cylinders that were cured in a moist curing room (73 F, 100 percent relative humidity).

3.4 FLEXURAL STRENGTH TESTS

Flexural strength tests were made only for grout mixtures DDCPPII, DDCPPIIB, and DDCPPIII. The test was conducted in accordance with CRD-C 16, "Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading" (Reference 2). The size beam used was 3-1/2 by 4-1/2 by 16 in. All beams were cured underwater until time of test and at the curing temperature histories shown in Fig. 3.1. They were tested immediately upon removal from their curing environment.

3.5 TENSILE SPLITTING TESTS

Tensile splitting tests were made only for grout mixture HMHS-1. They were conducted in accordance with CRD-C 77, "Standard Method of Test for Splitting Tensile Strength of Cylindrical Concrete Specimens" (Reference 2). The specimens were 3- by 6-in. cylinders. They were cured in water at temperatures corresponding to the curing temperature history curve of Fig. 3.3, and were tested immediately upon removal from their curing environment.

3.6 SHEAR TESTS

Single-plane shear tests were made only for grout mixtures DDCPPII, DDCPPIII, and HMHS-1. The tests were conducted in accordance with CRD-C 90, "Method of Test for Transverse Shear Strength, Confined, Single Plane or Double Plane" (Reference 2). The test specimens were 3- by 6-in. cylinders that were cured underwater and in accordance with the curing temperature history curves of Figs. 3.1 and 3.3. They were tested approximately 1 hour after removal from their curing environment.

3.7 BOND TESTS

Bond tests were conducted only for grout mixture DDCPPIIA and concrete mixture MLEH-1. The tests were done in accordance with CRD-C 24, "Method of Test for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel" (Reference 2). The test specimens were 6-in. cubes. They were cured underwater and in accordance with the temperature curves of Figs. 3.2 and 3.5. They were tested approximately 1 hour after removal from their curing environment.

3.8 MODULUS OF ELASTICITY

3.8.1 Static Modulus. Static modulus of elasticity determinations were made for grout mixtures DDCPPII, DDCPPIIA, DDCPPIIB, DDCPPIII, DTCS-1, DTCS-1A, DTCS-2, DTCS-3, NSG-1, and NSG-1A, and also for concrete mixture C1. The specimens were 3- by 6-in. cylinders for all mixtures except DDCPPIIA and DDCPPIIB which utilized 4- by 8-in. cores drilled from 2-ft cubes. All test specimens were cured underwater and in accordance with the curing temperature curves shown in Figs. 3.1 and 3.2. The tests were conducted using a compressometer and were in accordance with CRD-C 19, "Standard Method of Test for Static Young's Modulus of Elasticity and Poisson's Ratio in Compression of Cylindrical Concrete Specimens" (Reference 2). Ages of test varied from mixture to mixture with specimens at ages 3 and 84 days being evaluated. All specimens were tested immediately after being removed from their curing environment.

3.8.2 Dynamic Modulus. The dynamic modulus of elasticity was determined for grout mixtures DDCPPII, DDCPPIIA, DDCPPIIB, DDCPPIII, NSG-1, NSG-1A, and for concrete mixture C1. The test specimens for the grout mixtures were 3-1/2- by 4-1/2- by 16-in. beams. Mixture DDCPPIIB also had some tests conducted on 3- by 6-in. cylinders and 4- by 8-in.

drilled cores. Concrete mixture C1 had 3- by 3- by 11-in. beam specimens. All specimens, except the drilled cores, were cured underwater and in accordance with the curing temperature curves of Figs. 3.1 and 3.2 and were tested immediately upon removal from their curing environment. Tests were conducted in accordance with CRD-C 18, "Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens" (Reference 2) with the exception of the 3- by 6-in. cylinders of grout mixture DDCPPIIB. The modulus determination for these cylinders was obtained by dropping a large weight from a drop tower tester onto the cylinder which had been instrumented with SR-4 electrical strain gages. The output from these gages and a recording load cell produced a dynamic stress-strain curve from which a modulus value was determined. As in the case of the static modulus tests, the age of test varied from 3 to 84 days.

3.9 ULTRASONIC PULSE VELOCITY TESTS

Ultrasonic pulse velocity tests were made for grout mixtures DDCPPII, DDCPPIIA, DDCPPIIB, and DDCPPIII and also for concrete mixture MLEH-1. The tests were conducted in accordance with CRD-C 51, "Tentative Method of Test for Pulse Velocity Through Concrete" (Reference 2). The test specimens for the DIAMOND DUST (DDCPP series) mixtures were 2-ft cubes cast for the temperature development study. All cubes were evaluated at 7 days age. Nine readings were made for each cube. The location of these readings is shown in Fig. 3.6.

Only one 6- by 12-in. cylinder was evaluated for the MLEH-1 concrete mixture. The same cylinder was evaluated at both 3 and 7 days age. The specimen was cured underwater and in accordance with the curing temperature history curve of Fig. 3.5.

3.10 CONSTRAINED STRESS TESTS

Constrained stress or the stress exerted on a container as the results of the expansion of a grout contained in the container was measured only for grout mixture DDCPPII. The container was a 9-in.-diameter by 18-in.-deep steel cylinder of a thickness calculated to approximate the restraint of in-situ tuff. The restraint modulus was 1×10^6 psi. Strain gages were attached to the walls of the container in both vertical and horizontal directions to monitor stresses. The upper and lower ends of the cylinder were restrained by rigid steel plates. The analysis was done in accordance with procedures described in Reference 1. Due to gage failure, no stresses or pressures were obtained in the longitudinal direction. All testing was done at 73 F.

3.11 SLUMP LOSS TESTS

Slump loss tests were made for grout mixture DDCPPIIB and for all the concrete mixtures except C2 and MLEH-1. Slumps were measured in accordance with CRD-C 5, "Standard Method of Test for Slump of Portland-Cement Concrete" (Reference 2). All tests were conducted at 73 F. The procedures for determining slump loss with time were dictated by the handling requirements of the job on which the concrete was to be used. These requirements produced a number of different mix-hold-remix cycles for the various mixtures.

3.11.1 Grouts. Mixture DDCPPIIB was batched and continuously mixed for 4 minutes and then rested for 3 minutes before the initial slump determination was made. The mixture was then continuously mixed for 1 hour before the slump was measured again.

3.11.2 Concretes. The initial cycle for mixture C1 mixed the concrete for 2 minutes, then rested for 3 minutes and remixed for 1 minute. The initial slump was then determined. After each of four additional 30-minute rest periods, the concrete was remixed 2 minutes and a slump determination made.

The initial cycle for mixtures CCC4 and CCC5 was to mix the concrete for 2 minutes, then rest it for 3 minutes, and remix it for 2 minutes. The initial slump was then determined. A continuous rest-mix cycle of 3:2 minutes was then begun and continued for 2 hours with slump determinations being made at 30-minute intervals.

The same mix cycle used for mixture C1 was used for mixture DDC-1. The slump loss was determined only at 1 hour after casting, however.

Mixture CAM4 used a continuous rest-mix cycle of 4:1 minute from the start of batching, with slump determinations being made at 5, 30, and 60 minutes.

3.12 FLOW DETERMINATION TESTS

Measurements of the efflux time of grout mixtures DTCS-1A, HMHS-1, NSG-1, and NSG-1A were made in accordance with CRD-C 79, "Method of Test for Flow of Grout Mixtures (Flow-Cone Method)" (Reference 2). All tests were made at 73 F.

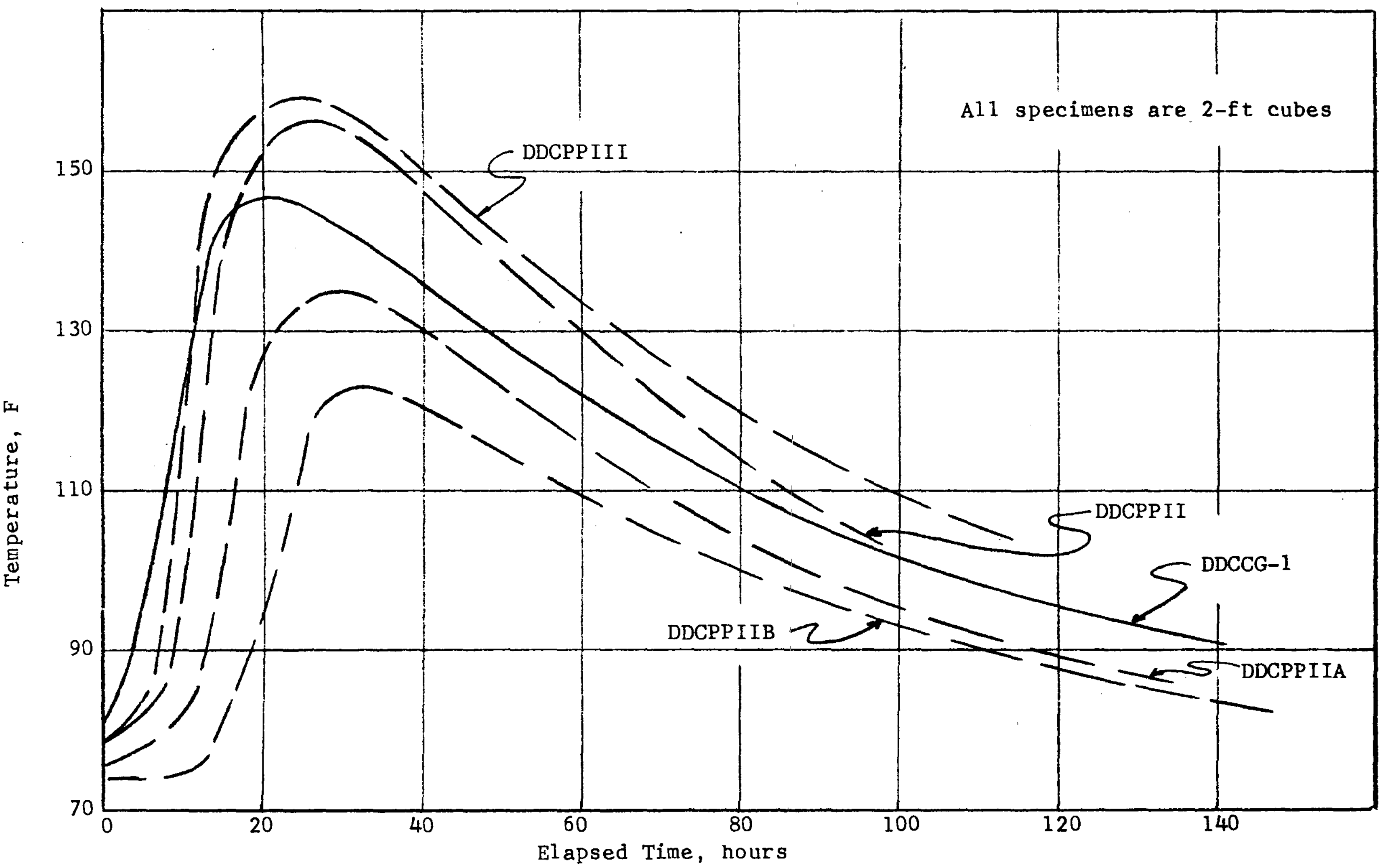

Figure 3.1 Temperature Rise and Curing History Curves for the DIAMOND DUST (DD) Grout Mixtures

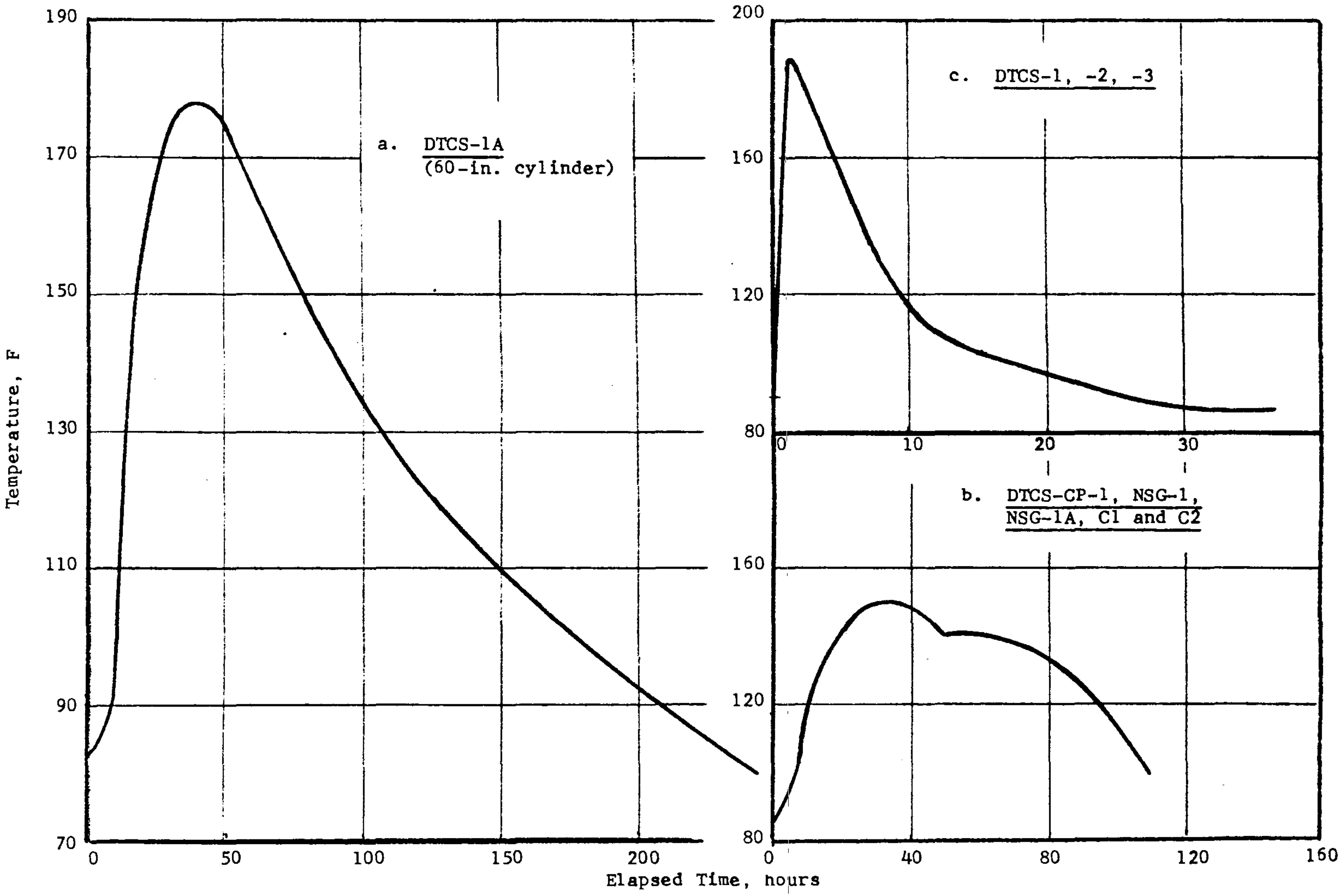

Figure 3.2 Temperature Rise (DTCS-1A) and Curing History Curves for DIESEL TRAIN Grout Mixtures and Naturalite Aggregate Grout and Concrete Mixtures

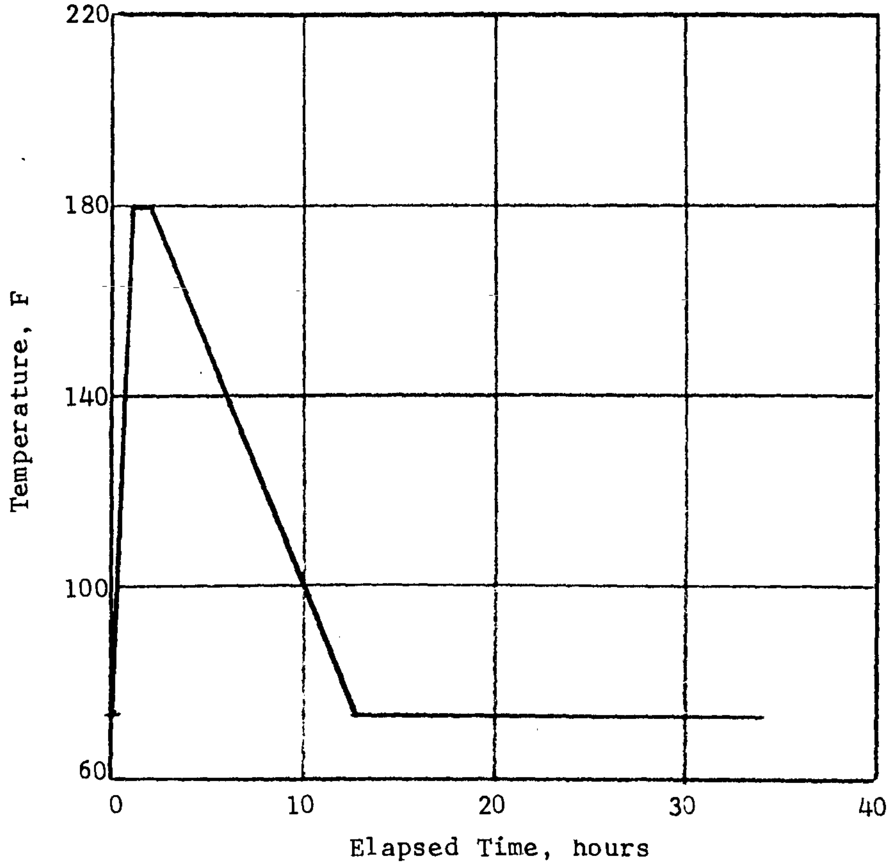

Figure 3.3 Curing Temperature History for Grout Mixture HMHS-1

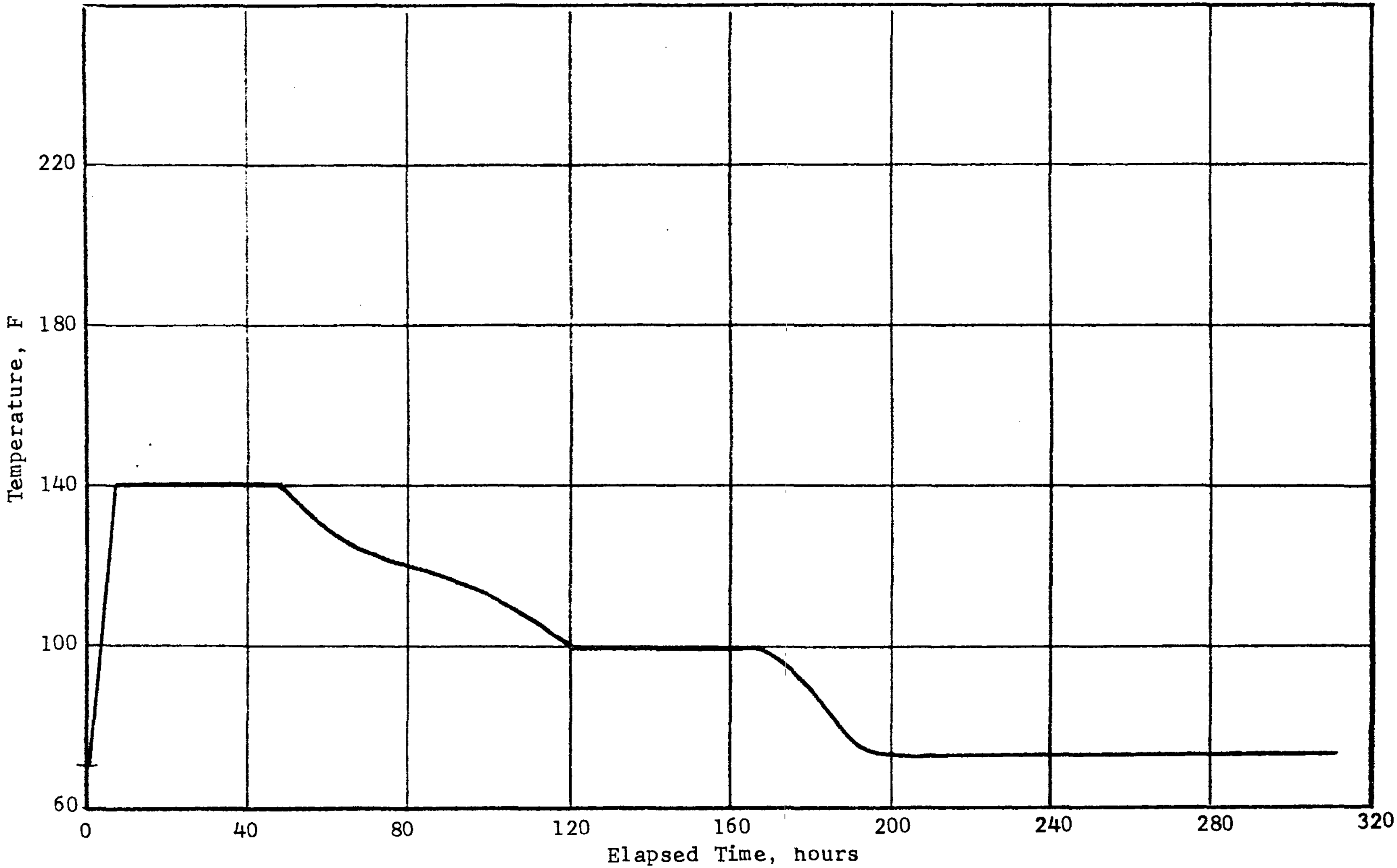

Figure 3.4 Curing Temperature History for Concrete Mixture CAM4

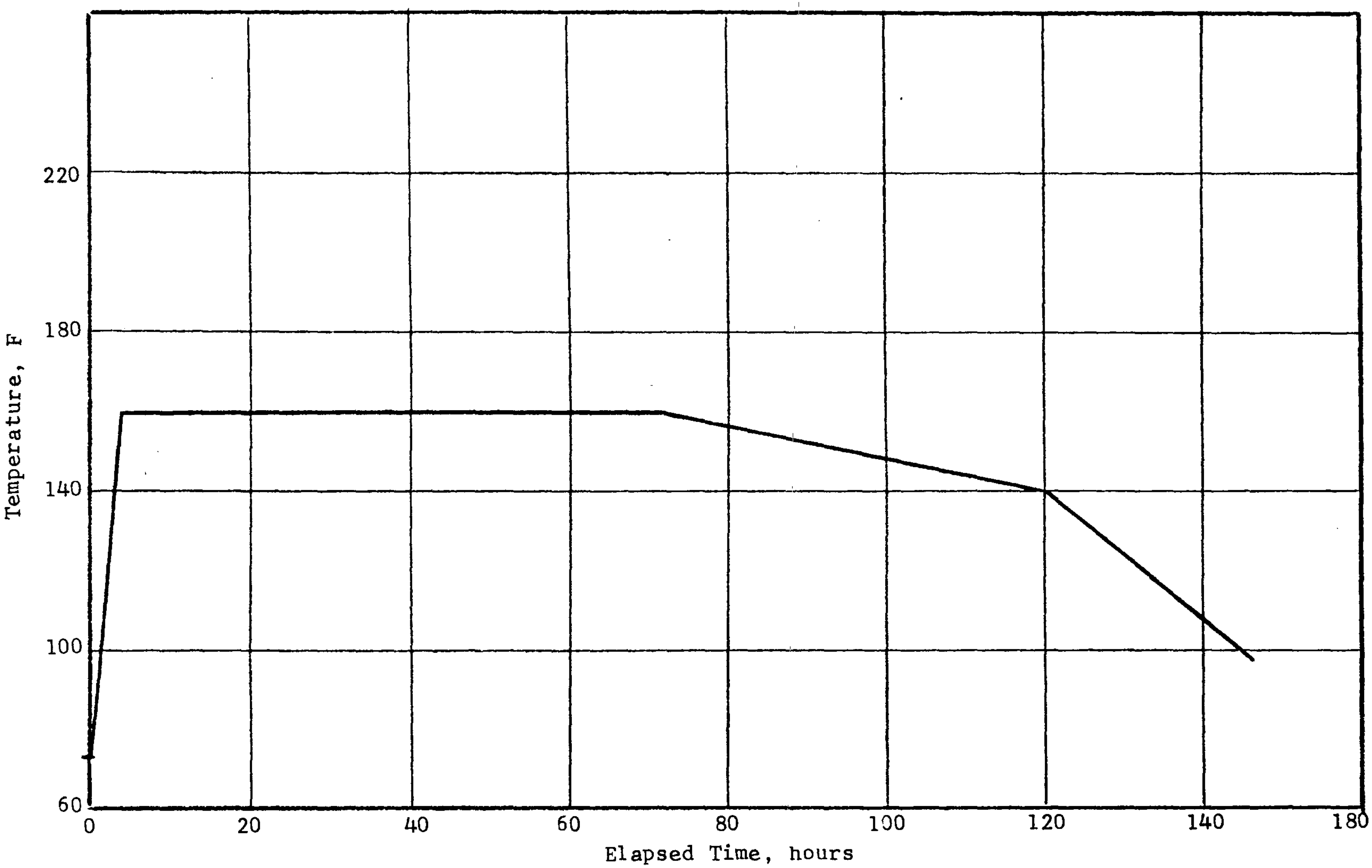

Figure 3.5 Curing Temperature History for Concrete Mixture MLEH-1

NOTE: Reading points are 3-in. from cube edge and on 6-in. centers.

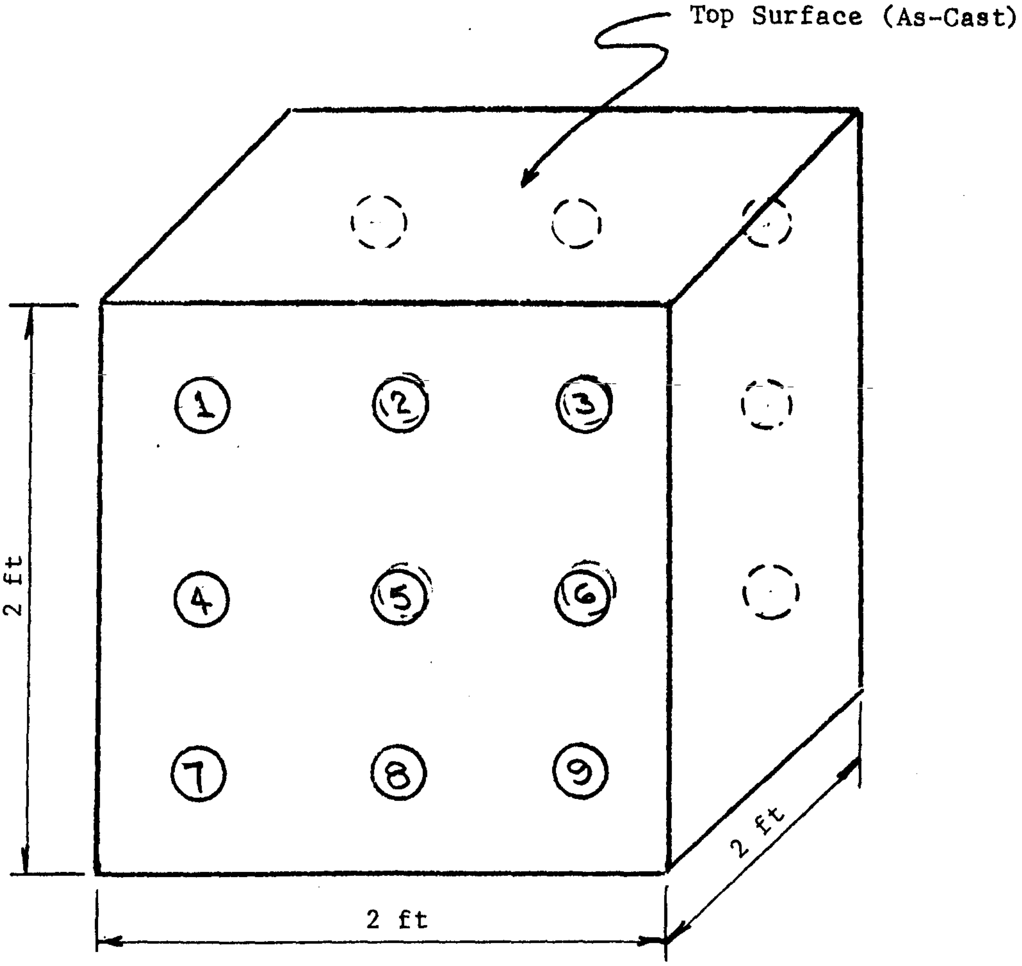

Figure 3.6 Location of Ultrasonic Pulse Velocity Reading Points on DIAMOND DUST Grout Cubes

CHAPTER 4

TEST RESULTS

4.1 TEMPERATURE-RISE TESTS

The results of the temperature development in the 2-ft cubes of the DIAMOND DUST grout mixtures and the 30- by 60-in. cylinder of mixture DTCS-1A are shown in Figs. 3.1 and 3.2, respectively. Peak temperatures and their times of occurrence after batching are as follows.

Mixture Designation	Cement Content, bg/cu yd	W/C Ratio, by Wt	Peak Temp, F	Time of Occurrence, hr
DDCPPII	8	0.59	156	26
DDCPPIIA	6	0.60	135	29
DDCPPIIB	5	0.52	123	32
DDCPPIII	6.2	0.63	159	25
DDCCG-1	9.1	1.00	148	20
DTCS-1A	7.2	0.80	178	41

The varying mixture proportions (Table 2.1) and ingredients make comparisons of the temperature data difficult. It can be noted, however, that DDCPPII and DDCPPIIA are comparable mixtures with the cement content being the major variable. A reduction of cement content of 2 bags/yard produced a decrease in peak temperature of 21 F and an increase in occurrence time of 3 hours. This can be considered to be normal behavior.

Mixtures DDCPPIIA and DDCPPIII can also be considered as comparable mixtures with the cement type being the major difference. The type II cement mixture (DDCPPIIA) produced lower temperatures (135 F) than the 159 F of the type III cement mixture (DDCPPIII). All other things being considered equal, the increase in temperature is probably due to increase in the fineness of type III cement over that of type II cement. With more cement surface area available in finer cements, more initial hydration products are formed with the subsequent liberation of more hydration heat, and hence higher peak temperatures at earlier ages.

4.2 EXPANSION TEST RESULTS

The length change observed in test bars of expansive cement grouts and concretes depends, in general, on the thermal effects, internal chemistry of the materials, and the degree of restraint imposed on the specimens. The numerical description of the length change is also a function of the initial length determination which, in turn, is determined by the thermal state and chemistry effects at the time of initial measurement.

All of the grout and concrete mixtures in this report had some or all of their expansion bars cured at temperatures other than 73 F which is considered to be a control temperature for laboratory measurements. The actual test data are shown in Figs. 4.1 to 4.11. Concrete mixture MLEH-1 does not have its data depicted graphically but experienced bar length changes of +0.006 and -0.004 percent at 3 and 7 days age, respectively, when the bars were cured underwater and in accordance with the curing temperature history shown in Fig. 3.5.

4.2.1 Thermal Effects. The test bars for the grouts and concretes (Section 3.2.1) have small mass to area ratios. The initial chemical reactions occurring in the mass are such that no large initial exotherms result. From these conditions, it is reasonable to assume that internal heat development is probably dissipated shortly after its occurrence and that the effect on length change due to internal heat is negligible. This may not be the case when mass to area ratios are large.

The effects of external heat are somewhat different, however. External heat affects the length change of the bars both thermally and by causing the chemical reactions in the bars to proceed at different rates than they normally do. The effects of initial curing at elevated temperatures as great as 189 F (Fig. 3.2) for grout mixtures DTCS-1, 2, and 3 can be seen in Figs. 4.1 to 4.4. When the ambient temperature decreases, the length of the bars also decrease. Similar results can be seen in Figs. 4.5 to 4.9 for the remaining grout and concrete mixtures. The increased temperature effect on bar length can perhaps be more easily seen by observing the somewhat uniform difference in total bar length over an extended period of time for the 28-degree constant difference in storage temperature for some bars from DTCS-1, 2, and 3 (Figs. 4.1, 4.2, and 4.3). It can also be seen in Fig. 4.4 where the same bar was measured at both elevated temperatures and at 73 F. The expansion (or shrinkage) caused by external temperature changes depends both on the composition of the mixture and on its moisture condition at the time of temperature change. The thermal expansion of concrete or grout varies only a little with the proportion of aggregate present, but varies considerably with the type of aggregate used. The chemical composition and fineness of the cement affect the thermal expansion only insofar as they influence the properties of the cement gel at early ages. The moisture condition of the grout or concrete influences thermal expansion by producing the least amount of length change per degree of temperature change for a given mixture when the moisture content of the grout or concrete is at zero or 100 percent. At all humidities between these values, the length change tends to be greater with a maximum occurring between 50 and 70 percent humidity. The presence of normal amounts of air voids is not a factor. For large structures, where considerable restraint in movement exists, the total expansion per degree temperature increase will be reduced.

4.2.2 Restraint. The effect of either internal or external restraint is to reduce expansion of materials undergoing that phenomenon. This can be seen for the length change bars of grout mixtures DDCPPII and DDCPPIII (Fig. 4.8) and concrete mixture C1 (Fig. 4.9). Mixture CAM4 also had restrained expansion measurements made (Fig. 4.10) but did not have unrestrained bars evaluated. The percent expansion reduction due to the restraint imposed by the internal bar and end plates of the test specimens appears to be of a uniform amount for the entire period of observation. Expansions observed for the unrestrained test specimens (Fig. 4.1 to 4.9) of this report should be considered as limiting values. The actual expansions in large-section prototypes made with the same mixtures may not experience the same expansions, but instead expand less because of internal restraints and the restraints and constants imposed by adjoining surfaces.

4.2.3 Curing Conditions. The effects of curing temperature were discussed in Section 4.2.1. In addition, however, it should be noted that evidence exists that at temperatures of 180 F or greater, the formation of the expansion-producing ettringite ceases and hence cannot contribute further to the overall expansion of a test specimen.

The moisture condition during curing of grout or concrete made with any type of cement directly affects the volume stability of the material. It is especially critical when expansive cements are used. Most of the specimens from the mixtures discussed previously were cured underwater and hence had a continual supply of free water available for the process of forming expansion products. ~~All of these specimens~~ (Figs. 4.1 to 4.10) appear to have positive expansion at early ages. Some of the results, as in Figs. 4.5 and 4.10, are somewhat clouded by the large influence of temperature and the thermal expansions present.

In some instances, the expansion bars were cured in plastic bags (Figs. 4.1 to 4.3) or in plastic jars containing water which was not in direct contact with the specimens (Fig. 4.4). The plastic bags containing the expansion bars were kept at relative humidities between 90 to 95 percent in an attempt to prevent any appreciable amount of moisture from escaping from the bags. The exact humidity inside the bags was not known. The data shown in Figs. 4.1, 4.2, and 4.3 indicate that, while some positive expansion occurred during the first 2 days, the specimens then began to decrease in length. At 5 days age, they had returned to their originally measured length and then continued to get shorter with increasing age.

This phenomenon is most likely the result of internal self-desiccation of the cement as it uses up its free water during hydration with no direct moisture replacements. In the case of the bars stored over water (Fig. 4.4), however, expansion is apparently continuing even though the bar is not in direct contact with the water. The humidity in the jars containing the specimens is, for all practical purposes, 100 percent. It is from this condition that the test specimens can draw the extra moisture needed to sustain the expansion-producing phenomenon. It is not known if the effects of the availability of water as witnessed for the small expansion bar specimens will produce similar behavior in large mass sections where the time of moisture transfer to the inner regions of the mass may be quite long.

4.2.4 Expansion Determinations. The formation of the expansion-producing compounds in the cement begins immediately upon the addition of the mixing water. Until the mixture has stiffened sufficiently to produce a structure upon which the additional formation of ettringite can push and cause expansion, the mixture will not expand and will decrease in volume, particularly if it is a bleeding mixture. A typical shape for a length change versus time curve for a sanded grout mixture probably resembles that shown in Fig. 4.12.

The expansion of the test bar is expressed as the percent increase of the initially measured length of the bar. Depending on the time after mixing when the initial length measurement is made, various values of percent expansion can be obtained for the same bar. All of the mixtures with expansion bars had the initial bar length measurements made 24 hours after mixing with the exceptions of mixtures DDCPPII and DDCPPIII (Fig. 4.8) and mixture CAM4 (Fig. 4.10) which had the initial measurements made at 18 and 20 hours age, respectively. The age of the bars when the initial measurement is made is principally dictated by the time at which the bars can be demolded and handled without damaging them and also by the convenience of a daytime work shift. Most of the mixtures described in this report have stiffened sufficiently in the first 10 hours after mixing so that positive expansion can begin. The delayed time of initial measurement of 18 to 24 hours means the values for expansion shown in Figs. 4.1 to 4.11 are, for the most part, somewhat ~~lower than the actual total expansion~~ of each mixture.

4.2.5 Expansive Cement Content. The only mixtures which can be compared for the effect of expansive cement concrete are grout mixtures DTCS-1, 2, and 3. Their results are shown in Fig. 4.11. As might be expected, increasing amounts of expansive cement resulted in increased expansions. The amounts of the increases are not significant, however, being generally less than 0.01 percent for an increase in expansive cement content from 0.3 to 0.7 lb/cu ft of grout. Care must be exercised when increasing the expansive cement content as excessive expansions will have detrimental effects on the overall integrity of the hardened material.

4.3 STRENGTH TEST RESULTS

4.3.1 Compressive Strength. Because of the variability in mixture ingredients and proportions, curing conditions, age of test, and specimen size between all of the grout and concrete mixtures, no comparisons of strength data were made. A summary of all the test results is shown in Table 4.1, however.

4.3.2 Flexural Strength. The flexural strength testing produced the following results:

Mixture Designation	DDCPPII	DDCPPIIB	DDCPPIII
Number of Specimens	2	1	2
Modulus of Rupture (Avg), psi			
4 days	425	-	390
7 days	455	560	400

The flexural strength to cube strength ratios at 7 days age for DDCPPII, DDCPPIIB, and DDCPPIII were 0.121, 0.142, and 0.116, respectively. These ratios are comparable to those of standard grouts.

4.3.3 Tensile Splitting Strength. Two cylinders from grout mixture HMHS-1 were tested at both 7 and 28 days age. The average splitting strengths at these ages were 370 and 375 psi, respectively. The splitting strength to cube compressive strength at 7 days age was 0.101. This ratio is comparable to those of standard grouts.

4.3.4 Shear Strength. The single plane shear testing produced the following results:

Mixture Designation	DDCPPII	DDCPPIII	HMHS-1
Number of Specimens	3	3	2
Shear Strength (Avg), psi			
4 days	525	465	-
7 days	565	495	570
28 days	-	-	715

The ratios of shear strength to cube compressive strength at 7 days age for DDCPPII, DDCPPIII, and HMHS-1 were 0.15, 0.143, and 0.155, respectively. These values are comparable to those of standard grouts.

4.3.5 Bond Strength.

The bond strength for grout mixture DDCPPIIA as measured on one specimen at 7 days age was 120 psi. The average bond strengths for concrete mixture MLEH-1 as measured on three specimens at both 3 and 7 days age were 670 and 900 psi, respectively. The ratios of bond strength to cube compressive strength for DDCPPIIA and MLEH-1 at 7 days age were 0.046 and 0.135, respectively.

4.4 MODULUS OF ELASTICITY TEST RESULTS

For the same reasons described in Section 4.3.1, no comparisons of modulus of elasticity test results were made. A summary of the test results is shown in Table 4.2, however. The values obtained for both static and dynamic modulus appear to be reasonable and within the range of values observed for normal grouts and concretes, with the dynamic modulus being generally 20 to 30 percent greater than the static modulus.

4.5 ULTRASONIC PULSE VELOCITY TEST RESULTS

A summary of the ultrasonic pulse velocity data is shown in Table 4.3. The average pulse velocity for each 2-ft cube is given; however, some comment on the distribution of the velocities is also needed. In all cubes, the lowest velocities were obtained for the top third of the cube (readings 1, 2, and 3 of Fig. 3.6), and the highest velocities were measured in the bottom third (readings 7, 8, and 9). The difference between the average for the cube and the average for the set of readings in both the top and bottom third of the cube was, in general, between 100 and 150 fps for cubes made of mixtures DDCPPII, DDCPPIIA, and DDCPPIIB. The differences for mixture DDCPPII were approximately 300 fps. This increase in pulse velocity with increasing depth into the cube is probably indicative of small increases in density, i.e., concentration of solids per unit volume with depth of specimen. The density increase is not an unusual phenomenon in large sections of pumpable grouts. No measurements of density in the hardened cube were made.

4.6 CONSTRAINED STRESS TEST RESULTS

The results of the constrained stress measurements made for grout mixture DDCPPII are shown in Table 4.4. The reduction of stress after 2 days is due, for the most part, to the reduction of some of the thermal expansion that resulted from the heat generated during early hydration. With time, this heat is lost through the walls of the container. Upon cooling, the grout mass contracted and reduced the amount of strain in the metal, which is used to calculate the stress in the grout.

4.7 SLUMP LOSS TEST RESULTS

A summary of the slump loss test results is shown in Table 4.5. Grout mixture DDCPPIIB, which contained a water-reducing admixture (WRA) but no retarder, experienced a 1-in. slump loss after 1 hour of continuous mixing. Concrete mixture C1 contained both a WRA and a retarder but experienced substantial slump loss with time. It had a high cement content (10.2 bags/yd) and an extended rest:mix cycle of 30:2. Mixture CAM4 contained one admixture that acted as both a WRA and retarder and with a rest:mix cycle of 4:1 and lower cement content (5.7 bags/cu yd) did not experience the same amounts of slump loss as did mixture C1. Mixtures CCC4, CCC5, and

DDC-1 contained only retarders in the quantities of 6, 6, and 7.1 fl oz/ bag of cement. With a rest:mix cycle of 3:2, the CCC4 and CCC5 mixtures experienced relatively small slump losses with time, while DDC-1, with a rest:mix cycle of 30:2, experienced a 3-in. loss in 1 hour time. Ignoring differences in mixture ingredients, mixture DDC-1, with a higher retarder dosage and somewhat lower cement content, intuitively might have been expected to experience the same amount or less slump loss than mixtures CCC4 and CCC5. Principal differences exist in the type of coarse aggregate and the rest:mix cycles, however; and it is probable that both of these factors did affect slump loss.

4.8 FLOW DETERMINATION TEST RESULTS

The efflux times for grout mixtures DTCS-1A, HMHS-1, NSG-1, and NSG-1A were 13.9, 12.6, 16.0, and 14.0 seconds, respectively. These flow times indicate grout consistencies excellent for pumpability. All of the mixtures except HMHS-1 contained a friction-reducing admixture (AD-420) in the quantities of 0.3, 0.66, and 0.3 lb/bag of cement for mixtures DTCS-1A, NSG-1, and NSG-1A, respectively. Mixture HMHS-1 contained no admixtures of any kind.

Table 4.1

Summary of Compressive Strength Test Results

Mixture Designation	Curing Temperature History	Specimen Size, in.	No. of Specimens	Average Compressive Strength, lb/sq in. Age, Days								
				3	4	5	7	10	14	28	56	84
Grouts												
DDCPPII	See fig. 3.1	2-in. cube	3	-	3080	-	3770	-	-	-	-	-
DDCPPIIA	See fig. 3.1	2-in. cube	3	1685	-	-	2585	-	-	-	-	-
DDCPPIIB	See fig. 3.1	2-in. cube	3	2720	-	-	3930	-	-	-	-	-
		4x8 core	2	-	-	-	-	3670	-	-	-	-
DDCPPIII	See fig. 3.1	2-in. cube	3	-	2860	-	3460	-	-	-	-	-
DDCCG 1	See fig. 3.1	2-in. cube	3	-	-	-	1265	-	-	-	-	-
		4x8 core	4	-	-	-	1030	-	-	-	-	-
DTCS-1	See fig. 3.2	2-in. cube	2	-	-	3610	3980	-	-	4200	4170	-
DTCS-1A	See footnote 1	2-in. cube	3	-	-	2430	2690	-	-	-	-	-
	See fig. 3.2	2-in. cube	3	-	1960	-	2340	-	-	2620	-	-
DTCS-2	See fig. 3.2	2-in. cube	2	-	-	3760	4090	-	-	4420	-	-
DTCS-3	See fig. 3.2	2-in. cube	2	-	-	3340	3720	-	-	4030	-	-
	See footnote 6	2-in. cube	2	-	-	-	4310	-	-	4715	-	-
	100°F, 20%RH	2-in. cube	2	-	-	-	2740	-	-	4390	-	-
DTCS-CP-1	See fig. 3.2	2-in. cube	3	4710	-	-	5320	-	-	6510	-	-
HMHS-1	See fig. 3.3	2-in. cube	2	-	-	-	3670	-	-	4600	-	-
NSG-1	See fig. 3.2	2-in. cube	3	3900	-	-	3970[2]	3980[2]	4070	5780	6645	-
NSG-1A	See fig. 3.2	2-in. cube	3	1820	-	-	2690	2890	2970	3180	3280	-
Concretes												
C1	See fig. 3.2	3x6 cyl	2	-	-	-	7000	-	-	7155	7430	7920
C2	See fig. 3.2	3x6 cyl	3	-	-	-	4740	-	-	4870	4960	5420
DDC-1	See footnote 3	3x6 cyl	3	1420[4]	-	-	2400	-	-	2860	-	-
	See footnote 5	3x6 cyl	3	1280	-	-	1610	-	-	2115	-	-
CAM4	See fig. 3.4	3x6 cyl	2	-	-	-	3940	-	-	4490	-	-
	73°F, 100 RH	3x6 cyl	4	-	-	-	3370	-	-	4540	-	-
MLEH-1	See fig. 3.5	6x12 cyl	3	5800	-	-	6650	-	-	-	-	-

---

[1] Cured at 180 F for 4 days, then 150 F, 140 F, and 130 F for the next 3 days respectively. Relative humidity was 100%.

[2] Average of two specimen tests.

[3] Cured at 150 F for 2 days, then 100 F for 12 days and at 75 F for the remainder of the time.

[4] Two days age.

[5] Cured underwater at 100 F for 12 days and at 75 F for the remainder of the time.

[6] Cured underwater at 190 F for 1 day, then 180 F for 3 days, then 160 F for 2 days, and then 130 F for the remainder of the time.

Table 4.2

Summary of the Static and Dynamic Modulus of Elasticity Test Results

Mixture Designation	Curing Temperature History	Age, Days	Static Modulus of Elasticity Specimen Size in.	Static Modulus of Elasticity No. of Specimens	Static Modulus of Elasticity Avg E, psi	Dynamic Modulus of Elasticity Specimen Size in.	Dynamic Modulus of Elasticity No. of Specimens	Dynamic Modulus of Elasticity Avg E, psi
Grouts								
DDCPPII	See fig. 3.1	4	3x6 cylinder	3	2.01	3½x4½x16 beam	4	2.60
		7		3	2.34		2	2.85
DDCPPIIA	See fig. 3.1	7		-	-	3½x4½x16 beam	3	3.08
		10	4x8 core	2	2.37	-	-	-
DDCPPIIB	See fig. 3.1	7		-	-	3½x4½x16 beam	3	4.61
		10	4x8 core	2	3.51	4x8 core	2	4.35
		18		-	-	3x6 cylinder	2	3.64[1]
DDCPPIII	See fig. 3.1	4	3x6 cylinder	3	1.95	3½x4½x16 beam	4	2.39
		7		3	1.99		2	2.61
DTCS-1	See fig. 3.2	5	3x6 cylinder	2	1.90	-	-	-
		7		2	2.39	-	-	-
		28		2	2.29	-	-	-
DTCS-1A	See fig. 3.2	4	3x6 cylinder	2	1.40	-	-	-
		7		2	1.70	-	-	-
		28		2	2.11	-	-	-
DTCS-2	See fig. 3.2	5	3x6 cylinder	2	2.04	-	-	-
		7		2	2.32	-	-	-
		28		2	2.48	-	-	-

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[1] Drop tower technique used to determine E

(Continued)

(Sheet 1 of 2)

Table 4.2 (Concluded)

Mixture Designation	Curing Temperature History	Age, Days	Static Modulus of Elasticity Specimen Size in.	Static Modulus of Elasticity No. of Specimens	Static Modulus of Elasticity Avg E, psi	Dynamic Modulus of Elasticity Specimen Size in.	Dynamic Modulus of Elasticity No. of Specimens	Dynamic Modulus of Elasticity Avg E, psi
DTCS-3	See fig. 3.2	5	3x6 cylinder	2	2.04	-	-	-
		7		2	2.21	-	-	-
		28		2	2.47	-	-	-
NSG-1	See fig. 3.2	3	3x6 cylinder	3	1.98	3½x4½x16 beam	3	2.51
		7		3	2.30		3	2.74
		10		3	2.48		3	2.80
		14		3	2.48		3	2.85
		28		3	2.50		3	2.90
		56		3	2.53		3	2.99
NSG-1A	See fig. 3.2	3	3x6 cylinder	3	1.00	3½x4½x16 beam	3	1.78
		7		3	1.52		3	2.06
		10		3	1.54		3	2.10
		14		3	1.56		3	2.18
		28		3	1.72		3	2.21
		56		3	1.87		3	2.27
<u>Concrete</u>								
C1	See fig. 3.2	7	3x6 cylinder	2	3.17	3x3x11 beam	2	3.59
		28		2	3.26		2	3.71
		56		2	3.30		2	3.86
		84		2	3.36		2	3.92

(Sheet 2 of 2)

Table 4.3

Summary of Ultrasonic Pulse Velocity Data

Mixture Designation	Age, Days	Specimen Size	No. of Specimens or Reading	Ultrasonic Pulse Velocity, fps		
				Range	Average	Standard Deviation
Grouts						
DDCPPII	7	2 ft cube	9, see fig. 3.6	10,810 to 11,110	10,960	100
DDCPPIIA	7	2 ft cube	9, see fig. 3.6	10,640 to 10,990	10,800	115
DDCPPIIB	7	2 ft cube	9, see fig. 3.6	12,270 to 12,500	12,440	115
DDCPPIII	7	2 ft cube	9, see fig. 3.6	10,810 to 11,430	11,080	225
Concrete						
MLEH-1	3	6- by 12-in. cylinder	1	-	14,395	-
	7	6- by 12-in. cylinder	1	-	14,130	-

Table 4.4

Stress Exerted by Grout Mixture DDCPPII

Age	Circumferential Strain in Metal μin./in.	Circumferential Stress in Metal psi	Internal Grout Stress, psi
2 hr	6	192	2
18 hr	69	2206	27
1 day	82	2622	33
2 days	130	4156	52
4 days	96	3056	38
~~5 days~~	~~93~~	~~2973~~	37
6 days	87	2731	35

Table 4.5

Summary of Slump Loss Determinations

Mixture Designation	Rest:Mix Cycle After Initial Mixing min:min	Slump, inches				
		Initial Slump	30 min Slump	60 min Slump	90 min Slump	120 min Slump
Grouts						
DDCPPIIB	Continuous Mixing	7-1/2	--	6-1/2	--	--
Concretes						
C1	30:2	6-3/4	4-1/2	2-3/8	1-7/8	1-5/8
CCC4	3:2	10	9-3/4	9-1/2	9-1/4	8-1/4
CCC5	3:2	10	9-1/2	8-3/4	8	7
DDC-1	30:2	8-1/2	--	5-1/4	--	--
CAM4	4:1	8-3/4	8	7-1/2	--	--

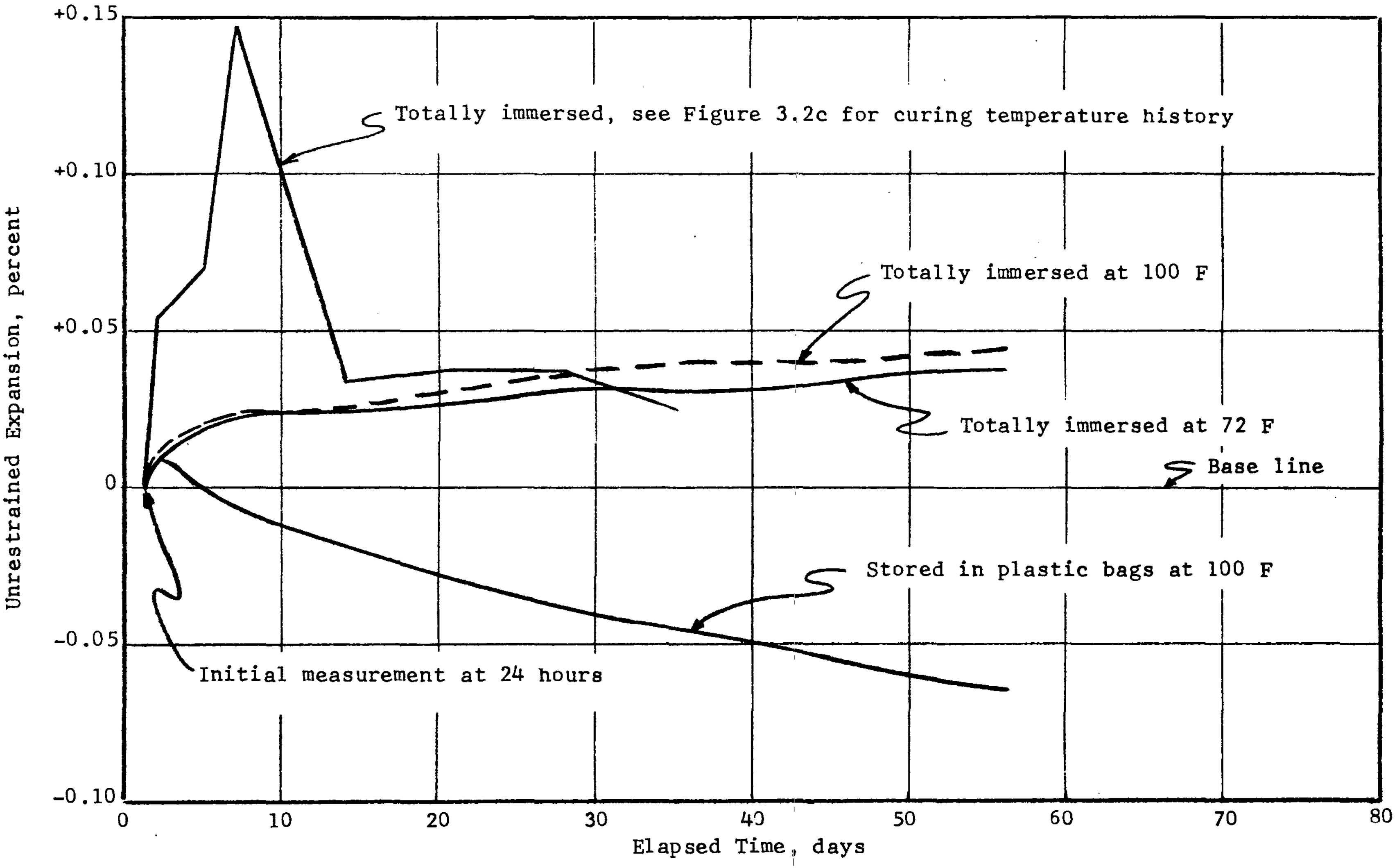


Figure 4.1 Mixture DTCS-1: Unrestrained Expansion Versus Time Relation Showing Effects of Curing Temperature and Available Moisture

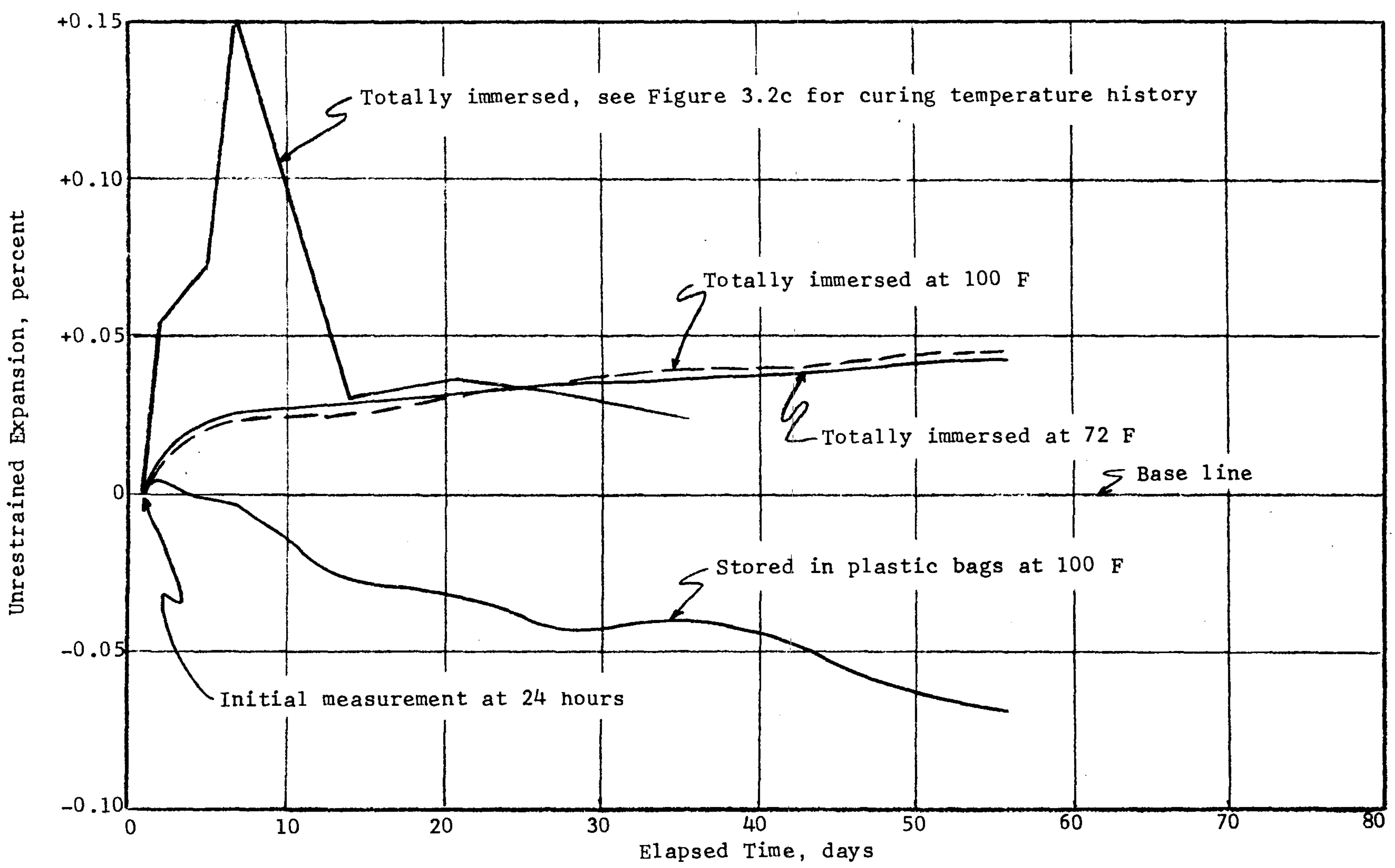


Figure 4.2 Mixture DTCS-2: Unrestrained Expansion Versus Time Relation Showing Effects of Curing Temperature and Available Moisture

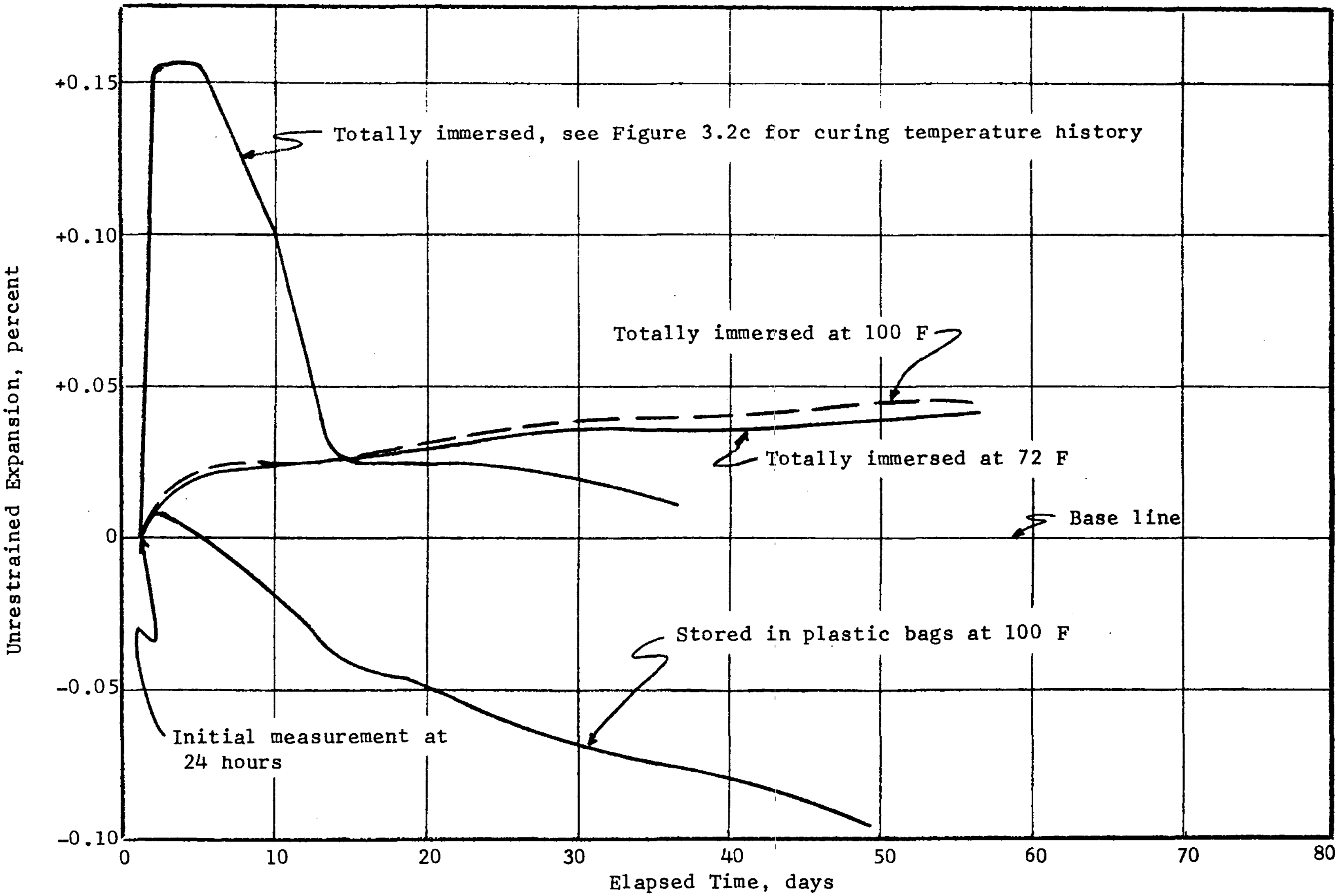
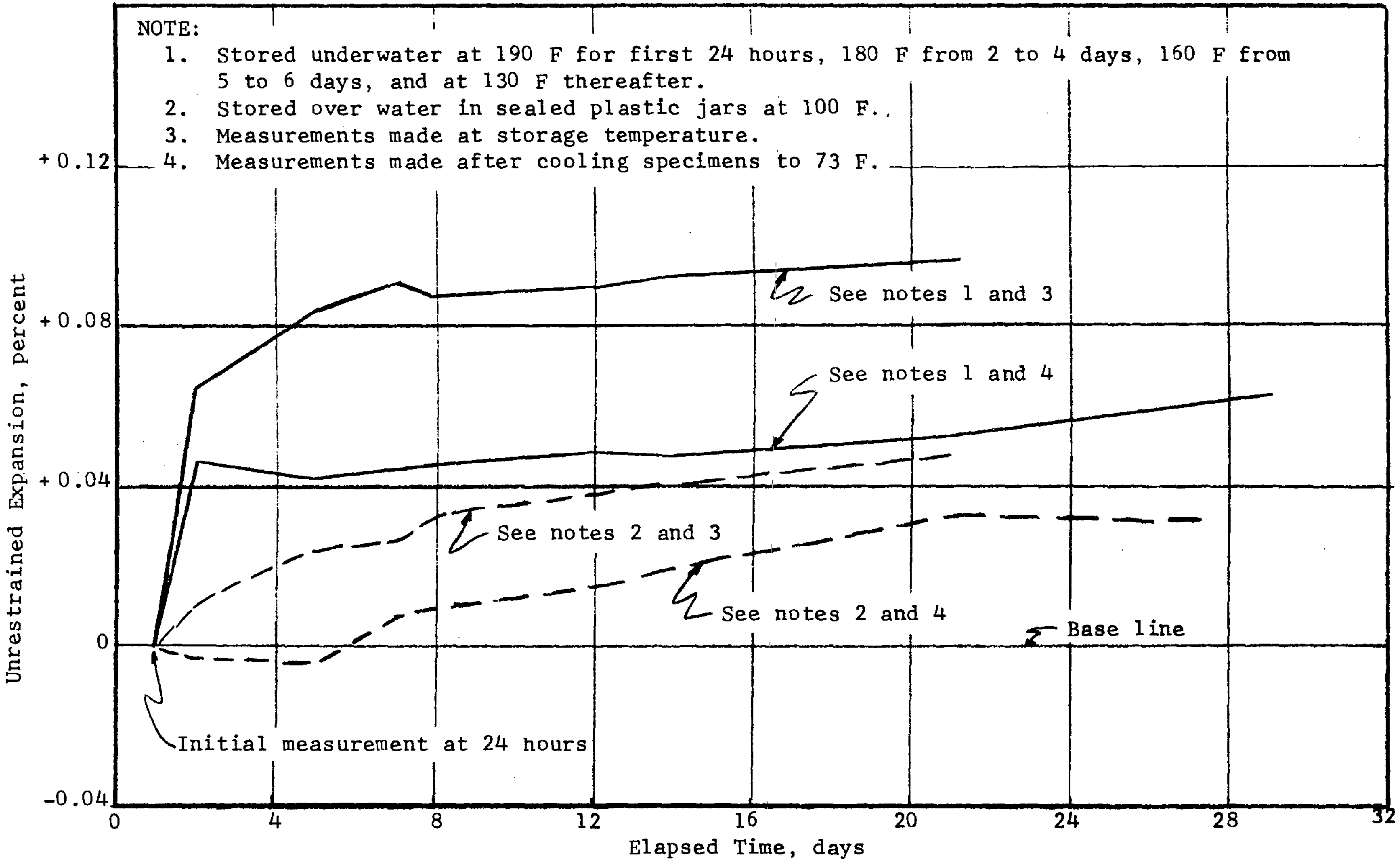


Figure 4.3 Mixture DTCS-3: Unrestrained Expansion Versus Time Relation Showing Effects of Curing Temperature and Available Moisture



NOTE:
1. Stored underwater at 190 F for first 24 hours, 180 F from 2 to 4 days, 160 F from 5 to 6 days, and at 130 F thereafter.
2. Stored over water in sealed plastic jars at 100 F.
3. Measurements made at storage temperature.
4. Measurements made after cooling specimens to 73 F.

Figure 4.4 Mixture DTCS-3: Unrestrained Expansion Versus Time Relation for Various Curing and Reading Temperatures

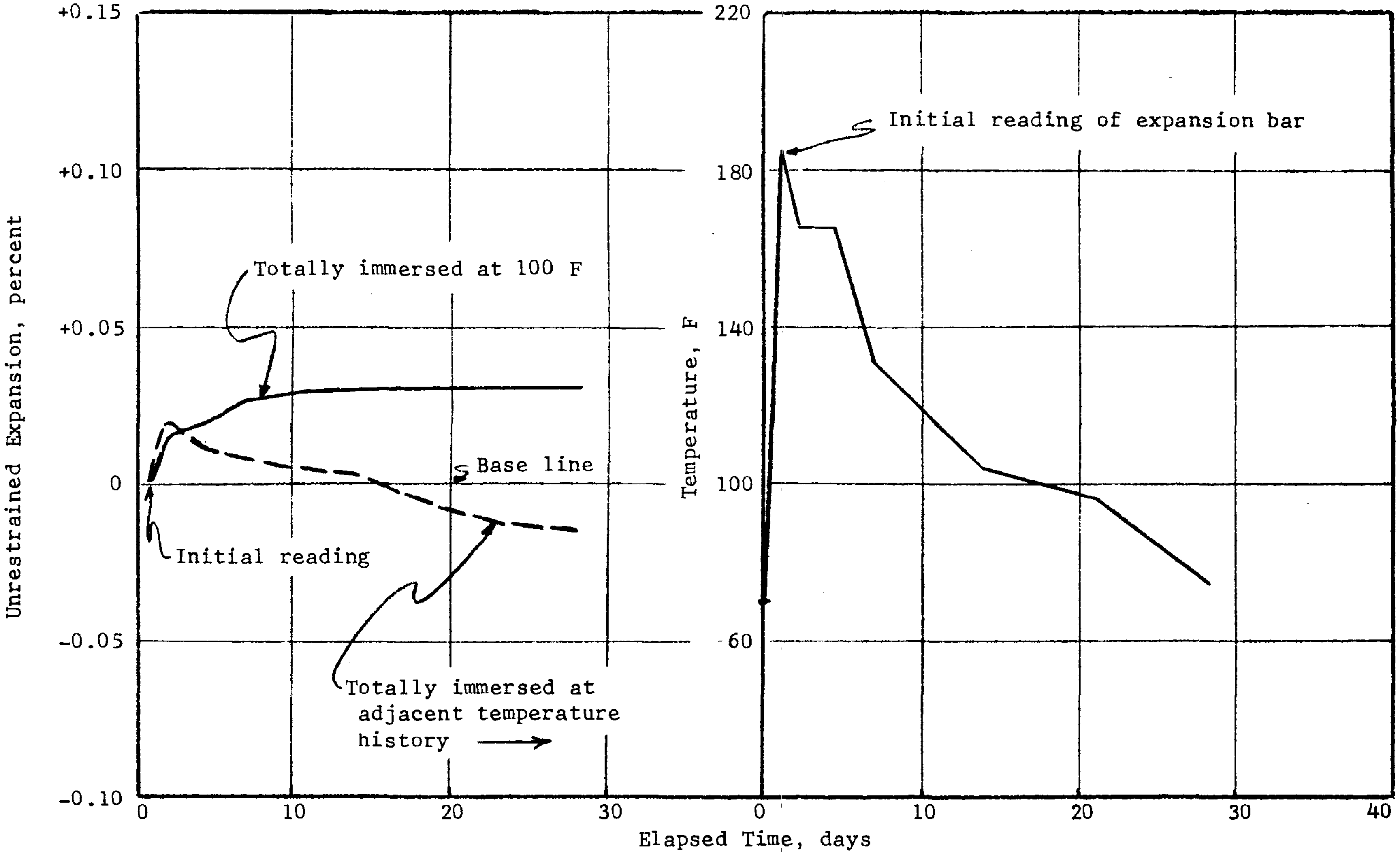


Figure 4.5 Mixture DTCS-1A: Unrestrained Expansion and Curing Temperature History Versus Time Relations

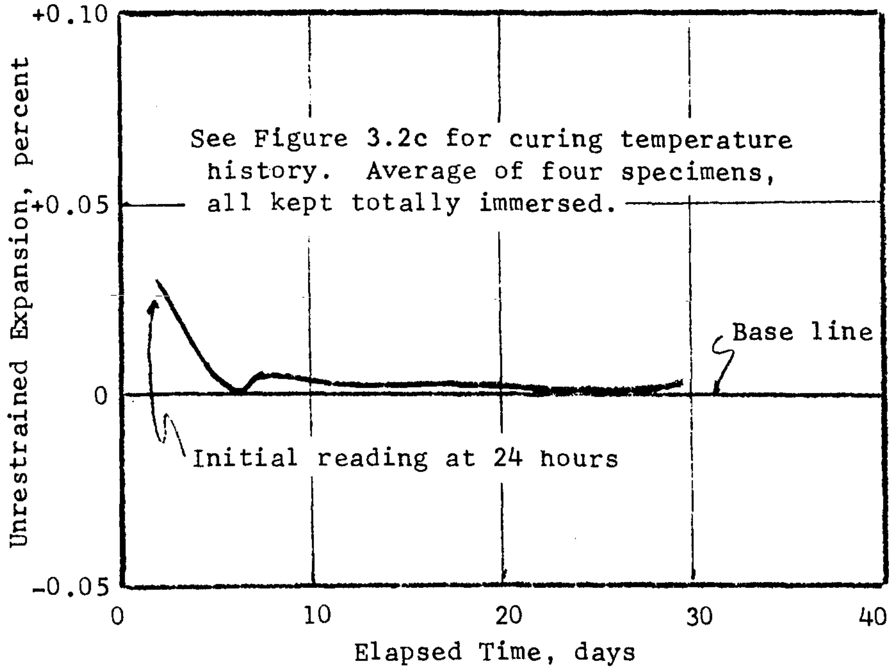


Figure 4.6 Mixture DTCS-CP-1: Unrestrained Expansion Versus Time Relation

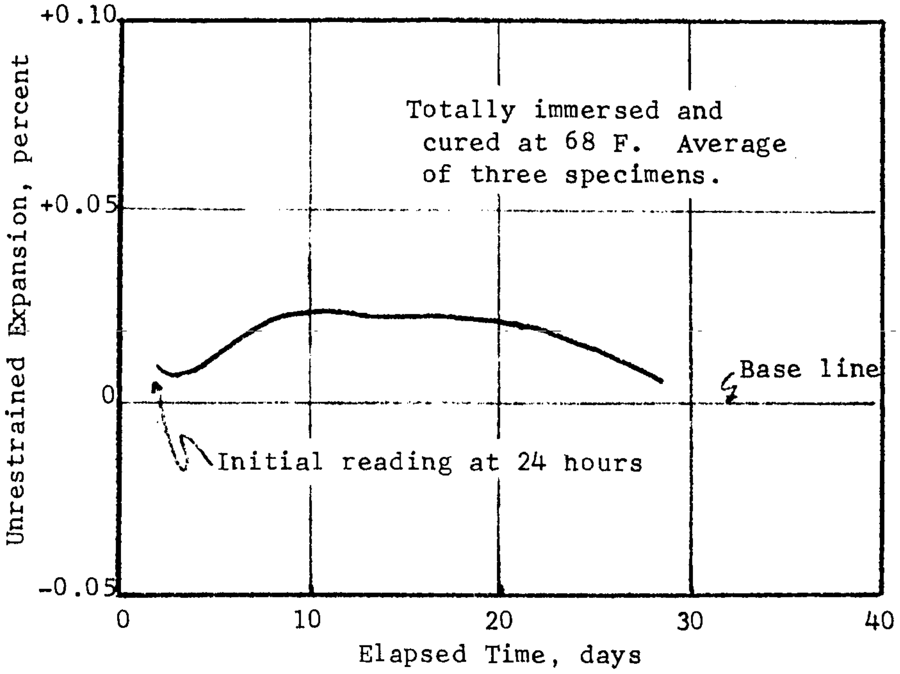
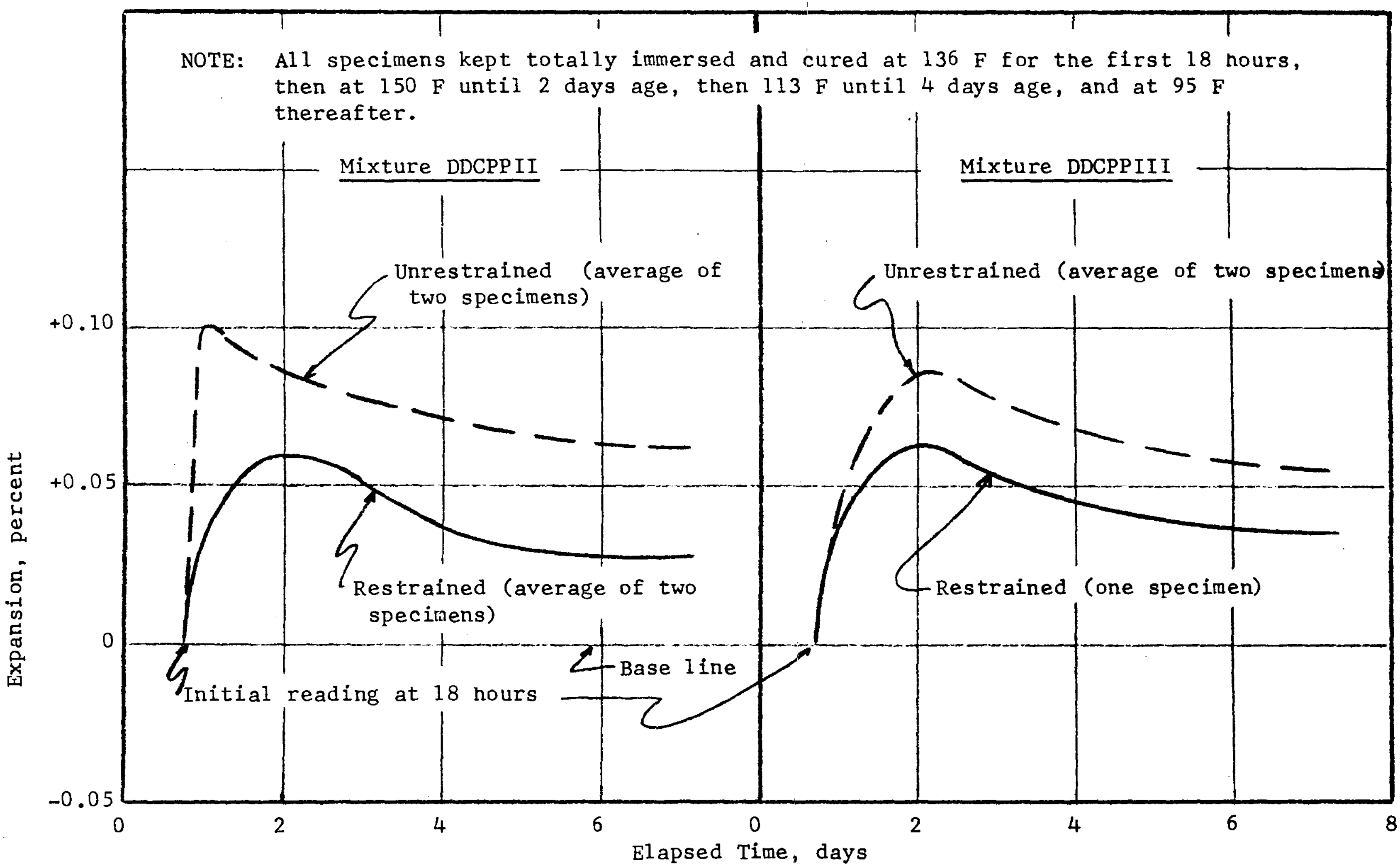
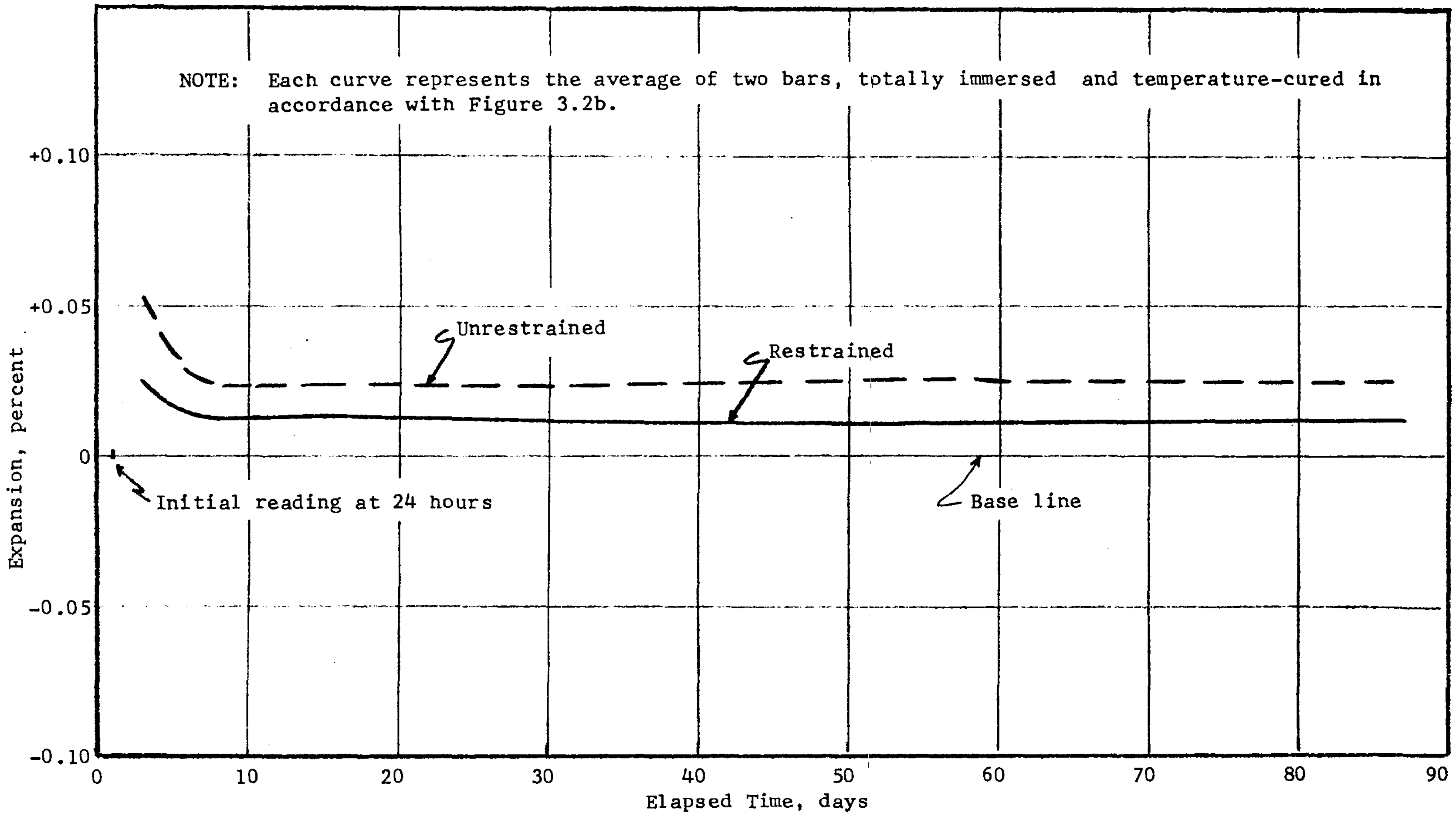


Figure 4.7 Mixture DD-1: Unrestrained Expansion Versus Time Relation



NOTE: All specimens kept totally immersed and cured at 136 F for the first 18 hours, then at 150 F until 2 days age, then 113 F until 4 days age, and at 95 F thereafter.

Figure 4.8 Mixtures DDCPPII and DDCPPIII: Expansion Versus Time Relations Showing Effects of Restraint



NOTE: Each curve represents the average of two bars, totally immersed and temperature-cured in accordance with Figure 3.2b.

Figure 4.9 Mixture C1: Expansion Versus Time Relation Showing Effect of Restraint

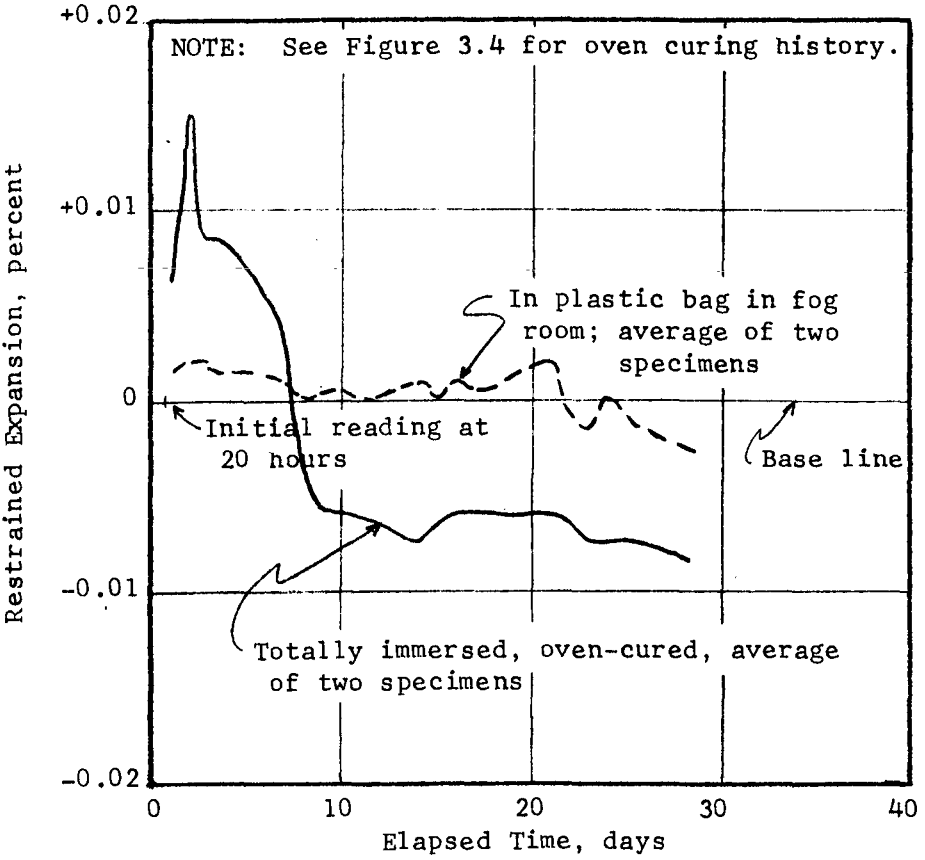


Figure 4.10 Mixture CAM-4: Restrained Expansion Versus Time Relation

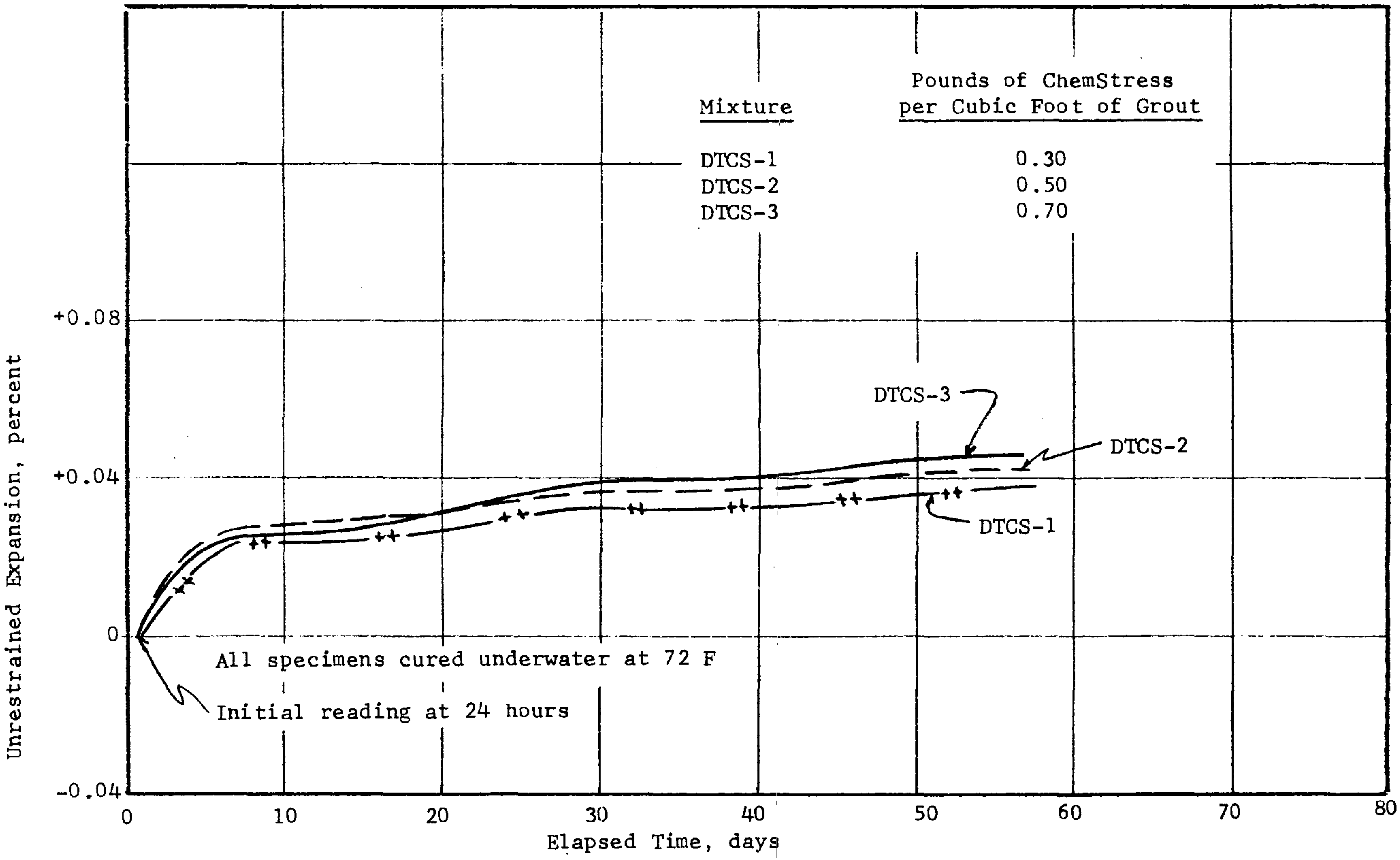


Figure 4.11 Unrestrained Expansion Versus Time Relation for DTCS Grout Mixtures Showing Effect of Expansive Cement Content

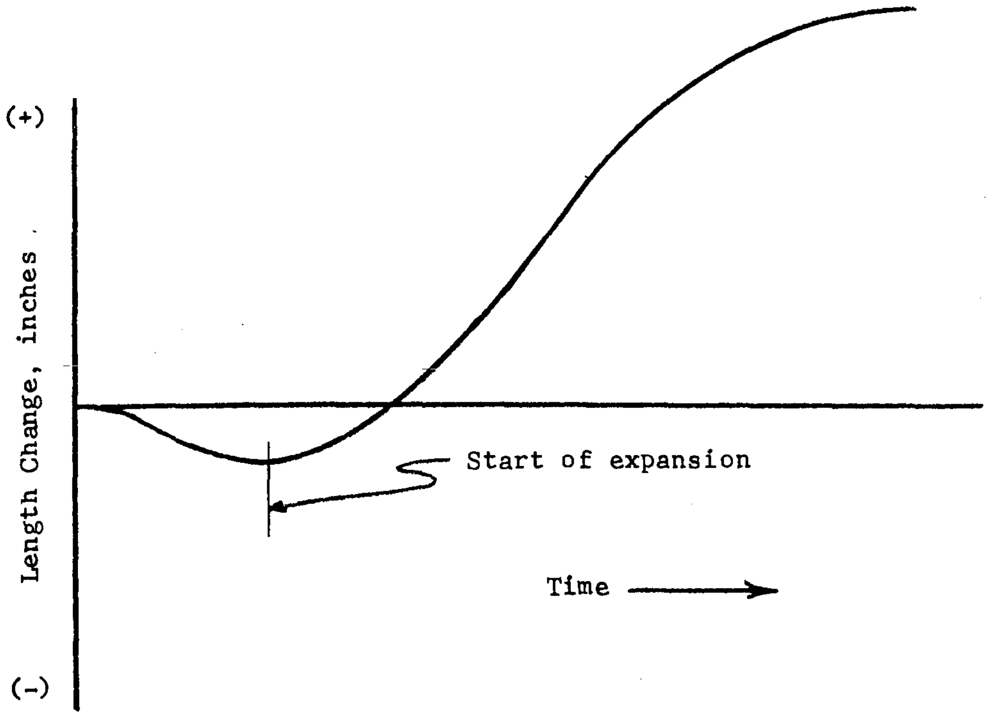


Figure 4.12 Assumed Length Change-Time Relation for an Expansive Cement Grout

APPENDIX A

SPECIAL CONTROL STUDIES

The special control studies were initiated as a pilot to a more exhaustive laboratory research effort into the behavior of expansive cement grouts and concretes. These studies examined: (a) some of the test methods that might be used for determining expansion, (b) the effects of demolding times on expansion bars, (c) the effects of various curing conditions, and (d) the test method used for determining constrained pressure.

A.1 MATERIALS AND MIXTURES

Three basic mixtures were used and were designated SCS-1, -2, and -3. These mixtures contained type K expansive cement (RC-610(2)) in proportions of 20, 10, and 30 percent, respectively, of the cementitious material in the mixture. The various amounts of expansive cement were to provide a range of practical expansions for prototype use. A summary of the materials and mixture proportions is shown in table A.1. Control mixtures were made for all three expansive cement mixtures. These controls were made at the same proportions as the test mixtures, but the expansive cement fraction was replaced by class G oil well cement (RC-616) on a volume basis.

A.2 EXPANSION TESTS AND MEASUREMENTS

One of the more commonly used length change specimens for determining the expansion of mortars or sanded and unsanded grouts is a 2-in.-square bar having a gage length of 10 in. After removing the specimen from its casting mold, an initial length measurement is made using a comparator. The specimen is then subjected to a specified curing with subsequent length measurements being made. Length change is then expressed as a percent of the initial gage length. When using this technique for evaluating mixtures used in prototype sections, the value for length change is qualitative in nature when related to the length or volume changes of the prototypes. The magnitude of the value for length change is dependent on a number of factors. In the case of expansive cement mixtures, the most significant of these factors is the time at which the test specimens are initially measured. Changes in volume (length) begin to occur from the time the water and cement come in contact. When standard bars are made from the mixture, the restraints provided by the casting mold affect the amount and rate of change. The time at which the initial length measurement is made is usually specified when routine mixtures are evaluated. In the case of the mixtures described in the main text of this report, this approach is not feasible because of the wide variation in stiffening rates and hardening times that can result. A standard demolding and length measurement time would produce somewhat misleading results. This can be seen for mixture SCS-1 in fig. A.1. Expansions of bars demolded at 6 hr are shown to be three times those of bars demolded at 18 hr. The true hypothetical expansion for all bars should have been the same, however. Consider the hypothetical expansion-time relation in fig. A.2a. Neglecting any reductions in expansion because of external restraints encountered during hardening, the effect of referencing the expansion to a given point in time can be readily observed in fig. A.2b. In reality, the casting molds restrain the expansion somewhat and may cause the expansion rates immediately after demolding to be somewhat greater than might normally be anticipated.

The length change bars can also be restrained by end plates and a restraining bar as described in section 3.2.1. This restraint occurs both during hardening and after the bars are removed from the casting molds. Comparisons of restrained expansions for mixture SCS-1 and its control and for the unrestrained and restrained bars for mixture SCS-1 can be seen in figs. A.3 and A.4, respectively. The amount of the reduction in expansion as shown in fig. A.4 appears to be fairly constant over a considerable time period. The relevance of the expansions obtained with this type of restraint to the design of prototype sections is not clear. It is a useful, reproducible, acceptance test, especially when high expansions are anticipated. Unrestrained high-expansion specimens tend to expand themselves to pieces. This method does give an indication of field control versus laboratory control and is adaptable to field use. The values for expansion obtained using this procedure need to be related to prototype behavior before they can be effectively used in design.

The expansion of a prototype section results from both chemical and thermal phenomena and is effected to varying degrees by the internal and external restraints it encounters. To better understand the behavior that produces the ultimate size of a prototype section, the volume change history from the time the mixture ingredients are put together until all volume change phenomena have been dissipated should be known. This volume (length) change history cannot be easily obtained from standard expansion bars. To aid in the determination of this history, the test configuration shown in fig. A.5 was developed. The test specimen is a 6-in.-diameter by 14-in.-high cylinder and is contained in a flexible neoprene sleeve. It has 6-in.-diameter by 1/2-in.-thick glass plates on both the top and bottom. The sleeve is clamped to the glass plates to form a sealed unit. The test frame is composed of steel plates and invar rods. A linear variable differential transformer (LVDT) is screwed into the top plate with its movable displacement rod extending through the plate and touching the surface of the top glass plate. The test specimen is prepared by filling the rubber sleeve with the desired mixture immediately after mixing and putting the top glass plate inplace. The filling is accomplished by rodding and light tamping of the material. The LVDT is then put inplace and the movements of the glass plate monitored electronically. Length change or expansion is expressed as the percent change with regard to the 14-in. specimen height.

The above configuration appears to give satisfactory results provided the mixture being evaluated is a nonbleeding mixture. When bleeding occurs, as happens in most pumpable grout mixtures, there is a collection of free moisture on the top surface of the specimen prior to hardening. With time, this moisture is absorbed back into the specimen with a subsequent downward movement of the glass plate. This gives the illusion of specimen shrinkage where in fact the hardened portion of the specimen is expanding. In reality the overall length of the cylinder is reduced, however. This then becomes a problem of definition as to whether to relate expansion to the initial unhardened volume or the initial hardened volume. Mixtures SCS-1 through 3 were bleeding mixtures. Figure A.6 shows a typical test record for a vertical specimen of mixture SCS-1. The specimen bled and the test record reflects the expansion from the time the bleed water disappeared. An identical specimen was also made and then laid on its side. The LVDT then measured length change without the effects of bleeding behind the glass plate. The record from that test is also shown in fig. A.6. Figures A.7 and A.8 show the expansion-time curves for horizontal cylinders from mixture SCS-1. The curve in fig. A.7 reflects the entire early-age behavior of a cylinder cast vertically and immediately laid on its side. The specimens of fig. A.8 were allowed to stiffen somewhat before being laid over. The test record began at that time and thus does not reflect the very early behavior.

The major problem associated with casting a vertical specimen and then putting it on its side is the matter of sag of the rubber membrane. It was originally believed that this sag was the cause of the apparent shrinkage of the specimen as seen for the control specimens of fig. A.6. Some attempts to eliminate this were made as in the case of the specimens of fig. A.8. Attempts to use two types of rigid sleeves around the neoprene sleeve at early ages were also made. Cardboard and polyvinyl chloride (PVC) tubes were used around the neoprene. After some period of stiffening of the mixture, the tube was split and removed. The specimen behavior for the cardboard and PVC tube confinement is shown in figs. A.9 and A.10. It was concluded that the use of these tubes contributed little and did tend to interfere with the expansion behavior. In reality, the sag of the specimen does not contribute to the entire apparent decrease in specimen length. During stiffening of the cement paste, some self-desiccation does occur and should be reflected as shrinkage in the overall length (volume) of the unhardened specimen.

For comparison purposes, the expansion-time relations for SCS-2 and SCS-3 using the horizontal cylinder technique are shown in figs. A.11 and A.12.

A.3 CURING CONDITIONS

The effects of varying the curing conditions of unrestrained and restrained expansion bars can be seen in figs. A.1, A.3, A.4, A.13, and A.14. In general, whenever the bars are removed from the 95 to 100 percent relative humidity environment and placed in a 50 percent relative humidity environment, their length stability or rate of length increase is destroyed and reductions in length begin to occur. Upon relocation in the higher humidity environment, the bars again begin to expand and may achieve some plateau of length stability.

There appears to be a distinction to be made when specifying a 95 to 100 percent relative humidity for optimum curing. The specimen in fig. A.13 that was cured in a plastic bag was at approximately 100 percent relative humidity as was the specimen cured in the fog. The bag-cured specimen did not expand much more than the control specimens. In its curing, the bagged specimen had no access to additional free moisture, as did the fog-cured specimen whose surfaces were continually wetted. It appears that the availability of free moisture is beneficial in achieving a higher level of expansion from the standard bars. For comparison purposes, the expansion-time relations for specimens made from SCS-2 and -3 with controls are shown in fig. A.15 for continuous curing in fog.

A.4 CONSTRAINED PRESSURE

The constrained pressure tests were similar in configuration and procedure to those described in section 3.10 with the exception that the top surface was not restrained by a steel plate. The top end was unrestrained and kept covered with a substantial layer of water. Three test cans each and two control cans each for mixtures SCS-1, SCS-2, and SCS-3 were evaluated. All test cans for each mixture were made from one batch representing that mixture. Both control cans for a given mixture also came from one batch.

The test results for mixtures SCS-1, -2, and -3 are shown in figs. A.16, A.17, and A.18, respectively. The gages from one test can of SCS-1 became unbonded and no record was obtained. Thermocouples were used in each of the test cans and the average temperature development for the mixtures is shown in figs. A.17 and A.18.

The test results were not encouraging. Considering the fact that the material in each set of cans representing a particular mixture was from the same batch, the differences in the pressure levels of the three test cans of both mixtures SCS-2 (fig. A.17) and SCS-3 (fig. A.18) are considerable at later ages. The scatter at 45 days age, for instance, is approximately 12 and 10 percent, respectively, around a mean value. What is also surprising is the fact the control cans exerted as much pressure as they did and that at 45 days age the test can mean pressures were approximately 55 and 25 percent greater than the controls of SCS-2 and SCS-3, respectively. No explanation can be given as to why the pressures exerted by SCS-1 (fig. A.16), which had a higher expansive potential than SCS-2, produced pressures that were significantly less than those generated by SCS-2.

A review of the physical properties of a number of other specimens made from the same batch that was used in casting each set of test cans indicated that it was not the material that was variable. This then suggested that perhaps the test equipment or procedure was causing the lack of reproducibility. A detailed review seemed to implicate both.

The material comprising the test cans appears to be somewhat uniform. The most suspect area of the can is the welded seam which joins the metal together in forming the circular section. An expansion of the can is witnessed by the strain gages only if the metal beneath the gage is strained. If some expansion is absorbed in movement or deformation of the seam, it cannot be monitored by the gages. This would result in a calculation of lower pressures than could have actually occurred with a more perfect constrainment. A number of solutions are possible to alleviate this problem: (a) seamless or extruded cans might be used; (b) the seamed cans might be preconditioned by pressure cycling to reduce the possibility of seam slippage and deformation; and (c) the use of strain gages could be discontinued and the pressure determination be related to diameter change which could be measured by LVDT's. This measurement would ignore slippage at the seam.

Assuming that a reliable container can be obtained, the effects of temperature must then be minimized. For a constant ambient test temperature, the thermal effects on the can result from the heat developed in the concrete during the hydration of the cement. This heat affects the attached strain gages, their adhesive, the can itself, and the material contained in the can. The expansion of the material in the can due to temperature increases is real behavior that, in general, need not be compensated for. If compensation were necessary, it would only be approximate, because a realistic measure of the coefficient of thermal expansion of the concrete at that stage of the materials development would be extremely difficult to obtain. The increased internal temperatures of the material also cause the metal can to expand. This may or may not be a problem, depending on the level of expansion of the mixture. When higher levels of expansion are present, the expansion of the can due to temperature is quickly overridden by the expansion of the material. For very low expansions or even shrinkage, the can may expand more due to temperature than to forces exerted by the mixture and thus produce misleading results.

Temperature also affects the stability of the gages from both the standpoint of gage resistance and performance of the adhesive. The temperature coefficient of each gage is not exactly the same, and when using temperature-compensating gages where only small strains are involved, the errors in correction are liable to be large. This problem and that of the adhesive performance may be circumvented by obtaining the complete temperature history for each can prior to test. This can be done by installing the gages to be used on the test can and then temperature cycling the can within the expected range of test temperatures until the hysteresis in the temperature-strain history is removed. Strains due to temperature during actual test can then be identified and removed from the test record.

A.5 RECOMMENDATIONS

When using either restrained or unrestrained length change bars to give indications of the expansive potential of a mixture, the time of demolding and initial length determination should be tied to the stiffening or hardening characteristics of the mixture. As the bars must have sufficient strength in order to be demolded, the time of demolding must occur at some interval after the mixture has reached its final set. It is recommended that the demolding time be defined as some time increment after the mixture has reached its final set as determined by CRD-C 86 (reference 2) (ASTM Designation C 403). This time increment will have to be determined by test as there is insufficient data on this subject.

Consideration should be given to using an unrestrained expansion specimen, such as the 6-in.-diameter by 14-in.-high cylinder described in section A.1, when attempting to determine the complete expansion history of a mixture. The specimen configuration and procedures for evaluating the specimen behavior as used with the SCS mixtures does require some additional development work, however.

The curing of laboratory expansion bars should be done in a limewater bath. The use of fog curing appears to be adequate but is susceptible to inadvertent humidity decreases which will affect the expansive behavior. Total immersion does not have this problem.

Additional development of the constrained pressure test is needed. Evaluations of pressure and temperature cycling procedures for the test cans are essential. Some consideration should be given to relating the expansive pressure to diameter change of the test cylinders rather than to circumference increase as determined from strain gages.

TABLE A.1

SPECIAL CONTROL STUDIES (SCS)

MATERIALS AND MIXTURE PROPORTIONS

Mixture Designation	Mixture Proportions for a 1-cu-ft Batch, lb		
	SCS-1	SCS-2	SCS-3
Cement			
Type G (RC-616)	26.30	28.56	23.87
Type K (RC-610(2))	10.43	5.04	16.20
Fly ash	15.42	16.75	14.00
Oceanside sand	41.72	45.32	37.86
Gel	1.61	1.75	1.46
Water	27.64	26.69	28.65
CFR-2	0.30	0.33	0.27
Theoretical unit weight	123.4	124.4	122.3
Theoretical cement factor,[1] bags per cu yd	10.5	9.7	11.5
Water-cementitious ratio[2]	0.53	0.53	0.53

---

1. This is the amount of all cements in the mixture.
2. The cementitious fraction includes all cements plus the fly ash.

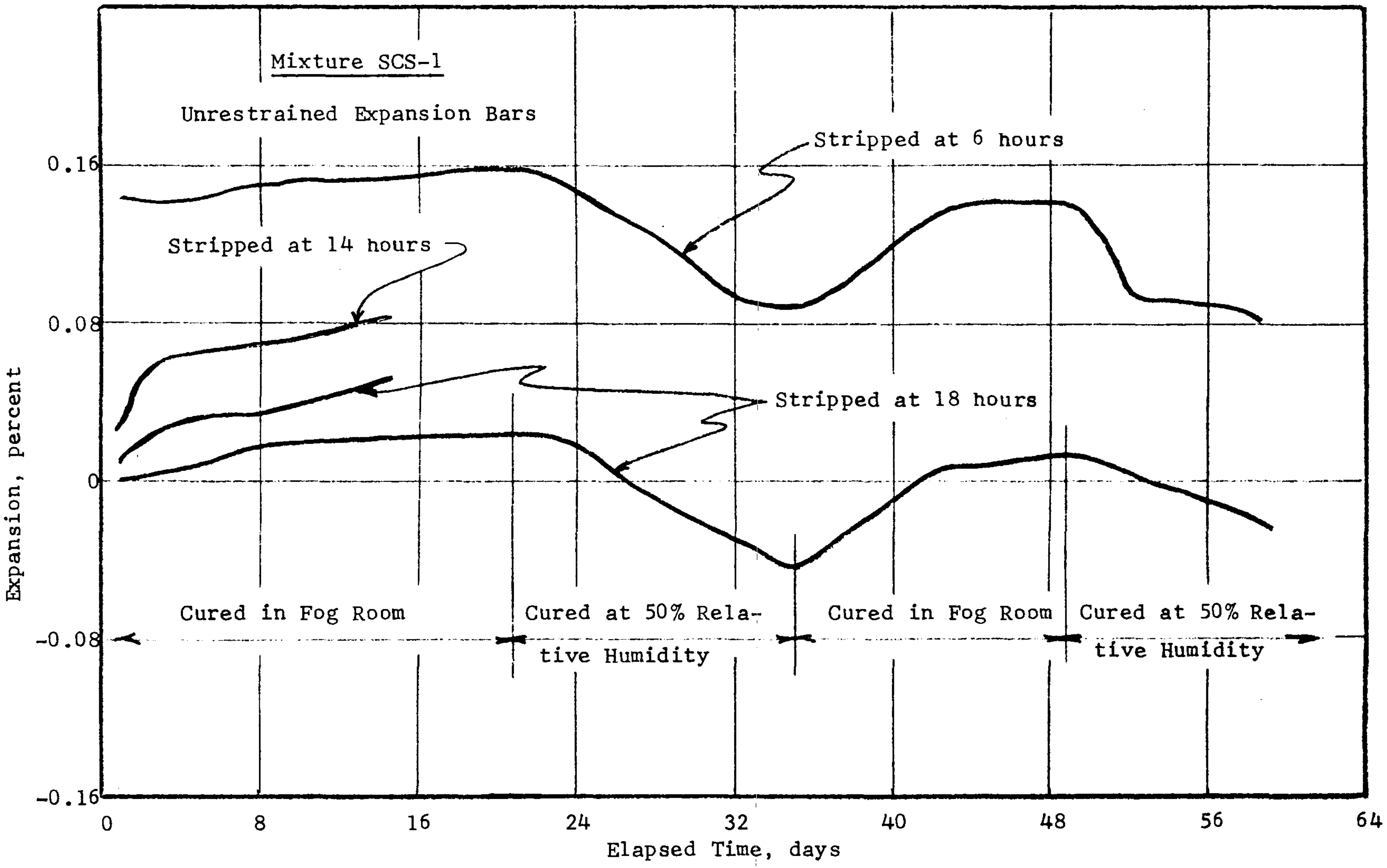
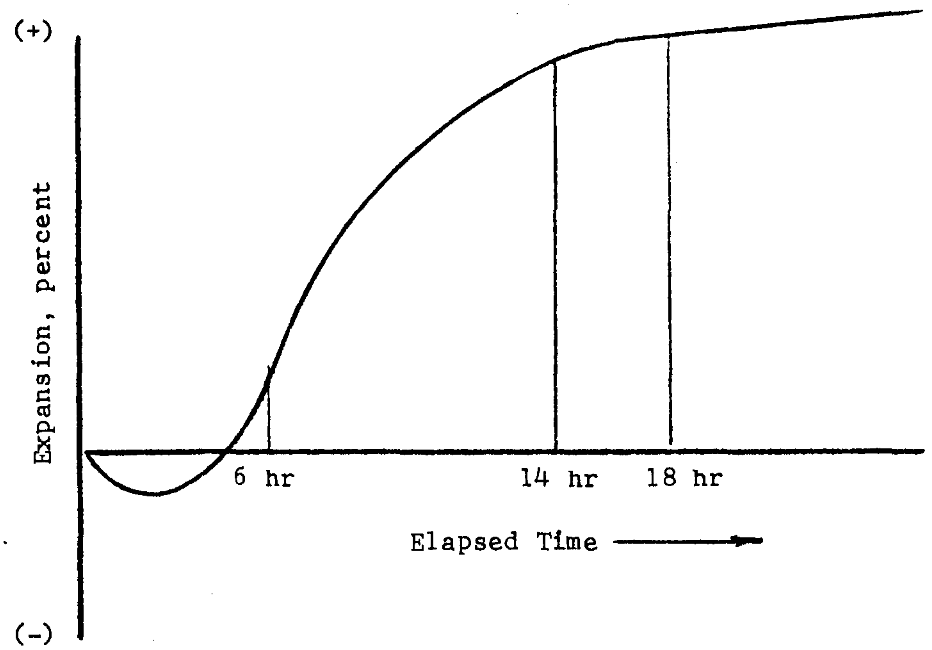
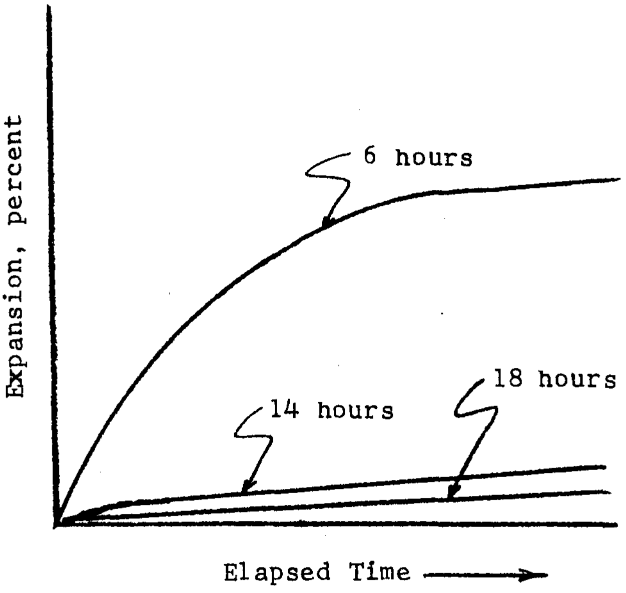


Figure A.1 Effects of Demolding Times and Curing Conditions on Expansion



a. Hypothetical Expansion Curve



b. Reported Expansion Curve

Figure A.2 Effect of Demolding Time on Expansion

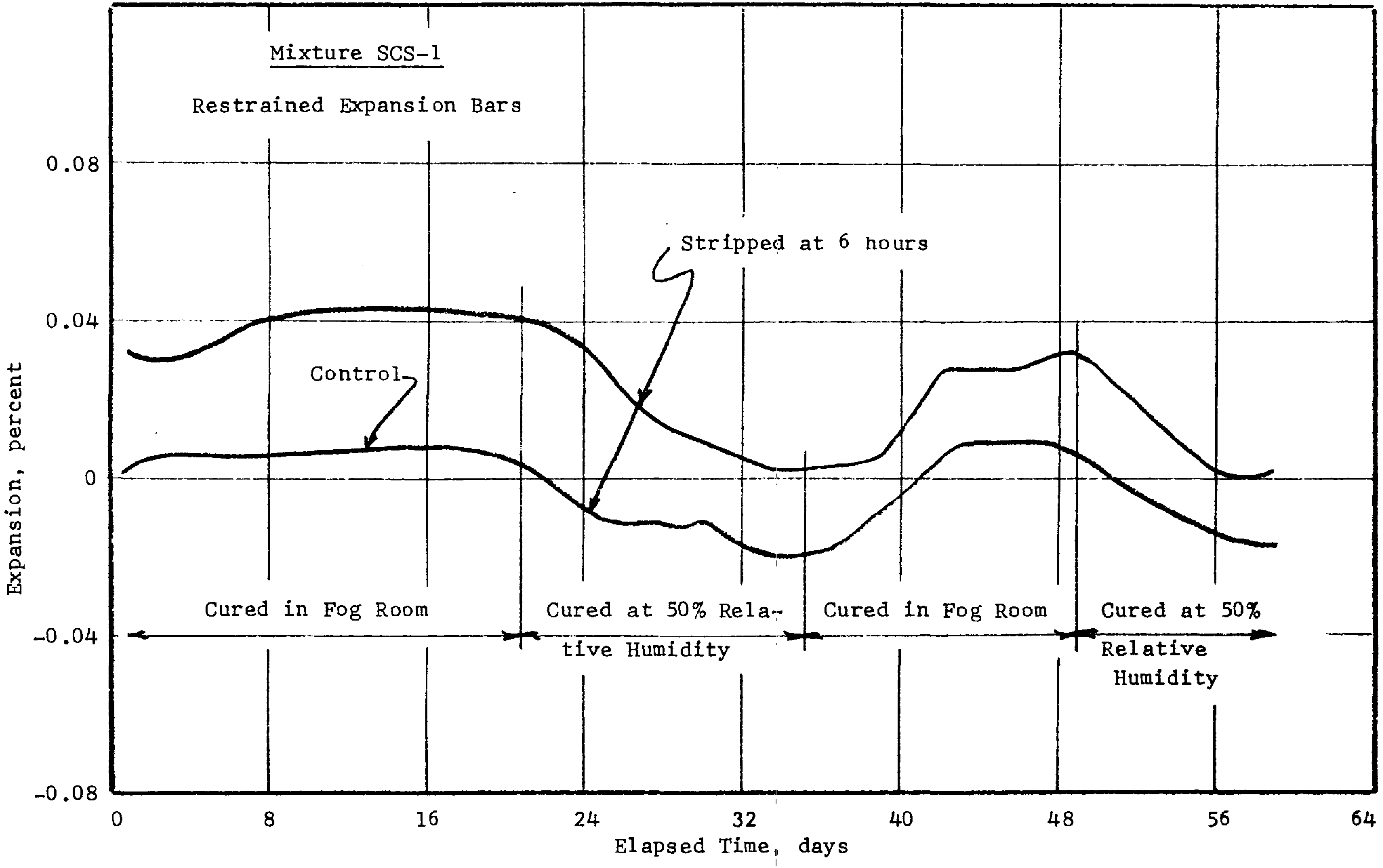


Figure A.3 Restrained Expansion for Mixture SCS-1 and Control

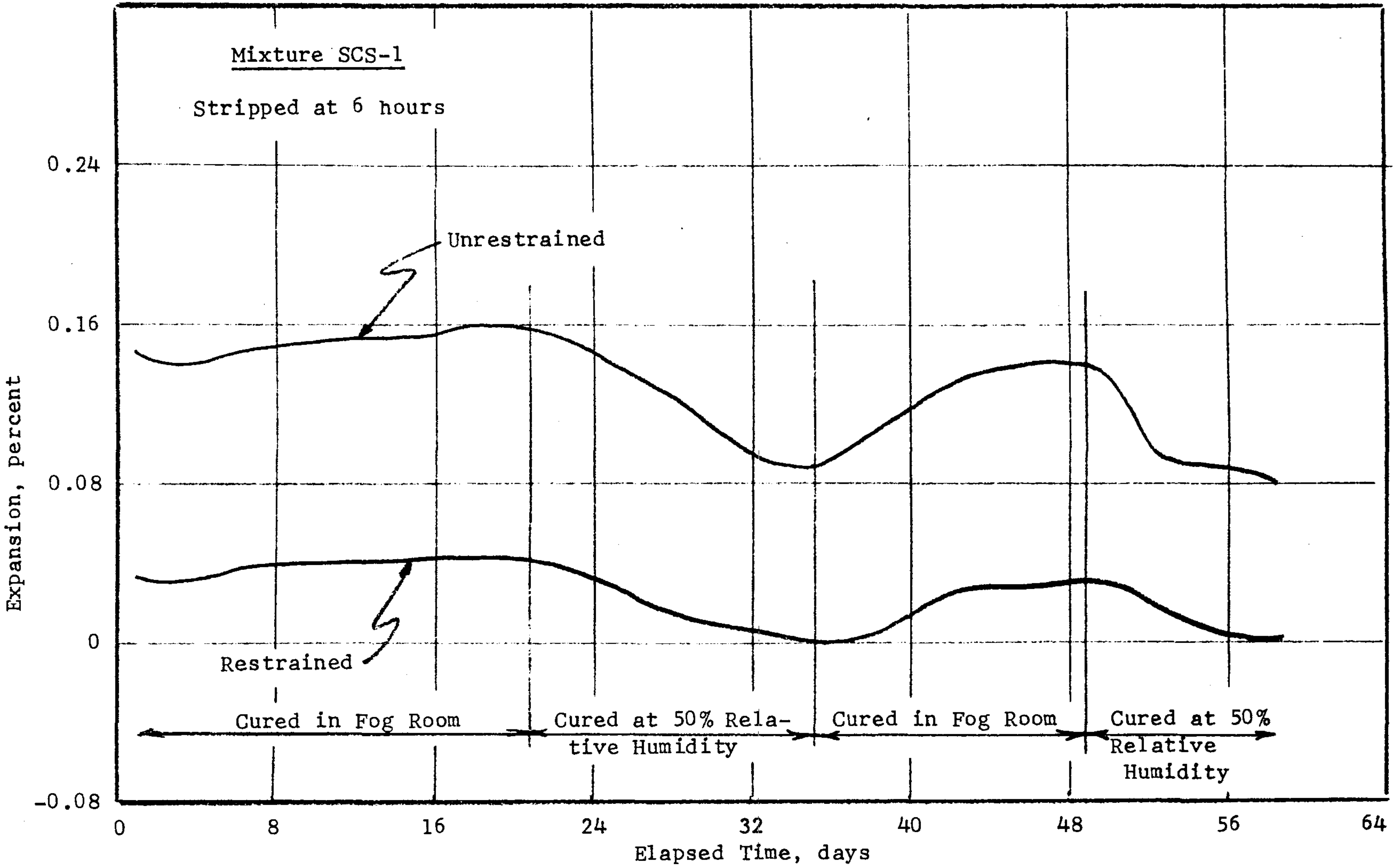


Figure A.4 Effect of Standard Restraint on Expansion

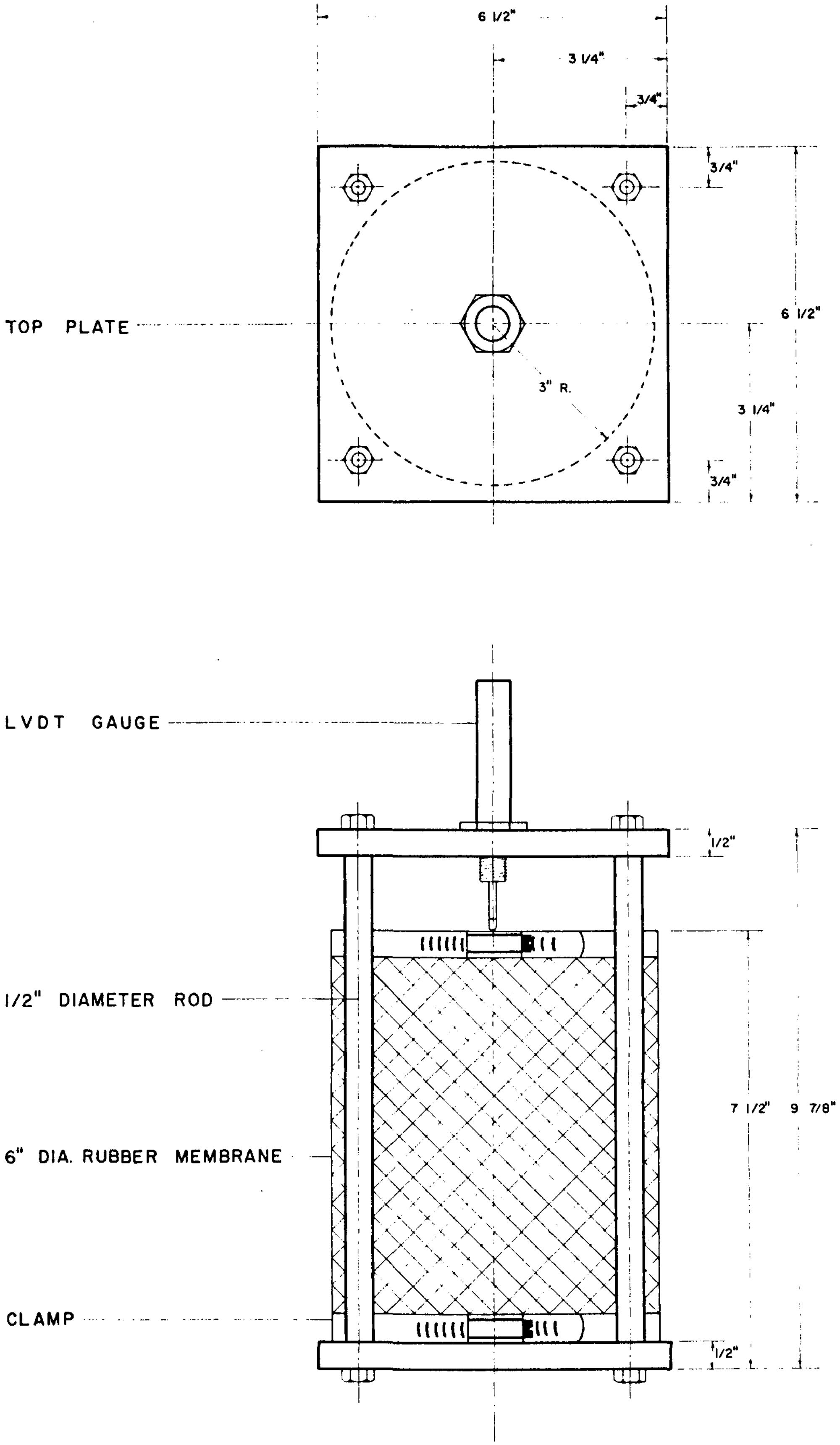


Figure A.5 Unrestrained, Early-Age Expansion Cylinder

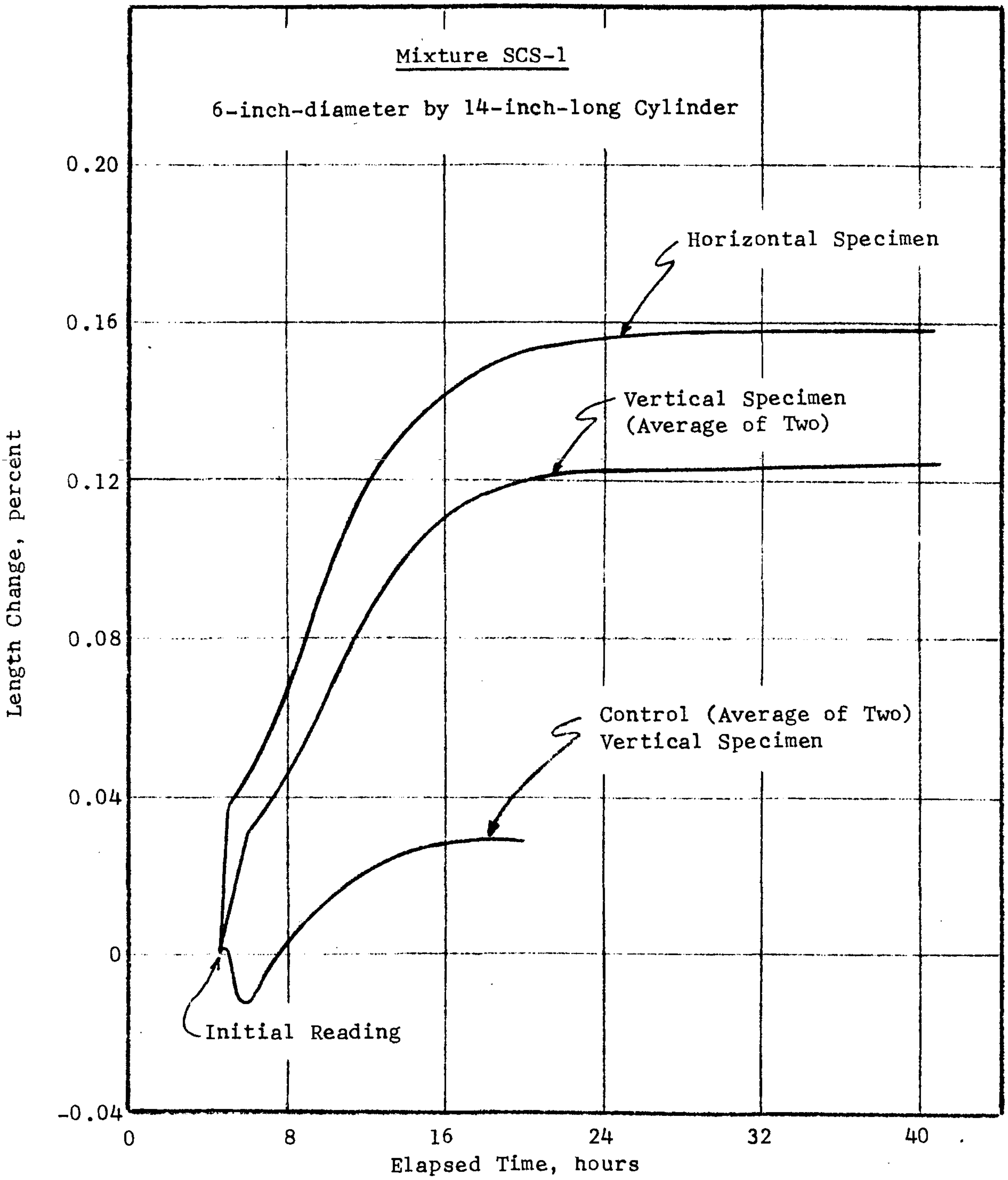


Figure A.6 Expansion-Time Behavior for Vertical and Horizontal Cylinders

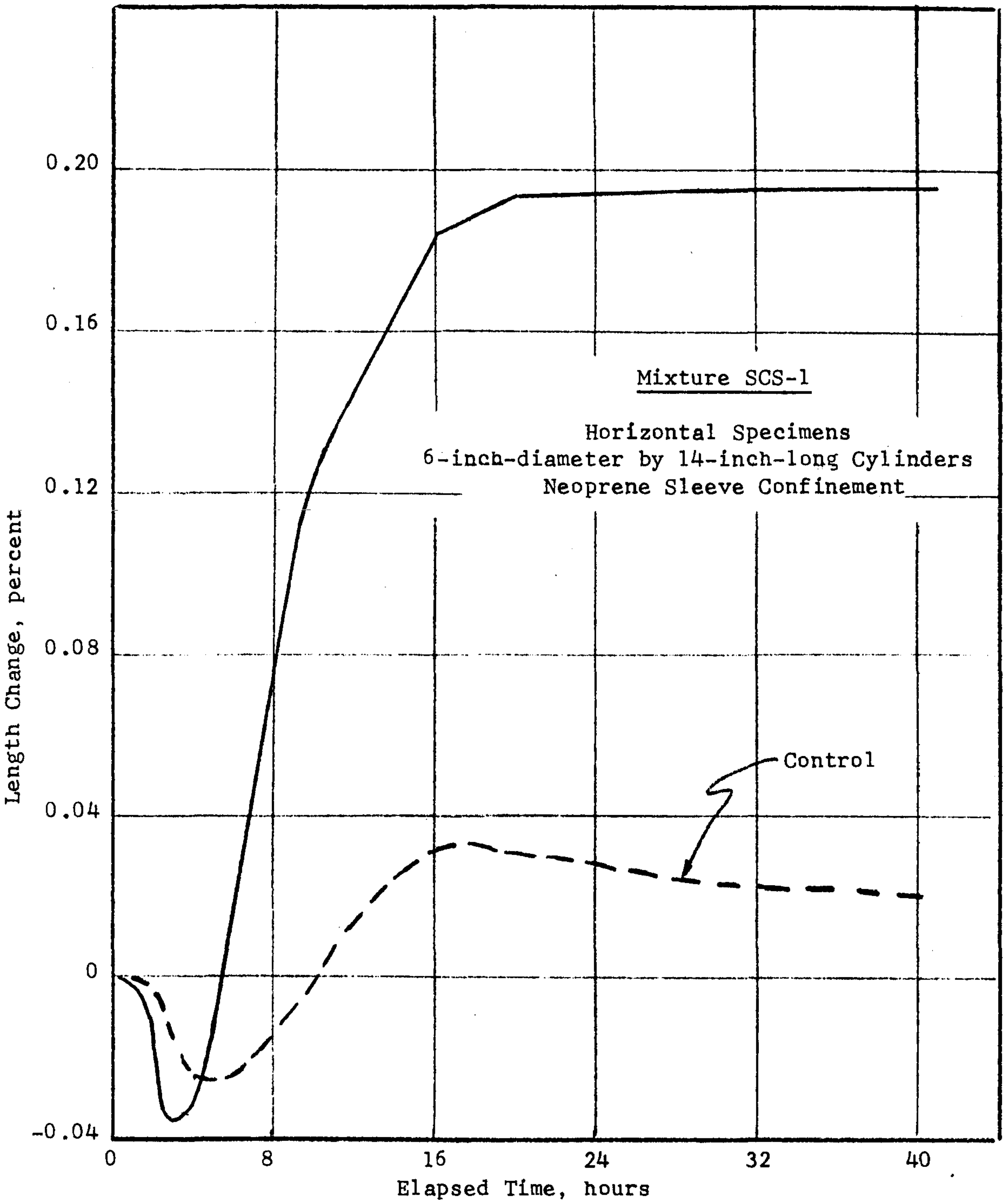


Figure A.7 Complete Early-Age Expansion-Time Relation for SCS-1 and Control

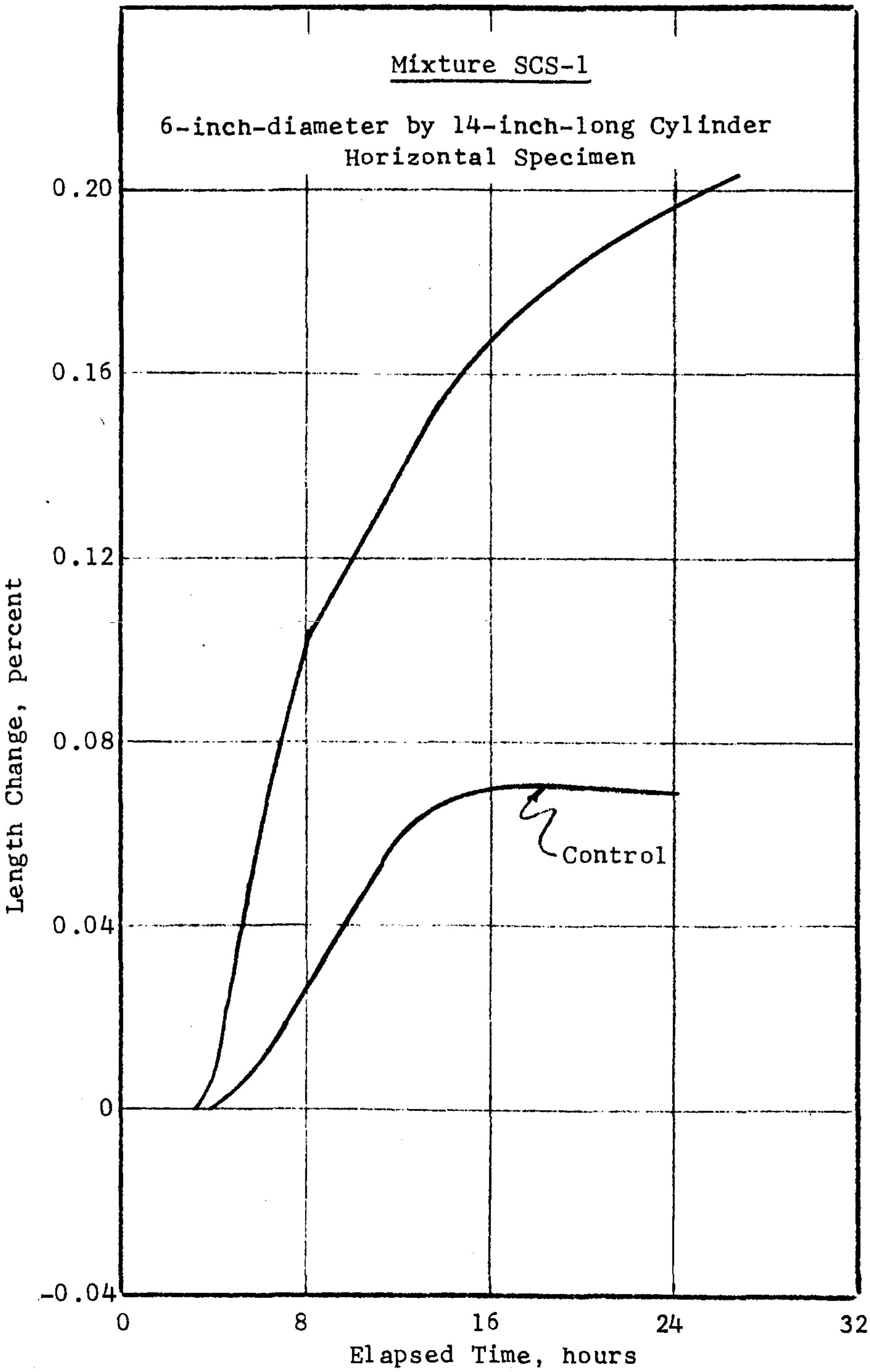


Figure A.8 Modified Early-Age Expansion-Time Relation for SCS-1 and Control

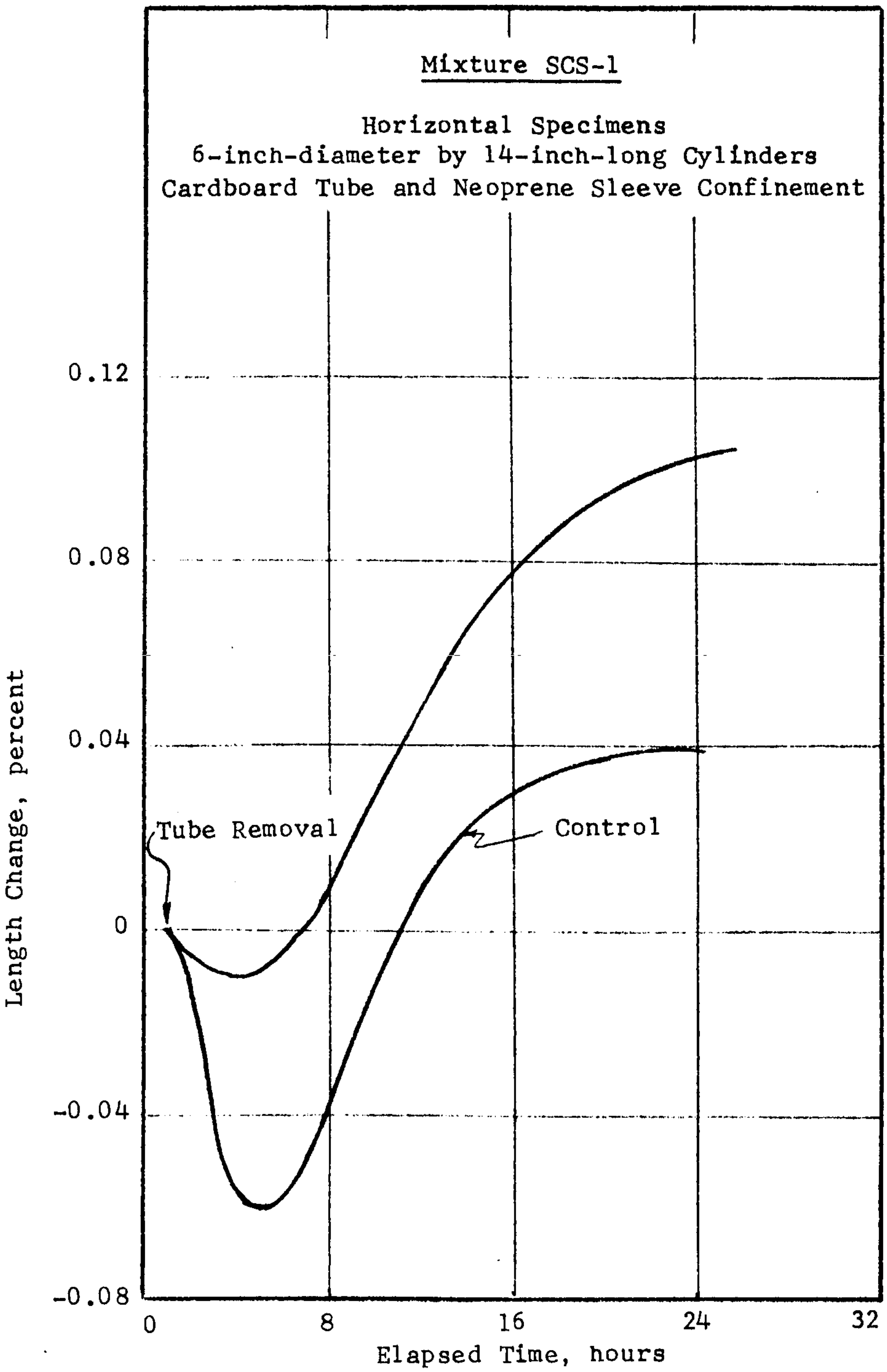


Figure A.9 Expansion-Time Relation for SCS-1 and Control Using Cardboard Tubes for Early-Age Confinement

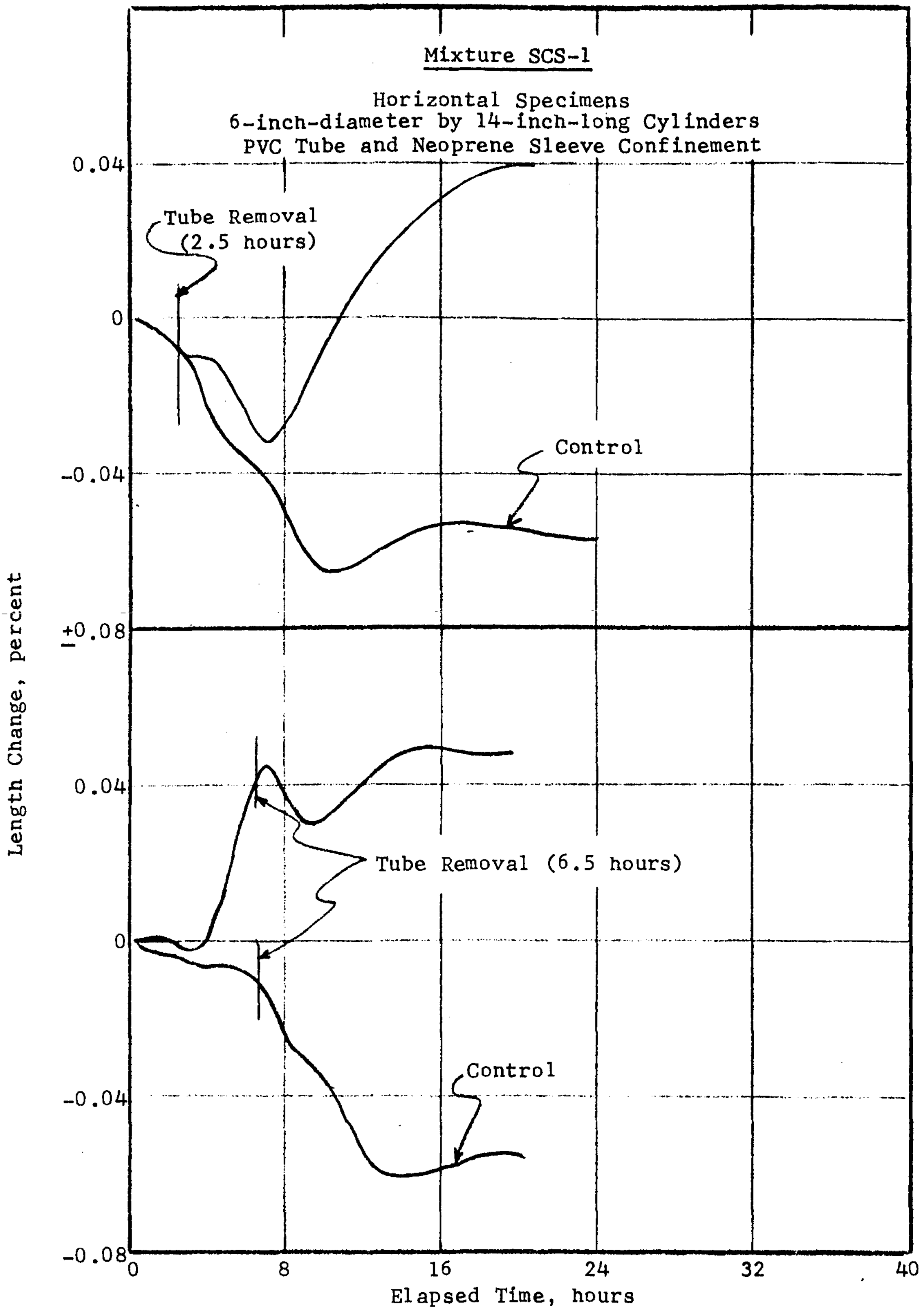


Figure A.10 Expansion-Time Relation for SCS-1 and Control Using PVC Tubes for Early-Age Confinement

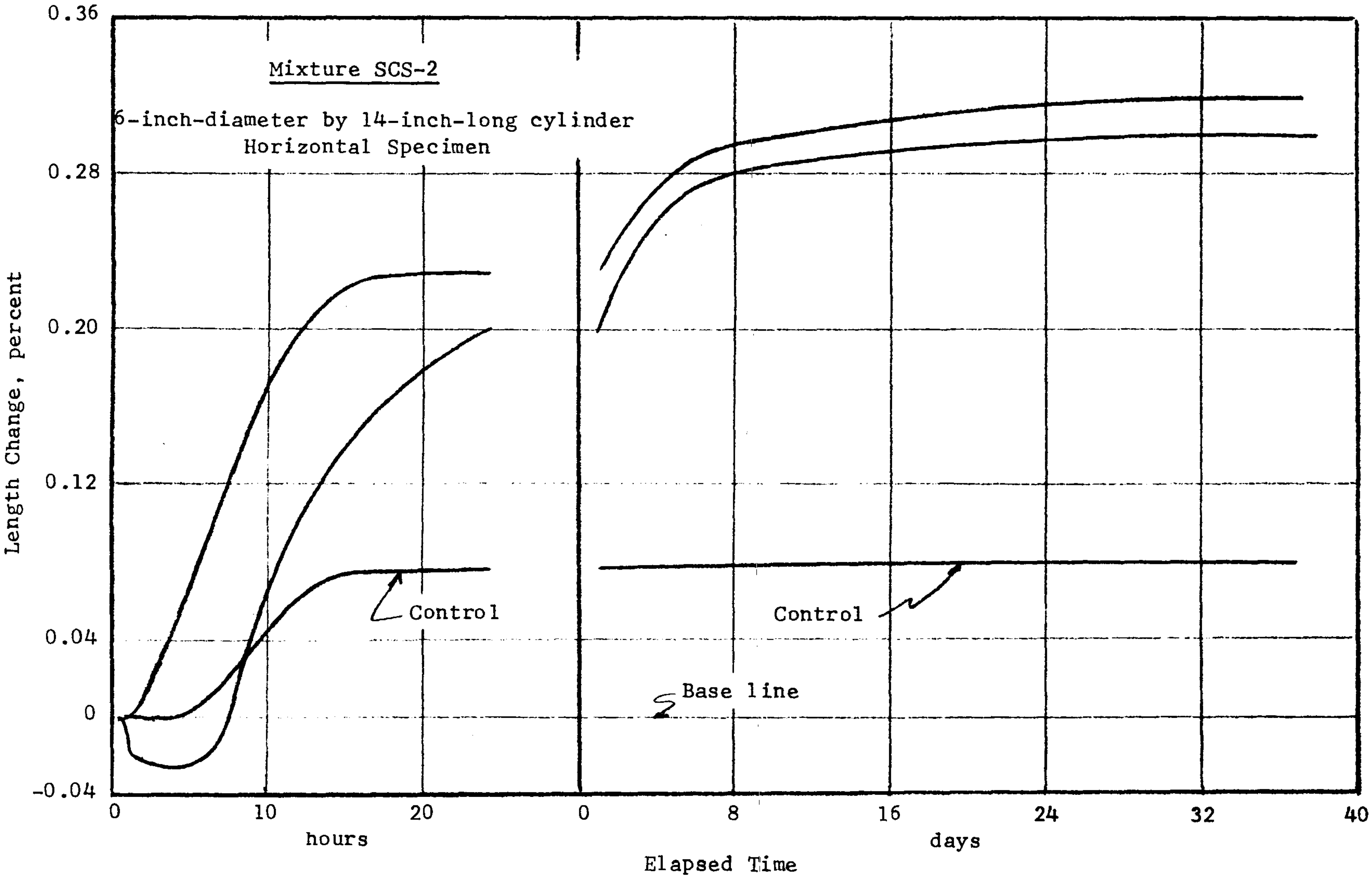


Figure A.11 Expansion-Time Relation for SCS-2 and Control

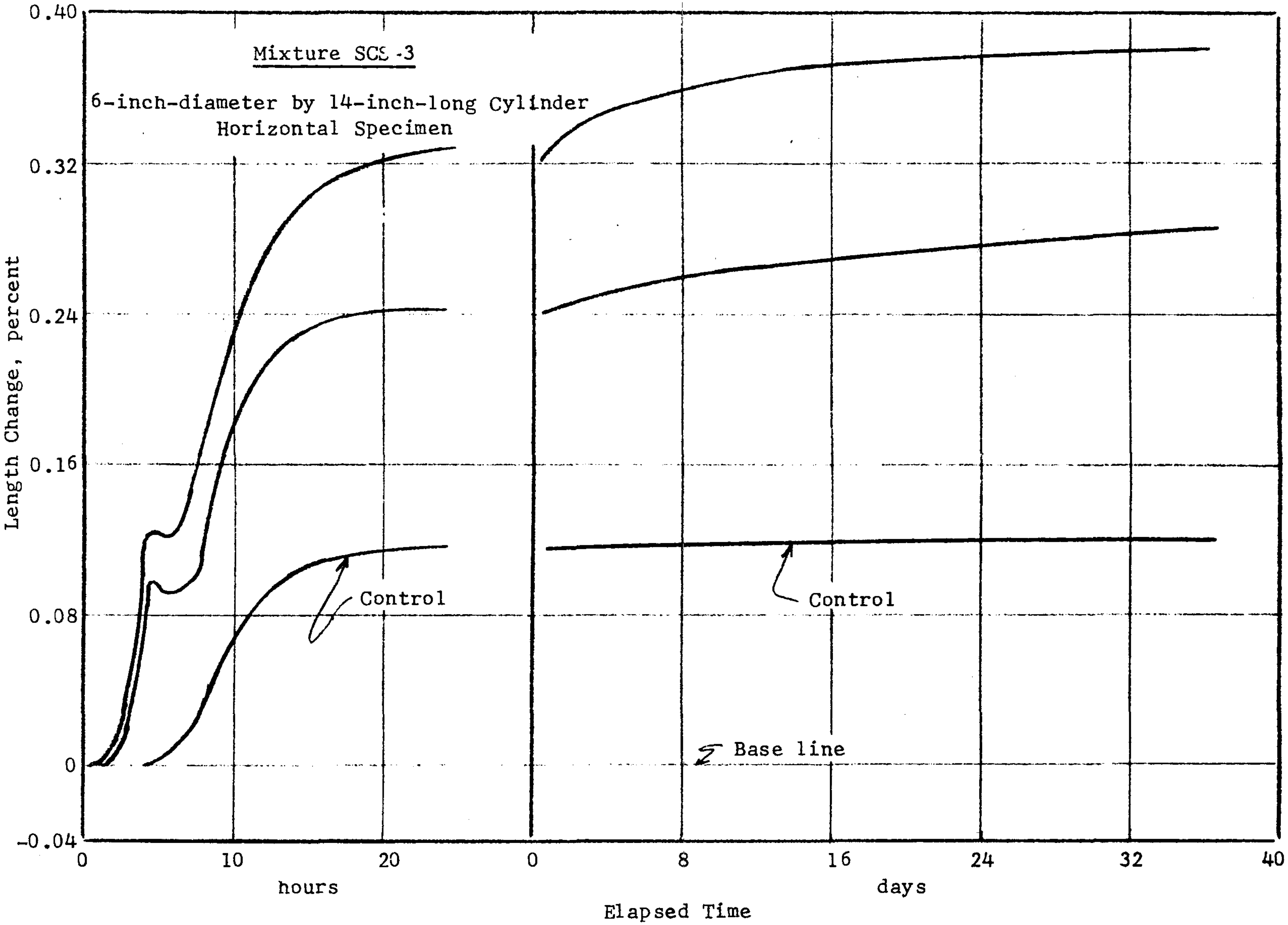


Figure A.12 Expansion-Time Relation for SCS-3 and Control

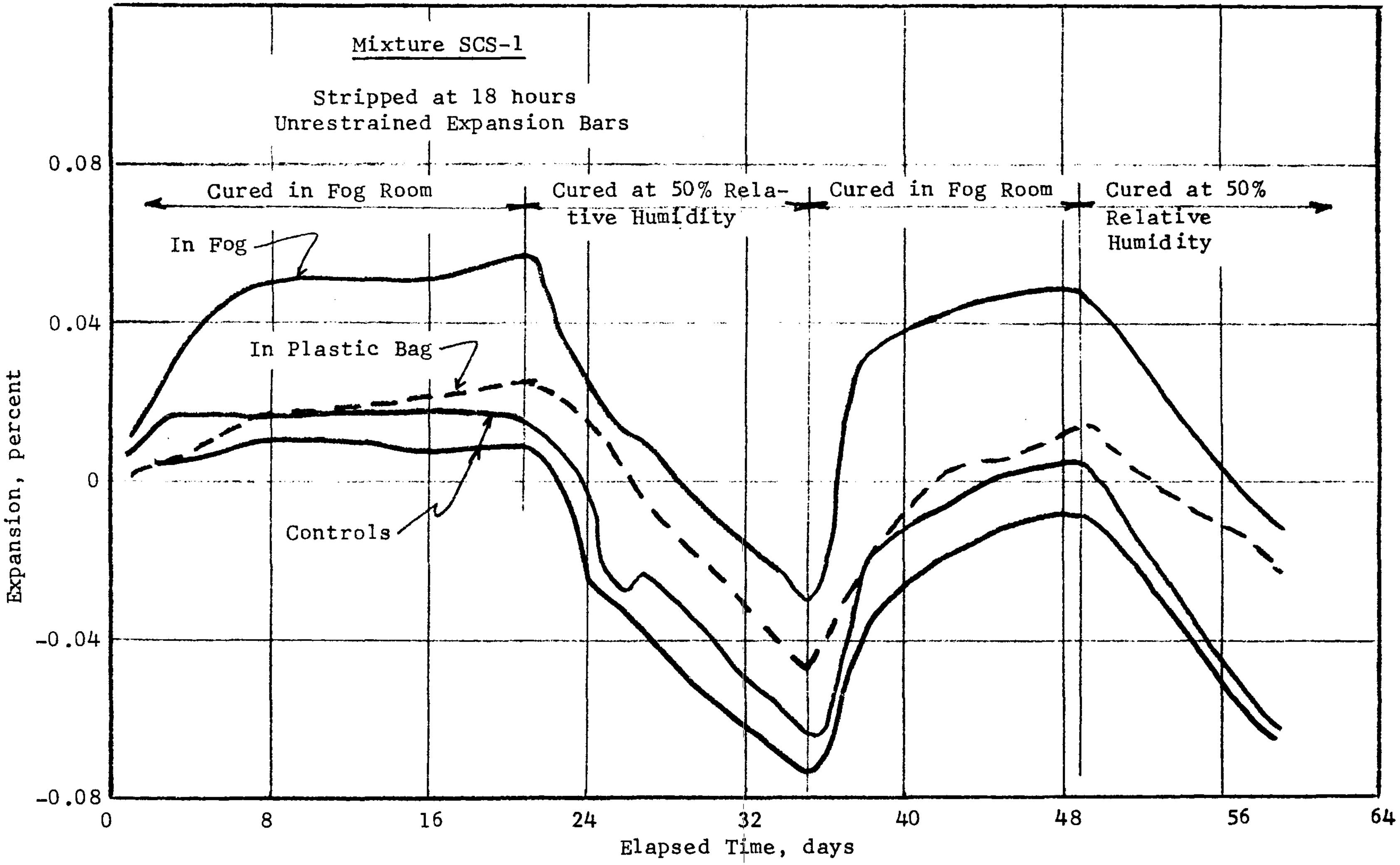


Figure A.13 Effects of Curing Conditions on Expansion-SCS-1 and Controls

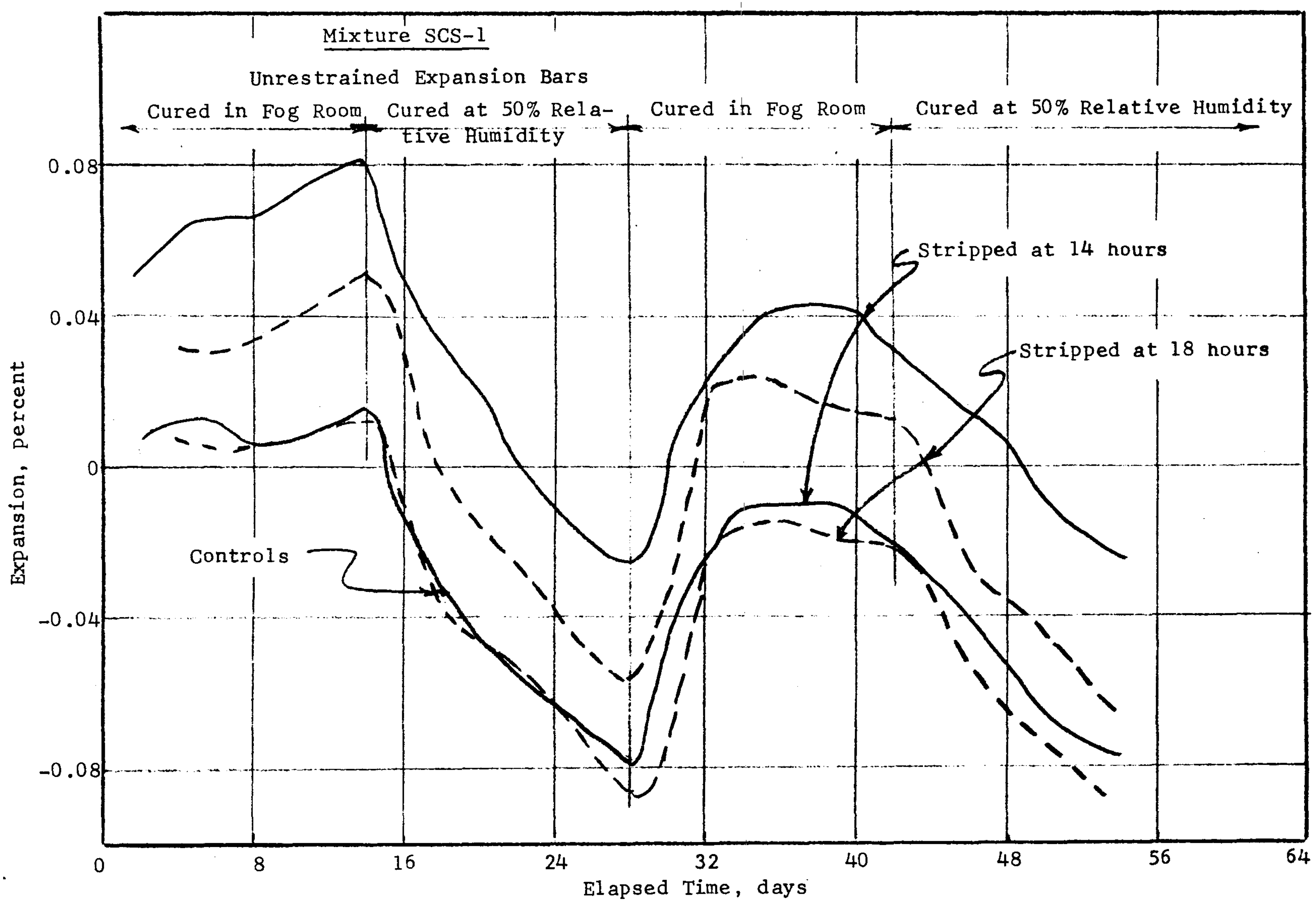


Figure A.14 Effects of Curing Conditions and Demolding Times on Expansion - SCS-1 and Controls

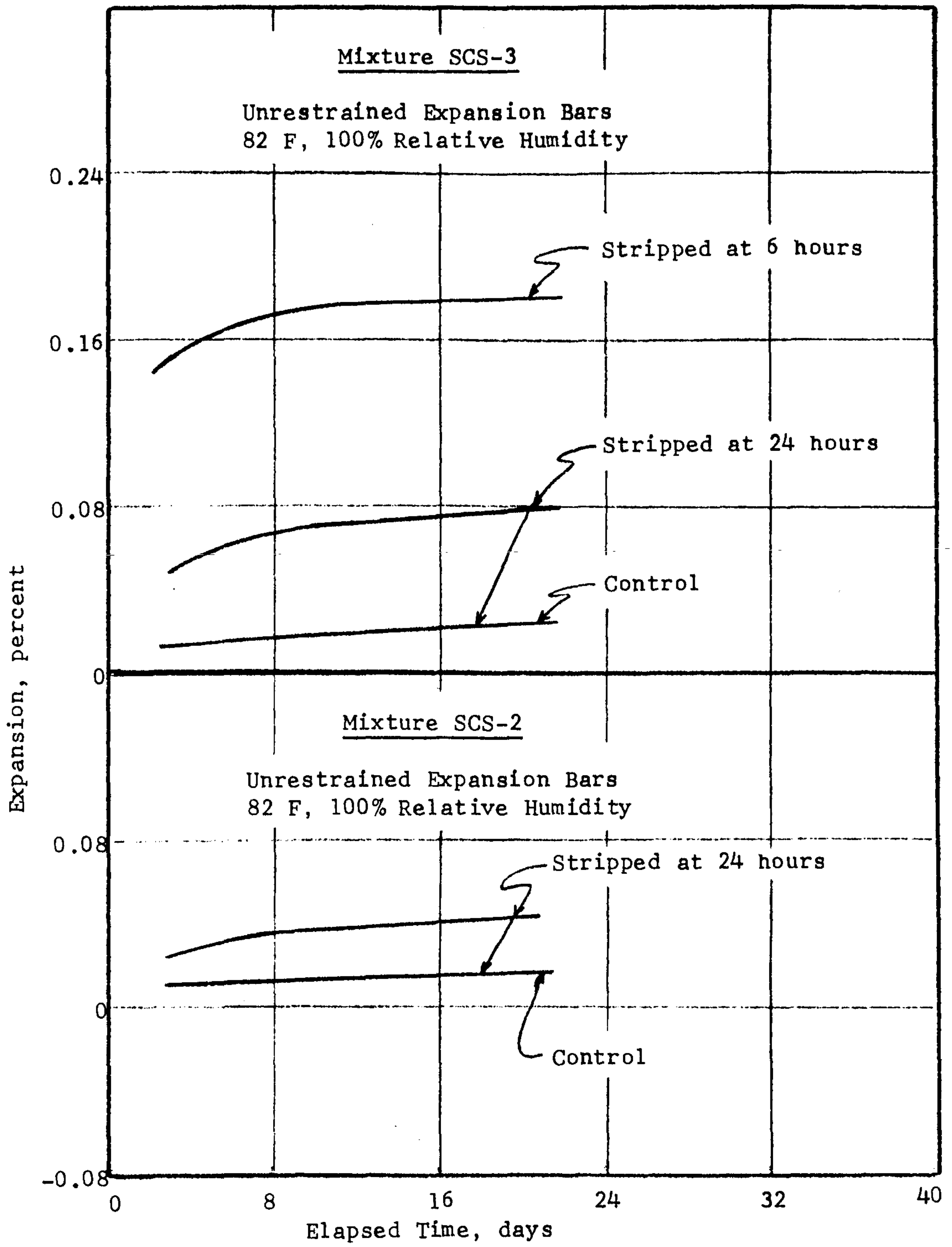


Figure A.15 Expansion-Time Relations for SCS-2, SCS-3, and Controls

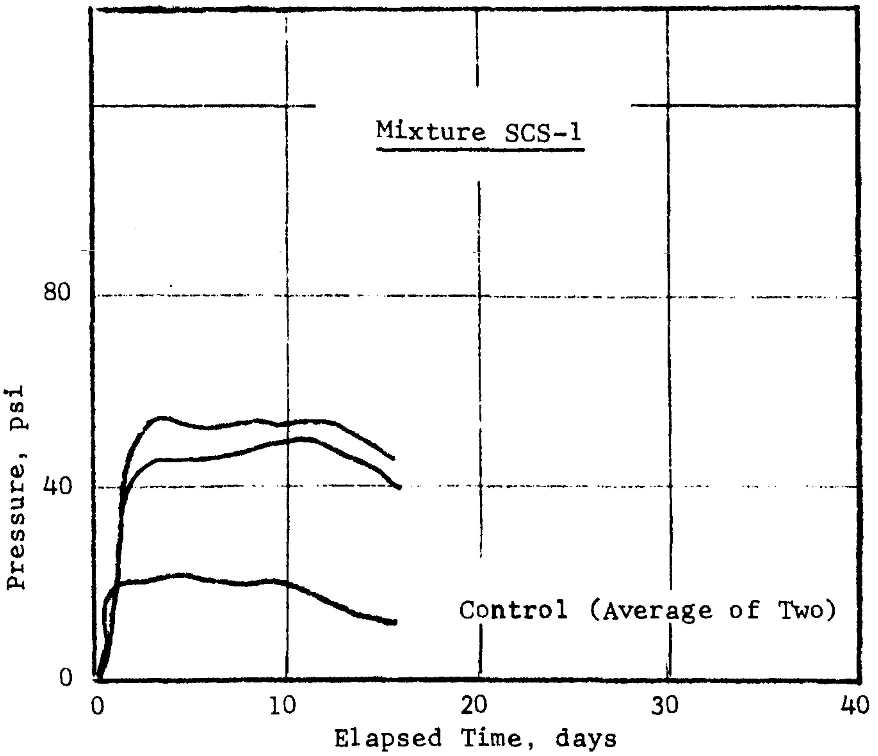


Figure A.16 Pressure-Time Curves for SCS-1 and Controls

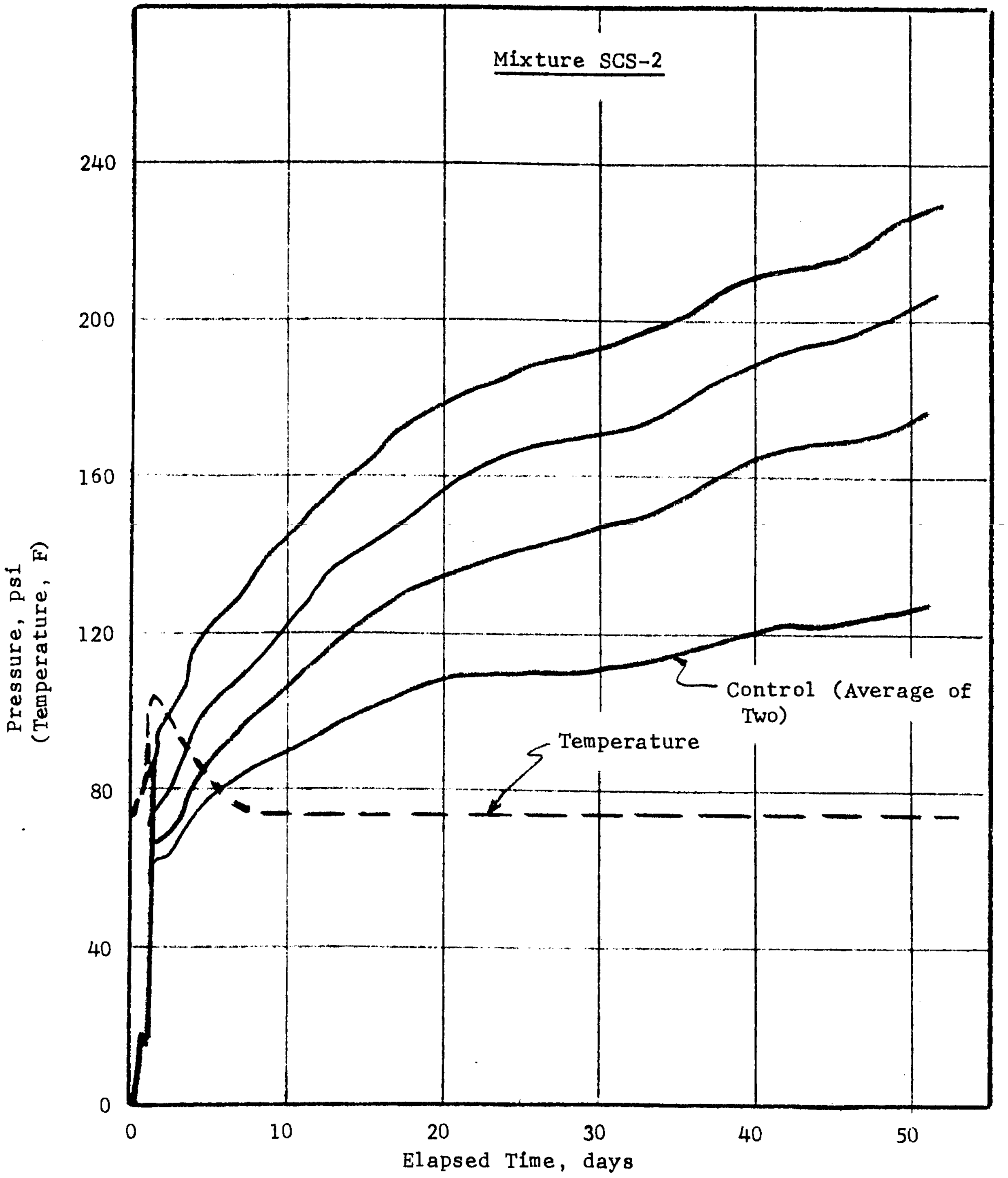


Figure A.17 Pressure-Time Curves for SCS-2 and Controls

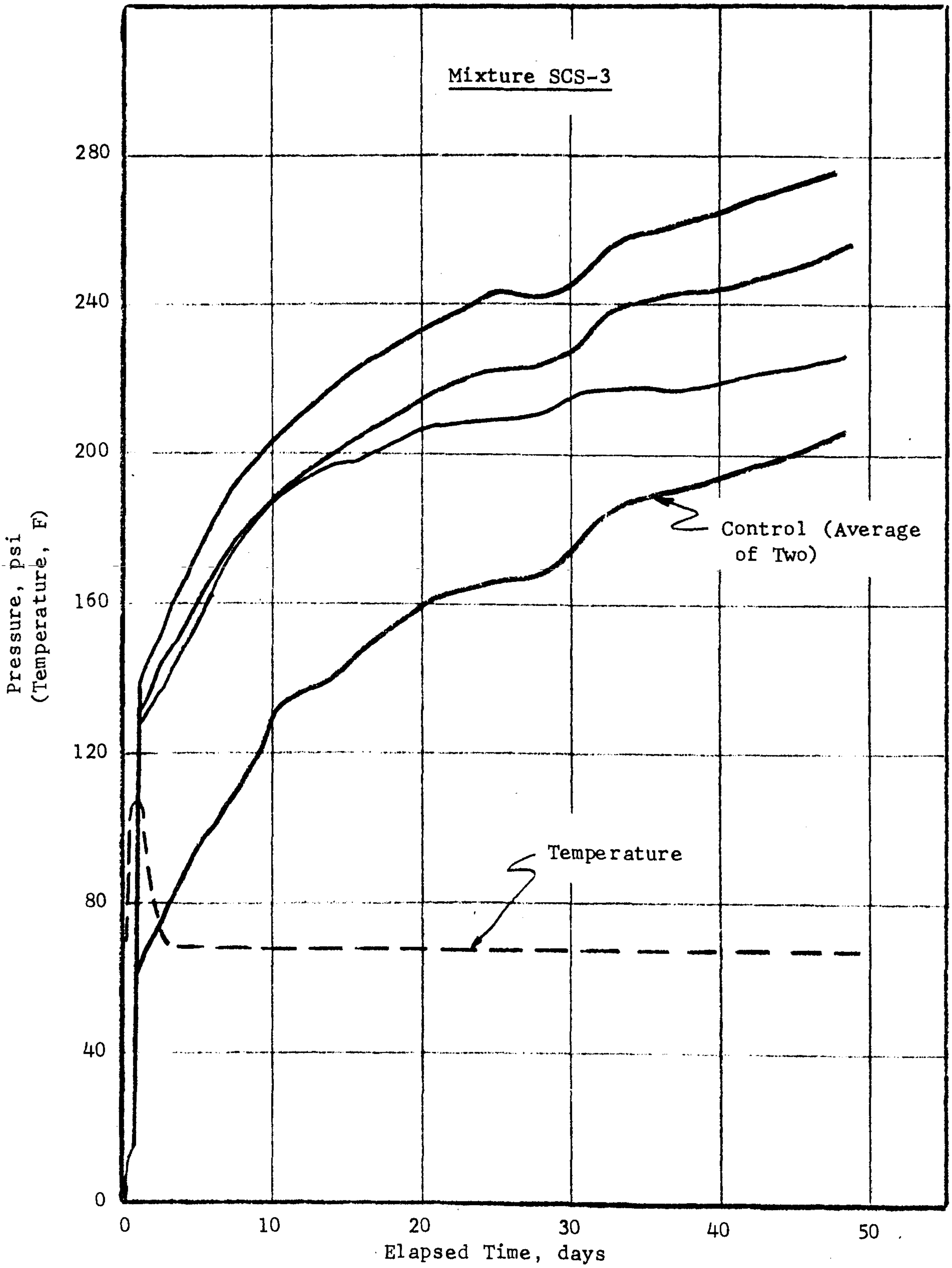


Figure A.18 Pressure-Time Curves for SCS-3 and Controls

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13. ABSTRACT

Laboratory evaluations were made of 14 grout mixtures and 7 concrete mixtures, all of which contained type K expansive cement wholly or in part. The mixtures were developed for field use on a number of different projects. They varied widely in ingredients, proportions, curing, and the type of evaluations made. Very few direct comparisons of behavior among mixtures could be made. Three special control study mixtures were also evaluated as a pilot study. Both shrinkage-compensating and self-stressing type K expansive cements were used. The self-stressing cement was used as a portion of the total cement, while the shrinkage-compensating cement was used as the only cement in the mixture. Each mixture was evaluated for some, but not all, of the following: expansion, strength, modulus of elasticity, compressional wave velocity, constrained pressure, temperature rise, slump loss, and efflux time. Comparisons were made as appropriate. Temperature rise values as high as 178 F were recorded. The various mixtures developed 3-day compressive strengths ranging from less than 1300 psi to more than 4700 psi. Maximum compressive strength noted was 7155 psi on one mixture at 28 days age; other 28-day strengths on other mixtures were as low as 2115 psi. Static modulus of elasticity values were between 1.0 and 3.5 million psi with corresponding dynamic moduli being 20 to 30 percent greater. Greatest unrestrained expansion observed was 0.158 percent; this included both thermal and chemical expansions. Most expansions were considerably less, however. Restrained expansions were always less than unrestrained expansions. Compressional wave velocities from 10,800 to 14,395 fps were observed. A constrained stress of 52 psi was measured for one grout mixture. Slump loss evaluations indicated that the amount of loss was a function of the mixture ingredients and proportions as well as the mixing cycle.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Concretes						
Expansive cements						
Grout						
Portland cements						