TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-85/4+311-3		

4. Title and Subtitle
EVALUATION OF ACCELERATED CONCRETE AS A RAPID SETTING HIGHWAY REPAIR MATERIAL

5. Report Date
April 1984

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.
Research Report 311-3

9. Performing Organization Name and Address
Center for Transportation Research
The University of Texas at Austin
Austin, Texas 78712-1075

10. Work Unit No.

11. Contract or Grant No.
Research Study 3-9-82-311

12. Sponsoring Agency Name and Address
Texas State Department of Highways and Public Transportation; Transportation Planning Division
P. O. Box 5051
Austin, Texas 78763

13. Type of Report and Period Covered
Interim

14. Sponsoring Agency Code

15. Supplementary Notes
Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges"

16. Abstract

Accelerating admixtures used in combination with portland cement concrete are widely used as rapid setting highway repair materials. There are a wide variety of accelerators available, most of which contain calcium chloride. Several non-chloride type accelerators have recently become available due to corrosion problems which have been associated with the use of calcium chloride accelerators. The behavior of these accelerators is not as well known.

This report provides an evaluation of the performance of five different types of accelerators. Four of these are non-chloride type accelerators. Both laboratory tests and actual field repairs were used to evaluate the performance of these accelerators as rapid setting highway repair materials. The effect of temperature and brand of cement on the effectiveness of the accelerators was also investigated.

17. Key Words
concrete, accelerated, highway, repair material, rapid-setting, calcium chloride, non-chloride, laboratory tests, field repairs, temperature

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	116	

Form DOT F 1700.7 (8-69)

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by

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David W. Fowler
Alvin H. Meyer

Research Report Number 311-3

Research Project 3-9-82-311

conducted for

State Department of Highways and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
The University of Texas at Austin

April 1984

PREFACE

The authors are indebted to many people for the information presented in this report. George Randolph (D-9), Fred Schindler (D-9), Ralph Banks (D-18), Gerald Peck (D-8), and Edward Kristaponis of the Federal Highway Administration were very generous with the time they gave to review the questionnaire, suggest evaluation tests, provide information on materials, and coordinate field tests. The field tests were also made possible by the helpful cooperation of many districts throughout the state. The help of all of the state and federal personnel is greatly appreciaated. Valuable assistance in the laboratory was provided by Kevin Smith and David Whitney. Valuable assistance was also provided by Nancy Zett who typed and assembled the report.

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ABSTRACT

Accelerating admixtures used in combination with portland cement concrete are widely used as rapid setting highway repair materials. There are a wide variety of accelerators available, most of which contain calcium chloride. Several non-chloride type accelerators have recently become available due to corrosion problems which have been associated with the use of calcium chloride accelerators. The behavior of these accelerators is not as well known.

This report provides an evaluation of the performance of five different types of accelerators. Four of these are non-chloride type accelerators. Both laboratory tests and actual field repairs were used to evaluate the performance of these accelerators as rapid setting highway repair materials. The effect of temperature and brand of cement on the effectiveness of the accelerators was also investigated.

SUMMARY

The evaluation of accelerated concrete for use as a rapid setting repair material for portland cement concrete pavements is described. The results of a survey of the districts of the Texas State Department of Highways and Public Transportation on their use of accelerated concrete for highway repairs are presented. Five different types of accelerators were evaluated in the laboratory. The concrete mix used to evaluate the performance of these accelerators was based on the Texas State Department of Highways and Public Transportation specifications for class "K" concrete. A laboratory testing program consisting of nine different tests was used for the evaluation of the accelerators. The results of the testing program are presented along with a summary of the field application in which accelerated concrete was used.

IMPLEMENTATION STATEMENT

The results of this study should be implemented as soon as possible for repairs requiring early strength gain. Daraset and Darex Corrosion Inhibitor, both non-calcium chloride accelerators, and Hydraset, a calcium chloride based accelerator, yielded the best results for initial and final set times and strength gains in the laboratory. Field tests using several of the accelerators have not revealed any significant differences in performance to date.

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CHAPTER 1. INTRODUCTION

1.1 Background

Rapid setting materials are in great demand for the repair of portland cement concrete pavements and bridge decks. High traffic volumes in urban areas require materials that will cure rapidly, in order to minimize traffic interruption, yet provide adequate strength and durability. One such rapid setting material is accelerated concrete, which consists of portland cement concrete used in combination with an accelerating admixture (1,2).

The best known and most widely used accelerator is calcium chloride. Many other materials have been found to accelerate the strength gain of concrete but only limited information concerning their effect on the properties of concrete is available. Most of the information available on accelerators applies mainly to the use of calcium chloride. Other chemicals which accelerate the rate of hardening of concrete include some other soluble chlorides, carbonates, sulfates, nitrates, nitrites, silicates, fluosilicates, alkali hydroxides, fluorides, formates, aluminates, and some organic compounds such as triethanolamine (1,2,3,4).

Most of the accelerators marketed in the U.S. are calcium chloride based. However, in response to the corrosion problems which some researchers have associated with the use of calcium chloride in reinforced concrete, several non-chloride and supposedly non-corrosive accelerators have been marketed recently (5,6). The behavior of these accelerators is not as well known as calcium chloride.

1.2 Scope

As part of Research Study 311, "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges", the performance of several different types of accelerators was studied, as well as the mechanical and durability properties of accelerated concrete which are important to its overall performance as a rapid setting repair material. This report summarizes the results of this study.

Chapter 2 is a summary of a survey of the districts of the Texas State Department of Highways and Public Transportation on their use of accelerated concrete for highway repairs. Chapter 3 describes the materials and mix proportions tested. Chapter 4 outlines the experimental tests conducted. Chapter 5 is a presentation and discussion of the experimental test results. Chapter 6 describes actual highway repairs made in Texas using accelerated concrete. Chapter 7 presents conclusions and recommendations.

CHAPTER 2. SURVEY OF TEXAS HIGHWAY DEPARTMENT DISTRICTS

2.1 District Questionnaire

A two page questionnaire was sent to each of the twenty-five State Department of Highways and Public Transportation Districts in Texas to obtain their experience with the use of accelerating admixtures in portland cement concrete for highway pavement repairs. The questionnaire had two basic parts.

The first part was to determine which districts had used accelerated concrete for highway repairs, when (time of year) they had used it, and the reasons for its use (i.e. early opening to traffic). It also determined which districts had not used accelerated concrete, their reasons for not using it, and whether they would consider using it in the future.

The second part of the questionnaire was an evaluation of the performance of each accelerator used by the districts. It determined which accelerators had been used by each district, the amount of accelerated concrete used per year, the types of repairs for which it was used, and the relative performance of the accelerated concrete for each type of repair. It also evaluated accelerated concrete in terms of cost, durability, ease of use, working time, and strength gain for each accelerator used, as well as an overall rating of the accelerator.

2.2 Use of Accelerated Concrete by Districts

The results of the first part of the survey indicated that twelve districts had used accelerated concrete for highway repairs in the past ten years and ten districts had not. Of those districts using accelerated concrete, the major reason for their use was to enable early opening of the repair to traffic. Most of those districts also reported that they used accelerated concrete year round, and did not limit their use to a specific season. Several districts did however comment that they do not use accelerated concrete in cold weather.

Most districts which had not used accelerated concrete in the past, report that they would consider using it in the future. The most common reason for not using accelerated concrete for highway pavement repairs was that they used other types of rapid-setting materials. A few districts reported that they did not have enough repairs to justify the use of accelerated concrete.

2.3 Accelerators Reported by District

Table 2.1 summarizes the use of accelerated concrete by district. Only those districts which responded to the questionnaire are listed. All accelerators reported are shown at the top of the table. The amount reported by each district is shown in cubic yards of accelerated concrete per year. The symbol XX indicates that the amount used was not reported. The absence of a number or symbol indicates that no use of that accelerator was reported by the district.

The questionnaire asked for all accelerators used in the past ten years to be reported. A total of ten different accelerators were reported. Cel-set® and Hydraset®[a] were the only accelerators reported

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[a]Trademark symbols are shown the first time product brand name is used; the symbols are omitted on subsequent usage of brand names.

Table 2.1. District Use of Accelerated Concrete[a]

District[b]	Cal Seal	Cel-Set	Dowel fl Calcium Chloride	Hydra-Set	LL-880 Master Builders	MB-122 HE	PSI-HE (Gifford Hill)	Sika-set	S. St. Bldg. Sp. CAS	Tri-cene HE
1				100						
2		100		100						
3				100						
4										
5										
6	5									
7			XX							
8										
9		125						100		
10		300								
11[c]										
12				XX	1200	XX	2730			250
13[c]										
14										
16										
17		500								
18				300					125	
19										
20										
21										
23										
25										

[a]Amount used in cubic yards of concrete per year
[b]Questionnaires not received from Districts 15, 24, and HU. District 22 combined with District 15.
[c]Districts 11 and 13 reported using accelerators but did not give type used.

Symbol: XX amount used not reported.

by more than one district. All other accelerators reported were used by only one district.

2.4 Evaluation of Use and Performance of Accelerator

Districts were asked to rank the accelerators they had used on a scale of one to five, with five indicating the best performance or lowest cost, for: (1) performance in different types of repairs; (2) cost; (3) durability; (4) ease of use; and (5) overall rating. They were also asked for approximate working time and strength gain time (time from placing to opening to traffic) based on temperature conditions. This evaluation is summarized in Table 2.2. The numerical rating is an average of the ratings provided by each district, and is not weighted for the amount of accelerator reported. It should be noted that the evaluations for accelerators which have been used only in small quantities by only one district may not be very meaningful.

The districts were also asked if they used the accelerator with reinforcing steel present, and if so, did they have any corrosion problems. Most districts reported that they did use the accelerator where reinforcing steel was present and had not had any corrosion problems reported to date. The type of each accelerator is also shown in Table 2.2. There were eight calcium chloride based accelerators and two non-chloride type accelerators reported.

Table 2.2. Summary of Accelerator Evaluations[a]

Accelerator	Type of Accelerator	Type of Repair: Pavement Repairs: Spall	Pavement Repairs: Small Punchout	Pavement Repairs: Large Punchout	Bridge Deck: Spall	Bridge Deck: Overlays	Pier or Abutment Spall	Guard Rail Posts	Cost	Durability	Ease of Use	Working Time (min.): Hot Weather (above 90°F)	Working Time (min.): Warm Weather (50°–90°F)	Working Time (min.): Cold Weather (below 50°F)	Strength Gain Time (min.): Hot Weather	Strength Gain Time (min.): Warm Weather	Strength Gain Time (min.): Cold Weather	Overall Rating
CAL SEAL	$CaCl_2$	3.0	NR[b]	NR	NR	NR	NR	5.0	1.0	2.0	3.0	15	20	30	30	45	60	4.0
CEL-SET	$CaCl_2$	3.0	4.0	3.8	3.5	NR	NR	NR	4.0	3.3	4.3	25	35	50	240	280	390	3.8
DOWEL FLAKE CALCIUM CHLORIDE	$CaCl_2$	NR	NR	NR	5.0	NR	NR	NR	5.0	5.0	4.0	NR	NR	NR	NR	NR	NR	5.0
HYDRA-SET	$CaCl_2$	1.0	3.8	4.0	3.0	2.0	2.0	2.0	3.6	4.0	4.6	30	40	50	230	290	380	4.0
LL-880	Non Cl	NR	NR	5.0	NR	NR	NR	NR	1.0	5.0	5.0	NR	30	NR	NR	240	NR	5.0
MB-122HE	$CaCl_2$	NR	4.0	NR	NR	NR	NR	NR	1.0	4.0	4.0	25	35	NR	180	240	NR	4.0
PSI-HE	Non Cl	5.0	NR	5.0	NR	NR	NR	NR	1.0	4.0	4.0	NR	30	NR	NR	240	NR	5.0
SIKA SET	$CaCl_2$	NR	3.0	4.0	3.0	NR	NR	NR	2.0	3.0	3.0	20	25	40	240	300	420	4.0
SOUTHERN ST. BLDG. SPEC. CAS	$CaCl_2$	NR	NR	5.0	5.0	NR	NR	NR	4.0	5.0	5.0	NR	20	30	NR	60	105	5.0
TRICENE-HE	$CaCl_2$	NR	5.0	5.0	NR	NR	NR	NR	1.0	5.0	5.0	25	35	NR	180	240	NR	4.0

[a]Evaluations are based on a subjective scale of 1 to 5 with 5 representing the best performance or lowest cost.
[b]NR indicates no response.

CHAPTER 3. MATERIALS TESTED

3.1 Introduction

After consultation with the Materials and Test Division of the State Department of Highways and Public Transportation, four accelerators were selected for laboratory testing. Three of these were non-chloride type accelerators: Acceleguard 80®, Darex Corrosion Inhibitor®, and LA-40®. The fourth was a calcium chloride based accelerator, Hydraset®. A fifth accelerator, Daraset®, also a non-chloride, was added after testing had begun.

3.2 Accelerators

3.2.1 Acceleguard 80

Acceleguard 80 is a calcium nitrate ($Ca(NO_3)_2$) based accelerator manufactured by the Euclid Chemical Company. It is classified as an ASTM C-494 Type E admixture. The manufacturer's recommended dosage rate is 16 to 32 fluid ounces per 100 pounds of cement (1.04 to 2.09 liters/100 kg), depending on ambient temperature and acceleration required. The maximum dosage rate of 32 fluid ounces per 100 pounds of cement (2.09 liters/100 kg) was used in these tests.

3.2.2 Darex Corrosion Inhibitor

Darex Corrosion Inhibitor is a calcium nitrite ($Ca(NO_2)_2$) based accelerator and corrosion inhibitor manufactured by W.R. Grace. It is classified as an ASTM C-494 Type C admixture. The manufacturer's recommended dosage rate is 85 to 170 fluid ounces per 100 pounds of cement (5.54 to 11.08 liters/100 kg). The optimum dosage rate for acceleration was found to be 100 fluid ounces per 100 pounds of cement. (6.52 liters/100 kg). This dosage rate was used in these tests.

3.2.3 LA-40

LA-40 is a sodium thiocyanate (Na SCN) based accelerator manufactured by Master Builders. It is classified as an ASTM C-494 Type C admixture. The manufacturer's recommended dosage rate is 2 to 6 fluid ounces per 100 pounds of cement (0.13 to 0.39 liters/100 kg) depending upon the amount of acceleration desired. A dosage rate of 6 fluid ounces per 100 pounds of cement (0.39 liters/100 kg) was used in these tests.

3.2.4 Hydraset

Hydraset is a calcium chloride ($CaCl_2$) based accelerator manufactured by W.R. Meadows. It is classified as an ASTM C-494 Type C admixture. The manufacturer's recommended dosage is one pint to 2 quarts per bag of cement (1.11 to 4.44 liters/100 kg). A dosage rate of 2 quarts per bag (4.44 liters/100 kg) was used in these tests. This dosage rate corresponds to approximately 2 percent calcium chloride by weight of cement.

3.2.5 Daraset

Daraset is a non-chloride type accelerator which contains calcium nitrite ($Ca(NO_2)_2$) and calcium nitrate ($Ca(NO_3)_2$). It is manufactured by W.R. Grace and is classified as an ASTM C-494 Type C admixture. Daraset was suggested by the manufacturer as performing as well as Darex Corrosion Inhibitor, but at a lower cost. A dosage rate of 100 fluid ounces per 100 pounds of cement (6.52 liters/100 kg) was used in these tests.

3.3 Class "K" Concrete

The concrete mix used for all tests except the mortar cube compression tests, was based on the Texas State Department of Highways and Public Transportation specifications for class "K" concrete. These specifications are shown in Table 3.1. The actual mix designs for all five accelerators tested as well as a control mix with no accelerator are shown in Table 3.2. Because these accelerators are high volume liquid admixtures, the water added to the concrete mixes is reduced by the amount of accelerator added.

3.3.1 Cement

The specifications for class "K" concrete call for seven sacks of Type III cement per cubic yard of concrete. Two brands of Type III cement were used. Capitol Type III cement was used for most tests, and Alamo Type III cement was used only for selected strength versus time tests at 75°F (24°C).

The mixes using Alamo Type III cement were stiffer and more difficult to place and finish than the mixes using Capitol Type III cement.

3.3.2 Aggregate

The coarse aggregate used in all mixes was a 3/8 in. (9.5-mm) maximum size pea gravel with a unit weight of 96.7 lb /ft^3 (1550 kg /m^3), a bulk specific gravity (dry) of 2.58 and an absorption of 1.4 percent.

Table 3.1. Specifications for Class "K" Concrete (13).

Cement Type	Min. Sacks Cement Per Cubic Yard	Min. Flex Strength psi	Max. Water Cement Ratio
III	7	500*	5-1/2 gals./bag

Slump Range in.	Coarse Aggregate No.	Fine Aggregate No.	Fineness Modulus
1-3	4	1	2.6-2.8

*Min. flexural strength reached in 3 days.

Class "K" concrete shall be designed to have an entrained air content of 3 to 6 percent and a high early strength using concrete admixtures. Air-entraining admixtures shall conform to the requirements of ASTM C260. Nonchloride-type water-reducing set-accelerating admixtures meeting requirements of ASTM C494, Type E, shall be used to achieve the earliest possible concrete setting times.

Table 3.2 Accelerated Concrete Mix Proportions.

MATERIALS PER CUBIC YARD (SSD)	CONTROL	ACCELEGUARD 80	DARASET	DAREX CORROSION INHIBITOR	HYDRASET	LA-40
Accelerator (fl. oz) (liter)	0 0	211 6.24	658 19.46	658 19.46	448 13.25	39.5 1.17
Cement (lb) (Type III) (kg)	658 298.5	658 298.5	658 298.5	658 298.5	658 298.5	658 298.5
Coarse Aggregate (lb) (kg)	1854 841	1854 841	1854 841	1854 841	1854 841	1854 841
Fine Aggregate (lb) (kg)	1022 463.6	1022 463.6	1022 463.6	1022 463.6	1022 463.6	1022 463.6
*Water (gal) (liter)	34.76 131.58	33.11 125.34	29.62 112.12	29.62 112.12	31.26 118.33	34.25 130.41
Air Entraining (fl. oz) Admixture (liter)	9.1 0.27	9.1 0.27	9.1 0.27	9.1 0.27	9.1 0.27	9.1 0.27
*High Range (fl. oz) Water Reducer (liter)	91.3 2.70	91.3 2.70	91.3 2.70	91.3 2.70	91.3 2.70	91.3 2.70

*The High Range Water Reducer was not used in mixes tested at 40°F (4°C). The amount of water used in these mixes was increased by the volume of High Range Water Reducer shown above.

The fine aggregate used was a silicious sand with a fineness modulus of 2.53, a specific gravity (SSD) of 2.59, and an absorption of 0.8 percent. While this fineness modulus was slightly out of the range given in the class "K" specifications, it was felt that it would not significantly affect the results.

3.3.3 Other Admixtures

The specifications for class "K" concrete also call for air entrainment of 3 to 6 percent. The air entraining admixture used was Septair, manufactured by Monier Resources. A dosage rate of 1.3 fluid ounces per sack of cement (90 ml/100 kg) was used in all mixes.

A high range water reducer (super plasticizer) was also used in the mixes tested at 75°F (24°C) and 110°F (43°C) to provide a more workable mix. It was not used in the mixes tested at 40°F (4°C) because increased workability was not required. The high range water reducer used was Pozzolith 400N, manufactured by Master Builders. A dosage rate of 13 fluid ounces per sack of cement (0.90 liters/100 kg) was used.

3.3.4 Mixing Procedure

The procedure used to mix the materials for class "K" concrete is important in achieving the proper performance of the concrete admixtures. The admixtures should not come in contact with each other before being introduced into the concrete mix.

The mixing procedure used for class "K" concrete in these tests was as follows:

1) the fine and coarse aggregate were introduced into the concrete mixer along with 75 percent of the total mixing water and the air entraining admixture. The air entraining admixture was diluted into half of this water before being introduced into the mixer. These materials were mixed for 2 minutes.

2) After 2 minutes of mixing, the cement was added along with the final 25 percent of the mix water and mixed until all of the cement had been wetted.

3) After all the cement had been completely wetted, the accelerator was added and the concrete was mixed for another 2 minutes.

4) Finally, the high range water reducer was added and the concrete was mixed for another 1 to 2 minutes, before being cast into the molds.

3.4 Accelerated Mortar

The mix proportions for the mortar cube specimens were based on those given in ASTM C-109, "Compressive Strength of Hydraulic Cement Mortars", and are shown in Table 3.3. Again, the amount of water added was reduced by the amount of accelerator added. The accelerator dosage rates used for the mortar mixes were the same as those used in the class "K" concrete mixes. The sand used was standard Ottawa sand graded according to ASTM C-109 specifications.

Table 3.3. Mortar Cube Mix Proportions.

MATERIAL (12 Specimens)	CONTROL	ACCELEGUARD 80	DARASET	DAREX CORROSION INHIBITOR	HYDRASET	LA-40
Accelerator (fl. oz) (ml)	0 0	0.71 21	2.2 65	2.2 65	1.50 44	0.13 3.9
Cement (Type III) (lb) (kg)	2.20 1.0	2.20 1.0	2.20 1.0	2.20 1.0	2.20 1.0	2.20 1.0
Sand (ASTM C109 Ottawa) (lb) (kg)	6.06 2.75	6.06 2.75	6.06 2.75	6.06 2.75	6.06 2.75	6.06 2.75
Water (fl. oz) (ml)	16.37 484	15.66 463	14.17 419	14.17 419	14.87 440	16.24 480

CHAPTER 4. EXPERIMENTAL TEST PROCEDURES

4.1 Introduction

Nine tests were conducted to evaluate the performance of each accelerator as well as to determine the mechanical and durability properties of accelerated concrete. Six of these tests were American Society of Testing and Materials (ASTM) standard tests (7) and were carried out following ASTM specifications with as few modifications as possible; three were non-standard tests.

All nine tests were conducted at ambient laboratory conditions, approximately 75°F (24°C) and 50 percent relative humidity. In addition, four tests were conducted at both 40°F (4°C) and 110°F (43°C) in order to determine the effect of temperature on the rate of strength gain and set time of accelerated concrete. The four tests were: mortar cubes, compressive cylinders, flexural strength, and set time. These tests were carried out in a temperature regulated environmental chamber. All materials were placed in the chamber twelve hours before mixing in order to insure a uniform temperature in all materials. The accelerated concrete was mixed, placed and cured in the environmental chamber and the specimens were not removed from the chamber until the time of testing.

4.2 Compressive Strength

4.2.1 Mortar Cubes

The mortar cube compressive strength test was performed according to ASTM C 109-80, "Compressive Strength of Hydraulic Cement Mortars."

The specimens were cast in 2-in. x 2-in. x 2-in. (50.8-mm x 50.8-mm x 50.8-mm) steel molds and tested at ages of 4 hours, 8 hours, 24 hours, and 3 days. Specimens cast at 75°F (24°C) were placed in a moist curing chamber immediately after casting. Specimens cast at 40°F (4°C) and 110°F (43°C) were covered with a damp cloth and cured at these temperatures. The specimens were removed from the molds either at time of testing or 24 hours after casting.

4.2.2 Cylinders

Compression cylinders were cast and tested according to ASTM C39-81, "Compression Strength of Cylindrical Concrete Specimens." The specimens tested were 3-in. x 6-in. (76.2-mm x 152.4-mm) cylinders which were cast in cardboard molds. Cylinders were tested at ages of 4 hours, 8 hours, 24 hours, and 3 days. All specimens were capped to provide a smooth loading surface. Specimens cast at 75°F (24°C) were covered with a damp cloth immediately after casting. The 4 hour and 8 hour specimens were removed from the molds at the time of testing. The 24 hour and 3 day test specimens were removed from the molds and placed in a moist curing chamber eight hours after mixing. Specimens cast at 40°F (4°C) and 110°F (43°C) were covered with a damp cloth and cured at these temperatures. These specimens were removed from molds either at time of testing or 24 hours after mixing.

4.3 Flexural Strength

The flexural strength test was performed according to ASTM C78-75, "Flexural Strength of Concrete." The specimens were cast in 2-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 304.8-mm) steel molds.

The beams were tested using a third-point loading on a span of 6-in. (152.4-mm), at 4 hours, 8 hours, 24 hours, and 3 days. Specimens cast at 75°F (24°C) were covered with a damp cloth immediately after casting. The 4 hour and 8 hour specimens were removed from the molds at the time of testing. The 24 hour and 3 day test specimens were removed from the molds and placed in a moist curing chamber eight hours after mixing. Specimens cast at 40°F (4°C) and 110°F (43°C) were covered with a damp cloth and cured at these temperatures.

4.4 Set Time

The set time of the accelerated concrete was determined according to ASTM C403-80, "Time of Setting of Concrete Mixtures by Penetration Resistance." The wet concrete was sieved through a No. 4 sieve and the resulting mortar was placed into a 6-in. x 6-in. (152.4-mm x 152.4-mm) cardboard cylinder and tested using the penetrometer shown in Fig. 4.1.

4.5 Flexural Bond

Flexural bond strength of accelerated concrete to existing portland cement concrete (PCC) was investigated in this test (8). Two-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 304.8-mm) PCC beams were cast and cured for 28 days. Mix proportions for PCC beams are given in the Appendix. These beams were then broken in flexure in the middle. The resulting 2-in. x 2-in. x 6-in. (50.8-mm x 50.8-mm x 152.4-mm) beams were placed in 2-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 304.8-mm) steel molds and accelerated concrete was cast against the broken faces. The resulting beams were tested in flexure after 24

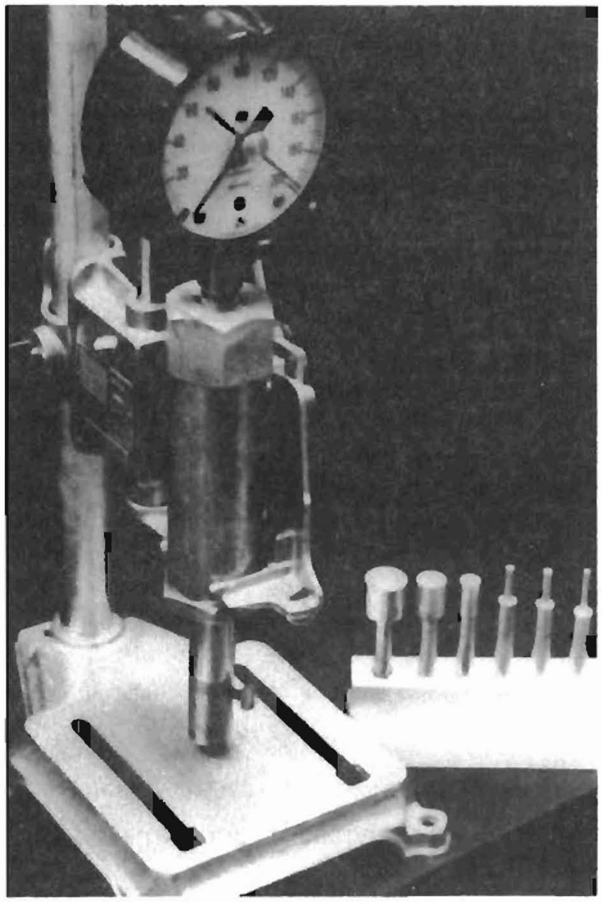


Fig. 4.1. Penetrometer Used for Penetration Resistance Set Time Test.

hours using a third-point loading, as shown in Fig. 4.2. Four types of bonding surfaces were investigated: wet (soaked in water for 24 hours), dry, mortar grout, and epoxy. The proportions of the mortar grout are given in the Appendix. The type of epoxy used was Concresive 1001 LPL manufactured by the Adhesive Engineering Company.

4.6 Sandblast Abrasion

The abrasion resistance test was performed according to ASTM C418-76, "Abrasion Resistance of Concrete by Sandblasting." The specimens used for this test were 5-in. x 5-in. x 1-in. (127-mm x 127-mm x 25.4-mm) plates which were moist cured for seven days. The weight of material lost due to abrasion was measured rather than the depth and volume of the abraded cavity.

4.7 Length Change

The relative length change of accelerated concrete was investigated in this test. The test specimens were cast in 2-in. x 2-in. x 11-1/4-in. (50.8-mm x 50.8-mm x 287.75-mm) steel molds conforming to ASTM C-490. Gage studs were cast in both ends of the beams in order to accurately measure the changes in length. The specimens were moist cured in the molds for 24 hours. They were then removed from the molds and the initial length was measured. The specimens were moist cured for 7 days after removal from the molds. They were then air cured at a temperature of 75°F (24°C) and relative humidity of 50 percent, neither of which were controlled. The change in length of the specimen was periodically measured with an extensometer as shown in Fig. 4.3.

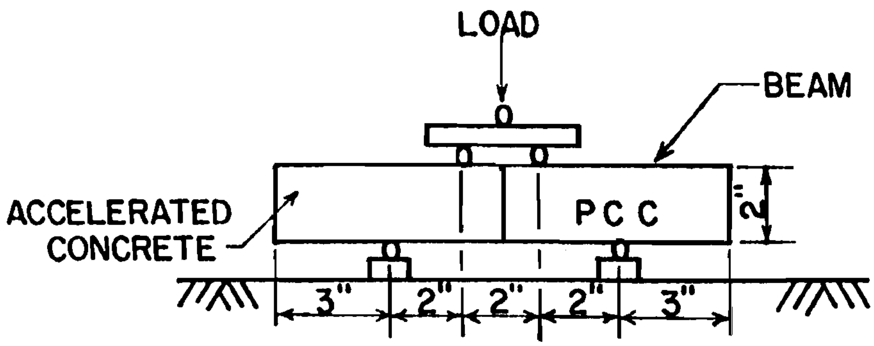


Fig. 4.2. Loading Arrangement for Flexural Bond Test.

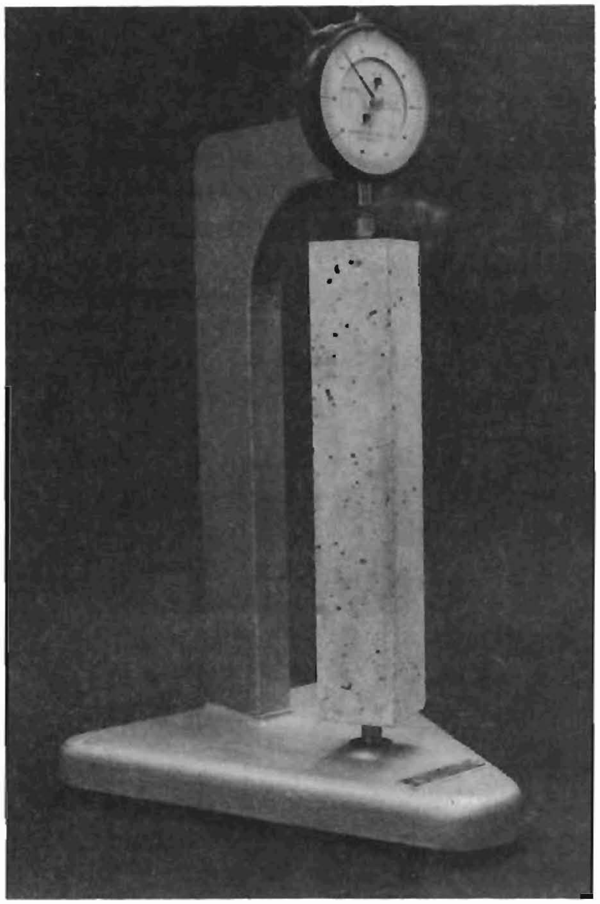


Fig. 4.3. Extensometer Used for Length Change Test.

4.8 Freeze-Thaw Resistance

The freeze-thaw resistance test was performed in accordance with ASTM C666-80, "Resistance of Concrete to Rapid Freezing and Thawing." The specimens were cast in 3-in. x 3-in. x 16-in. (76.2-mm x 76.2-mm x 406.4-mm) steel molds and were moist cured for 7 days before being subjected to freeze-thaw cycles. Procedure A of ASTM C666, rapid freezing and thawing in water, was used in these tests. Four freeze-thaw cycles per day were obtained using the freeze-thaw cabinet shown in Fig. 4.4. The apparatus used to measure the fundamental transverse frequency of the specimens is shown in Fig. 4.5.

4.9 Corrosion Tests

The potential for corrosion of embedded steel in accelerated concrete was investigated in these tests (11). The test specimens were 3-in. x 6-in. (76.2-mm x 152.4-mm) cylinders cast with a 4-in. (101.6-mm) long No. 3 deformed steel bar embedded in the concrete with a minimum cover of 1/2-in. (12.7-mm). A lead wire was attached to the No. 3 bar. The specimens were moist cured for 28 days. After 28 days the specimens were placed in one of two types of environmental conditions. A non-corrosive environment was simulated by placing the specimens in a moist curing chamber. A corrosive environment was simulated by placing the specimens in a salt water solution (0.36% NaCl), so that two-thirds of the specimen was submerged in the salt water and one-third of the specimen was exposed to air. The electrochemical potential and polarization curve of each specimen was determined at one, two, four, and six months after casting, using a Model 350-Corrosion

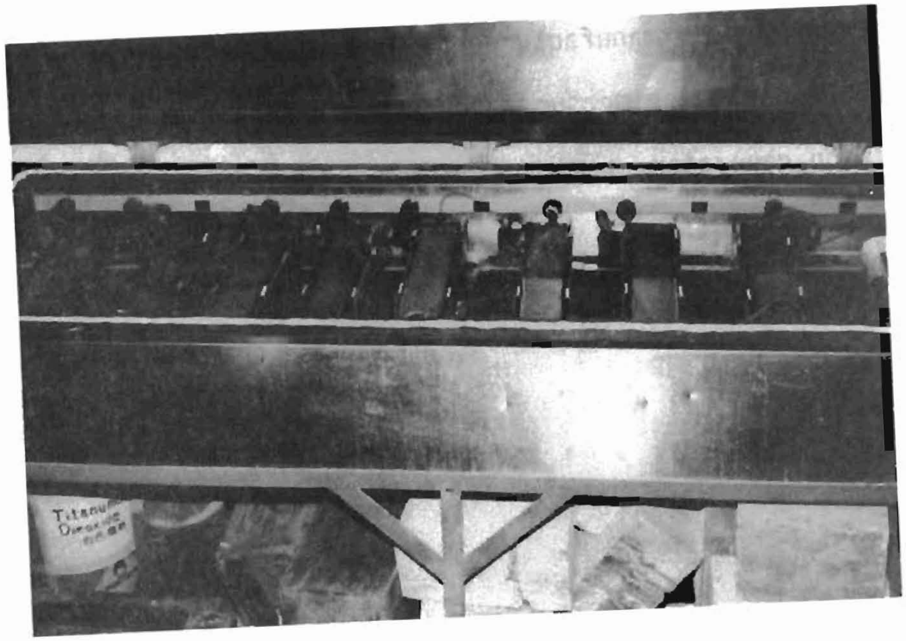


Fig. 4.4. Freeze-Thaw Cabinet.

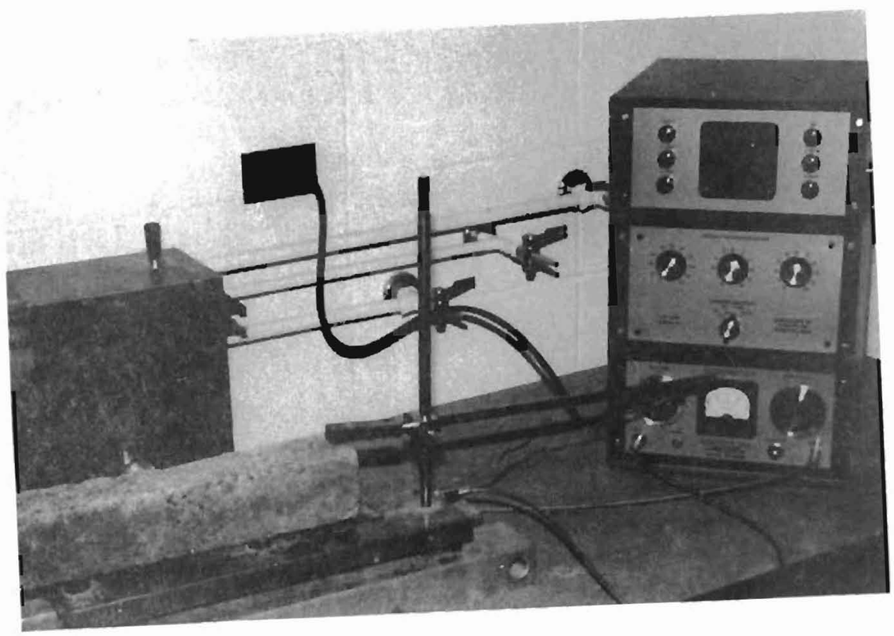


Fig. 4.5. Apparatus Used for Measurement of Fundamental Transverse Frequency of Freeze-Thaw Specimens.

Measurement System manufactured by Princeton Aplied Research. This particular corrosion measurement system consists of a potentiostat, a function generator, a microcomputer, and an X-Y recorder.

CHAPTER 5. EXPERIMENTAL TEST RESULTS

5.1 Introduction

The experimental tests outlined in the previous chapter were performed to evaluate the performance of each accelerator, as well as to evaluate the performance of accelerated concrete as a rapid setting repair material. All accelerators were tested for compressive strength, flexural strength, and set time at 75°F (24°C) using Capitol Type III cement. All accelerators except Daraset were tested for compressive strength, flexural strength, and set time at temperatures of 110°F (43°C) and 40°F (4°C) using Capitol Type III cement. Daraset was not included because it was added to the test program after these tests were concluded. However, because its chemical composition is similar to that of Darex Corrosion Inhibitor, its performance at these temperatures should be similar also.

After these strength gain tests were performed, the testing of Acceleguard 80 and LA-40 was discontinued because they did not provide the acceleration required of a rapid setting repair material. All tests, except freeze-thaw resistance, were also performed on a control mix, containing no accelerator, to provide a comparison with non-accelerated concrete.

5.2 Compressive Strength

5.2.1 Mortar Cubes

The compressive strength gain versus time of mortar cubes was determined for all five accelerators at 75°F (24°C). The results are tabulated in Table 5.1 and plotted in Fig. 5.1. Daraset, Darex Corrosion Inhibitor, and Hydraset performed substantially better than Acceleguard 80 and LA-40 with 8 hour compressive strength approximately twice those of Acceleguard 80 and LA-40.

The mortar cube compressive strength gain versus time was also determined for ambient temperatures of 110°F (43°C) and 40°F (4°C) for all accelerators except Daraset. These results are plotted in Fig. 5.2 and tabulated in Table 5.1. Again, Darex Corrosion Inhibitor and Hydraset outperformed Acceleguard 80 and LA-40 at both temperatures. Figure 5.2 also shows that temperature has a significant effect on the rate of strength gain of the mortar cubes. The 4-hour compressive strengths at 110°F (43°C) are greater than the 24-hour strengths at 40°F (4°C) for all accelerators.

The mortar cube compressive strength gain versus time was also determined using Alamo Type III cement for Daraset and Hydraset at 75°F (24°C). These results are plotted in Fig. 5.3 and tabulated in Table 5.1. The use of Alamo Type III cement instead of Capitol Type III did not affect the performance of Hydraset; however, Daraset did not perform as well with the Alamo brand of cement.

5.2.2 Cylinders

The compressive strength gain versus time of cylinders was determined for all five accelerators at an ambient temperature of 75°F (24°C). The results are tabulated in Table 5.2 and plotted in Fig. 5.4. The same trend was found for cylinder compressive strength as was found using mortar cubes. The rate of compressive strength gain

TABLE 5.1

COMPRESSIVE STRENGTH OF MORTAR CUBES

Temp.	Brand of Type III Cement	Accelerator	Average Compressive Strength 4 hr (psi)	4 hr (Mpa)	8 hr (psi)	8 hr (Mpa)	24 hr (psi)	24 hr (Mpa)	3 days (psi)	3 days (Mpa)
75°F (24°C)	Capitol	Control	30	0.21	440	3.03	3390	23.37	5550	38.27
		Acceleguard 80	155	1.07	925	6.38	3495	24.09	5290	36.47
		Daraset	495	3.41	1515	10.44	4335	29.88	7125	49.13
		Darex Corrosion Inh	310	2.14	1280	8.83	4235	29.20	6885	47.47
		Hydraset	390	2.69	1600	11.03	4270	29.44	6670	45.99
		LA-40	30	0.21	715	4.93	3950	27.23	6050	41.71
110°F (43°C)	Capitol	Control	250	1.72	2110	14.55	4970	34.27	6700	46.20
		Acceleguard 80	680	4.69	2760	19.03	5375	37.06	6900	47.58
		Darex Corrosion Inh	1450	10.00	3280	22.62	6800	49.89	7490	51.64
		Hydraset	1980	13.65	3775	26.03	6640	45.78	8225	56.71
		LA-40	240	1.65	2325	16.03	5335	36.78	6775	46.71
40°F (4°C)	Capitol	Control	0	0	40	0.28	490	3.38	3240	22.34
		Acceleguard 80	30	0.21	80	0.55	460	3.17	2615	18.03
		Darex Corrosion Inh	30	0.21	85	0.59	895	6.17	3415	23.55
		Hydraset	30	0.21	100	0.69	1340	9.24	4210	29.03
		LA-40	20	0.14	45	0.31	755	5.21	4105	28.31
75°F (24°C)	Alamo	Control	30	0.21	305	2.10	2830	19.51	4640	31.99
		Daraset	205	1.41	675	4.65	3345	23.07	5610	38.68
		Hydraset	390	2.69	1645	11.34	4500	31.03	6565	45.27

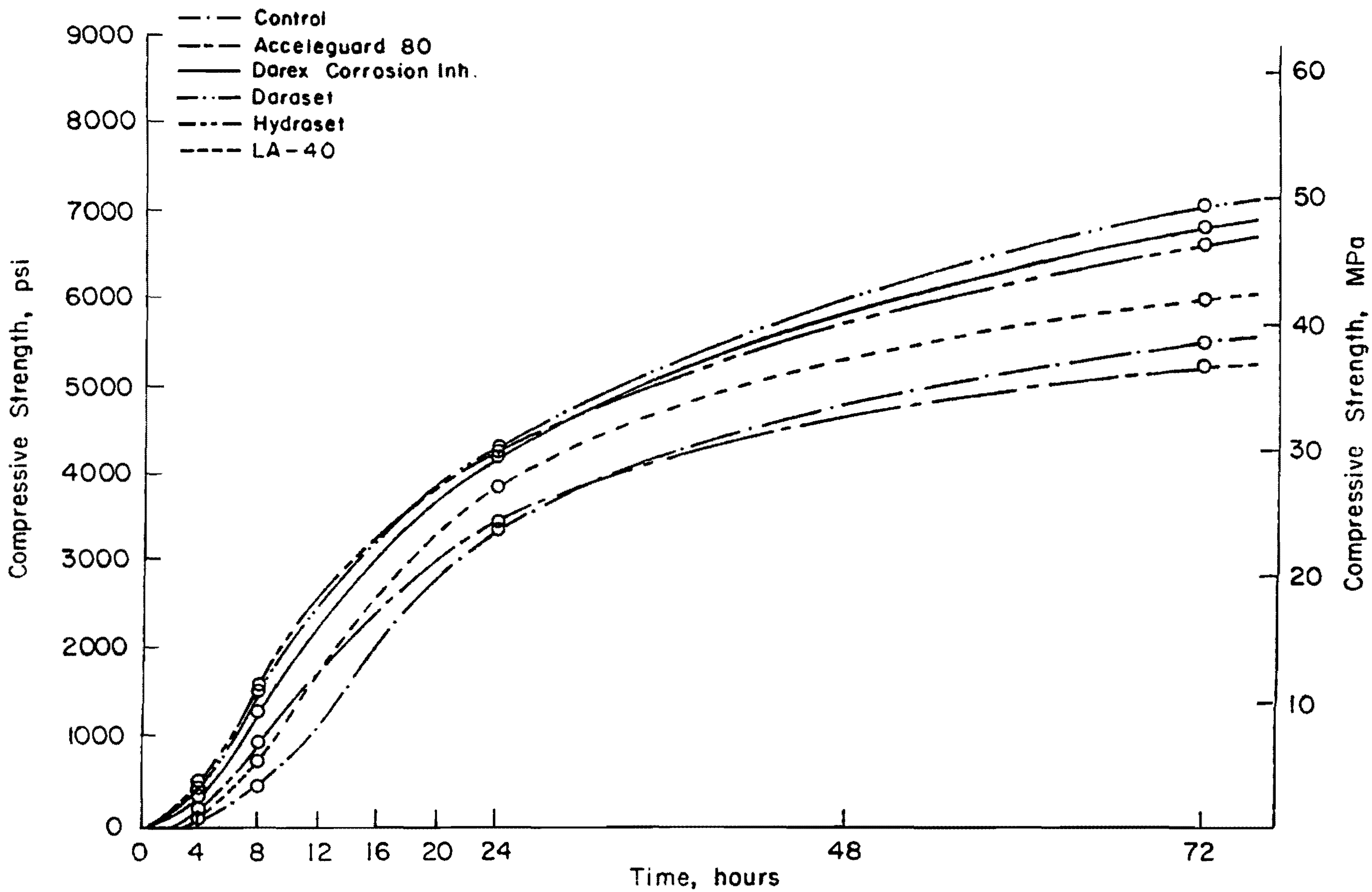


Fig. 5.1. Compressive Strength vs Time of Mortar Cubes with Capitol Type III Cement at 75°F (24°C).

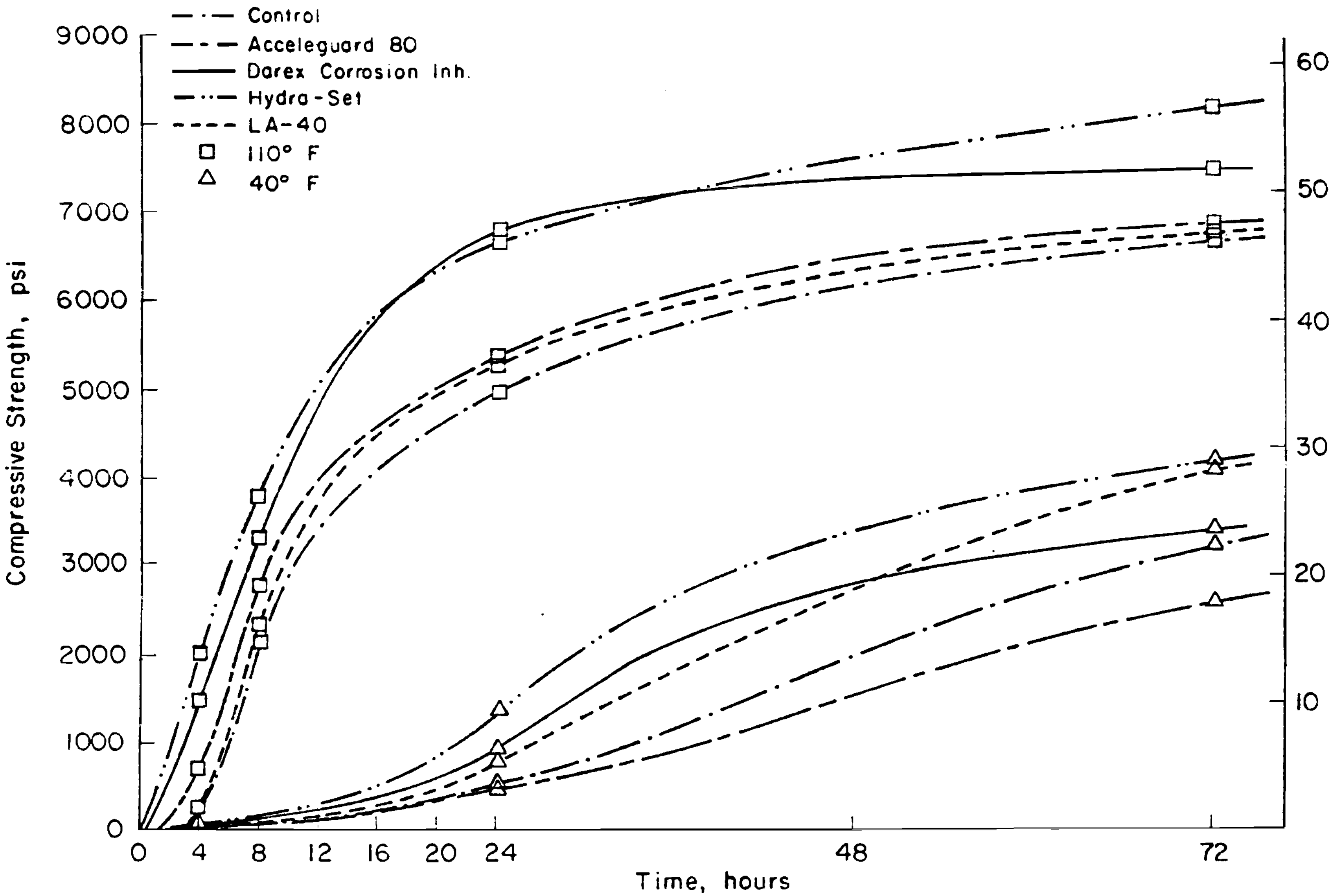


Fig. 5.2. Compressive Strength vs Time of Mortar Cubes with Capitol Type III Cement at 110°F (43°C) and 40°F (4°C).

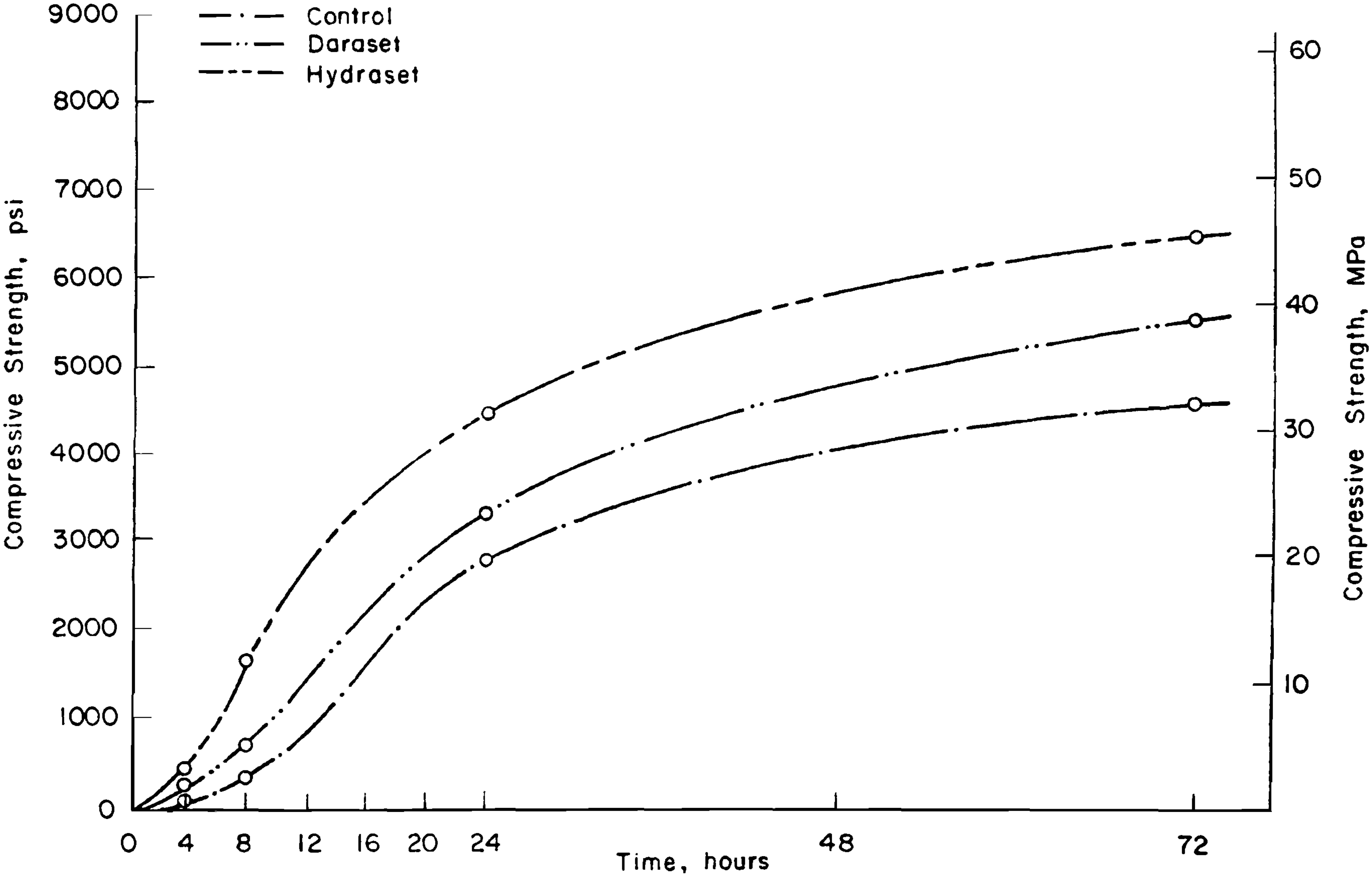


Fig. 5.3. Compressive Strength vs Time of Mortar Cubes with Alamo Type III Cement at 75°F (24°C).

TABLE 5.2

COMPRESSIVE STRENGTH OF CYLINDERS

TEMP.	BRAND OF TYPE III CEMENT	ACCELERATOR	AVERAGE COMPRESSIVE STRENGTH 4 hr (psi)	4 hr (MPa)	8 hr (psi)	8 hr (MPa)	24 hr (psi)	24 hr (MPa)	3 days (psi)	3 days (MPa)
75°F (24°C)	Capitol	Control	0	0	335	2.31	3400	23.44	5175	35.68
		Acceleguard 80	60	0.41	810	5.58	3490	24.06	5560	38.34
		Daraset	710	4.89	2575	17.75	4320	29.79	5850	40.34
		Darex Corrosion Inh.	445	3.07	2240	15.44	4160	28.68	5950	41.03
		Hydraset	555	3.83	2530	17.44	4330	29.86	5835	40.23
		La-40	0	0	740	5.10	3415	23.55	5400	37.23
110°F (43°C)	Capitol	Control	125	0.86	1990	13.72	4505	31.06	5290	36.47
		Acceleguard 80	380	2.62	2550	17.58	4565	31.48	5360	36.96
		Darex Corrosion Inh.	1390	9.58	3560	24.55	5425	37.41	6310	43.51
		Hydraset	2055	14.17	3930	27.10	5350	37.16	6215	42.85
		LA-40	125	0.86	2155	14.86	4585	31.61	5480	37.78
			* 6 hr							
40°F (4°C)	Capitol	Control	0	0	25	0.17	580	4.00	3090	21.31
		Acceleguard 80	25	0.17	40	0.28	380	2.62	2060	14.20
		Darex Corrosion Inh.	55	0.38	95	0.65	1140	7.68	3770	25.99
		Hydraset	50	0.34	150	1.03	1660	11.45	3800	26.20
		LA-40	0	0	25	0.17	680	4.69	3250	22.41
75°F (24°C)	Alamo	Control	35	0.24	645	4.45	3320	22.89	5300	36.54
		Daraset	540	3.72	2010	13.86	4405	30.37	6290	43.37
		Hydraset	665	4.58	2705	18.65	4605	31.75	6320	43.58

* – Specimens tested at 40°F did not have sufficient strength to be removed from the molds at 4 hrs. They were tested at 6 hrs. instead.

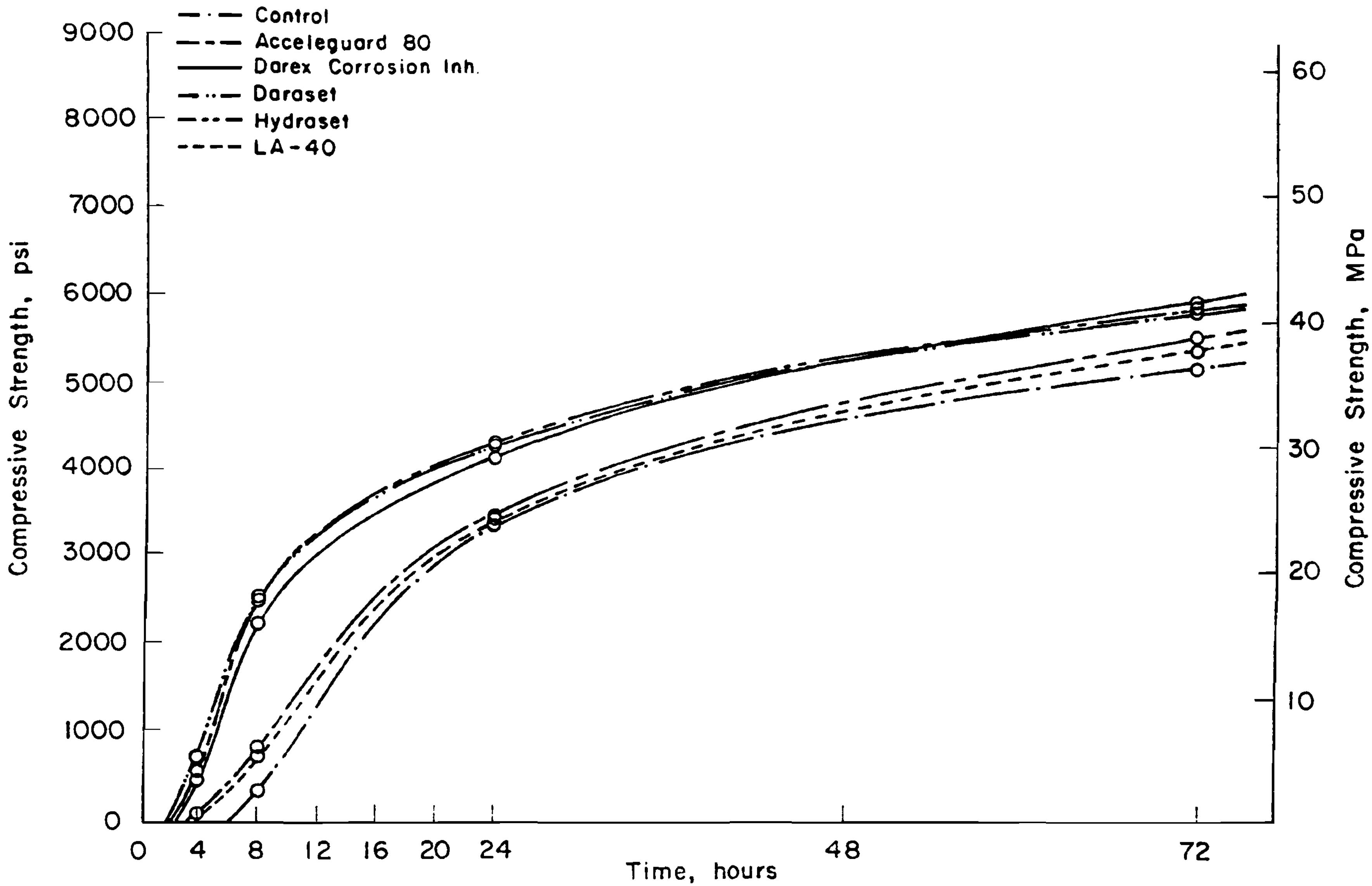


Fig. 5.4. Cylinder Compressive Strength vs Time with Capitol Type III Cement at 75°F (24°C).

was substantially greater for Daraset, Darex Corrosion Inhibitor and Hydraset, with 8-hour compressive strength of approximately three times those of Acceleguard 80 and LA-40.

The cylinder compressive strength versus time was also determined for temperatures of 110°F (43°C) and 40°F (4°C) for all accelerators except Daraset. These results are plotted in Fig. 5.5 and tabulated in Table 5.2. The rate of cylinder compressive strength gain was similar to that of mortar cubes at these temperatures. The mortar cubes, however, achieved higher ultimate strengths than the cylinders.

The cylinder compressive strength gain versus time was determined using Alamo Type III cement for Daraset and Hydraset at 75°F (24°C). These results are plotted in Fig. 5.6 and tabulated in Table 5.2. There was little difference in the rate of cylinder compressive strength gain between the two brands of cement for these two accelerators.

5.3 Flexural Strength

The flexural strength gain versus time of 2-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 304.8-mm) beams was determined for all five accelerators at 75°F (24°C). The results are tabulated in Table 5.3 and plotted in Fig. 5.7. The rate of flexural strength gain was very similar for Daraset, Darex Corrosion Inhibitor, and Hydraset, all of which achieved a flexural strength of 400 psi (2.75 MPa) in 8 hours. Acceleguard 80 and LA-40 achieved only 200 psi (1.38 MPa) in 8 hours.

The flexural strength gain versus time was also determined for temperatures of 110°F (43°C) and 40°F (4°C) for all accelerators except

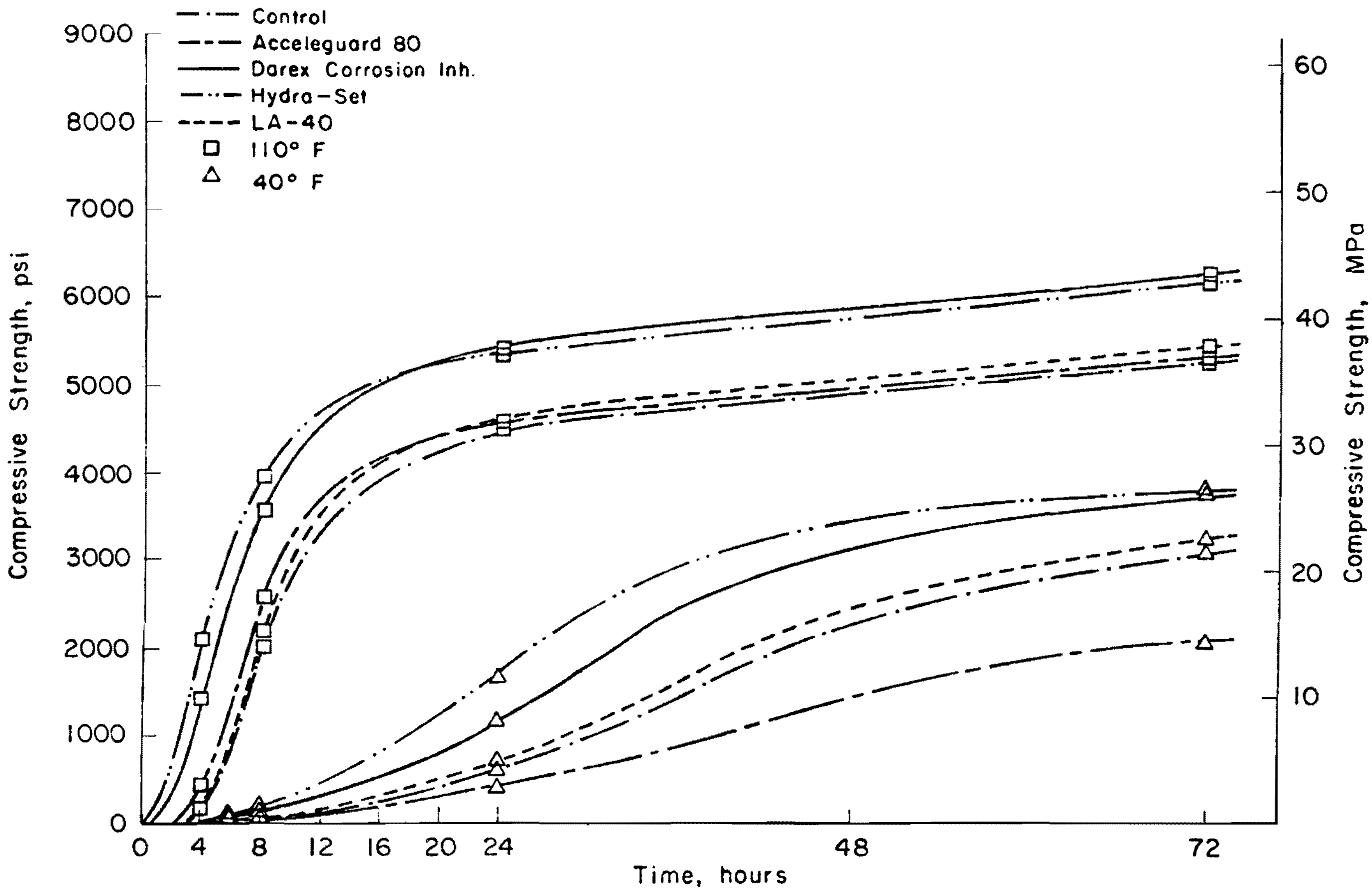


Fig. 5.5. Cylinder Compressive Strength vs Time with Capitol Type III Cement at 110°F (43°C) and 40°F (4°C).

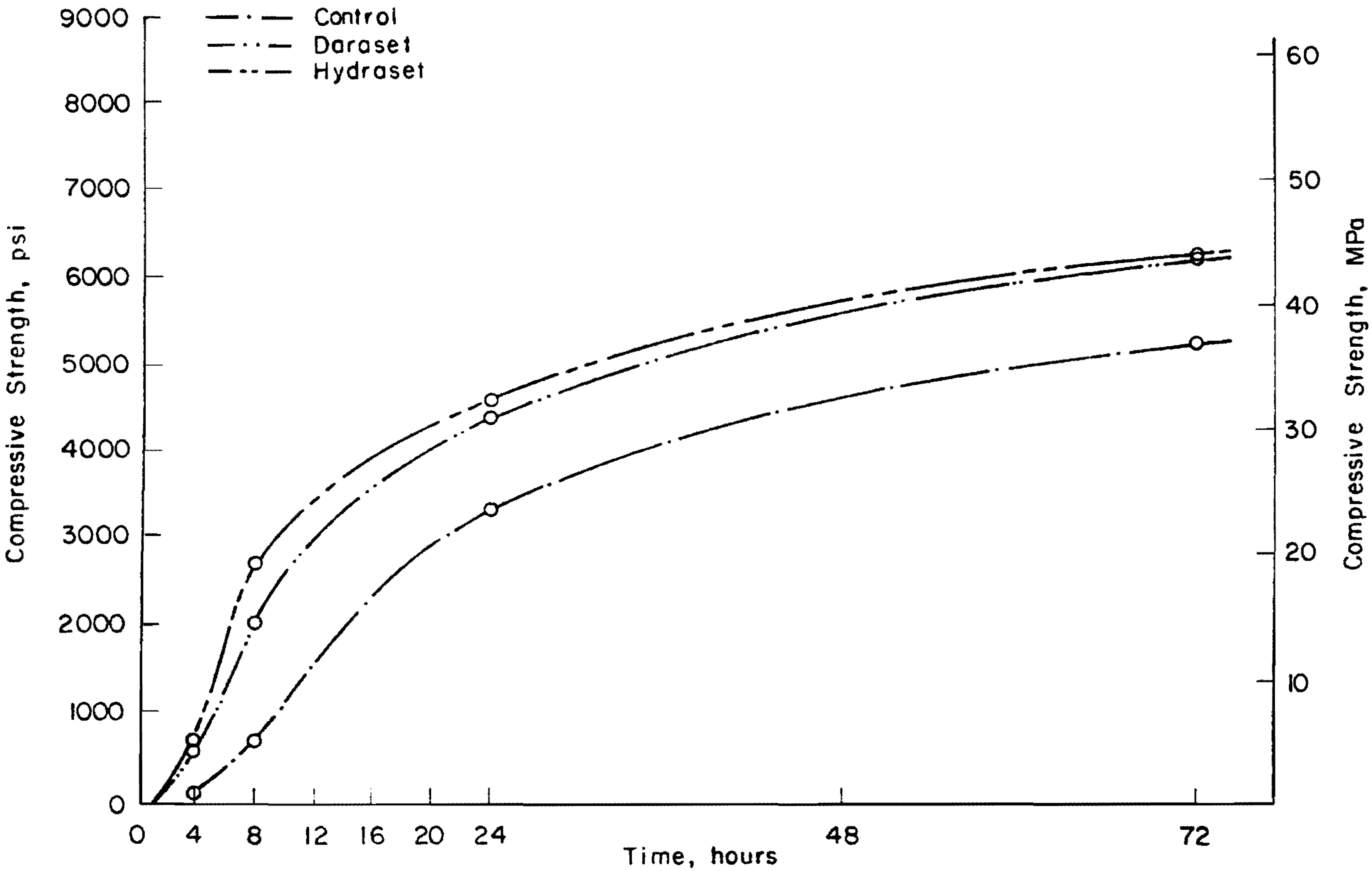


Fig. 5.6. Cylinder Compressive Strength vs Time with Alamo Type III Cement at 75°F (24°C).

TABLE 5.3

FLEXURAL STRENGTH

TEMP.	BRAND OF TYPE III CEMENT	ACCELERATOR	AVERAGE FLEXURAL STRENGTH 4 hr (psi)	4 hr (MPa)	8 hr (psi)	8 hr (MPa)	24 hr (psi)	24 hr (MPa)	3 days (psi)	3 days (MPa)
75°F (24°C)	Capitol	Control	0	0	85	0.59	585	4.03	760	5.24
		Acceleguard 80	20	0.14	200	1.38	610	4.21	840	5.79
		Caraset	135	0.93	380	2.62	655	4.52	885	6.10
		Darex Corrosion Inh.	115	0.79	390	2.69	655	4.52	850	5.86
		Hydraset	115	0.79	405	2.79	660	4.55	875	6.03
		LA-40	0	0	185	1.28	605	4.17	810	5.58
110°F (43°C)	Capitol	Control	25	0.17	315	2.17	670	4.62	675	4.65
		Acceleguard 80	85	0.59	460	3.17	720	4.96	760	5.24
		Darex Corrosion Inh.	255	1.76	525	3.62	830	5.72	885	6.10
		Hydraset	310	2.14	595	4.10	770	5.31	870	6.00
		LA-40	20	0.14	330	2.28	735	5.07	770	5.31
			* 6 hr							
40°F (4°C)	Capitol	Control	0	0	5	0.03	135	0.93	635	4.38
		Acceleguard 80	0	0	5	0.03	50	0.34	450	3.10
		Darex Corrosion Inh.	10	0.07	25	0.17	285	1.96	650	4.48
		Hydraset	10	0.07	40	0.28	385	2.65	625	4.31
		LA-40	0	0	10	0.07	200	1.38	600	4.14
75°F (24°C)	Alamo	Control	0	0	145	1.00	670	4.62	880	6.07
		Daraset	90	0.62	325	2.24	685	4.72	845	5.83
		Hydraset	120	0.83	395	2.72	690	4.76	885	6.10

* Specimens tested at 40°F (4°C) did not have sufficient strength to be removed from the molds at 4 hrs. They were tested at 6 hrs. instead.

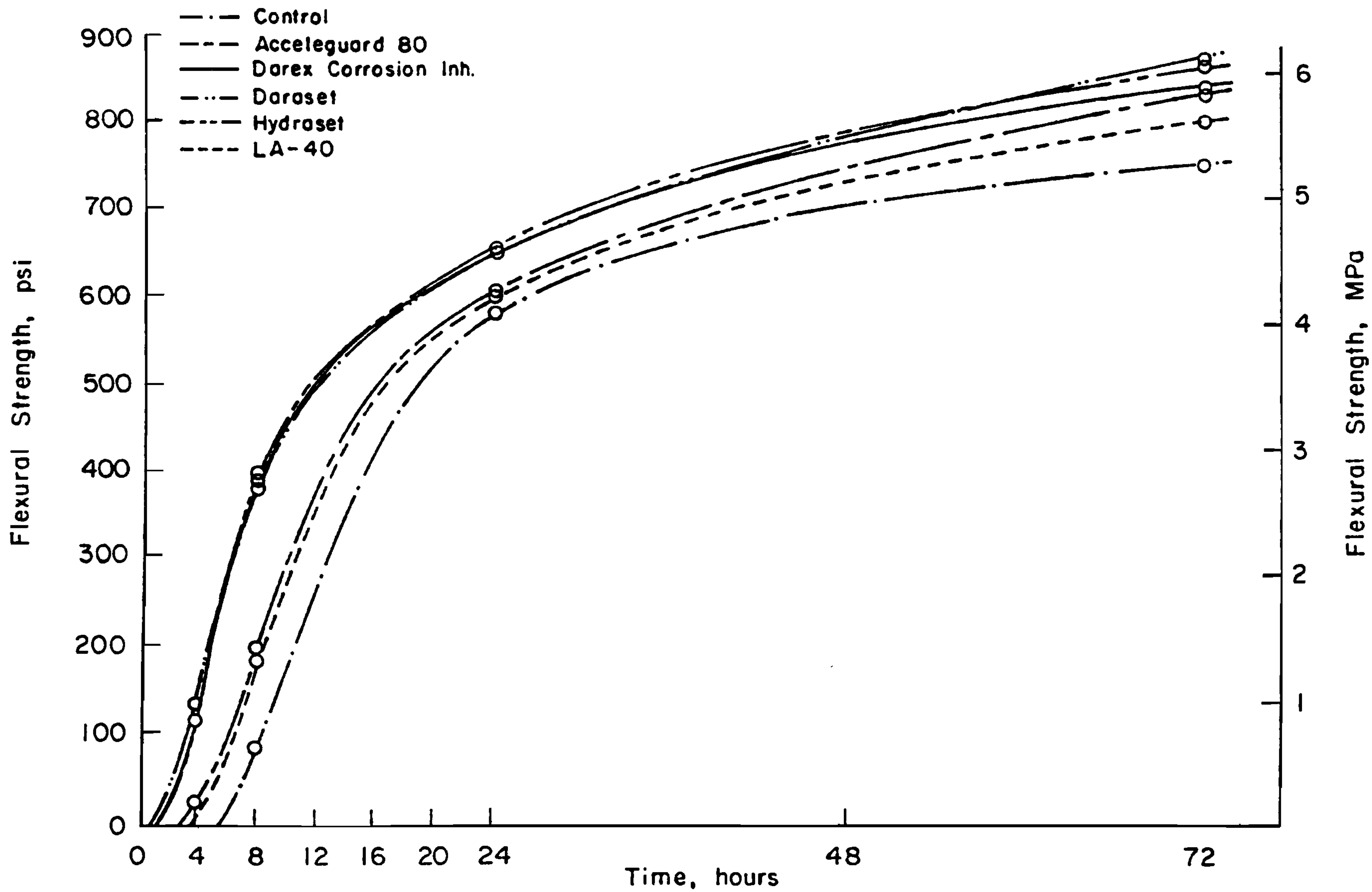


Fig. 5.7. Flexural Strength vs Time with Capitol Type III Cement at 75°F (24°C).

Daraset. These results are plotted in Fig. 5.8 and tabulated in Table 5.3. Again, Darex Corrosion Inhibitor and Hydraset outperformed Acceleguard 80 and LA-40, and 4-hour flexural strengths at 110°F (43°C) were similar to 24-hour strengths at 40°F (4°C).

The flexural strength gain versus time was determined using Alamo Type III cement for Daraset and Hydraset at 75°F (24°C). These results are plotted in Fig. 5.9 and tabulated in Table 5.3. Again, there was little difference in the rate of flexural strength gain between the two brands of cement for these two accelerators.

5.4 Set Time

Initial and final set times were determined by penetration resistance for all accelerators at 75°F (24°C). Set times were also determined for all accelerators except Daraset at 110°F (43°C) and 40°F (4°C). Also, the initial and final set times were determined using Alamo Type III cement for Daraset and Hydraset at 75°F (24°C). These results are shown graphically in Fig. 5.10 and are tabulated in Table 5.4. Daraset, Darex Corrosion Inhibitor and Hydraset provided the most rapid initial and final set times in all cases. LA-40 provided very little acceleration in initial or final set times compared with the control mix.

5.5 Flexural Bond

The flexural bond test was conducted using Darex Corrosion Inhibitor and Hydraset as well as the control mix at 75°F (24°C). The ultimate load was converted to a flexural bond strength by the standard modulus of rupture formula. The average 24-hour flexural bond strength

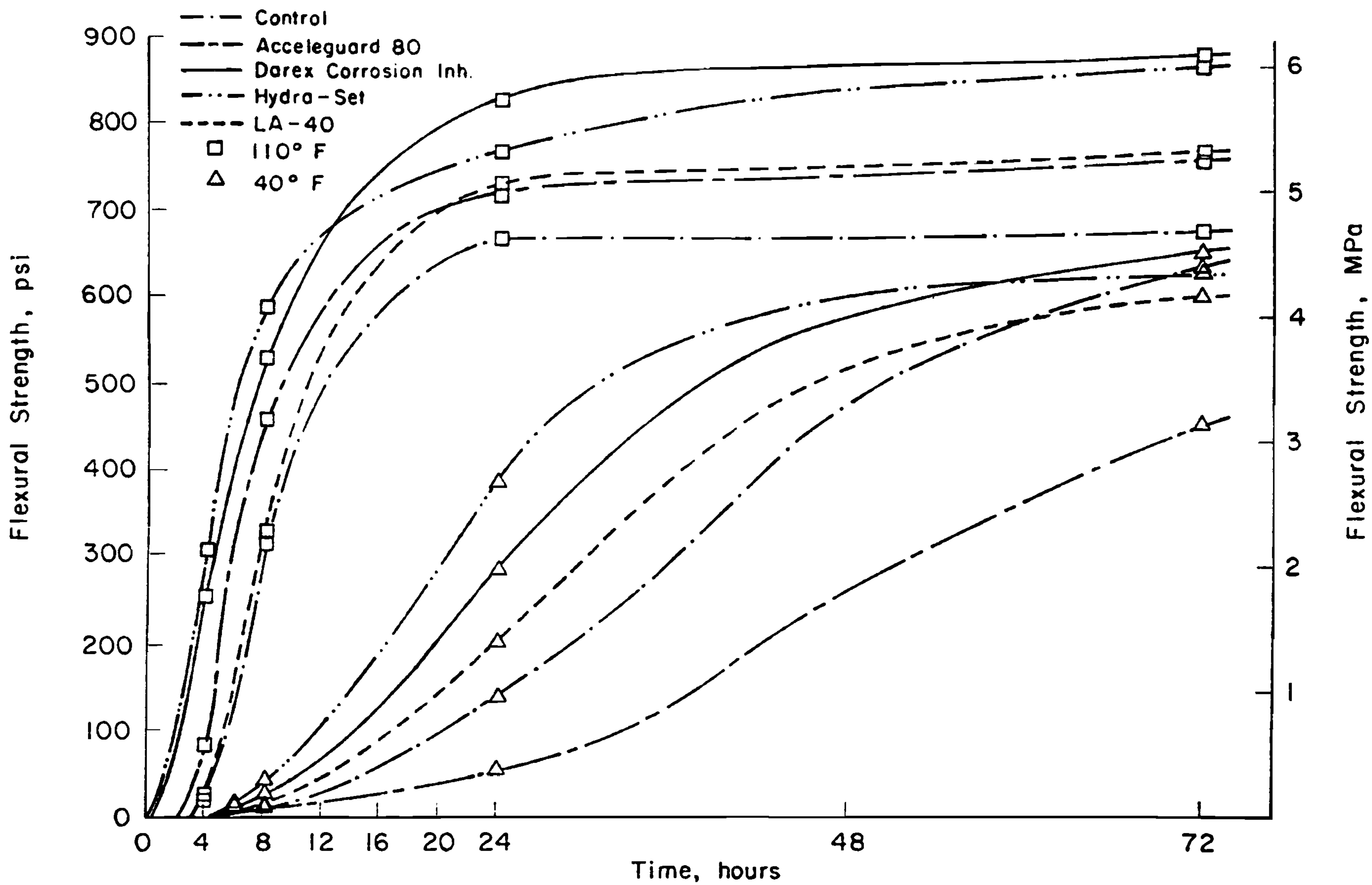


Fig. 5.8. Flexural Strength vs Time with Capitol Type III Cement at 110°F (43°C) and 40°F (4°C).

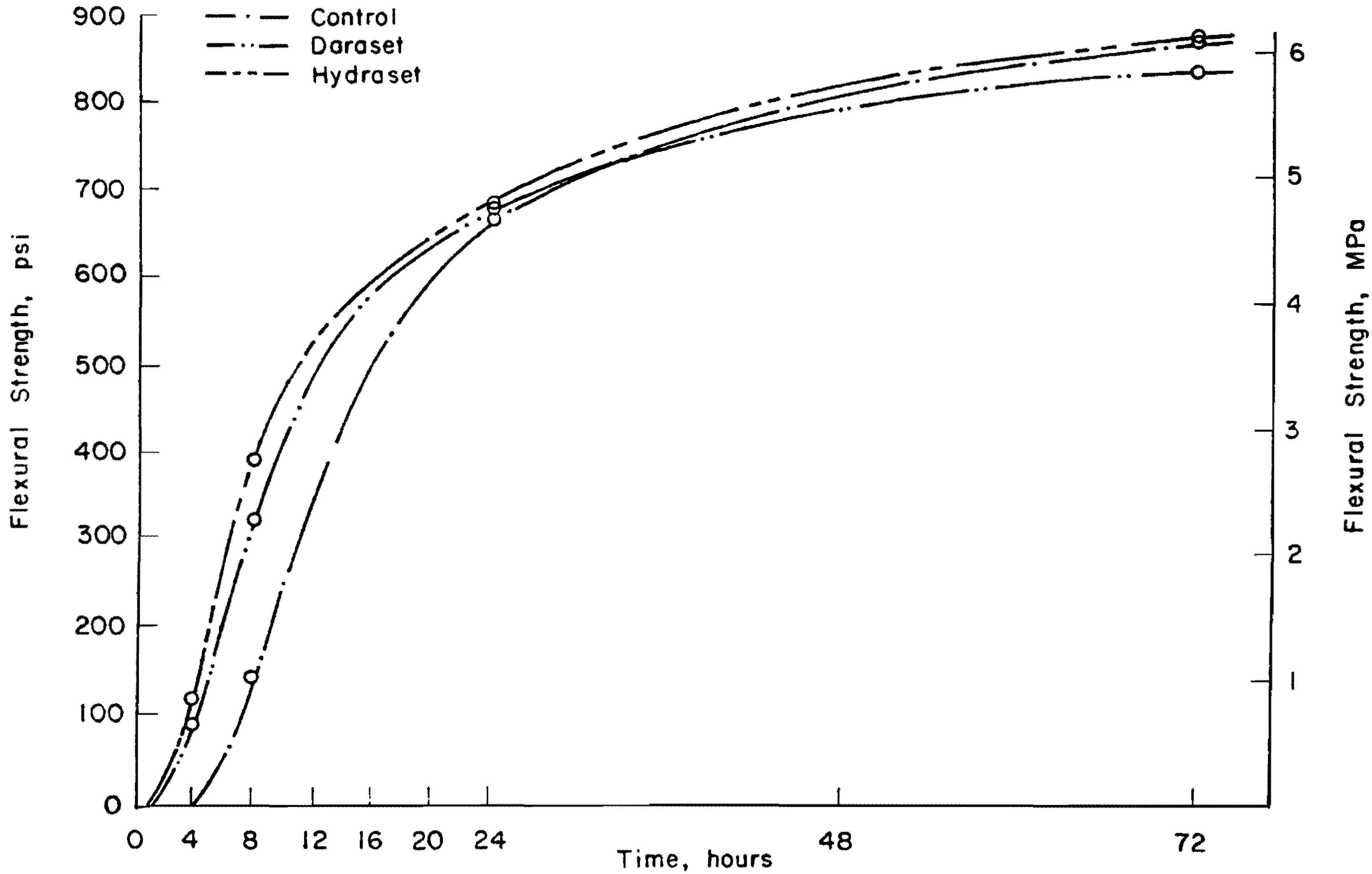


Fig. 5.9. Flexural Strength vs Time with Alamo Type III Cement at 75°F (24°C).

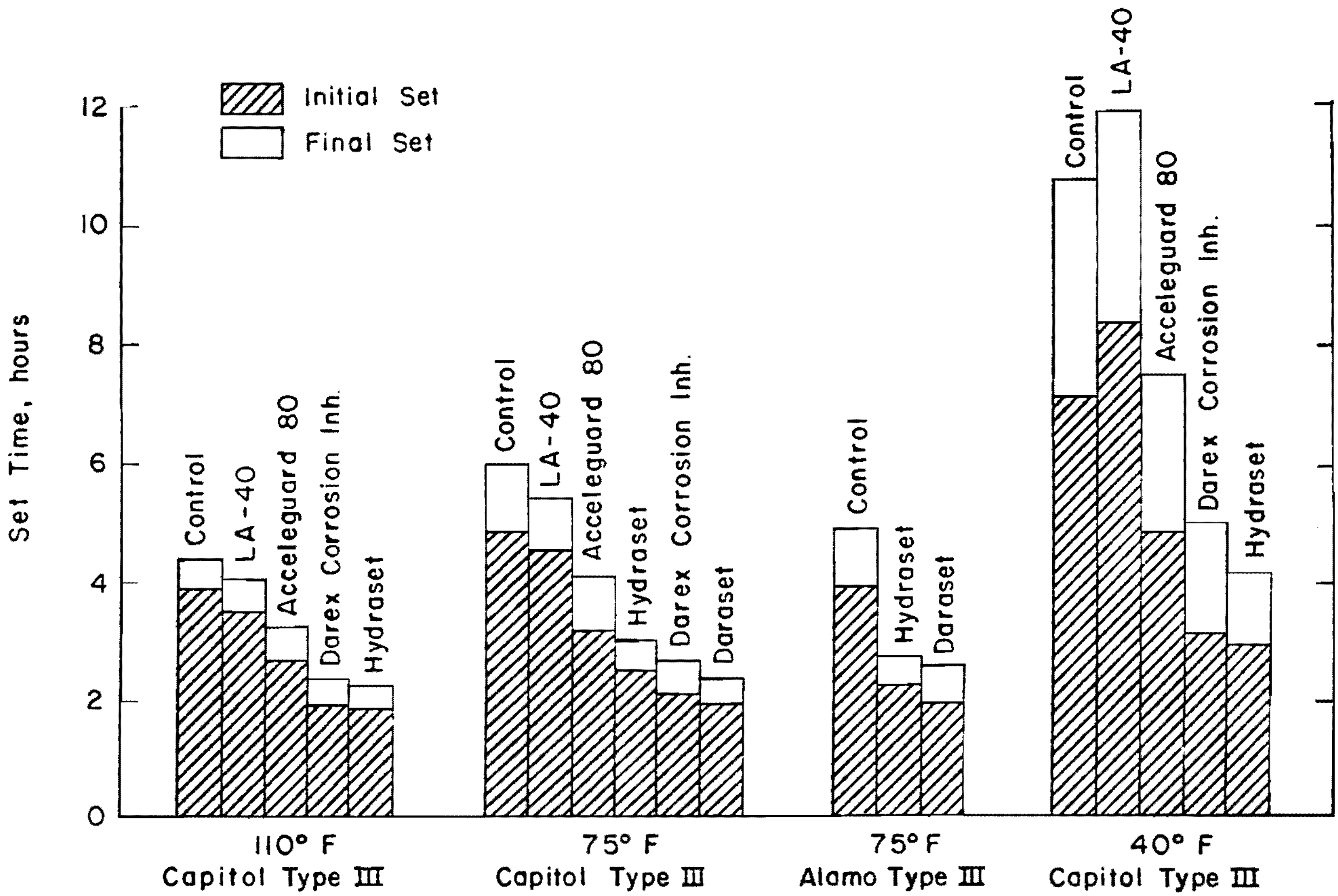


Fig. 5.10. Set Time of Accelerated Concrete at 110°F (43°C), 75°F (24°C), and 40°F (4°C).

TABLE 5.4

SET TIME

TEMP.	BRAND OF TYPE III CEMENT	ACCELERATOR	INITIAL SET (hr: Min)	FINAL SET (hr: Min)
75°F (24°C)	Capitol	Control	4:50	6:00
		Acceleguard 80	3:10	4:05
		Daraset	1:55	2:20
		Darex Corrosion Inh.	2:05	2:40
		Hydraset	2:30	3:00
		LA-40	4:35	5:25
110°F (43°C)	Capitol	Control	3:55	4:25
		Acceleguard 80	2:40	3:15
		Darex Corrosion Inh.	1:55	2:20
		Hydraset	1:50	2:15
		LA-40	3:30	4:05
110°F (4°C)	Capitol	Control	7:10	10:50
		Acceleguard	4:50	7:30
		Darex Corrosion Inh.	3:05	5:00
		Hydraset	2:55	4:10
		LA-40	8:25	12:00
75°F (24°C)	Alamo	Control	3:55	4:55
		Daraset	1:55	2:35
		Hydraset	2:15	2:45

for each of the four bonding surface conditions (dry, wet, mortar grout, and epoxy) is shown in Table 5.5. Nearly all failures occurred at the bond interface (Fig. 5.11). Only the Darex Corrosion Inhibitor and Hydraset specimens with epoxy bonding surface exhibited a non-bond type of failure. These specimens failed in flexure, with an initial tension crack occurring in the accelerated concrete very close to the bond surface. This type of failure is shown in Fig. 5.12.

The results of the flexural bond test show that the epoxy bonding surface provided the best bond strength for both Darex Corrosion Inhibitor and Hydraset. However, the epoxy did not perform as well on the control specimens, with failures occurring in the bond between the epoxy and the fresh concrete. Also, the dry bonding surface provided significantly better flexural bond strength than the wet bonding surface in all cases and the mortar grout bonding surface did not significantly increase the bond strength compared with the dry bonding surface. In fact, the flexural bond strength was decreased by the use of a mortar grout compared with a dry bond surface for Hydraset and the control mix.

5.6 Sandblast Abrasion

The sandblast abrasion test was performed with the accelerated concrete using Darex Corrosion Inhibitor and Hydraset as well as the control mix with no accelerator at 75°F (24°C). The test results are summarized in Table 5.6. They show that the abrasion loss for all three mixes was very small and that the use of Darex Corrosion Inhibitor or Hydraset reduced the abrasion loss by approximately fifty percent compared with the control mix.

TABLE 5.5

FLEXURAL BOND STRENGTH AT 24 HOURS

ACCELERATOR	BONDING SURFACE	AVERAGE FLEXURAL BOND STRENGTH (psi)	(MPa)
Control	Dry	460	3.17
	Wet	300	2.07
	Mortar Grout	395	2.72
	Epoxy	315	2.17
Darex Corrosion Inhibitor	Dry	505	3.48
	Wet	375	2.59
	Mortar Grout	525	3.62
	Epoxy	640	4.41
Hydraset	Dry	455	3.14
	Wet	325	2.24
	Mortar Grout	375	2.59
	Epoxy	650	4.48

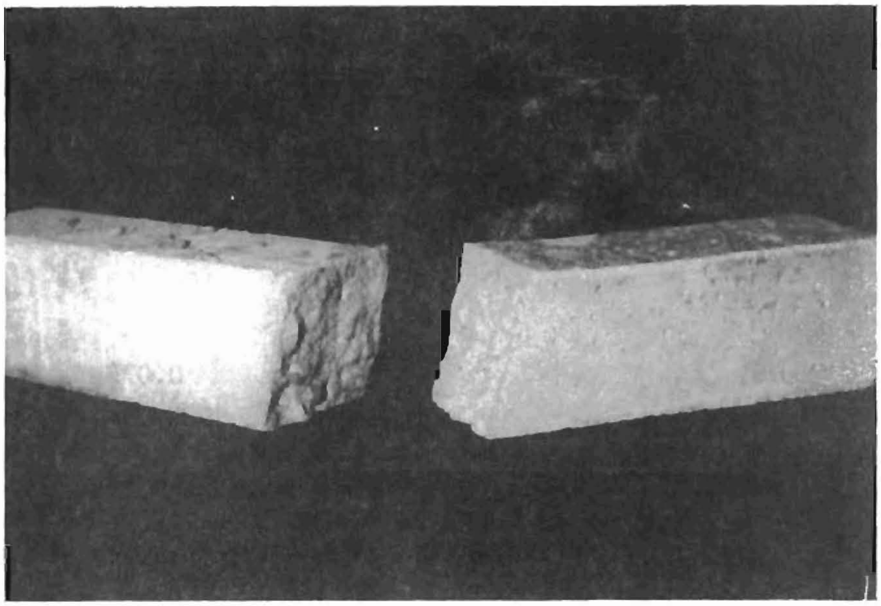


Fig. 5.11. Flexural Bond Specimen with the Failure Plane at the Bond Interface.

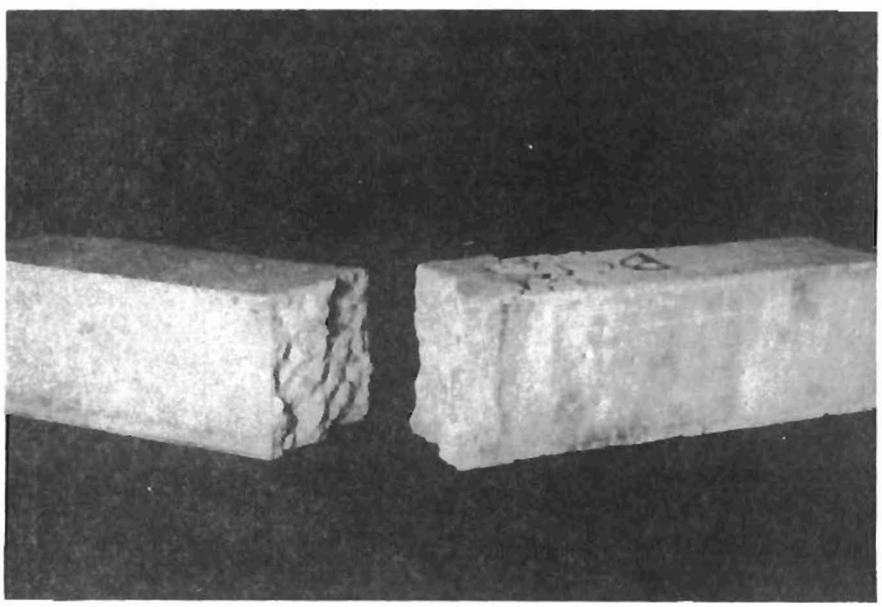


Fig. 5.12. Flexural Bond Specimen with the Failure Plane in the Accelerated Concrete.

TABLE 5.6

SAND BLAST ABRASION COEFFICIENTS

ACCELERATOR	AVERAGE ABRASION COEFFICIENT (cm^3/cm^2)
Control	0.025
Darex Corrosion Inh.	0.012
Hydraset	0.011

5.7 Length Change

The length change test was performed using all accelerators except Daraset at 75°F (24°C). The change in length versus time curves are shown in Fig. 5.13. All specimens tested except LA-40 expanded in length during the 7-day moist curing period. Hydraset and Darex Corrosion Inhibitor exhibited the most expansion; however, they also had the highest rate of drying shrinkage during the first 14 days of air curing. Most of the 100-day shrinkage occurred within the first 20 days for all accelerated concretes. The control specimen however, did not shrink as rapidly. The 100 day shrinkage was 0.05 percent of the initial length for Hydraset, Darex Corrosion Inhibitor, and the control specimen. It was nearly 0.06 percent for Acceleguard 80 and LA-40.

5.8 Freeze-Thaw Resistance

The freeze-thaw resistance of accelerated concrete was determined for Hydraset, Daraset, and Darex Corrosion Inhibitor. Because the amount of entrained air in the concrete is very important to its ability to resist deterioration due to freeze-thaw cycles, the air content of the accelerated concrete used in these tests was measured. A plot of relative dynamic modulus of elasticity versus freeze-thaw cycles is shown in Fig. 5.14, along with the amount of entrained air in each of the specimens. Failure is considered to occur when the relative dynamic modulus of elasticity reaches 60 percent of its initial value.

All specimens performed similarly up to about 150 freeze-thaw cycles with little reduction in relative dynamic modulus of elasticity

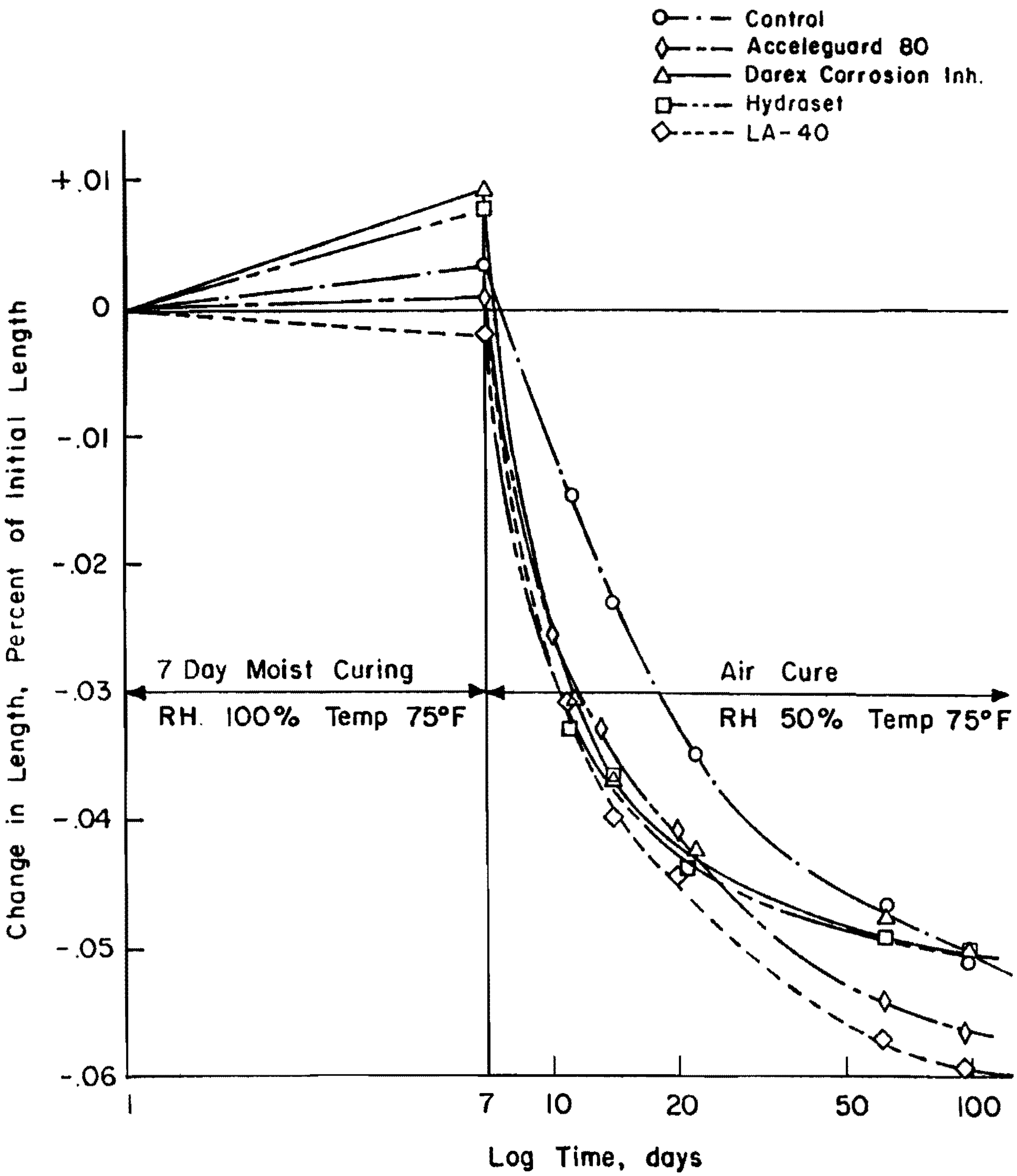


Fig. 5.13. Change in Length vs Time of Accelerated Concrete Beams.

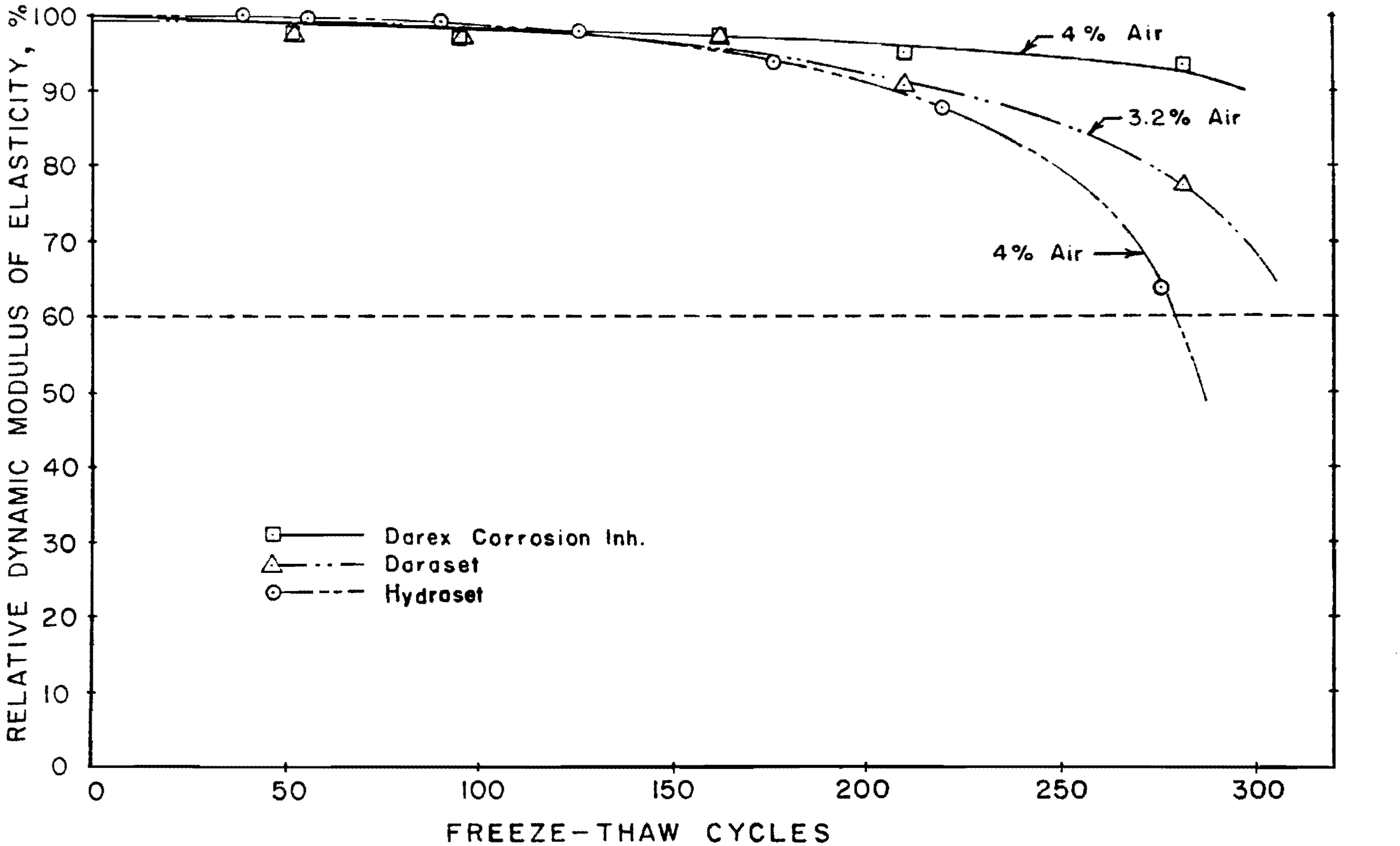


Fig. 5.14. Relative Dynamic Modulus of Elasticity vs Freeze-Thaw Cycles for Accelerated Concrete.

occurring. Above 150 cycles, Darex Corrosion Inibitor outperformed both Daraset and Hydraset. However, the difference in air content between Darex Corrosion Inhibitor and Daraset could account for the better performance of Darex Corrosion Inhibitor compared with Daraset.

5.9 Corrosion Tests

The corrosion tests were performed using Darex Corrosion Inhibitor, Hydraset, and the control mix, using both a corrosive environment and a non-corrosive environment. Figure 5.15 shows the 6-month Potentiodynamic Polarization Resistance curves for all specimens. In interpreting the results of these polarization curves, the current density at which the polarization curve becomes vertical, or nearly vertical, is a measure of the passivation film present at the steel-concrete interface. This passivation film is an extremely thin layer of Fe_2O_3 which protects the steel from corrosion. It has been found by some researchers that the presence of free chloride can lead to the breakdown of this passivation film rendering the reinforcement more susceptible to corrosion. For a given specimen, the smaller the value of current density at which the polarization curve becomes vertical, the better the passivation film and therefore, the less susceptible that specimen is to corrosion.

From Fig. 5.15, the Darex Corrosion Inhibitor specimens at both the standard curing condition (non-corrosive environment) and the salt water curing condition (corrosive environment) are least likely to have corrosion problems. The Hydraset at both environmental conditions and

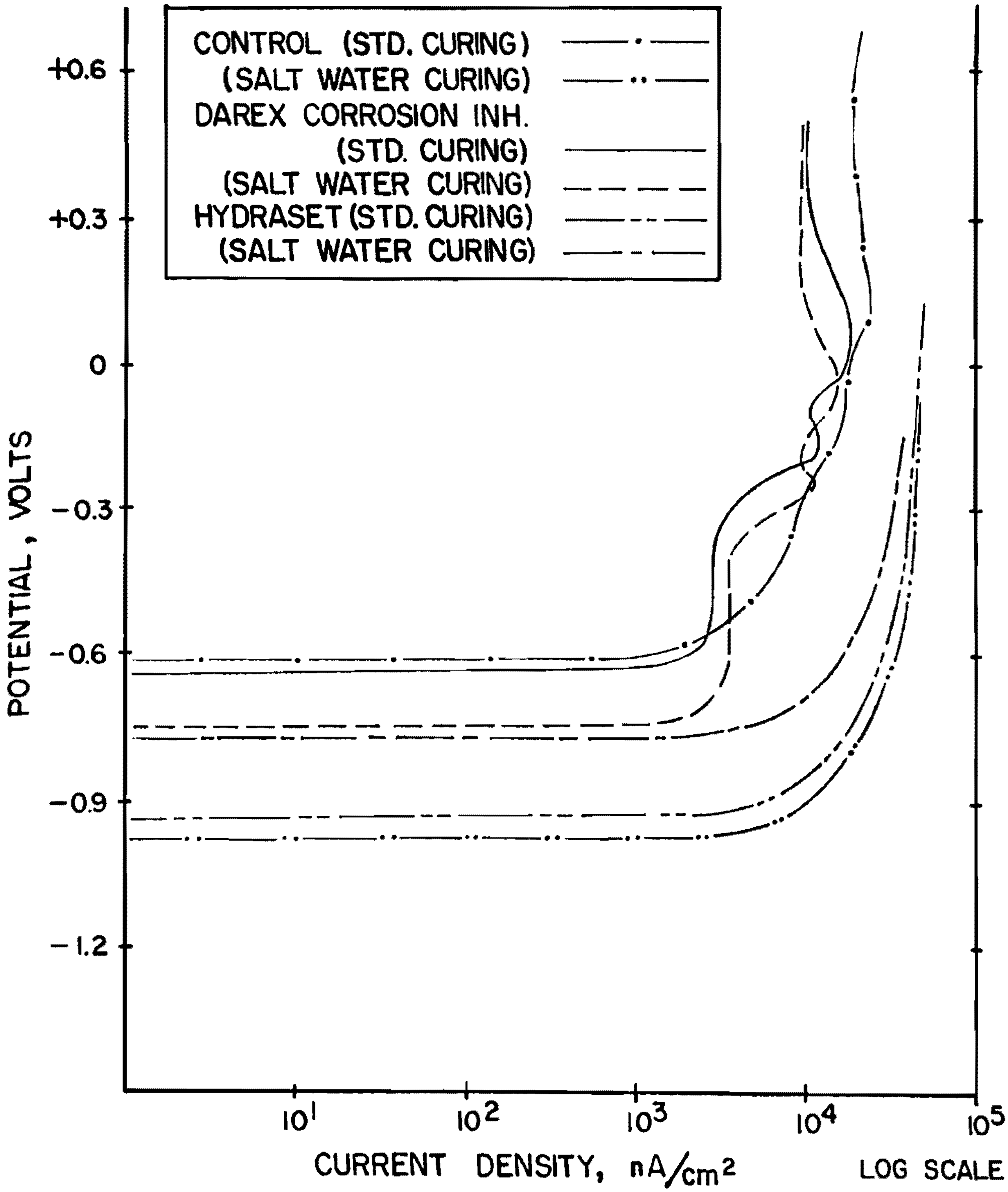


Fig. 5.15. Potentiodynamic Polarization Resistance Curves for Accelerated Concrete at 6 Months.

the control in the corrosive environment are more likely to have corrosion problems than the Darex Corrosion Inhibitor in both environmental conditions and the control in the non-corrosive environment. The specimens containing Hydraset, a calcium chloride accelerator, were slightly less susceptible to corrosion than the control specimen in a corrosive environment. However, they were more susceptible to corrosion than the control specimen in a non-corrosive environment.

Figure 5.16 is a plot of the corrosion current density versus time for all specimens at both environmental conditions. The corrosion current density is a measure of the corrosion rate of the steel bar. The higher the value of the corrosion current density, the higher the corrosion rate for that specimen. The interpretation of Fig. 5.16 is not clear for the first few months of curing. However, the results at 6 months become more clear. They indicate that after 6 months of curing, the Hydraset specimens in both environments and the control specimens in the corrosive environment are corroding approximately three times as fast as the Darex Corrosion Inhibitor specimens in both environments and the control specimens in the non-corrosive environment.

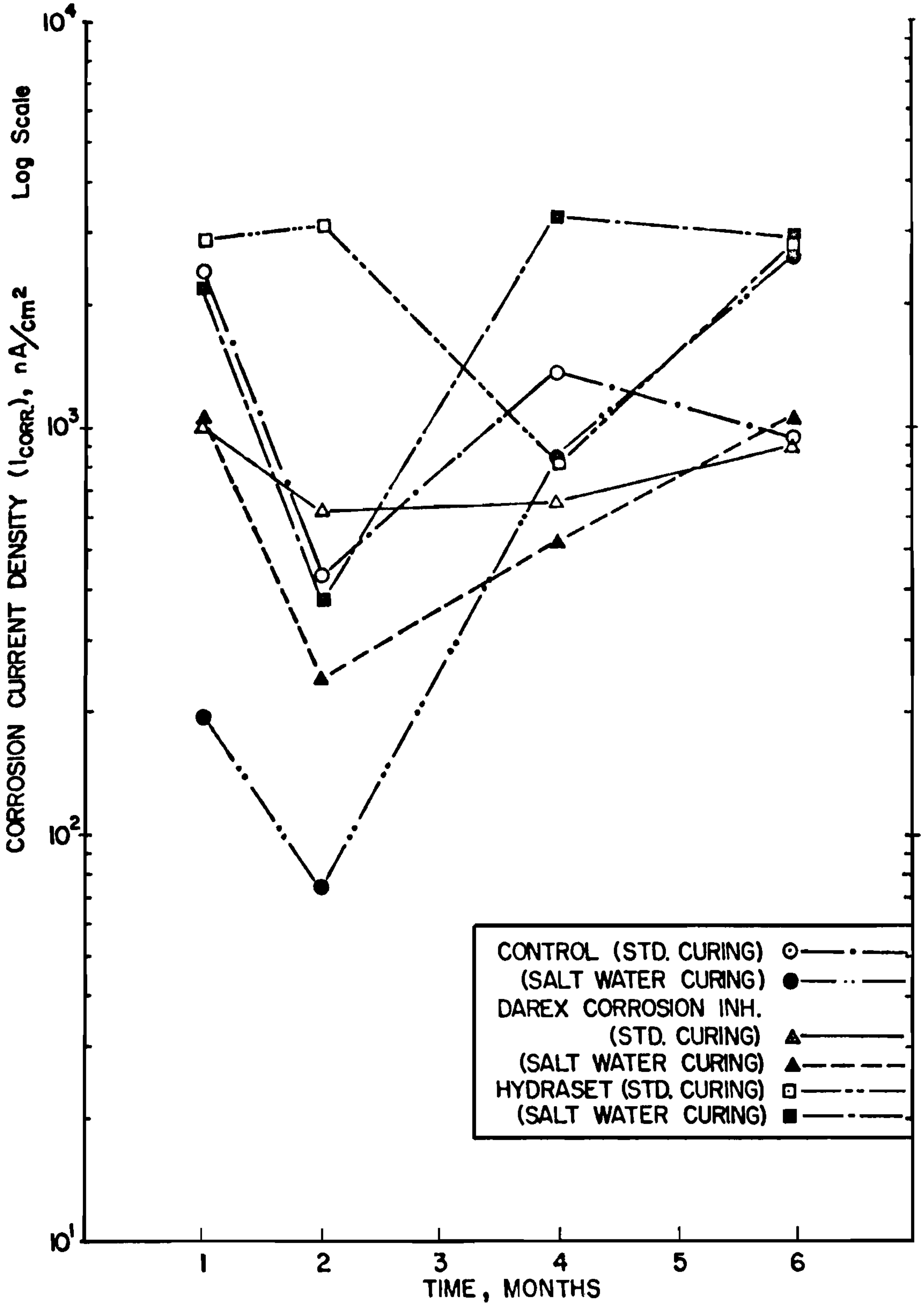


Fig. 5.16 Corrosion Current Density vs. Time for Accelerated Concrete

CHAPTER 6. FIELD APPLICATIONS

6.1 Introduction

This chapter describes the use of accelerated concrete for actual highway repairs in Texas. The specifications for class "K" concrete (Table 3.1) were used for these repairs. Five repairs were performed during the course of the research. One repair using Darex Corrosion Inhibitor was performed on IH-35 in Waco. Two repairs, one using Darex Corrosion Inhibitor and one using Hydraset, were performed on IH-40 in Amarillo. One repair using Darex Corrosion Inhibitor was performed on IH-45 in Dallas. Finally, one repair was made on IH-10 in Houston using Acceleguard 80. The performance of these repairs will be monitored during the next few years.

6.2 IH-35, Waco, Texas

6.2.1 Class "K" Concrete Repair

On September 28, 1983, a team from the Center for Transportation Research (CTR), in cooperation with the highway maintenance crew from District 9, made one class "K" concrete repair in Waco. The repair was on the outside lane of southbound IH-35 about 0.35 miles south of the Highway 396 overpass. The temperature was 88°F (31°C) with 5 to 10 mile per hour winds from the north and about 70 percent relative humidity.

The area to be repaired was 6-ft x 12-ft (1.83-m x 3.66-m), between two existing portland cement concrete patches as shown in Fig. 6.1. The edges of the area to be repaired were saw cut and the

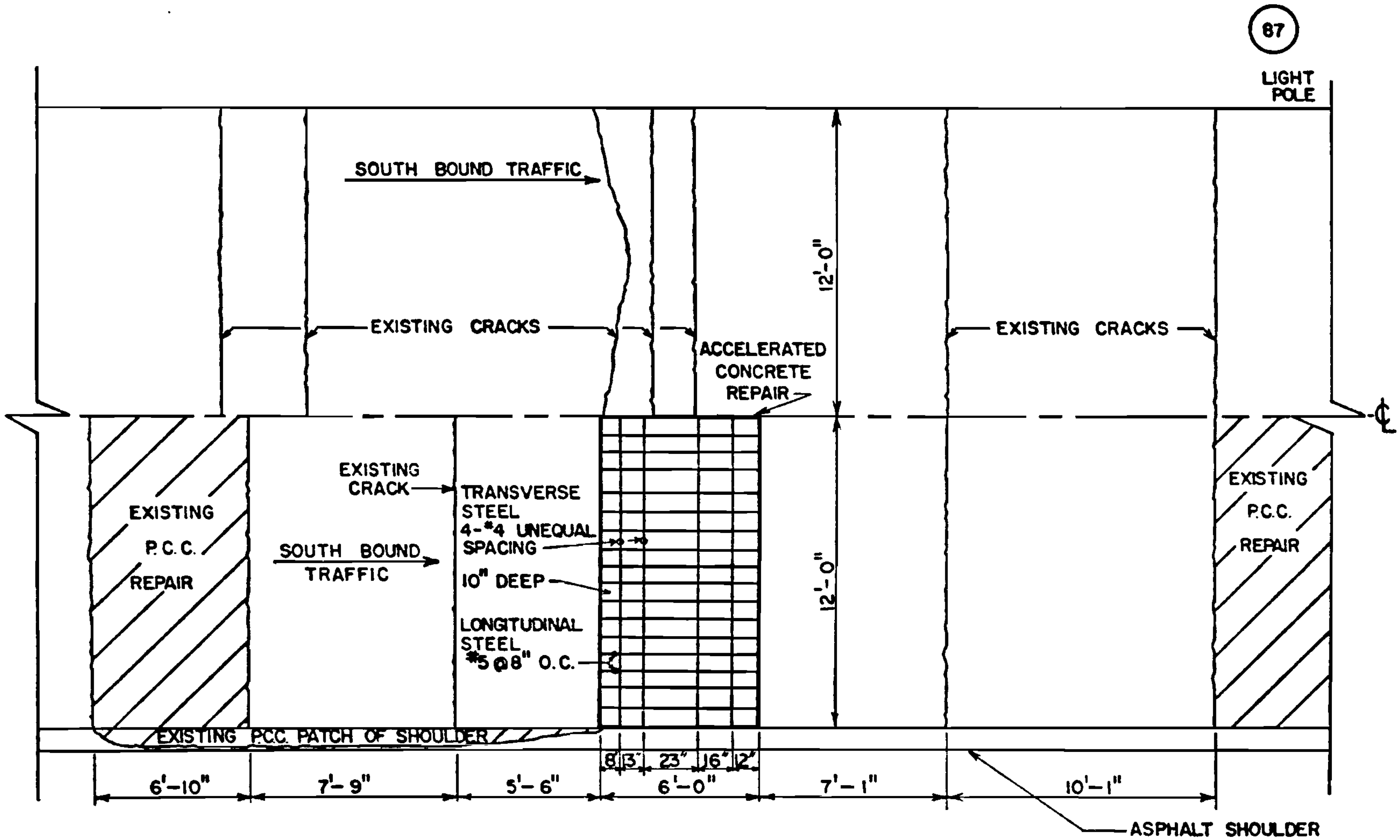


Fig. 6.1 Dimensions of Class "K" Concrete Repair at Waco

deteriorated concrete was removed with a jackhammer. The full 10-in. (254-mm) depth of the concrete pavement was broken out. The old reinforcing steel was burned off 12 in. (305-mm) from the edge of the repair and new steel was spliced to the existing steel. The spacing of the new reinforcing steel is shown in Fig. 6.1.

A local concrete batching plant supplied the class "K" concrete, except for the accelerator and the high range water reducer which were supplied by CTR. The concrete arrived at the repair site at 12:00 noon. The Darex Corrosion Inhibitor and the high range water reducer were added to the concrete truck at the repair site. Five gallons of water were also added to the concrete after about half of the repair had been placed because the mix was very stiff. The mix proportions used for this repair are shown in Table 6.1. Figures 6.2 and 6.3 show the class "K" concrete being placed and finished. Figure 6.4 shows the repair after completion.

The repair took 30 minutes to place and finish and required 3 cubic yards of concrete. It was opened to traffic at 5:00 p.m., 4-1/2 hours after being placed. The concrete was very difficult to place, consolidate and finish because it was very stiff. It was determined later that not all of the specified water had been added to the concrete mix at the batch plant. Instead of the specified water-cement ratio of 5.0 gal per bag, the concrete had only 4.6 gal per bag.

Three 6-in. x 12-in. (152.4-mm x 304.8-mm) cylinders and three 6-in. x 6-in. x 20-in. (152.4-mm x 152.4-mm x 528-mm) beams were cast from the remaining accelerated concrete. They were tested

TABLE 6.1

MIX PROPORTIONS AND 24-HOUR STRENGTH OF CLASS "K" CONCRETE USED IN WACO REPAIR

MIX PROPORTIONS

MATERIAL	QUANTITIES PER CUBIC YARD	
	ENGLISH UNITS	SI UNITS
* Darex Corrosion Inhibitor	5.2 gal.	19.7 lit.
Cement (Type III)	627 lbs.	248 kg.
Coarse Aggregate (Grade No. 4)	1850 lbs.	839 kg.
Fine Aggregate (5% Moisture)	1071 lbs.	486 kg.
Water	18.3 gal.	69.4 lit.
Air Entraining Admixture	6.7 fl. oz.	0.20 lit.
* High Range Water Reducer	85 fl. oz.	2.5 lit.

* - Added to concrete mix at repair site

24 HOUR STRENGTH

Ave. Compressive Strength - 4140 psi (28.55 MPa)

Ave. Flexural Strength - 850 psi (5.86 MPa)

Fig. 6.2. Placing Class "K" Concrete at Waco.

Fig. 6.3. Finishing Class "K" Concrete at Waco.

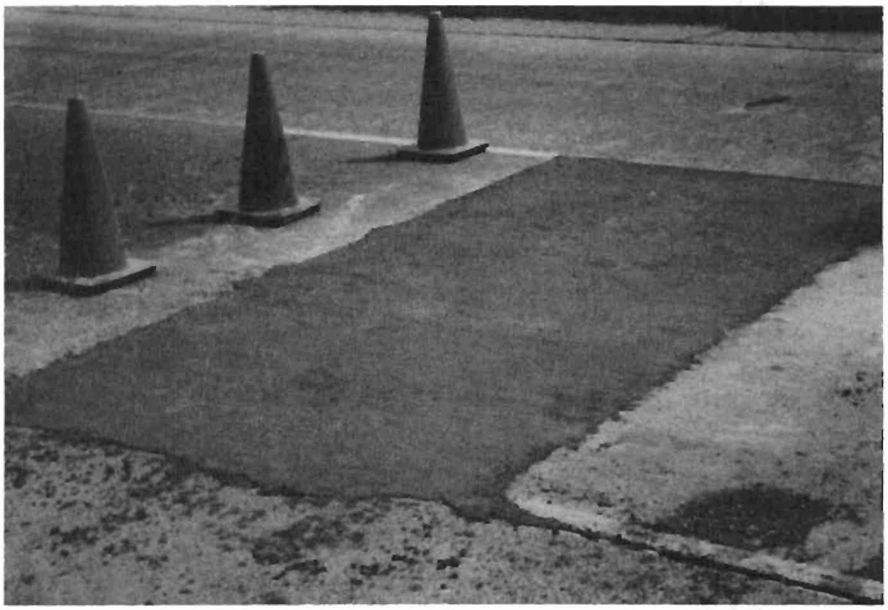


Fig. 6.4. Completed Class "K" Concrete Repair at Waco.

in the laboratory after 24 hours. The 24-hour compressive and flexural strengths are shown in Table 6.1.

6.2.2 Class "C" Accelerated Concrete Repair

Another accelerated concrete repair was made in Waco on September 28, 1983, entirely by the highway maintenance crew from District 9. This repair was a 4-ft x 6-ft (1.22-m x 1.83-m) full-depth repair located on the outside lane of southbound IH-35 approximately 150 yards south of the Highway 396 overpass. The concrete mix used for this repair was based on Texas State Department of Highways and Public Transportation specifications for class "C" concrete (12), except for the addition of an accelerating admixture. The accelerator used by District 9 was Cel-set, a calcium chloride based accelerator. The Cel-set was added to the concrete at the repair site. The repair was placed at 1:00 PM and was opened to traffic four hours later at 5:00 PM. The performance of this repair will be monitored along with the performance of the repair made with class "K" concrete in order to provide a comparison between the two.

6.3 IH-40, Amarillo, Texas

On October 27, 1983, a team from CTR, in cooperation with the highway maintenance crew from District 4, made two accelerated concrete repairs in Amarillo. The repair made using Darex Corrosion Inhibitor was designated Repair No. AMA-DCI. The repair made using Hydraset was designated Repair No. AMA-HS. These repairs were made on the outside lane of westbound IH-40 near mile marker 86 (Fig. 6.5). The

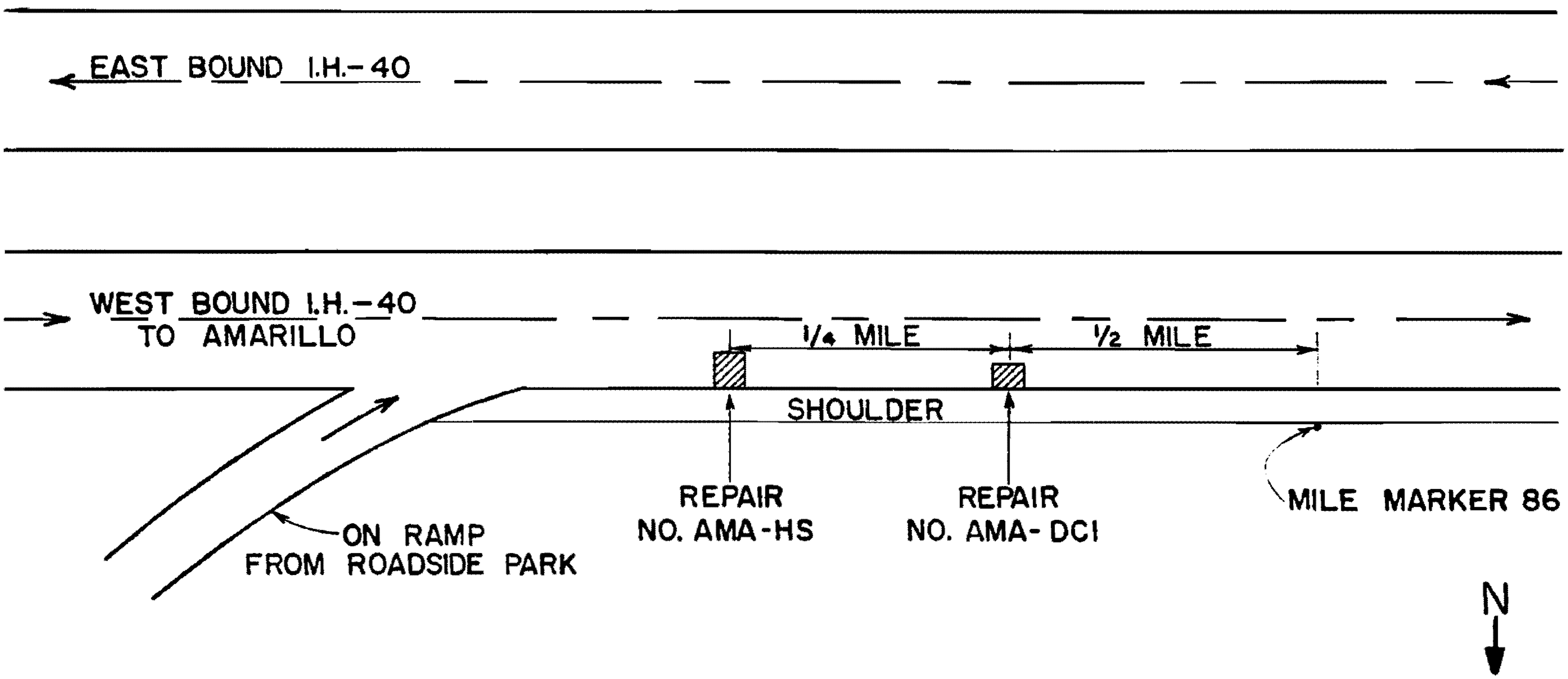


Fig. 6.5. Location of Amarillo Repairs.

temperature was between 60°F (16°C) and 70°F (21°C) with 20 mile per hour winds and about 20 percent relative humidity.

6.3.1 Repair No. AMA-DCI

Repair No. AMA-DCI was a 3-ft x 3-3/4-ft (0.914-m x 1.14-m) punchout. Figure 6.6 shows the condition of the area to be repaired before work had begun. The unsound concrete in the punchout was jack-hammered out to its full depth of 9-1/2 in. (241.3-mm). The old reinforcing steel was cut off and the base was compacted. New steel was spliced to the existing steel as shown in Fig. 6.7.

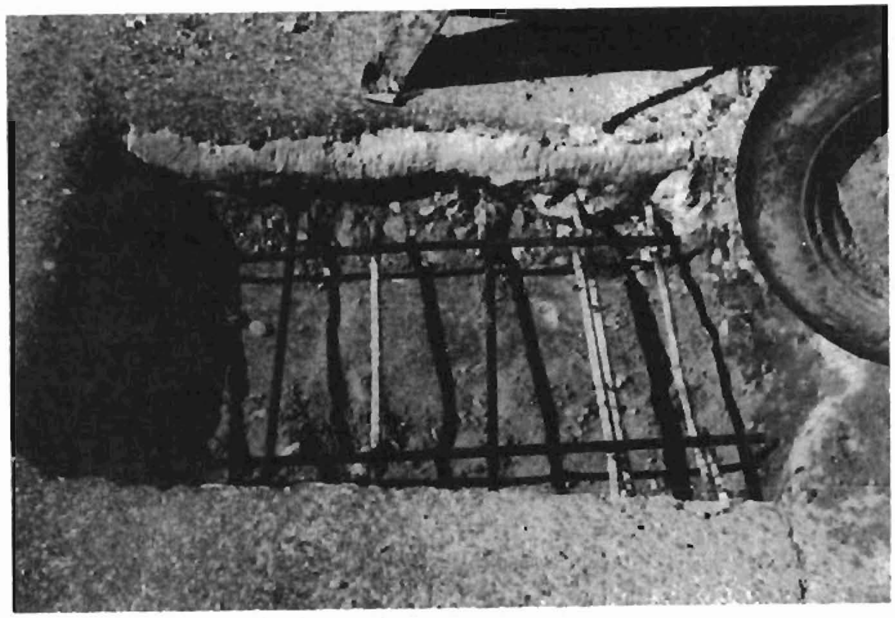
The accelerated concrete was mixed at the repair site in a 3-cubic foot concrete mixer supplid by District 4. The mix proportions used for this repair are shown in Table 6.2. Mixing was started at 12:00 noon and the repair was completed at 1:00 p.m. It required a total of 9 cubic feet of accelerated concrete, placed in three separate lifts. Figure 6.8 shows the completed repair. It was opened to traffic at approximately 6:30 p.m., 5-1/2 hours after being placed.

One 3-in. x 6-in. (76.2-mm x 152.4-mm) cylinder was cast from the remaining accelerated concrete. It was tested in the laboratory 4 days after casting. The 4-day compressive strength is shown in Table 6.2.

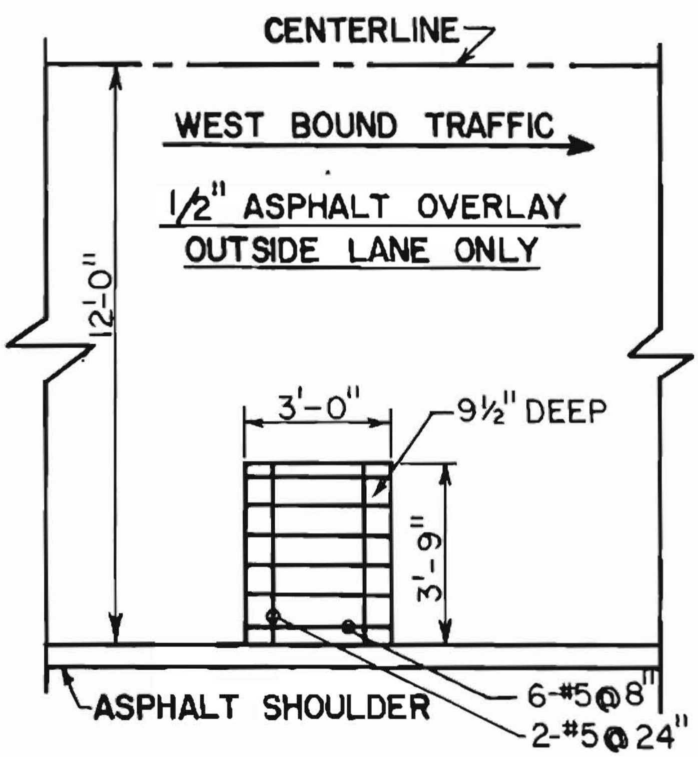
6.3.2 Repair No. AMA-HS

Repair No. AMA-HS was a 3-3/4-ft x 6-1/4-ft (1.14-m x 1.90-m) punchout. Figure 6.9 shows the condition of the area to be repaired before work had begun. The unsound concrete in the punchout

Fig. 6.6. Condition of Repair No. AMA-DCI Before Being Repaired.



A. Photo



B. Dimensions

Fig. 6.7. Amarillo Repair No. AMA-DCI.

TABLE 6.2

MIX PROPORTIONS AND 4-DAY STRENGTH OF ACCELERATED CONCRETE USED IN REPAIR NO. AMA-DCI

MIX PROPORTIONS

MATERIAL	QUANTITIES PER CUBIC YARD	
	ENGLISH UNITS	SI UNITS
Darex Corrosion Inhibitor	5.2 gal.	19.7 lit.
Cement (El Toro Type III)	658 lbs.	298.5 kg.
Coarse Aggregate (Grade No. 4)	1850 lbs.	839 kg.
Fine Aggregate (5.95% Moisture)	1080 lbs.	490 kg.
Water	25.3 gal.	95.8 lit.
Air Entraining Admixture	9.1 fl. oz.	0.27 lit.
High Range Water Reducer	121 fl. oz.	3.6 lit.

4 DAY STRENGTH

Compressive Strength - 4300 psi (29.65 MPa)

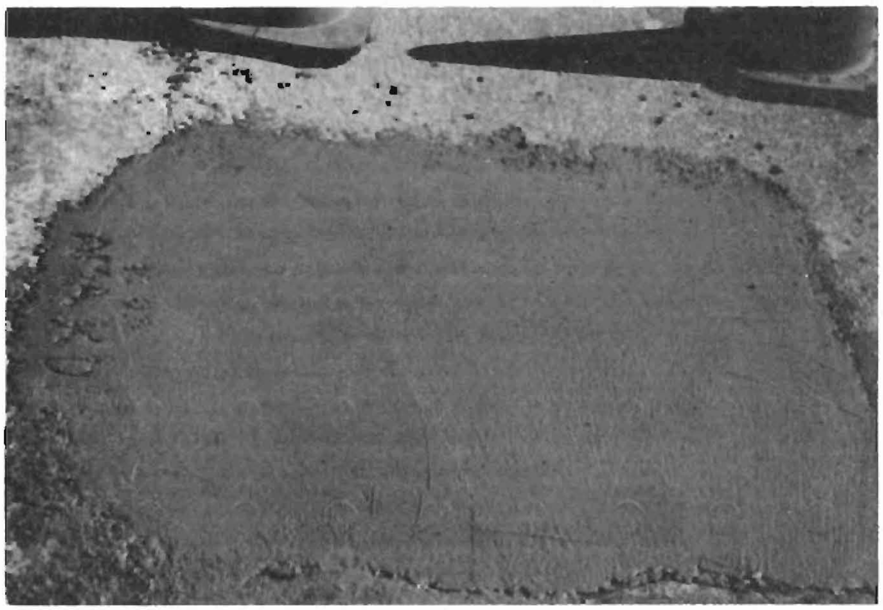


Fig. 6.8. Completed Repair No. AMA-DCI.

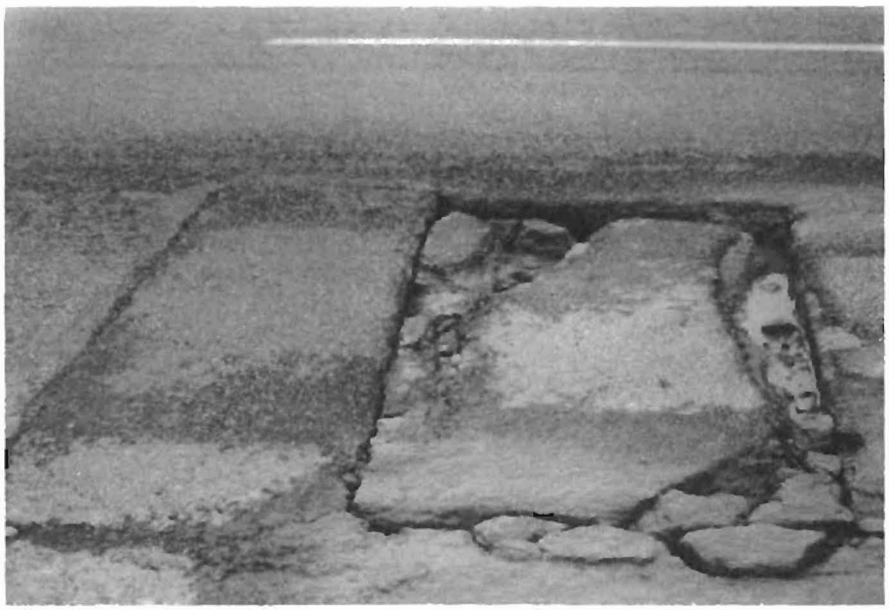


Fig. 6.9. Condition of Repair No. AMA-HS Before Being Repaired.

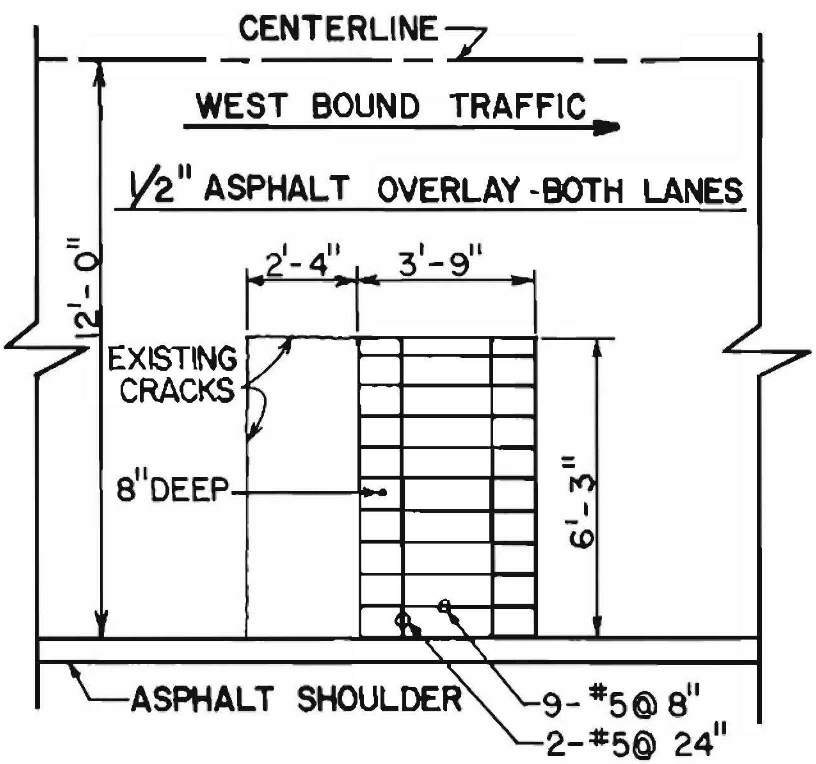
was jackhammered out to its full depth of 8-in. (203.2-mm). The existing reinforcing steel was cut at the center of the repair so that the base could be compacted. The existing steel was then spliced back together as shown in Fig. 6.10.

The accelerated concrete was again mixed at the repair site in a 3-cubic foot concrete mixer. The mix proportions used for this repair are shown in Table 6.3. Mixing was started at 1:30 p.m. and the repair was completed at 2:45 p.m. It required a total of 18 cubic feet of accelerated concrete, placed in 6 separate lifts. Figure 6.11 shows the completed repair. It was opened to traffic at approximately 6:30 p.m., 3-3/4 hours after being placed.

Two 3-in. x 6-in. (76.2-mm x 152.4-mm) cylinders and two 3-in. x 3-in. x 16-in. (152.4-mm x 152.4-mm x 406.4-mm) beams were cast from the remaining accelerated concrete. They were tested in the laboratory 4 days after casting. The 4-day compressive and flexural strength are shown in Table 6.3.

A water-cement ratio of 5-1/2 gal per bag was used in both Amarillo repairs because, 1) the use of El Toro brand of Type III cement resulted in a very "sticky" mix, and 2) the 3-cubic foot mixer which was used did not appear to thoroughly mix the stiff concrete. This higher water-cement ratio, along with the cool temperature in Amarillo, could be two of the reasons for the lower than expected 4-day compressive and flexural strengths.

A. Photo



B. Dimensions

Fig. 6.10. Amarillo Repair No. AMA-HS.

TABLE 6.3

MIX PROPORTIONS AND 4-DAY STRENGTH OF ACCELERATED CONCRETE USED IN REPAIR NO. AMA-HS

MIX PROPORTIONS

MATERIAL	QUANTITIES PER CUBIC YARD	
	ENGLISH UNITS	SI UNITS
Hydraset	3.5 gal.	13.2 lit.
Cement (El Toro Type III)	658 lbs.	298.5 kg.
Coarse Aggregate (Grade No. 4)	1850 lbs.	839 kg.
Fine Aggregate (5.9% Moisture)	1080 lbs.	490 kg.
Water	27 gal.	102 lit.
Air Entraining Admixture	9.1 fl. oz.	0.27 lit.
High Range Water Reducer	121 fl. oz.	3.6 lit.

4 DAY STRENGTH

Ave. Compressive Strength - 3500 psi (24.13 MPa)

Ave. Flexural Strength - 475 psi (3.28 MPa)

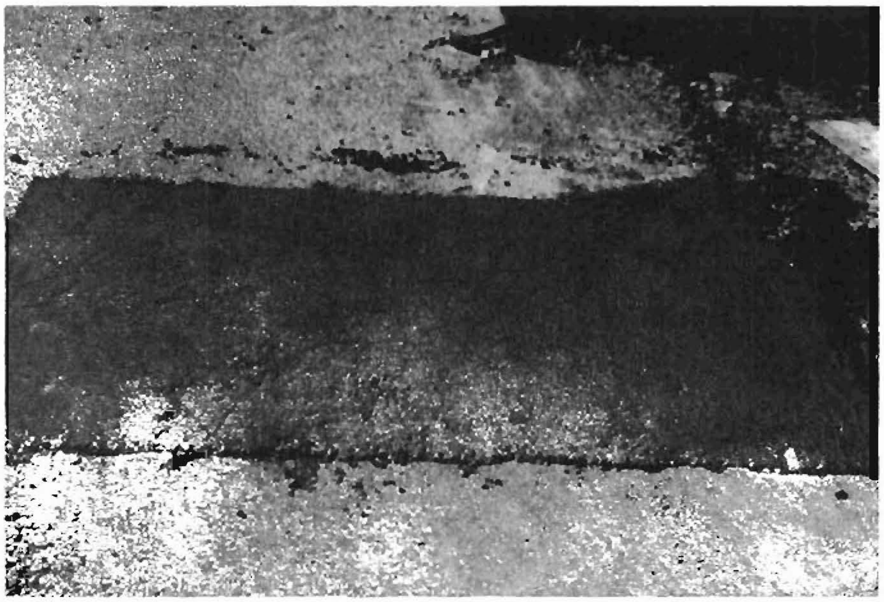


Fig. 6.11. Completed Repair No. AMA-HS.

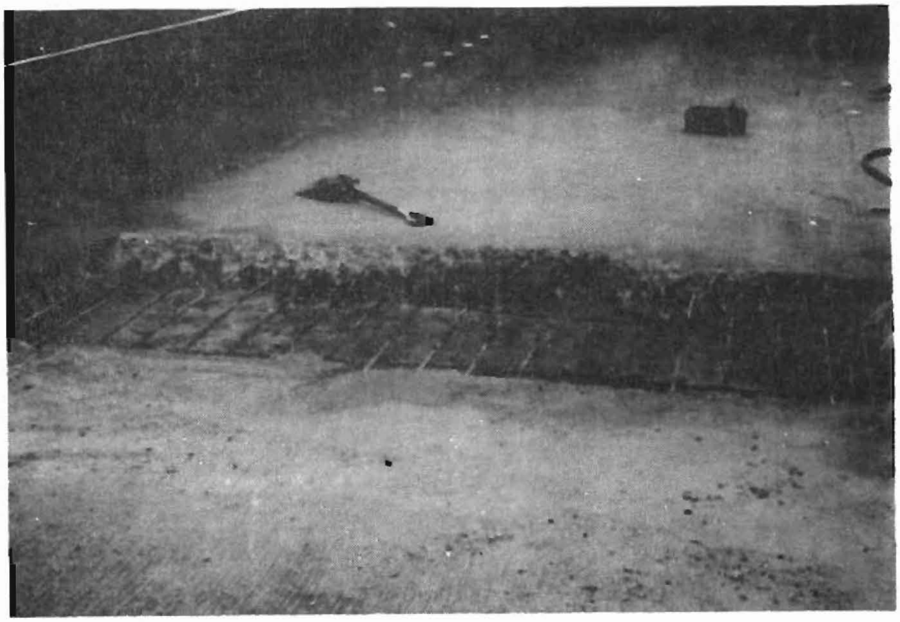
6.4 IH-45, Dallas, Texas

On October 22, 1983, a team from CTR, in cooperation with the highway maintenance crew from District 18, made one class "K" concrete repair in Dallas. The repair was on the middle lane of northbound IH-45 about 75 feet south of mile marker 281. The temperature was 76°F (24°C) with 15 mile per hour winds from the south and intermittent rain.

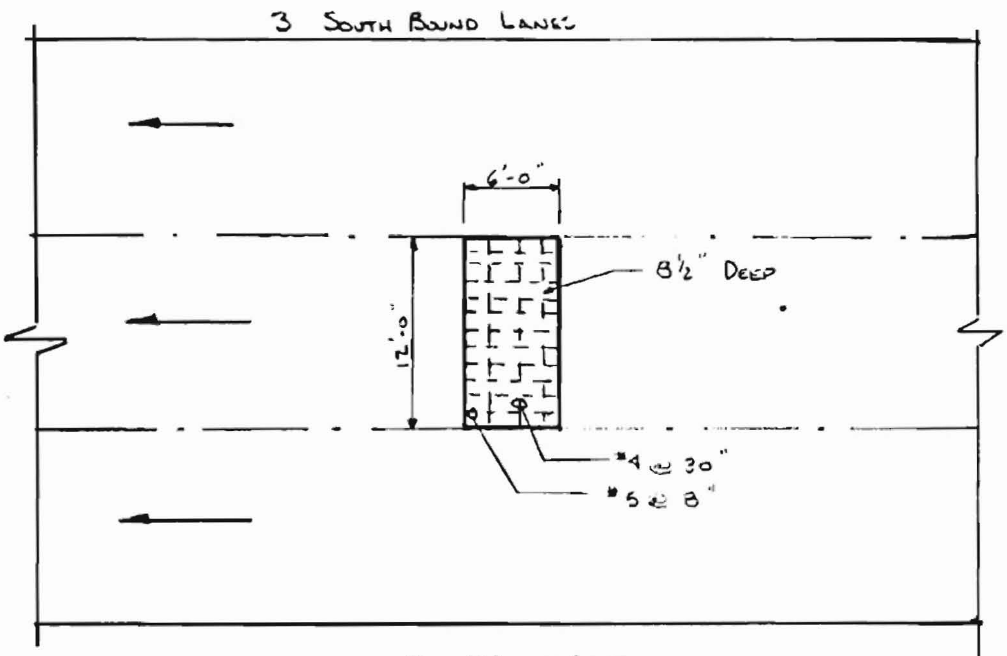
The repair was 6-ft x 12-ft (1.83-m x 3.66-m) punchout. The edges of the area to be repaired were saw cut and the deteriorated concrete was jackhammered out to its full depth of 8-1/2 in. (216-mm). The existing reinforcing steel was left in place. The dimensions and location of the Dallas repair are shown in Fig. 6.12.

A local concrete batching plant supplied the class "K" concrete, except for the accelerator and the high range water reducer which were supplied by CTR. The mix proportions used for this repair are shown in Table 6.4. Half of the specified high range water reducer was added at the batch plant in order to prevent the concrete from hydrating too quickly. The Darex Corrosion Inhibitor and the second half of the high range water reducer were added at the repair site.

The placing of the accelerated concrete was started at 10:30 AM. The slump and air content of the fresh concrete were determined and are given in Table 6.4. Figures 6.13 and 6.14 show the class "K" concrete being placed and finished. Figure 6.15 shows the repair after completion. The repair was completed at 11:00 AM and was opened to traffic at 5:00 PM, 6 hours after being placed.



A. Photo



B. Dimensions

Fig. 6.12. Class "K" Concrete Repair at Dallas.

Table 6.4. Mix Proportions and 24-Hour Strength of Class "K" Concrete Used in Dallas Repair.

Mix Proportions		
Material	Quantities per cu. yd. English units	SI units
*Darex Corrosion Inhibitor	5.2 gal	19.7 lit.
Cement (Type III)	658 gal	298.5 kg
Coarse Aggregate (Grade No. 4)	1850 lbs	839 kg
Fine Aggregate	1020 lbs	463 kg
Water	29.0 gal	109.8 lit.
Air Entraining Admixture	4.0 fl. oz.	0.12 lit.
**High Range Water Reducer	0.7 gal	2.6 lit.

*added to concrete mix at repair site

**added half of the total quantity at the batch plant and half at the repair site

slump - 3-3/4 in.
air content - 2.75 percent

<u>24-hour Strength</u>

Ave. Compressive Strength - 4640 psi (32.0 MPa)

Ave. Flexural Strength - 440 psi (3.03 MPa)

Fig. 6.13. Placing Class "k" Concrete at Dallas.

Fig. 6.14. Finishing Class "k" Concrete at Dallas.

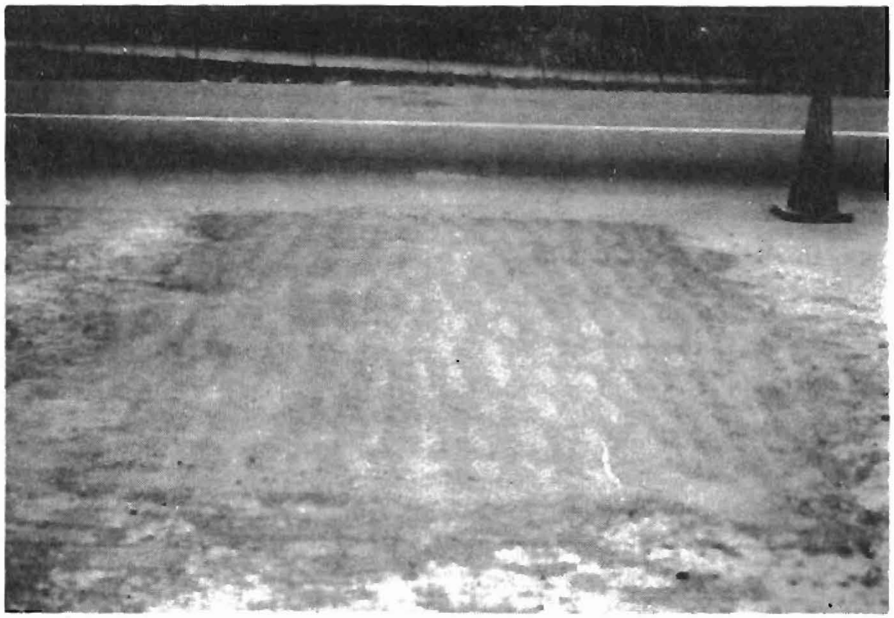


Fig. 6.15. Completed Class "k" Concrete Repair at Dallas.

Three 6-in. x 12-in. (152.40-mm x 304.8-mm) cylinders and three 3-in. x 3-in. x 16-in. (152.4-mm x 152.4-mm x 406.4-mm) beams were cast from the remaining accelerated concrete. They were tested in the laboratory after 24 hours. The 24-hour compressive and flexural strengths are shown in Table 6.4.

6.5 IH-10, Houston, Texas

On December 8, 1983, a class "K" concrete repair was made in Houston in cooperation with District 12. The repair was made on the outside lane of westbound IH-10 about 45 feet west of mile marker 740. The temperature was 75°F (24°C) with partly cloudy skies and about 50 percent relative humidity.

The repair was a 6-ft x 12-ft (1.83-m x 3.66-m) punchout at the edge of a joint. The edges of the area to be repaired were saw cut and the deteriorated concrete was jackhammered out to its full depth of 10-in. (254-mm). Wire mesh reinforcing steel was placed at middepth as shown in Fig. 6.16.

A local concete batching plant supplied the class "K" concrete including the Acceleguard 80 accelerator. The mix proportions are shown in Table 6.5. All materials, including the accelerator, were added at the batch plant. The placing of the accelerated concrete was started at 11:00 AM. The slump and air content of the fresh concrete were determined and are given in Table 6.5. Figures 6.17 and 6.18 show the class "K" concrete being placed and finished. Figure 6.19 shows the repair after completion. The repair was completed at 12:00 noon and was opened to traffic at 6:00 PM, 6 hours

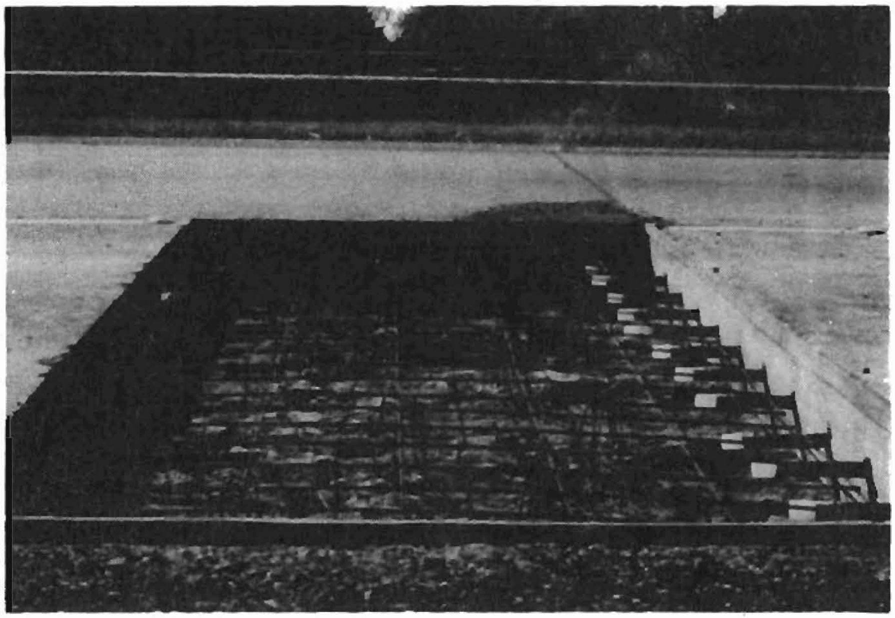


Fig. 6.16. Class "k" Concrete Repair at Houston.

Table 6.5. Mix Proportions and 6-Hour Strength of Class "K" Concrete Used in Houston Repair.

Mix Proportions		
	Quantities Per Cubic Yard	
Material	English Units	SI Units
Acceleguard 80	224 fl. oz.	6.6 lit.
Cement (TXI, Type III)	658 lb.	298.5 kg.
Coarse Aggregate (Grade No. 2)	2003 lb.	908 kg.
Fine Aggregate	902 lb.	409 kg.
Water	35 gal.	132 lit.
Air Entraining Admixture	3.5 fl. oz.	0.10 lit.

Slump - 3 in.
Air Content - 2.5%

6-Hour Strength

Ave. Flexural Strength - 273 psi (1.88 MPa)

Fig. 6.17. Placing Class "k" Concrete at Houston.

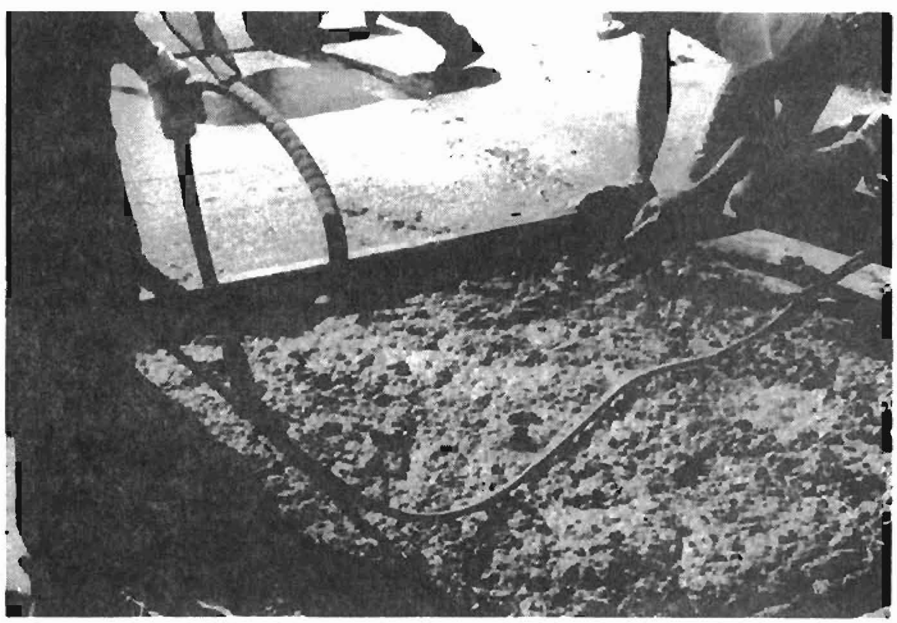


Fig. 6.18. Finishing Class "k" Concrete at Houston.

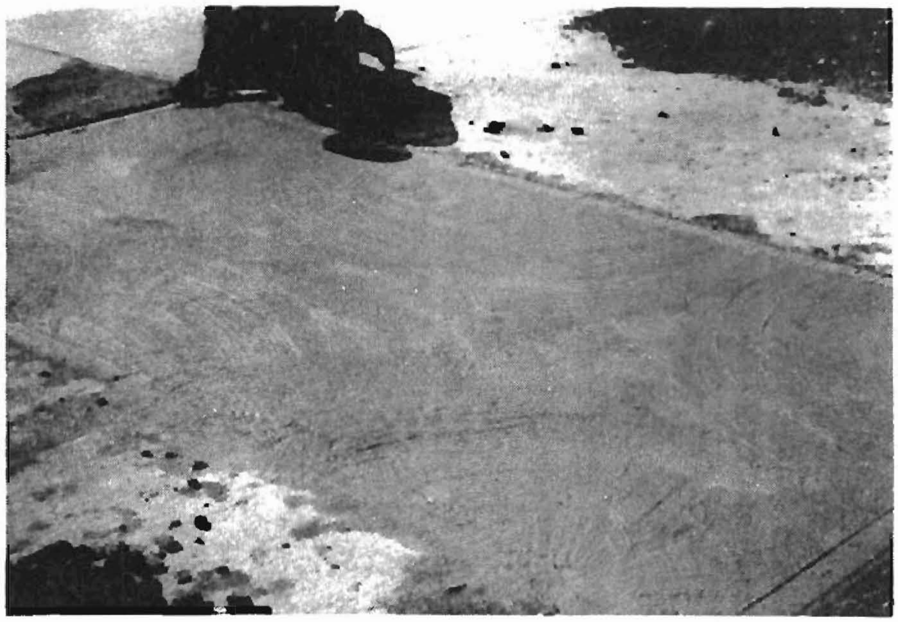


Fig. 6.19. Completed Class "k" Concrete Repair at Houston.

after being placed.

Two 6-in. x 6-in. x 20-in. (152.4-mm x 152.4-mm x 528 mm) beams were cast from the remaining accelerated concrete. They were tested in the field by District 12, 6 hours after the concrete had been placed. The 6-hour flexural strength is shown in Table 6.5.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The objective of this investigation was to evaluate the set time and strength gain acceleration properties of several different types of accelerating admixtures and to evaluate the performance of accelerated concrete as a rapid setting repair material for portland cement concrete pavements and bridge decks.

A survey of the districts of the Texas State Department of Highways and Public Transportation was taken to determine their experience with the use of accelerated concrete as a rapid setting repair material. The type of accelerator used and the amount of accelerated concrete used per year were obtained. Evaluations of each accelerator were made on the basis of types of repairs, cost, durability, ease of use, working time, and strength gain time.

Five different types of accelerators were evaluated in the laboratory. They were: Acceleguard 80, Darex Corrosion Inhibitor, LA-40, Hydraset, and Daraset. Hydraset, a calcium chloride based accelerator was chosen as being representative of most other brands of calcium chloride accelerators. The other four accelerators tested were non-chloride type. The concrete mix used to evaluate the performance of these accelerators was based on the Texas State Department of Highways and Public Transportation specifications for class "K" concrete. The performance of class "K" concrete as a repair material was also evaluated.

Nine different laboratory tests were conducted in the course of this investigation. They were: mortar cube compressive strength, cylinder compressive strength, flexural strength, set time, flexural bond, sandblast abrasion, length change, freeze-thaw resistance, and corrosion tests. The effect of temperature and brand of cement on compressive strength, flexural strength, and set time were also evaluated.

The performance of accelerated concrete was evaluated in actual field repairs performed in Texas. Three repairs were made using Darex Corrosion Inhibitor, one repair was made using Hydraset, and one repair was made using Acceleguard 80. The performance of these repairs will be monitored over the next several years.

7.2 Conclusions

Based upon the survey, the experimental results, and the field applications, the following conclusions can be made:

1) Twelve of the twenty-five districts reported that they use accelerated concrete for highway repairs. Eleven of those districts reported the use of calcium chloride based accelerators. Of the ten different brands of accelerators reported, only two were non-chloride type accelerators.

2) Hydraset, Darex Corrosion Inhibitor, and Daraset provided the most rapid strength gain for both compressive and flexural strengths at all temperatures tested. All three accelerators exhibited nearly the same rate of strength gain, with Hydraset obtaining a slightly higher early rate of strength gain than Darex Corrosion Inhibitor or Daraset.

3) Acceleguard 80 and LA-40 do not provide the strength gain required of a rapid setting repair material.

4) The ambient temperature at which the accelerated concrete is mixed and placed has a significant effect on the early rate of strength gain, both in compression and flexure. Strengths equivalent to the 4 hour strengths achieved at 110°F (43°C) were achieved in 8 hours at 75°F (24°C) and required 24 hour curing at 40°F (4°C).

5) The use of Alamo Type III cement instead of Capitol Type III cement did not have a significant effect on the rate of strength gain, in either flexure or compression. The mixes containing Alamo Type III cement were stiffer and more difficult to place and finish than the mixes containing Capitol Type III cement.

6) Daraset, Darex Corrosion Inhibitor, and Hydraset provided the most rapid initial and final set times in all cases. Initial set times of 2 to 2-1/2 hours and final set times of 2-1/2 to 3 hours were obtained at 75°F (24°C) with these accelerators. At 110°F (43°C) the initial set times were less than 2 hours and the final set times were about 2-1/4 hours. At 40°F (4°C) the initial set times were 3 hours and final set times were 4 to 5 hours.

7) The epoxy bonding surface provided the highest flexural bond strength. The dry bonding surface performed better than the wet bonding surface. The mortar grout bonding surface did not significantly increase the flexural bond strength compared with the dry bonding surface.

8) The use of accelerators reduced the abrasion loss due to sandblasting by approximately fifty percent compared with non-accelerated concrete after seven days of curing.

9) Hydraset and Darex Corrosion Inhibitor exhibited the highest rate of drying shrinkage during the first 14 days of air curing. Although the non-accelerated concrete did not shrink as rapidly during the early stages of drying, its 100 day shrinkage was equal to that of Hydraset and Darex Corrosion Inhibitor.

10) Darex Corrosion Inhibitor with 4 percent air content exhibited better resistance to deterioration due to freeze-thaw cycles than did Hydraset with the same air content. Daraset with 3.2 percent air content also exhibited better freeze-thaw resistance than Hydraset, but did not perform as well as Darex Corrosion Inhibitor in resisting freeze-thaw deterioration.

11) The specimens containing Hydraset (calcium chloride) were more susceptible to corrosion after 6 months of curing than those containing Darex Corrosion Inhibitor. However, these specimens were no more susceptible to corrosion than the non-accelerated specimens in a corrosive environment.

12) Accelerated concrete is easier to use in the field for large repairs where the concrete can be supplied by a ready-mix plant, rather than for smaller repairs in which the accelerated concrete is mixed in small batches at the repair site. However, the accelerator should be added to the mix at the job site to allow adequate time for

placing and finishing of the repair before the concrete reaches initial set.

7.3 Recommendations

The following recommendations are based upon the results of the laboratory tests and field applications of accelerated concrete.

1) The use of accelerated concrete as a rapid setting repair material for highway pavements and bridge decks appears to be best suited for large, full depth repairs in which the concrete can be supplied by a ready-mix plant.

2) The use of accelerated concrete for small repairs in which the concrete must be mixed in small batches at the repair site is not recommended.

3) When problems with corrosion of reinforcing steel are anticipated, the use of either Darex Corrosion Inhibitor or Daraset, both non-chloride accelerators, is recommended in lieu of a calcium chloride accelerator.

4) Additional field applications of accelerated concrete and continued observation of these applications to determine their long-term behavior is recommended, including the use of a concrete mobile mixer which could be used for smaller repairs which may be some distance apart.

APPENDIX

Table A.1 Mix Proportions for PCC Beams Used in Flexural Bond Tests

Materials		PCC For Flexural Bond
Cement	(lb)	50.0
(Type III)	(kg)	22.7
Coarse Aggregate	(lb)	96.0
	(kg)	43.5
Fine Aggregate	(lb)	139.4
	(kg)	63.2
Water	(gal)	3.7
	(liter)	14.0

Table A.2 Mix Proportions for Mortar Grout Used in Flexural Bond Tests

Materials		Mortar Grout
Cement	(lb)	2.0
(type I)	(kg)	0.91
Sand	(lb)	2.0
	(kg)	0.91
Water	(fl. oz)	11.5
	(ml)	340.0

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