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16. Abstract

Using fiber reinforcement with rapid-setting materials is a cost effective and simple way to improve some of the properties of the materials. Whereas the properties of portland cement concrete with fiber reinforcement and the properties of rapid-setting materials without fiber reinforcement are fairly well known, the effect of fibers on rapid-setting materials has not been fully investigated.

This report provides an evaluation of the performance of three different types of rapid-setting materials reinforced with three different types of fibers. Materials tested include gypsum modified portland cement concrete, magnesium phosphate concrete, and modified portland cement concrete. Fibers used in tests are hooked and half-round crimped steel fibers and polypropylene lattice bundles. The results of laboratory tests with varied coarse aggregate content and fiber application rates are given. Field repairs made in Paris, Texas, with fiber reinforced materials are described.

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EVALUATION OF FIBER REINFORCED RAPID-SETTING MATERIALS FOR HIGHWAY REPAIR

by

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Research Report Number 311-5

Research Project 3-9-82-311

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State Department of Highways and Public Transportation

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PREFACE

The authors are indebted to the State Department of Highways and Public Transportation and the members of the Materials and Tests Division for their assistance during the research which is described in this report. Valuable suggestions and guidance on materials and testing procedures were given by George Randolph, Fred Schindler, and Ralph Banks. Assistance in both the laboratory and field phases of this research was provided by Kevin Smith, David Macadam, Richard Ballou, and David Whitney. The work of Nancy Zett and Elizabeth Doubleday, who typed and assembled this report, is greatly appreciated.

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ABSTRACT

Using fiber reinforcement with rapid-setting materials is a cost effective and simple way to improve some of the properties of the materials. Whereas the properties of portland cement concrete with fiber reinforcement and the properties of rapid-setting materials without fiber reinforcement are fairly well known, the effect of fibers on rapid-setting materials has not been fully investigated.

This report provides an evaluation of the performance of three different types of rapid-setting materials reinforced with three different types of fibers. Materials tested includes gypsum modified portland cement concrete, magnesium phosphate concrete, and modified portland cement concrete. Fibers used in tests are hooked and half-round crimped steel fibers and polypropylene lattice bundles. The results of laboratory tests with varied coarse aggregate content and fiber application rates are given. Field repairs made in Paris, Texas with fiber reinforced materials are described.

SUMMARY

The evaluation of fiber reinforced rapid-setting materials is presented. Three candidate rapid-setting materials, chosen during previous CTR 311 tests, are described, along with two types of steel fibers and one type of polypropylene fiber. Laboratory tests for the determination of compressive strength, flexural strength, length change, and splitting tensile strength of the aggregate extended materials are described. Test variables include coarse aggregate content and fiber application rate. The results of the lab tests are given, along with a description of field repairs undertaken in Paris, Texas with fiber reinforced materials.

IMPLEMENTATION STATEMENT

The results of this study should be implemented as soon as possible for highway repairs requiring rapid-setting materials. The addition of fibers to these materials reduces the amount of cracking at an early age, prevents separation of material that does crack, and allows cracked material to continue carrying loads.

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CHAPTER 1
INTRODUCTION

1.1 Background

Due to higher than expected traffic volume and loads, many portland cement concrete (PCC) pavements have exceeded their design life. Because of this, the vast system of PCC highways is deteriorating at a rapid pace. Recent media coverage of the large scale failure of the infrastructure in general and the transportation system in particular has brought to light a special need for economical and durable materials that can be used for the rapid repair of the deteriorating systems.

Since the emphasis on the material used for a repair is frequently on the speed at which the material can be installed (especially in high traffic volume urban areas), many types of rapid-setting repair materials for PCC pavements have been developed and used. Type III PCC with set accelerator and other admixtures, chemical setting cements, and polymer concretes are three types of materials that have had widespread use in the repair of deteriorated PCC pavement. Besides the speed of application, the cost, mechanical properties, workability, and performance are other major factors that should be considered when choosing a material for a particular type of repair.

In order to improve some of the properties of the rapid repair materials, the addition of fiber reinforcement to the materials was suggested. Use of fiber reinforced concrete for pipe, paving block, wall panels, runways, and roadway overlays has been successful.[1] Improvements to material properties can often be made inexpensively and easily by the addition of fibers. Fibers can be fabricated out of such materials as steel (carbon and stainless), glass, alumina, polypropylene, and carbon.

1.2 Scope

Realizing the need for research in the area of rapid-setting patching materials, the Texas State Department of Highways and Public Transportation (TSDHPT) initiated Research Study 311, "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges," in September 1981. Under the direction of the Materials and Tests Division (D-9) and the Center for Transportation Research, Project 311 personnel first identified what rapid-setting materials were in current use. From these, the candidate materials Duracal, Set-45, Neco-crete,and GHP were selected. These were then subjected to a complete series of laboratory tests, at which time Neco-crete was deleted as a candidate material. In conjunction with the laboratory tests, field repairs were made with the candidate materials in different TSDHPT districts to evaluate installation procedures and repair performance.

Previous Research Study 311 results are included in Report 311-1, Results of a Survey on the Use of Rapid-Setting

Materials, Report 311-2, Laboratory Tests on Selected Rapid-Setting Repair Materials, Report 311-3, Evaluation of Accelerated Concrete as a Rapid-Setting Highway Repair Material, and Report 311-4, Laboratory and Field Evaluation of Rapid-Setting Materials Used for Repair of Concrete Pavements.

This report presents the results of laboratory tests on the fiber reinforced candidate materials along with the results of field repairs made in Paris, Texas with fiber reinforced and non-reinforced materials.

CHAPTER 2
MATERIALS TESTED

2.1 Introduction

Four candidate rapid-setting materials were tested by previous Project 311 personnel. Of these four, only three, Duracal, Set-45, and Gilco Highway Patch (GHP), were selected to be tested with fiber reinforcement.

Proportioning of all materials was done according to the manufacturer's recommendations. Aggregate mixes containing binder, fine aggregate, and coarse aggregate were used in all of the laboratory mixes and most of the field repair mixes. Proportions used in the laboratory tests of the three materials are shown in Tables 2.1, 2.2, and 2.3.

The coarse aggregate used in the laboratory specimens was a 3/8-in. (9.5-mm) maximum size silicious gravel with a 1.4 percent absorption. The fine aggregate used in the laboratory mixes was a silicious sand that had a fineness modulus of 2.8 and a 2.0 percent absorption. Fine aggregate was needed only for the Duracal mixes, since both Set-45 and GHP are packaged as a binder/fine aggregate mixture. All aggregate used in laboratory mixes was oven dried.

Mixing of the materials for flexure-relative toughness and splitting tensile specimens was done in a 1 cu ft (0.0283-

Table 2.1 Duracal Lab Mix Proportions

Packaged Material lb(kg)	Coarse Aggregate Ratio %	Coarse Aggregate lb(kg)	Fine Aggregate lb(kg)	Fiber Content lb/yd^3(kg/m^3)	Fiber Weight lb(kg)	Water gal.(liter)
50(22.7)	33	50(22.7)	50(22.7)	85(50.4)	3.15(1.43)	1.75(6.62)
50(22.7)	33	50(22.7)	50(22.7)	75(44.5)	2.78(1.26)	1.75(6.62)
50(22.7)	33	50(22.7)	50(22.7)	65(38.5)	2.41(1.09)	1.75(6.62)
50(22.7)	33	50(22.7)	50(22.7)	1.6(0.95)	0.059(0.027)	1.75(6.62)
50(22.7)	33	50(22.7)	50(22.7)	0	0	1.75(6.62)
50(22.7)	20	25(11.3)	50(22.7)	85(50.4)	2.36(1.07)	1.65(6.24)
50(22.7)	20	25(11.3)	50(22.7)	0	0	1.65(6.24)
50(22.7)	10	11.1(5.03)	50(22.7)	85(50.4)	2.22(1.01)	1.55(5.86)
50(22.7)	10	11.1(5.03)	50(22.7)	0	0	1.55(5.86)

Table 2.2 Set-45 Lab Mix Proportions

Packaged Material lb(kg)	Coarse Aggregate Ratio %	Coarse Aggregate lb(kg)	Fine Aggregate lb(kg)	Fiber Content lb/yd^3(kg/m^3)	Fiber Weight lb(kg)	Water gal.(liter)
50(22.7)	33	24.6(11.2)	a	85(50.4)	1.57(0.71)	0.5(1.89)
50(22.7)	33	24.6(11.2)	a	75(44.5)	1.38(0.63)	0.5(1.89)
50(22.7)	33	24.6(11.2)	a	65(38.5)	1.20(0.54)	0.5(1.89)
50(22.7)	33	24.6(11.2)	a	1.6(0.95)	0.029(0.013)	0.5(1.89)
50(22.7)	33	24.6(11.2)	a	0	0	0.5(1.89)
50(22.7)	20	12.5(5.67)	a	85(50.4)	1.31(0.59)	0.5(1.89)
50(22.7)	20	12.5(5.67)	a	0	0	0.5(1.89)
50(22.7)	10	5.56(2.52)	a	85(50.4)	1.17(0.53)	0.5(1.89)
50(22.7)	10	5.56(2.52)	a	0	0	0.5(1.89)

[a] Fine aggregate is included in the packaged material.

Table 2.3 GHP Lab Mix Proportions

Packaged Material lb(kg)	Coarse Aggregate Ratio %	Coarse Aggregate lb(kg)	Fine Aggregate lb(kg)	Fiber Content lb/yd^3(kg/m^3)	Fiber Weight lb(kg)	Water[b] gal.(liter)
55(24.9)	33	27.1(12.3)	a	85(50.4)	1.72(0.78)	1.0(3.78)
55(24.9)	33	27.1(12.3)	a	75(44.5)	1.52(0.69)	1.0(3.78)
55(24.9)	33	27.1(12.3)	a	65(38.5)	1.32(0.60)	1.0(3.78)
55(24.9)	33	27.1(12.3)	a	1.6(0.95)	0.032(0.015)	1.0(3.78)
55(24.9)	33	27.1(12.3)	a	0	0	1.0(3.78)
55(24.9)	20	13.8(6.24)	a	85(50.4)	1.44(0.65)	1.0(3.78)
55(24.9)	20	13.8(6.24)	a	0	0	1.0(3.78)
55(24.9)	10	6.11(2.77)	a	85(50.4)	1.28(0.58)	1.0(3.78)
55(24.9)	10	6.11(2.77)	a	0	0	1.0(3.78)

[a] Fine aggregate is included in the packaged material.

[b] These are manufacturer's recommended amounts. All GHP mixes required an additional 15 to 20 percent water to produce a workable mix.

cu meter) drum mixer, while the materials for the compression and shrinkage specimens were mixed in a one-third cu ft (0.0094-cu meter) mixer.

The various components of the mixes were combined and mixed in the following order: 1) for Duracal, add 1/2 of required water; for Set-45 and GHP, add all of water; 2) add coarse aggregate and fine aggregate (if needed); 3) if used, add required fibers and mix aggregate-water-fiber combination for one minute; 4) add Duracal, Set-45, or GHP; 5) if Duracal, add remaining water, and 6) mix for approximately two minutes.

2.2 Duracal

Duracal, manufactured by United States Gypsum, is a blend of portland cement and gypsum. It is a water activated material and is packaged neat. Although Duracal can be used as a neat or mortar (fine aggregate only) material, all mixes used in these tests contained both fine and coarse aggregate. The manufacturer recommends that Duracal should not be used at temperatures lower than 32°F (0°C) and that the material should be placed in a moistened hole with two-in. (51-mm) deep sawn edges and no feathered edges. The manufacturer also suggests that the repair can be opened to traffic only one hour after placement. Previous testing of Duracal's rate of strength gain (5), however, suggests that the repair should not be opened to traffic for at least two hours to maximize performance.

Mixed according to instructions, Duracal is a high slump material that is easily placed.

2.3 Set-45

This material, produced by Set-Products (a division of Master Builders), is a mixture of magnesia-phosphate powder and fine aggregate. Set-45 is a water activated material that is available in two formulations, one for hot weather use and one for cold (milder) weather use. All tests covered in this report used the cold weather formulation. Recommendations by the manufacturer include the use of a 1/2-in. (13-mm) minimum depth saw cut around the repair area and a minimum repair depth of 1/2-in. (13-mm). Also recommended is the use of a mortar mixer and that the material be mixed a maximum of 1 1/2 minutes.

Set-45, mixed according to instructions, is a fairly stiff, medium slump material. Although the manufacturer's recommendations allow up to 30 lb (13.6 kg) of coarse aggregate to be added to each bag, it was found that a maximum of 25 lb (11.3 kg) of aggregate per bag made the material easier to mix and place.

2.4 Gilco Highway Patch (GHP)

GHP, produced by Gifford-Hill, is a modified portland cement that is water activated. The modifiers are proprietary. Literature by the manufacturer recommends that a mortar mixer should be used and that the material should be mixed from 3 to

4 minutes. Further recommendations include a minimum 1-in. (25.4-mm) deep edge around the repair area (Saw cut or jack hammered) and that GHP should be placed in a moist hole not less than 1 in. (25.4 mm) deep.

When mixed for laboratory and field applications, GHP required 15 to 20 percent additional water beyond the manufacturer's recommended amount to produce a workable mix.

2.5 Fibers

2.5.1 Introduction

Three different types of fibers were mixed with the rapid-setting materials. Extensive tests were performed on mixes with hooked steel fibers, while a limited number of tests were made on mixes with crimped steel fibers and polypropylene lattice bundle fibers. Fig. 2.1 pictures the various fibers, while Table 2.4 shows the properties of the three fibers.

2.5.2 Hooked Steel Fibers

The hooked smooth drawn wire fibers used in these tests were Dramix fibers, manufactured by Bekaert Steel wire corporation. They are available in collated (ZP) and uncollated (ZL) forms and are produced with a diam of 0.0197 in. (0.5 mm). Both ZP and ZL fibers are available in 1.18-in. (30-mm) or 1.97-in. (50-mm) lengths. Uncollated (loose) fibers with a length of 1.18 in. (30 mm) were used in all tests. Dramix fibers were used at application rates of 65, 75 and 85 lb per cu yd (38.6, 44.5, and 50.4 kg per cu meter) of concrete.

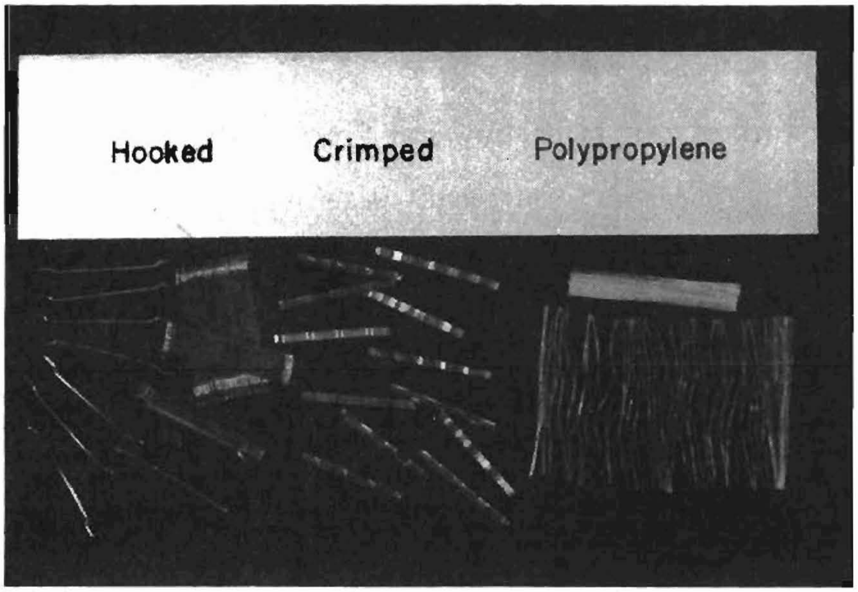

Fig. 2.1. Test Fibers

Table 2.4 Fiber Properties

Type	Material	Tensile Strength ksi(MPa)	Modulus of Elasticity ksi(GPa)	Aspect Ratio[a]
Hooked	steel	170-200(1172-1379)	29000(200)	60
Crimped	steel	170-200(1172-1379)	29000(200)	23
Lattice Bundle	Polypropylene	70-110(483-758)	500-700(3.4-4.8)	N.A.

[a] The aspect ratio is calculated by dividing the length of the fiber by its diameter. For the crimped fibers, the cross sectional area is used to compute a equivalent diameter.

2.5.3 Crimped Steel Fibers

The deformed crimped half round steel fibers used in tests were Xorex fibers, manufactured by the Ribbon Technology Corporation. Dimensions of the fibers used were 1 in. (25.4 mm) x 0.078 in. (1.98 mm) x 0.019 in. (0.48 mm). Xorex fibers were used at the rate of 85 lb per cu yd (50.4 kg per cu meter) of concrete.

2.5.4 Polypropylene Lattice Bundles

The polypropylene fibers used in tests were Forta-Fibre, produced by Forta-Fibre Inc. These fibers are produced as small bundles that, when mixed, spread out into the mix as three-dimensional lattices. Forta-Fibre was used at the manufacturer's recommended application rate of 1.6 lb per cu yd (0.95 kg per cu meter) of concrete.

CHAPTER 3
EVALUATION TESTS

3.1 Introduction

Previous work completed on Project 311 includes the performance of laboratory tests to establish which material properties are relevant in predicting field repair performance. CTR Report 311-2, Laboratory Tests on Selected Rapid-Setting Repair Materials presents the results of 12 types of tests performed at ambient laboratory conditions, approximately 72°F (22°C) and 50 percent R.H.

Of the 12 tests performed, only four, the cylinder compression test, flexural beam test, Gilmore needle set time, and shear bond test were judged to be useful for evaluating rapid-setting materials. Of these four, only the cylinder compression test and a modified version of the flexural beam test were deemed important in evaluating fiber reinforced rapid-setting materials. In addition to the compression and flexural tests, splitting tensile strength tests and length change tests were also performed on the three candidate materials.

Because of the rapid setting nature of the materials, the ASTM specifications for curing test specimens required some modification. Instead of the wet curing specified by ASTM, all specimens were air cured at ambient laboratory conditions until the time of testing.

All specimens were removed from their molds 1 to 2 hours after casting.

3.2 Compressive Strength

Tests to determine compressive strength were made according to ASTM C39-81 "Compressive Strength of Cylindrical Concrete Specimens." Test specimens were cast in 3-in. (76-mm) x 6-in. (152-mm) waxed paper cylinder molds. All specimens were capped to provide a smooth end surface. Compression tests were performed at the maximum ASTM recommended rate of 20,000 lb/min (9070 kg/min).

3.3 Flexural Strength - Relative Toughness

Flexural strength and the relative toughness of the fiber reinforced materials were determined according to a extended version of ASTM C78-75 "Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." Three-in. (76-mm) x 3-in. (76-mm) x 16-in. (406-mm) beam specimens were cast in lightly greased steel molds. The beams were loaded at the 3rd points of a 9-in. (229-mm) span with the loading rate being held at a constant 300 lb/min (136 kg/min) before and after cracking of the concrete.

The test set-up, shown in Fig. 3.1, used a hydraulic loading frame with a maximum load cell capacity of 80,000 lb (36281 kg). A DCDT was used to measure the relative deflection of the beam. The load applied to the beam was obtained from the loading frame's built-in load cell. The deflections from the

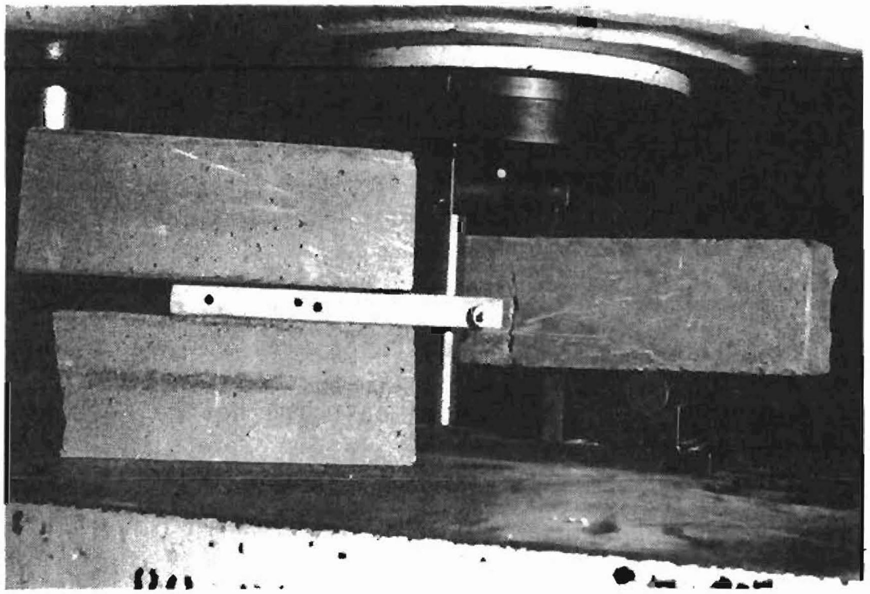

Fig. 3.1. Flexural Strength-Relative Toughness Test Set-up

DCDT and the loads from the load cell were relayed to a X - Y recorder, which plotted a load versus deflection curve for each specimen tested. The area under the load-deflection curves were then used to find the relative toughness of the fiber reinforced materials.

3.4 Length Change

Tests to determine the length change of the materials were performed according to a modified version of ASTM C157-80 "Length Change of Hardened Cement Mortar and Concrete." Two-in. (51-mm) x 2-in. (51-mm) x 12-in. (305-mm) beam specimens were cast in steel molds coated with a light lubricating grease. Beams were removed from their molds and measured after 1 to 2 hours of air curing instead of the ASTM required 28 days of curing in lime saturated water. The length change measuring device used is shown in Fig. 3.2.

3.5 Splitting Tensile Strength

Splitting tensile strength tests were performed according to ASTM C496-71 "Splitting Tensile Strength of Cylindrical Concrete Specimens." Three-in. (76-mm) x 6-in. (152-mm) waxed paper molds were used to form the specimens. Pressed wood panel strips were used as padding on the top and bottom surfaces of the cylinders, which were loaded at a rate of 300 lb/min (136 kg/min).

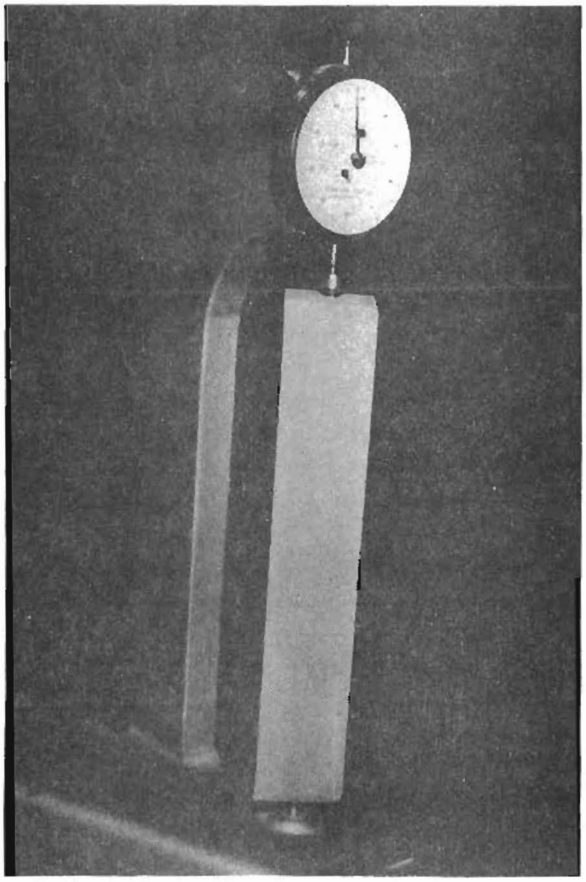

Fig. 3.2. Length Change Measuring Device

CHAPTER 4
RELATIVE TOUGHNESS OF FIBER REINFORCED MATERIALS

In this report, the measurement of absorbed energy and the computation of the relative toughness (RT) of a material was done in order to show the ability of a fiber reinforced patching material to stay together and still carry a load after the material has cracked.

The RT of a fiber reinforced concrete material is defined in this report as being a measure of the amount of energy required to deflect a 3-in. (76-mm) x 3-in. (76-mm) fiber reinforced beam 0.070 in. (1.78 mm) divided by the energy required to produce first crack in a non-reinforced beam. (Deflection is taken at the mid-point of a 9-in. (229-mm) span.) In other words, the RT of a fiber reinforced material is simply the ratio of the absorbed energy of a reinforced material to the absorbed energy of a non-reinforced material.

Since the area under a beam's load-deflection curve is the amount of energy absorbed by the material, the RT of the material can be computed by taking the area under the reinforced beam's load deflection curve and dividing it by the area under the non-reinforced beam's load deflection curve. Fig. 4.1 shows graphically how RT values were calculated.

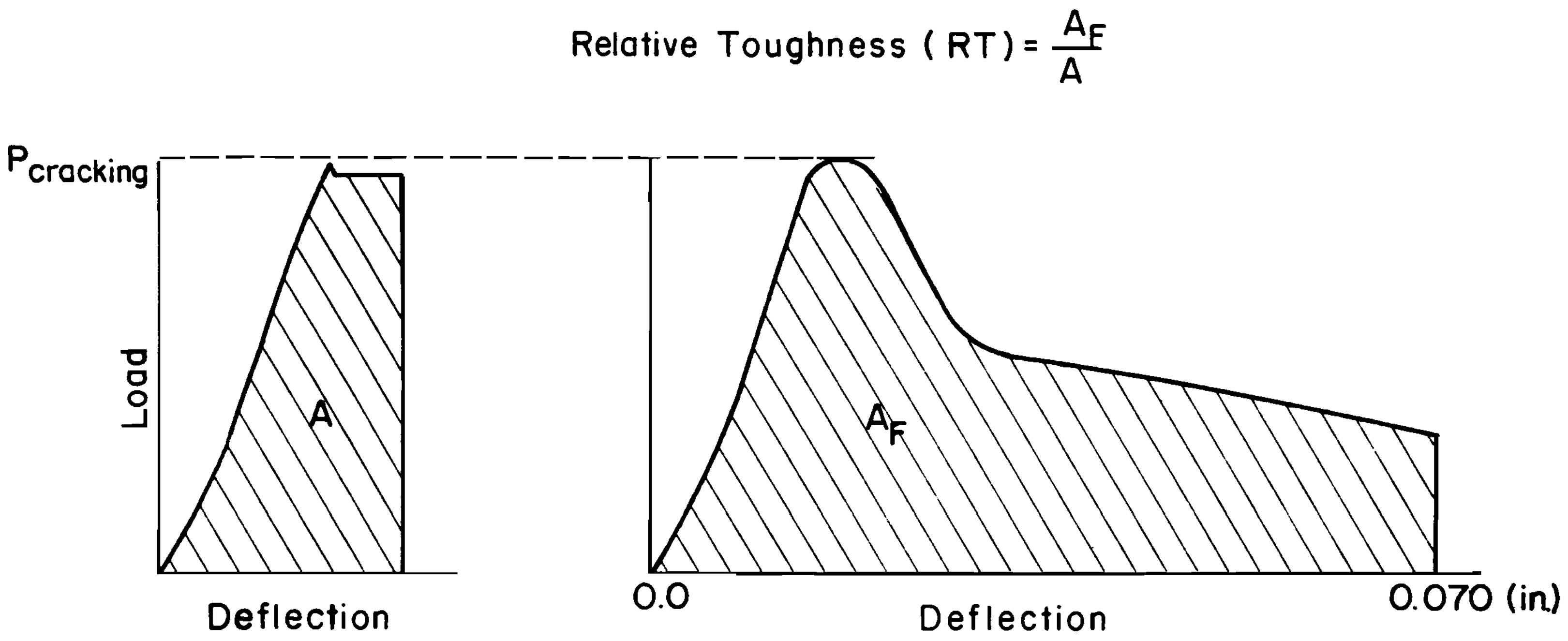

Fig. 4.1. Computation of Relative Toughness

CHAPTER 5
TEST VARIABLES

5.1 Fiber Quantity and Type

To determine the effect of fiber rate of application, compression, flexural-RT, and length change specimens were cast with hooked steel fibers at the rate of 65, 75, and 85 lb per cu yd (38.6, 44.5, 50.4 kg per cu meter) of concrete.

Polypropylene fibers were cast in splitting tension, flexural-RT, and length change specimens at the recommended application rate of 1.6 lb per cu yd (0.95 kg per cu meter) of concrete.

Because of limited time, only splitting tension and flexural-RT specimens were cast with crimped steel fibers. These specimens had a fiber rate of application of 85 lb per cu yd (50.4 kg per cu meter) of concrete.

All specimens with variable fiber quantities had a coarse aggregate (CA) ratio of 33 percent. The CA ratio of a mix was computed as being the weight of coarse aggregate used divided by the weight of all aggregates and cement.

In order to compute the RT's of the materials, flexural-RT beams were cast with a CA ratio equal to 33 per cent, but with no fibers. For the sake of comparison, compression cylinders and length change beams were made with a CA ratio of 33 percent but without fibers.

5.2 Coarse Aggregate (CA) Ratio

The effect of the CA ratio on the properties of fiber reinforced materials was investigated by varying the CA ratio while holding the fiber rate of application constant. Splitting tension, compression, and flexural-RT specimens were made with hooked fibers at the application rate of 85 lb per cu yd (50.4 kg per cu meter) of concrete and with CA ratios of 10 and 20 percent. Specimens with 85 lb per cu yd (50.4 kg per cu meter) of hooked fibers and a CA ratio of 33 percent had already been cast for the tests involving variable fiber contents.

As with the specimens for variable fiber contents, flexural-RT beams, splitting tension, and compression specimens were cast with no fibers but with CA ratios of 10 and 20 percent for the computation of RT values and for the sake of comparison.

CHAPTER 6
TEST RESULTS

6.1 Compressive Strength vs. Fiber Content

Figs. 6.1, 6.2, and 6.3 show the compressive strength vs time curves for Duracal, Set-45, and GHP with varied hooked fiber content and a CA ratio of 33 percent. Table 6.1 shows these results in a tabular form. As is typical of magnesia phosphate materials, Set-45 shows a faster strength gain than Duracal and GHP, which are modified portland cement materials. In addition to the more rapid strength gain, the compressive strength of Set-45 at any given time is typically 10 to 40 percent higher than that of Duracal or GHP.

Although the strengths vary from one material to another, the strengths of the different fiber content mixes do not vary significantly for the same material. For all three materials, the 85 lb per cu yd (50.4 kg per cu meter) mix gave the lowest strengths. The mixes without fibers always had strengths higher than the 85 lb per cu yd (50.4 kg per cu meter) mixes.

6.2 Compressive Strength vs CA Ratio

Figs. 6.4, 6.5, and 6.6 show the compressive strength vs time curves for the three rapid-setting materials with varied CA ratios. Tabulated results are shown in Table 6.1. As can be seen from the three figures, there is little or no correlation in

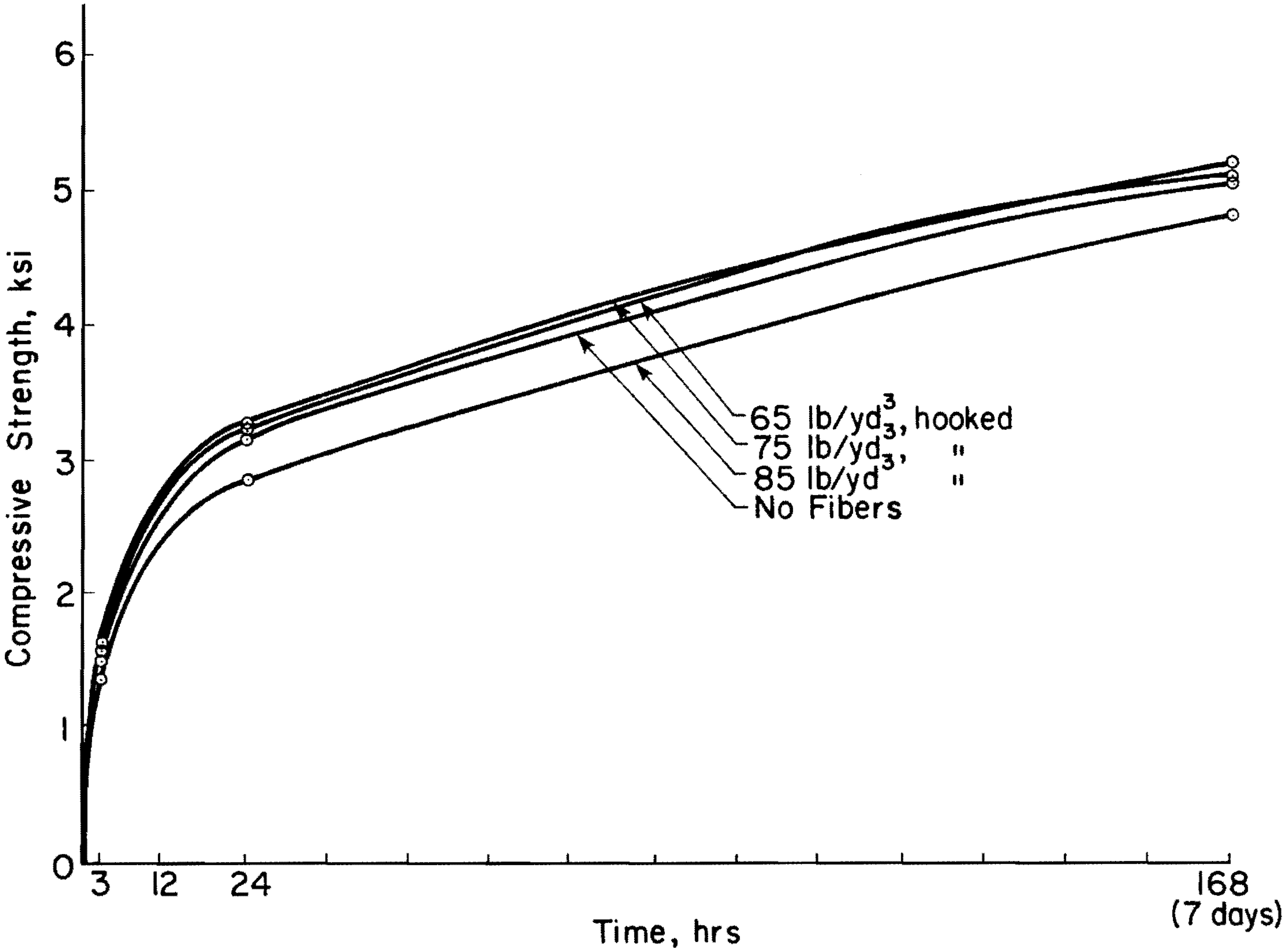

Fig. 6.1. Duracal Compressive Strength as a Function of Time: Varied Fiber Content, CA ratio = 33%

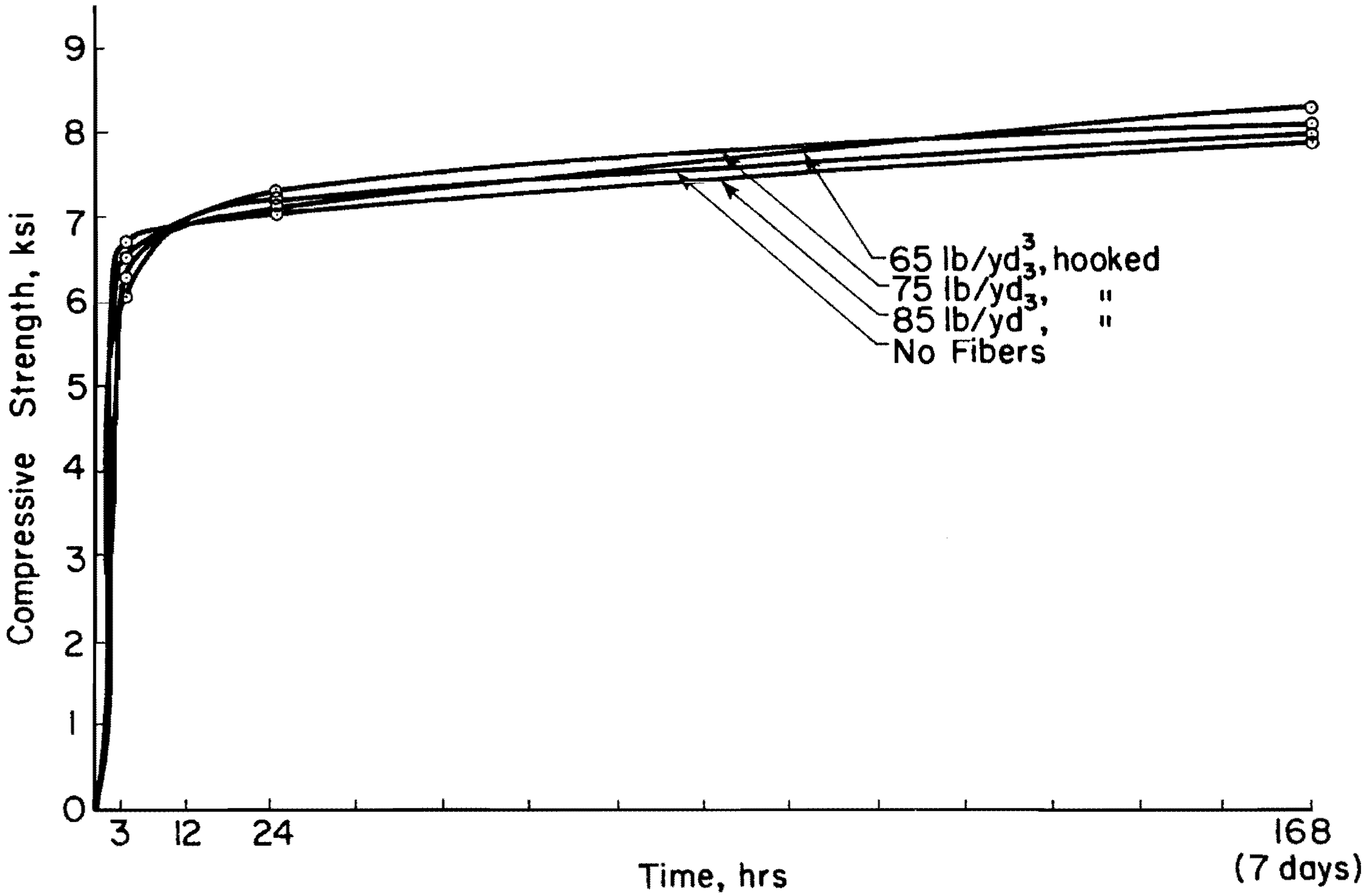

Fig. 6.2. Set-45 Compressive Strength as a Function of Time: Varied Fiber Content, CA ratio = 33%

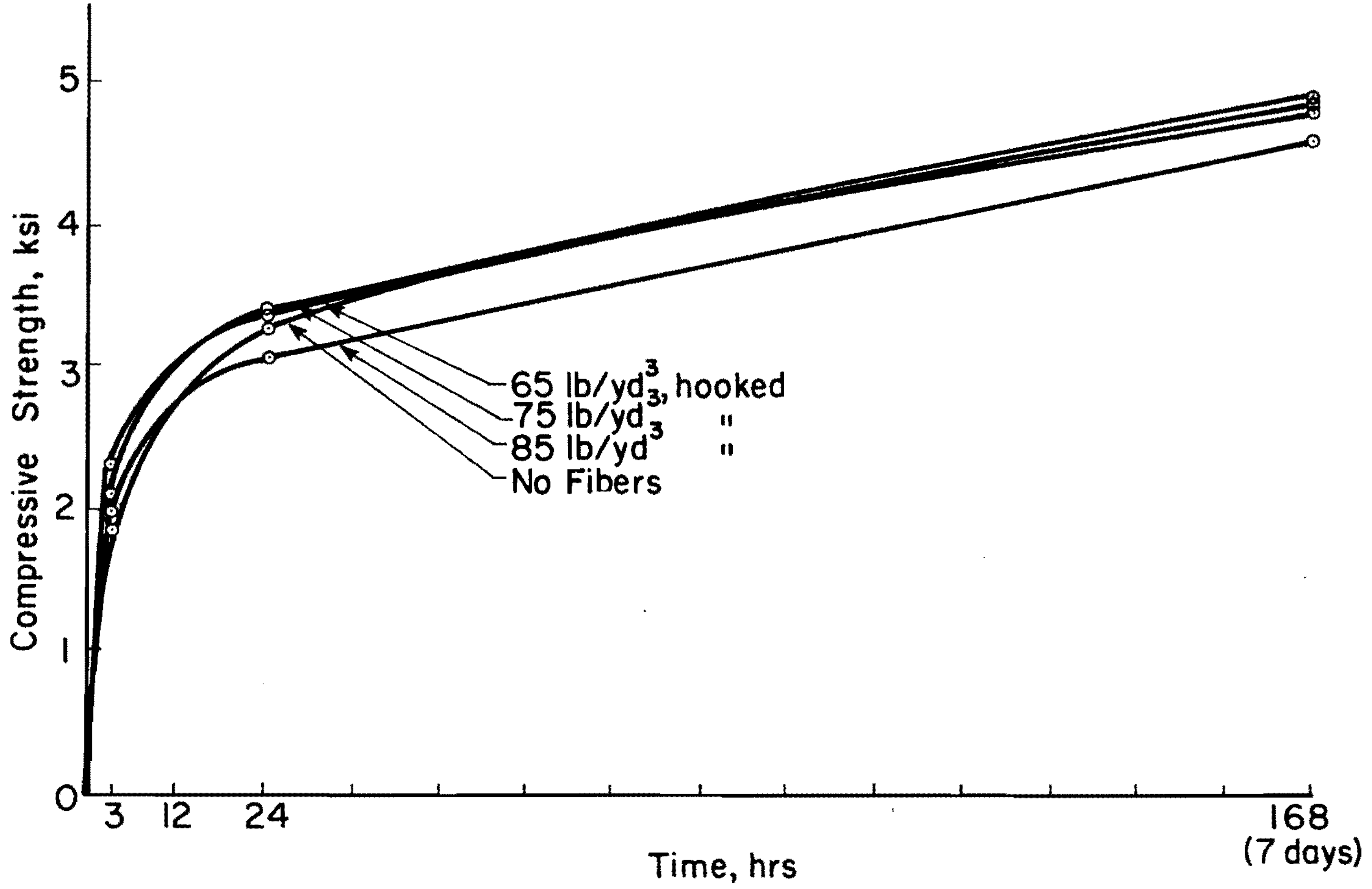

Fig. 6.3. GHP Compressive Strength as a Function of Time: Varied Fiber Content, CA ratio = 33%

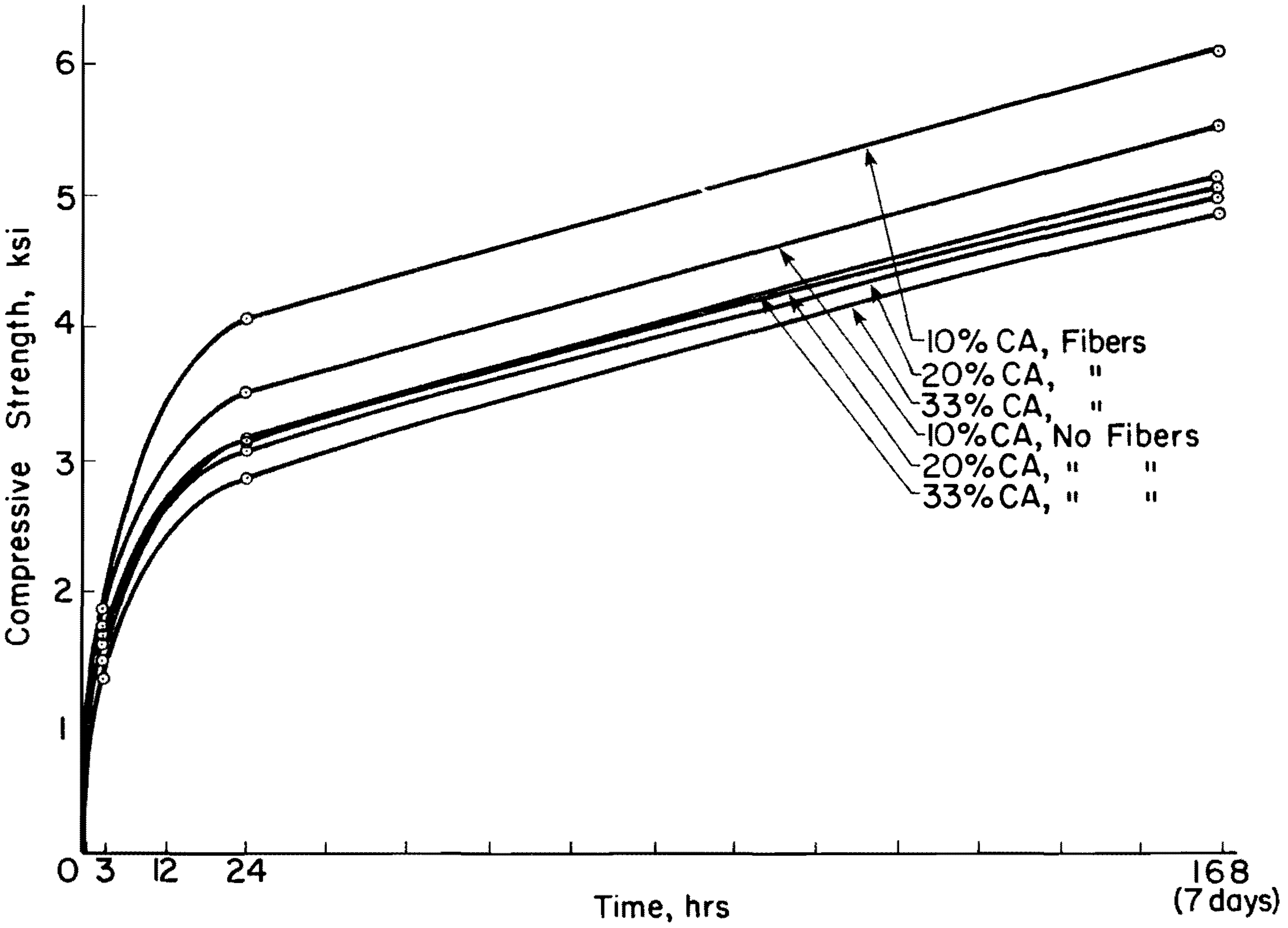

Fig. 6.4. Duracal Compressive Strength as a Function of Time:
Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

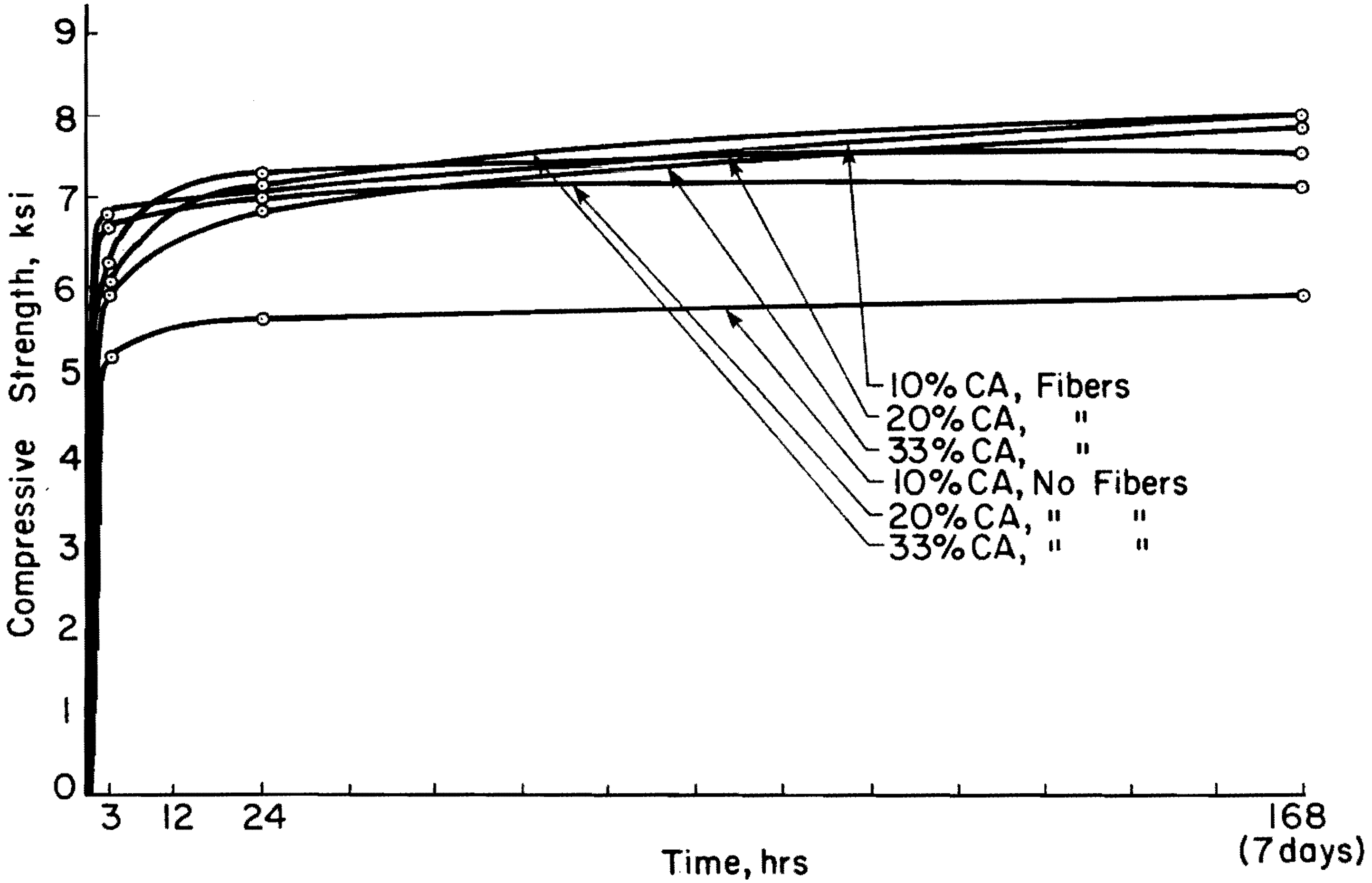

Fig. 6.5. Set-45 Compressive Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

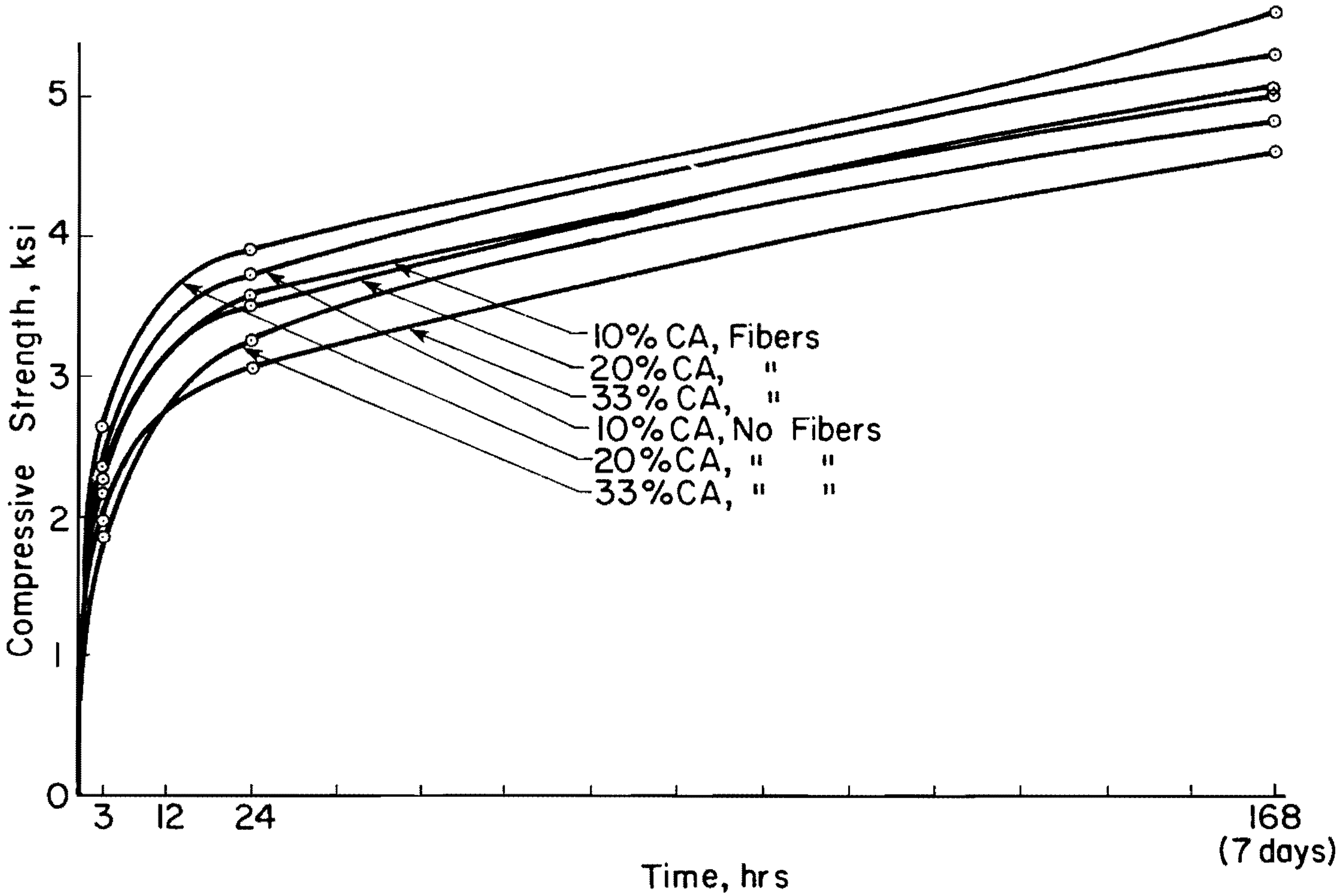

Fig. 6.6. GHP Compressive Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

Table 6.1 Compressive Strength Results

Material	C.A. Ratio %	Fiber Content lb/yd^3(kg/m^3)	Fiber Type	Compressive Strength					
				3 hour		24 hour		7 day	
				Psi	MPa	Psi	MPa	Psi	MPa
Duracal	10	0	-	1670	11.52	3530	24.35	5530	38.14
	10	85 (50.4)	hooked	1860	12.83	4080	28.14	6100	42.07
	20	0	-	1600	11.04	3160	21.80	5050	34.83
	20	85 (50.4)	hooked	1620	11.17	3110	21.45	4930	34.00
	33	0	-	1500	10.35	3150	21.73	5160	35.59
	33	85 (50.4)	hooked	1370	9.45	2820	19.52	4820	33.25
	33	75 (44.5)	hooked	1540	10.62	3280	22.62	5170	35.66
	33	65 (38.6)	hooked	1550	10.69	3270	22.55	5220	36.00
t-45	10	0	-	5170	35.66	5610	38.69	5960	41.11
	10	85 (50.4)	hooked	6740	46.49	7100	48.97	8040	55.46
	20	0	-	5810	40.07	6910	47.66	7270	50.14
	20	85 (50.4)	hooked	6310	43.52	7200	49.66	7600	52.42
	33	0	-	6040	41.66	7250	50.01	8040	55.46
	33	85 (50.4)	hooked	6690	46.14	7040	48.56	7980	55.04
	33	75 (44.5)	hooked	6560	45.25	7300	50.35	8210	56.63
	33	65 (38.6)	hooked	6300	43.45	7120	49.11	8360	57.66

(continued)

Table 6.1 Compressive Strength Results (Continued)

Material	C.A. Ratio %	Fiber Content lb/yd^3(kg/m^3)	Fiber Type	Compressive Strength					
				3 hour		24 hour		7 day	
				Psi	MPa	Psi	MPa	Psi	MPa
GHP	10	0	-	2350	16.21	3730	25.73	5340	36.83
	10	85 (50.4)	hooked	2190	15.11	3580	24.69	5070	34.97
	20	0	-	2620	18.07	3910	26.97	5630	38.83
	20	85 (50.4)	hooked	2290	15.80	3540	24.42	5100	35.18
	33	0	-	1850	12.76	3270	22.55	4880	33.66
	33	85 (50.4)	hooked	1990	13.73	3060	21.11	4610	31.80
	33	75 (44.5)	hooked	2100	14.48	3400	23.45	4850	33.45
	33	65 (38.6)	hooked	2230	15.38	3390	23.38	4920	33.94

strengths between similar CA ratio mixes of different materials. In other words, the varied CA ratio mixes with and without fibers do not follow a similar pattern of lowest to highest strengths when comparing the three materials. Fig. 6.4 shows that a 10 percent CA ratio mix with fibers tends to be the strongest Duracal mix, while Fig. 6.5 shows that a Set-45 mix with a 33 percent CA ratio and without fibers will give the highest overall compressive strength for that material. GHP strengths, shown in Fig. 6.6, were highest when a non-reinforced 20 percent CA ratio mix was used.

Although the ranking of the strengths of the various mixes did change from material to material, the difference in compressive strength for different CA ratio mixes of the same material was not very significant. (The range of values was small.)

6.3 Flexural Strength vs Fiber Content and Type

Flexural strength vs time curves for the varied fiber content mixes with a CA ratio of 33 percent are shown in Figs. 6.7, 6.8, and 6.9. Table 6.2 shows the tabulized results. The wider range in values for the fiber content mixes for each material shows that flexural strength is more sensitive to fiber content than is compressive strength. Fig. 6.7 shows that the 85 lb per cu yd (50.4 kg per cu meter) crimped fiber mix has high strength when used with Duracal. The polypropylene fiber mix and the no

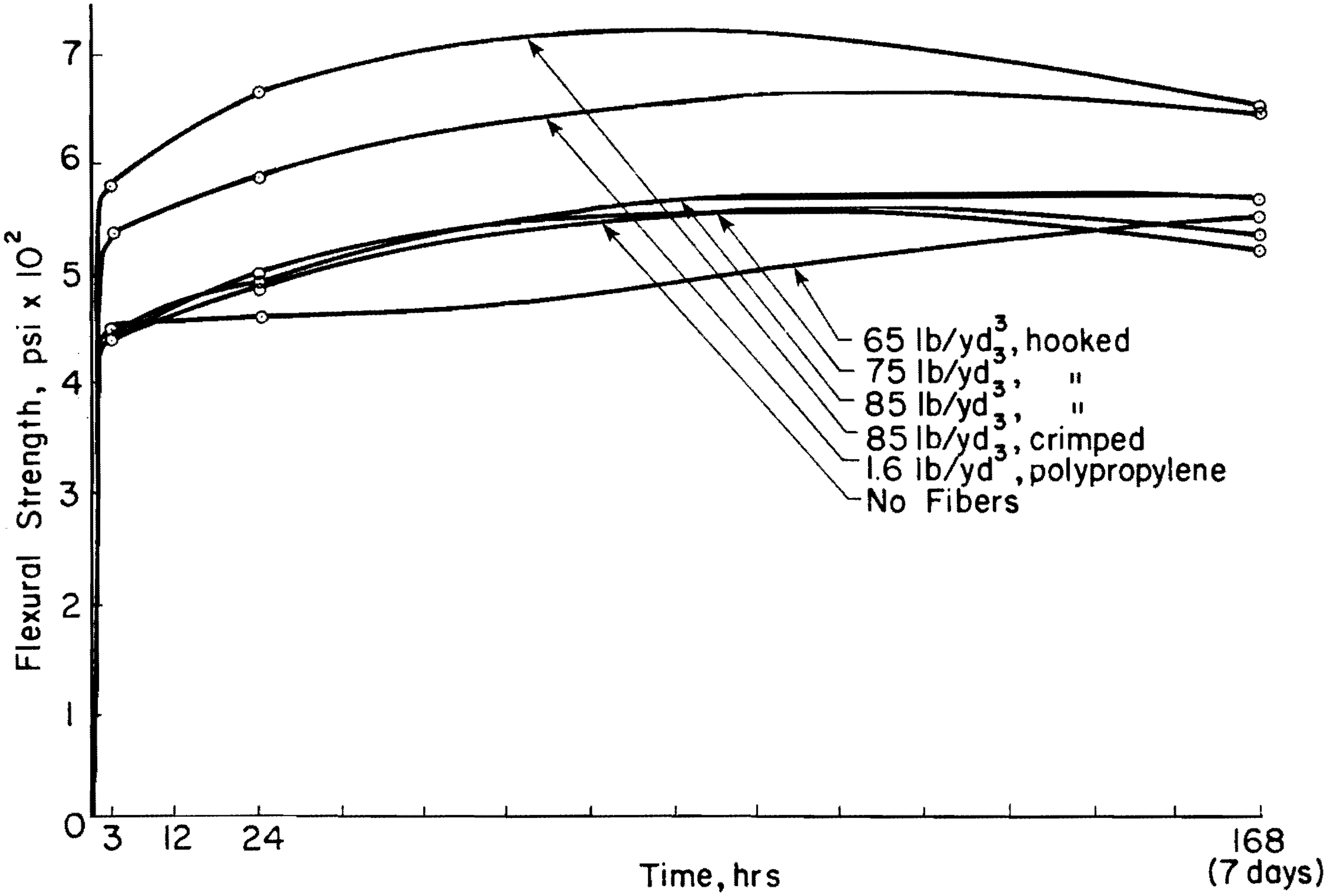

Fig. 6.8. Set-45 Flexural Strength as a Function of Time: Varied Fiber Content and Type, CA ratio = 33%

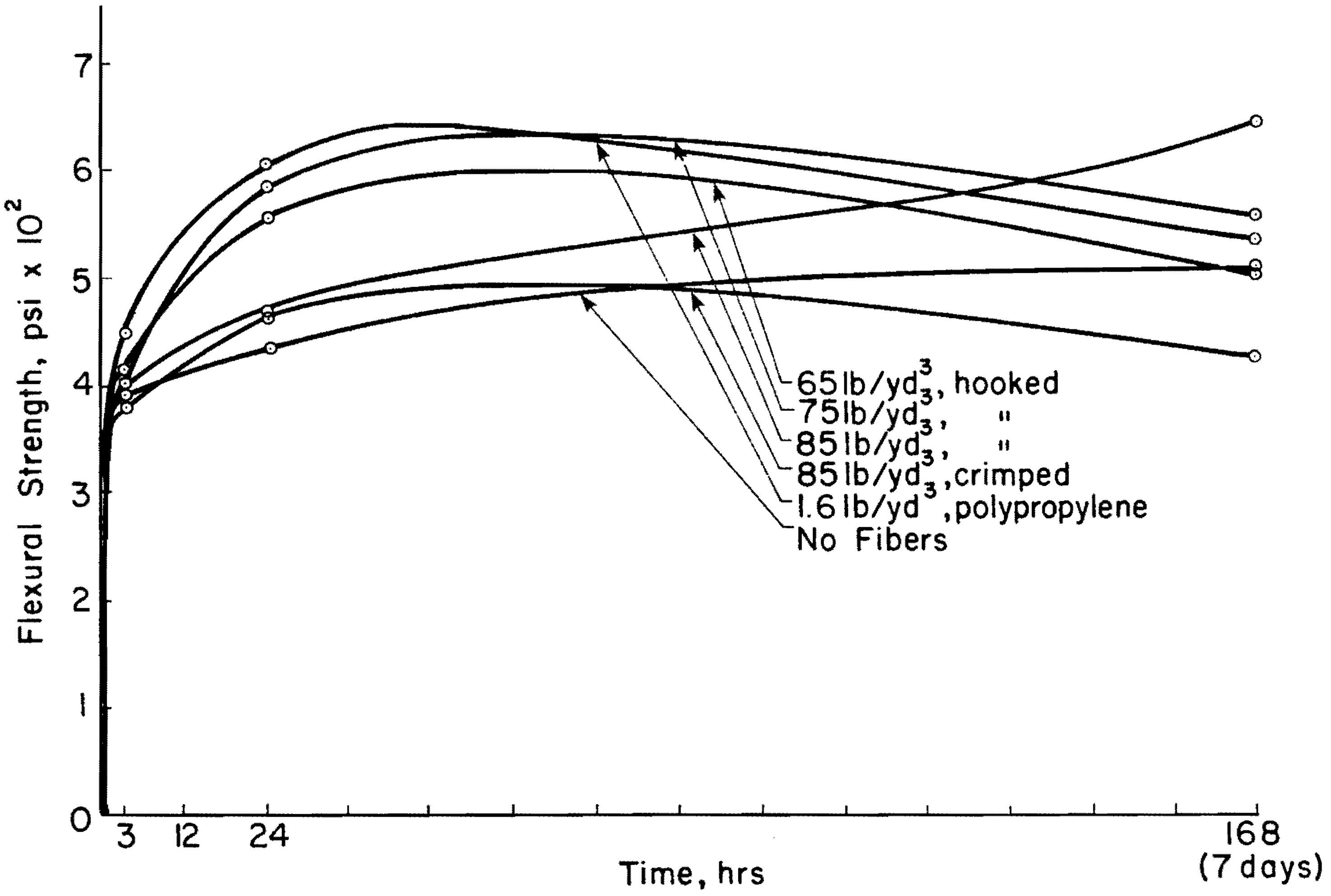

Fig. 6.9. Flexural Strength as a Function of Time: Varied Fiber Content and Type, CA ratio = 33%

fiber Duracal mixes show the lowest overall flexural strengths for that material. As with Duracal, the highest strength for Set-45 came from the 85 lb per cu yd (50.4 kg per cu meter) crimped fiber mix, which is shown in Fig. 6.8. The lowest strength for Set-45, however, was the 65 lb per cu yd (38.6 kg per cu meter) hooked fiber mix.

Fig. 6.9 shows that the 1.6 lb per cu yd (0.95 kg per cu meter) polypropylene fiber mix and the 75 lb per cu yd (44.5 kg per cu meter) hooked fiber mix have the highest early strengths for GHP mixes, but are overtaken by the 85 lb per cu yd (50.4 kg per cu meter) mix at approximately 5 1/2 days.

For all three materials, higher fiber content mixes did not necessarily give higher flexural strengths. The no fiber mixes of all three materials were consistently among the lowest flexural strengths, which was expected.

Some values of flexural strength remained the same or actually decreased between 24 hours and 7 days. This is relatively common with some types of rapid-setting materials, but is not dangerous, since the decrease is typically very small.

6.4 Flexural Strength vs CA Ratio

Figs. 6.10, 6.11, and 6.12 show the flexural strength vs time curves for Duracal, Set-45, and GHP mixes with varied CA ratios. Table 6.2 shows the results in tabular form. These curves are similar to the varied fiber content curves in the sense

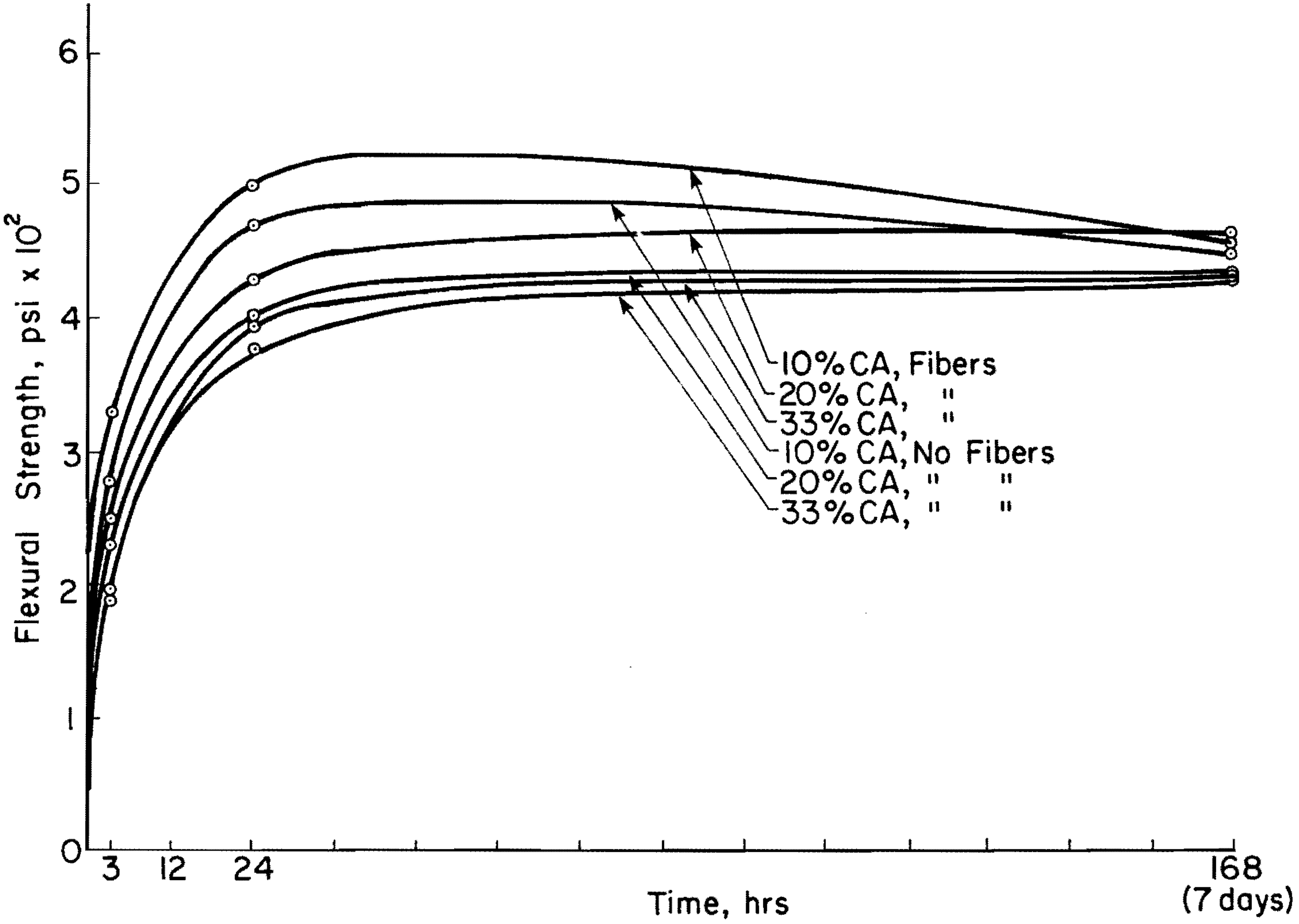

Fig. 6.10. Duracal Flexural Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

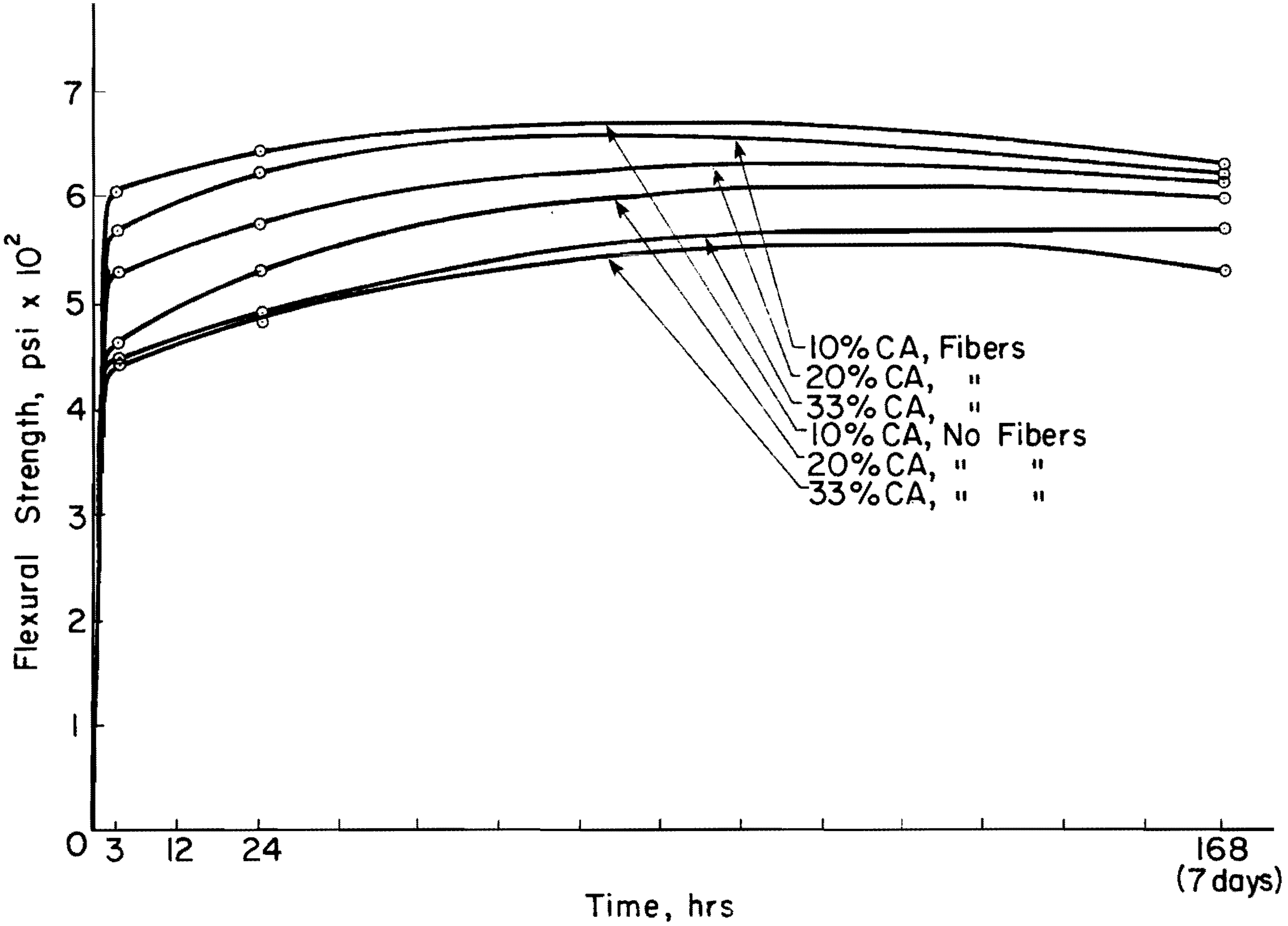

Fig. 6.11. Set-45 Flexural Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

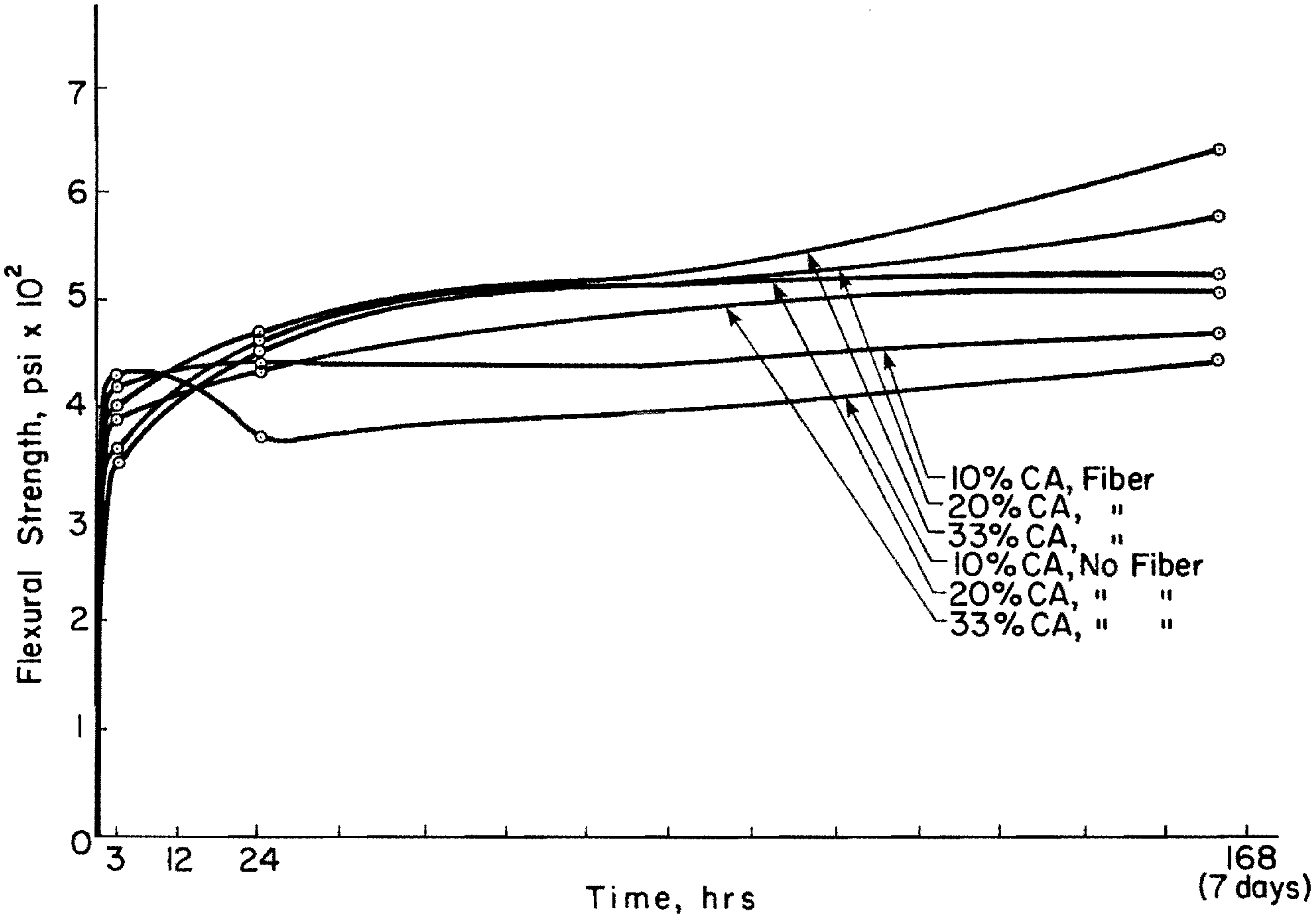

Fig. 6.12. GHP Flexural Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

Table 6.2 Flexural Strength Results

Material	C.A. Ratio %	Fiber Content lb/yd^3(kg/m^3)	Fiber Type	Flexural Strength					
				3 hour		24 hour		7 day	
				Psi	MPa	Psi	MPa	Psi	MPa
Duracal	10	0	-	280	1.93	470	3.24	450	3.10
	10	85 (50.4)	hooked	330	2.28	500	3.45	460	3.17
	20	0	-	230	1.59	400	2.76	440	3.03
	20	85 (50.4)	hooked	250	1.72	430	2.97	460	3.17
	33	0	-	200	1.38	380	2.62	430	2.97
	33	85 (50.4)	hooked	190	1.31	400	2.76	430	2.97
	33	75 (44.5)	hooked	240	1.66	420	2.90	450	3.10
	33	65 (38.6)	hooked	240	1.66	400	2.76	580	4.00
	33	85 (50.4)	crimped	240	1.66	470	3.24	560	3.86
	33	1.6 (0.95)	polypropylene	190	1.31	350	2.41	460	3.17
Set-45	10	0	-	610	4.21	640	4.41	640	4.41
	10	85 (50.4)	hooked	570	3.93	630	4.35	630	4.35
	20	0	-	460	3.17	530	3.66	600	4.14
	20	85 (50.4)	hooked	530	3.66	570	3.93	620	4.28
	33	0	-	440	3.03	480	3.31	540	3.72
	33	85 (50.4)	hooked	450	3.10	490	3.38	570	3.93
	33	75 (44.5)	hooked	440	3.03	490	3.38	520	3.59
	33	65 (38.6)	hooked	450	3.10	450	3.10	560	3.86
	33	85 (50.4)	crimped	580	4.00	670	4.62	660	4.55
	33	1.6 (0.95)	polypropylene	540	3.72	590	4.07	650	4.48

(continued)

Table 6.2 Flexural Strength Results (Continued)

Material	C.A. Ratio %	Fiber Content lb/yd^3(kg/m^3)	Fiber Type	Flexural Strength					
				3 hour		24 hour		7 day	
				Psi	MPa	Psi	MPa	Psi	MPa
GHP	10	0	-	430	2.97	380	2.62	450	3.10
	10	85 (50.4)	hooked	430	2.97	440	3.03	480	3.31
	20	0	-	370	2.55	470	3.24	540	3.72
	20	85 (50.4)	hooked	350	2.41	550	3.79	590	4.07
	33	0	-	390	2.69	440	3.03	520	3.59
	33	85 (50.4)	hooked	400	2.76	470	3.24	650	4.48
	33	75 (44.5)	hooked	400	2.76	590	4.07	570	3.93
	33	65 (38.6)	hooked	410	2.83	560	3.86	510	3.52
	33	85 (50.4)	crimped	380	2.62	470	3.24	430	2.97
	33	1.6 (0.95)	poly-propylene	440	3.03	610	4.21	540	3.72

that they are more spread out than the compressive strength curves and that they follow no consistent pattern from one material to another.

The highest strength Duracal mix, shown in Fig. 6.10, is the 10 percent CA mix with fibers, while the lowest is the 33 percent CA mix without fibers. The highest strength Set-45 mix, shown in Fig. 6.11, is the 10 percent CA mix without fibers. The Set-45 mix with the lowest strength was the 33 percent CA mix without fibers, the same one which gave the lowest strength for Duracal.

The GHP strengths, shown in Fig. 6.12, varied considerably. The 33 percent CA ratio mix with fibers shows the highest strength beyond 24 hours. The apparent drop in strength of the 10 percent CA ratio mix at 24 hours is probably due to an abnormally high 3 hour value and not to an unusually low 24 hour value.

6.5 Relative Toughness vs Fiber Content and Type

Relative Toughness (RT) vs time curves for the three materials with varied fiber content and a CA ratio of 33 percent are shown in Figs. 6.13, 6.14, and 6.15. Tabulized results are shown in Table 6.3. As with the compressive and flexural strength curves, the RT curves for the various fiber content mixes do not follow any set pattern from one material to another.

Fig. 6.13 shows that the 65 lb per cu yd (38.6 kg per cu meter) hooked fiber mix had the highest RT at 3 hours and 7 days for

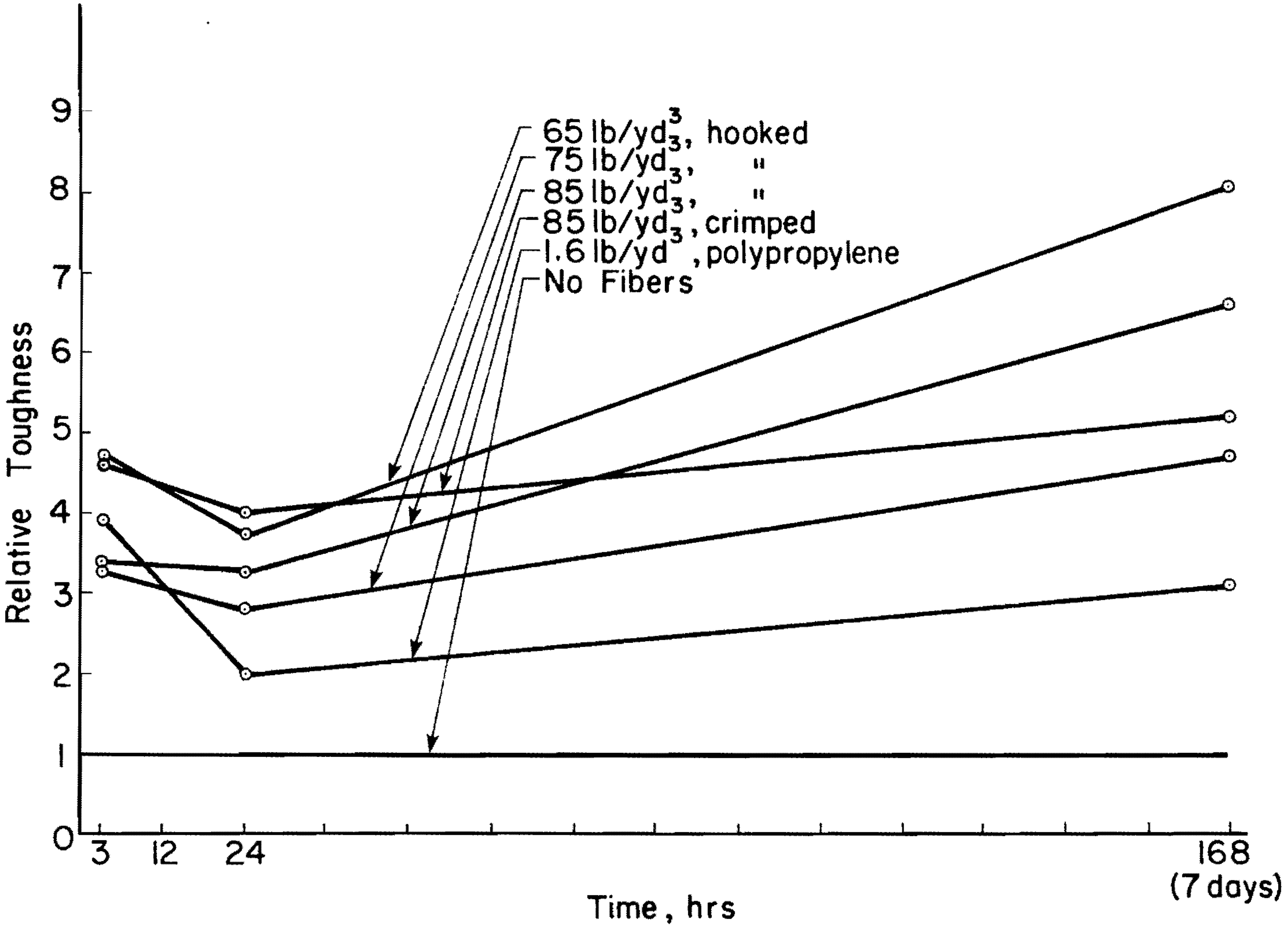

Fig. 6.13. Duracal Relative Toughness as a Function of Time: Varied Fiber Content and Type, CA ratio = 33%

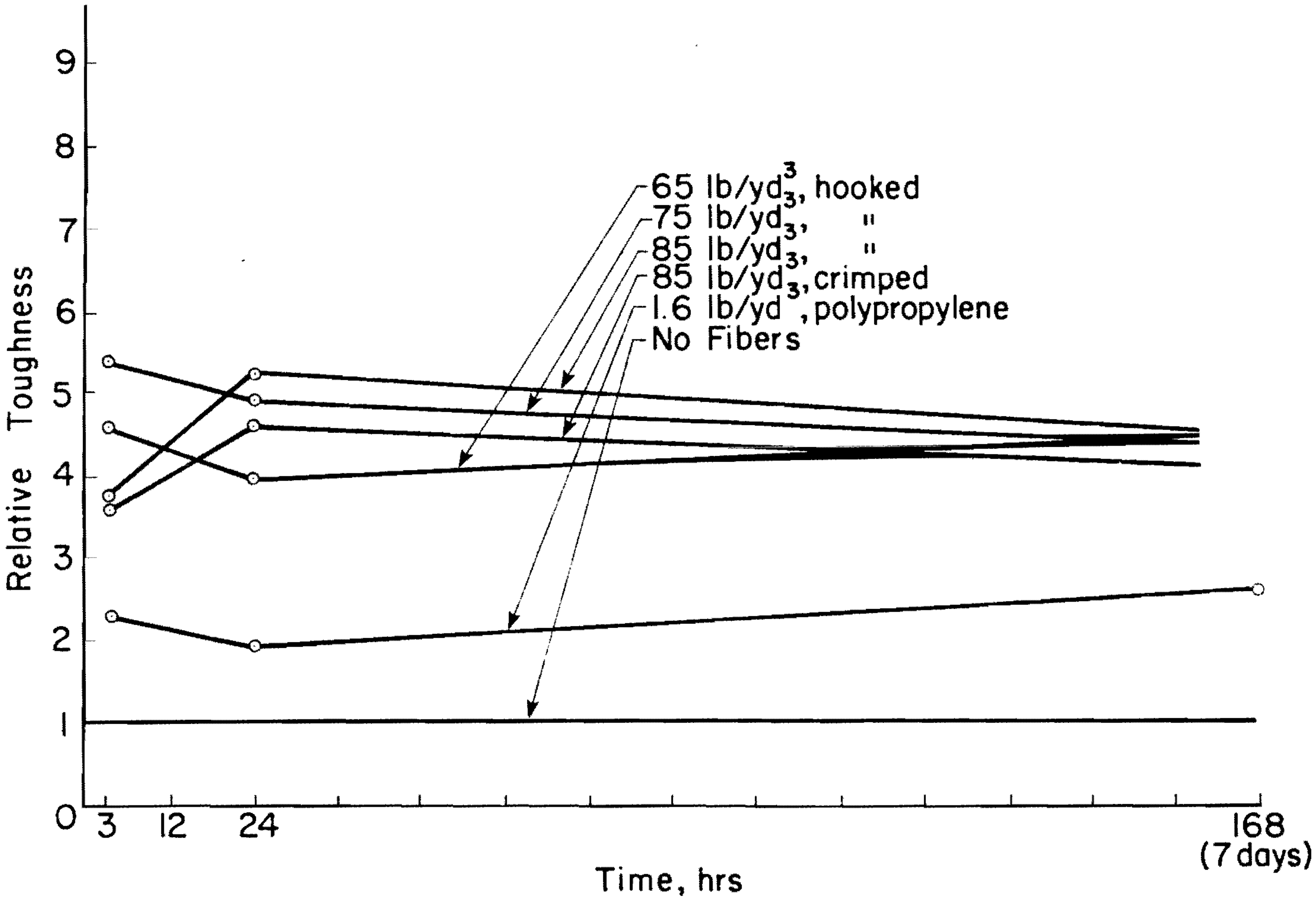

Fig. 6.14. Set-45 Relative Toughness as a Function of Time: Varied Fiber Content and Type, CA ratio = 33%

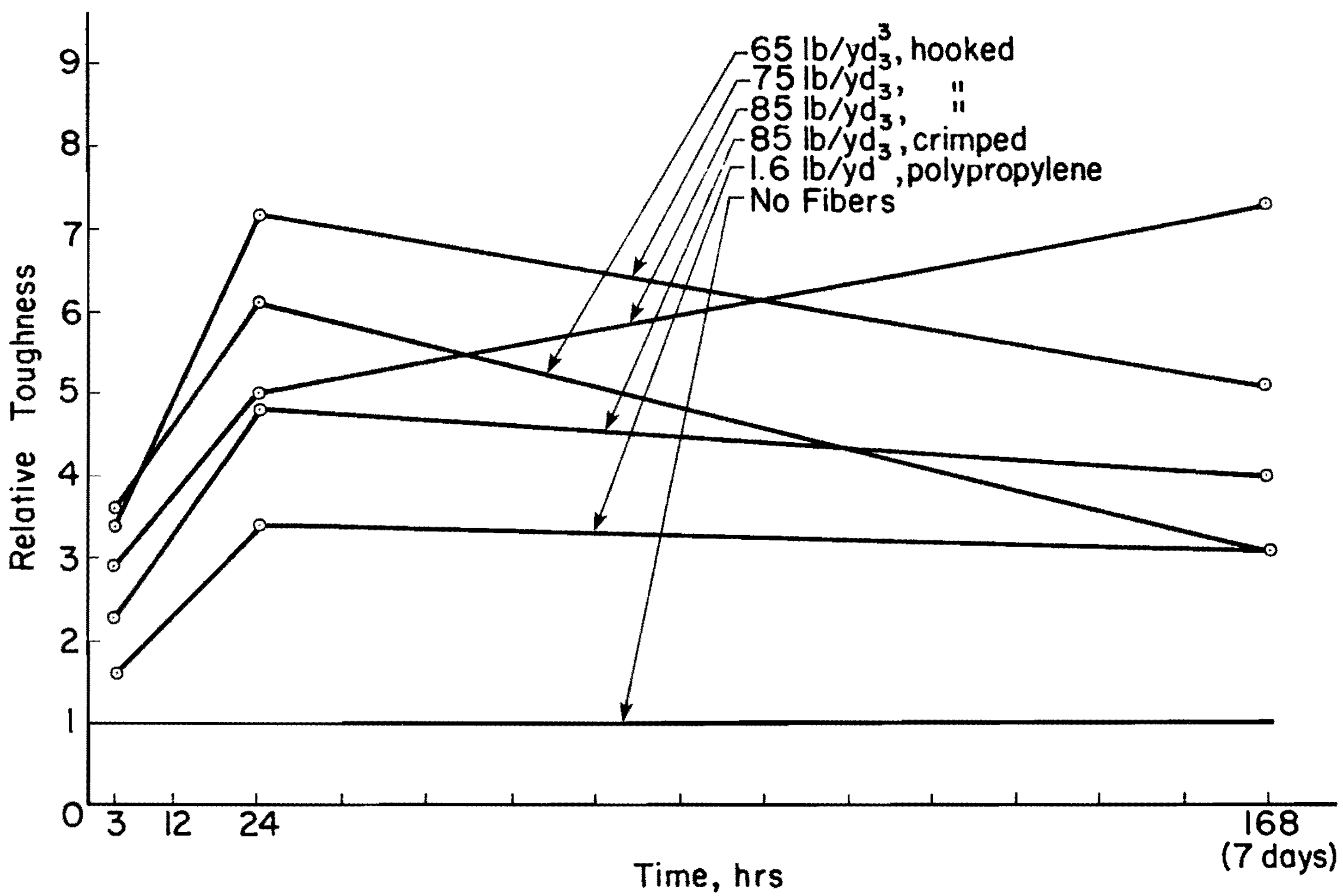

Fig. 6.15. GHP Relative Toughness as a Function of Time: Varied Fiber Content and Type, CA ratio = 33%

Duracal. The highest 24 hour RT value for Duracal came from the 85 lb per cu yd (50.4 kg per cu meter) crimped fiber mix. The Duracal fiber mix with the lowest RT values was the polypropylene mix, which also had the lowest values for Set-45 and GHP.

The Set-45 RT values are shown in Fig. 6.14. The mix with the highest RT at 3 hours was the 75 lb per cu yd (44.5 kg per cu meter) fiber mix, while the highest RT values at 24 hours and 7 days were shown by the 85 lb per cu yd (50.4 kg per cu meter) hooked fiber mix.

Fig. 6.15 shows the RT values for the GHP mixes. These curves, as with some of the Duracal and Set-45 curves, show a tendency for a decrease in RT after 24 hours. This decrease is due to the fact that: 1) the energy absorption (area under load-deflection curve) for the no fiber material increases at a faster pace than the energy absorption for the fiber reinforced material; or that 2) the energy absorption for the fiber reinforced material increases at a slower rate (or possibly decreases) in comparison to the energy absorption of the no fiber material. In either case, the ratio of energy absorption for the fiber reinforced material to energy absorption for the no fiber material would decrease.

6.6 Relative Toughness vs CA Ratio

Figs. 6.16, 6.17, and 6.18 show the RT vs time curves for the rapid-setting materials with varied CA ratios. Table 6.3 shows the results in tabular form. These curves, like the rest of

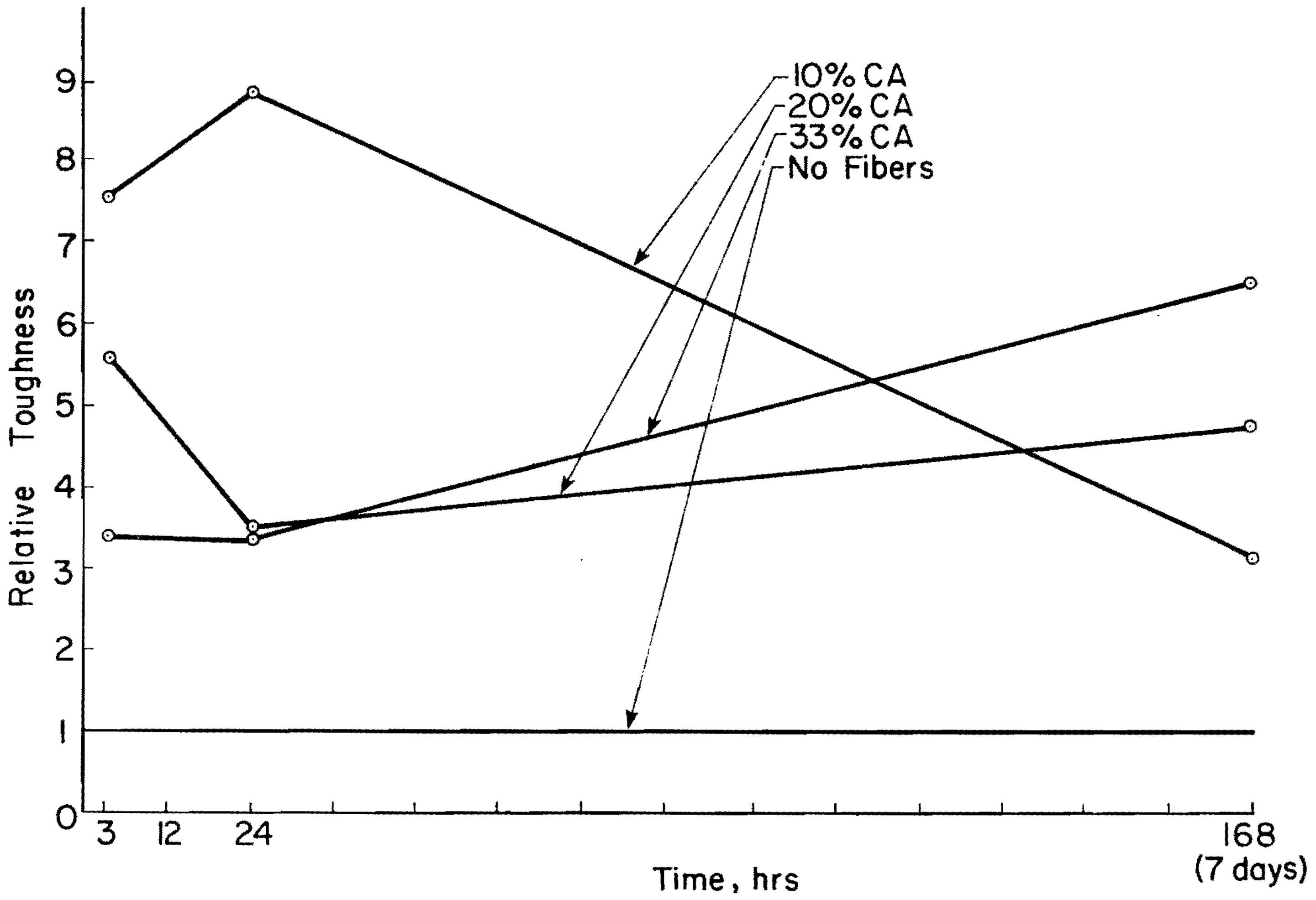

Fig. 6.16. Duracal Relative Toughness as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

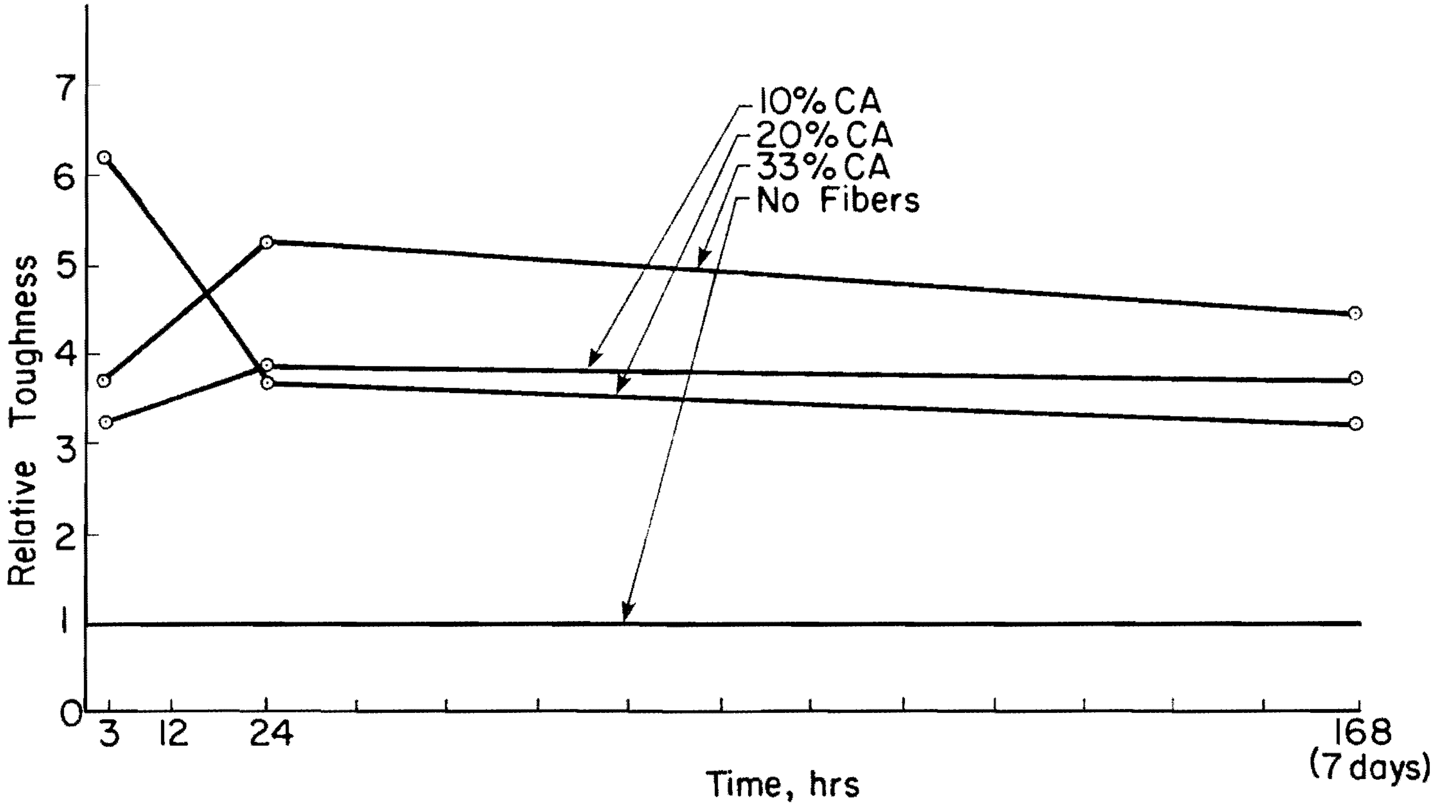

Fig. 6.17. Set-45 Relative Toughness as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

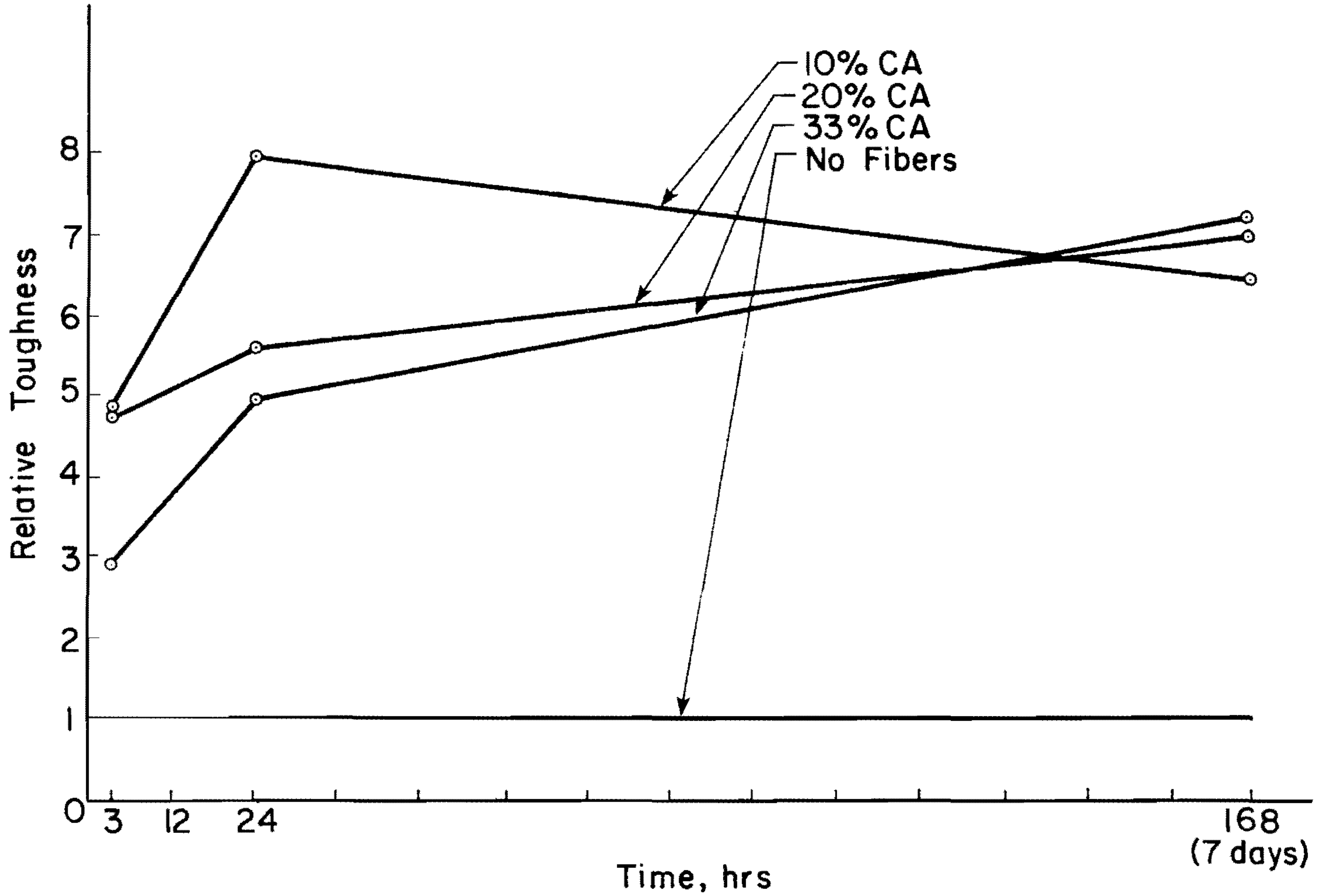

Fig. 6.18. GHP Relative Toughness as a Function of Time:
Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

Table 6.3 Relative Toughness Results

Material	C.A. Ratio %	Fiber Content lb/yd^3(kg/m^3)	Fiber Type	Splitting Tensile Strength					
				3 hour		24 hour		7 day	
				Psi	MPa	Psi	MPa	Psi	MPa
Duracal	10	0	-	180	1.24	310	2.14	570	3.93
	10	85 (50.4)	hooked	330	2.28	590	4.07	630	4.34
	20	0	-	150	1.03	370	2.55	590	4.07
	20	85 (50.4)	hooked	190	1.31	440	3.03	700	4.83
	33	85 (50.4)	crimped	190	1.31	480	3.31	660	4.55
	33	1.6 (0.95)	polypropylene	140	0.97	360	2.48	590	3.93
Set-45	10	0	-	700	4.83	680	4.69	860	5.93
	10	85 (50.4)	hooked	800	5.52	850	5.86	980	6.76
	20	0	-	500	3.45	630	4.34	670	4.62
	20	85 (50.4)	hooked	700	4.83	760	5.24	900	6.21
	33	85 (50.4)	crimped	640	4.41	780	5.38	800	5.52
	33	1.6 (0.95)	polypropylene	640	4.41	650	4.48	670	4.62
GHP	10	0	-	230	1.59	230	1.59	540	3.72
	10	85 (50.4)	hooked	340	2.34	400	2.76	630	4.35
	20	0	-	270	1.86	360	2.48	560	3.86
	20	85 (50.4)	hooked	360	2.48	510	3.52	790	5.45
	33	85 (50.4)	crimped	300	2.07	430	2.97	600	4.14
	33	1.6 (0.95)	polypropylene	270	1.86	470	3.24	600	4.14

(continued)

Table 6.3 Relative Toughness Results (Continued)

Material	C.A. Ratio %	Fiber Content lb/yd^3(kg/m^3)	Fiber Type	Area Under Load-Deflection Curve and Relative Toughness					
				3 hour		24 hour		7 day	
				Area	R. Toughness	Area	R. Toughness	Area	R. Toughness
GHP	10	0	-	36	1.0	26	1.0	31	1.0
	10	85 (50.4)	hooked	173	4.8	207	8.0	199	6.4
	20	0	-	31	1.0	42	1.0	38	1.0
	20	85 (50.4)	hooked	147	4.7	236	5.6	266	7.0
	33	0	-	38	1.0	28	1.0	34	1.0
	33	85 (50.4)	hooked	112	2.9	139	5.0	248	7.3
	33	75 (44.5)	hooked	131	3.4	201	7.2	172	5.1
	33	65 (38.6)	hooked	136	3.6	172	6.1	104	3.1
	33	85 (50.4)	crimped	86	2.3	134	4.8	135	4.0
	33	1.6 (0.95)	polypropylene	60	1.6	96	3.4	106	3.1

the data already given, follow no particular pattern from one material to another. Fig. 6.16 shows the RT values for the Duracal mixes. The 10 percent CA ratio mix has the highest values at 3 and 24 hours, but the 33 percent CA ratio mix has by far the largest value at 7 days.

Set-45 RT values are shown in Fig. 6.17. The 20 percent CA ratio mix has the highest RT value at 3 hours, while the 33 percent CA ratio mix has the highest values at 24 hours and 7 days.

Fig. 6.18 shows that the GHP mix with the highest RT values at 3 and 24 hours is the 10 percent CA ratio mix. The GHP mix with the highest RT value at 7 days is the 33 percent CA ratio mix.

6.7 Splitting Tensile Strength vs CA Ratio

Splitting tensile strength (STS) vs time curves for the three materials with varied CA ratio and fiber type are shown in Figs. 6.19, 6.20, and 6.21. Tabulized results are given in Table 6.4. The STS tests were originally proposed to see if their results with the varied CA ratio mixes were more consistent than the corresponding flexural strength results. To a certain extent this was true, since the 10 and 20 percent CA ratio mixes without fibers consistently had low STS values for all three materials. When comparing the high STS values for the three materials, however, there is little or no agreement.

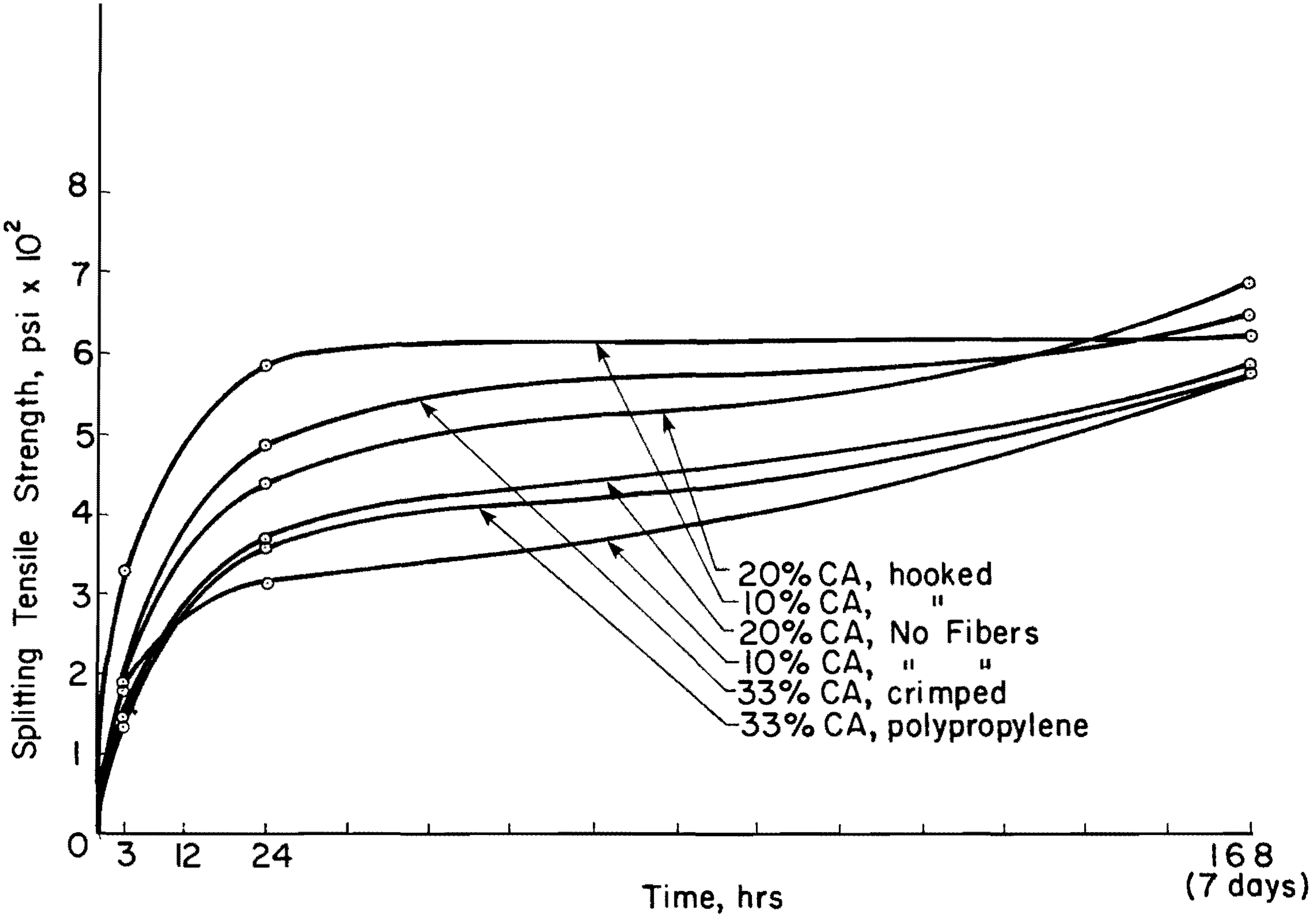

Fig. 6.19. Duracal Splitting Tensile Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

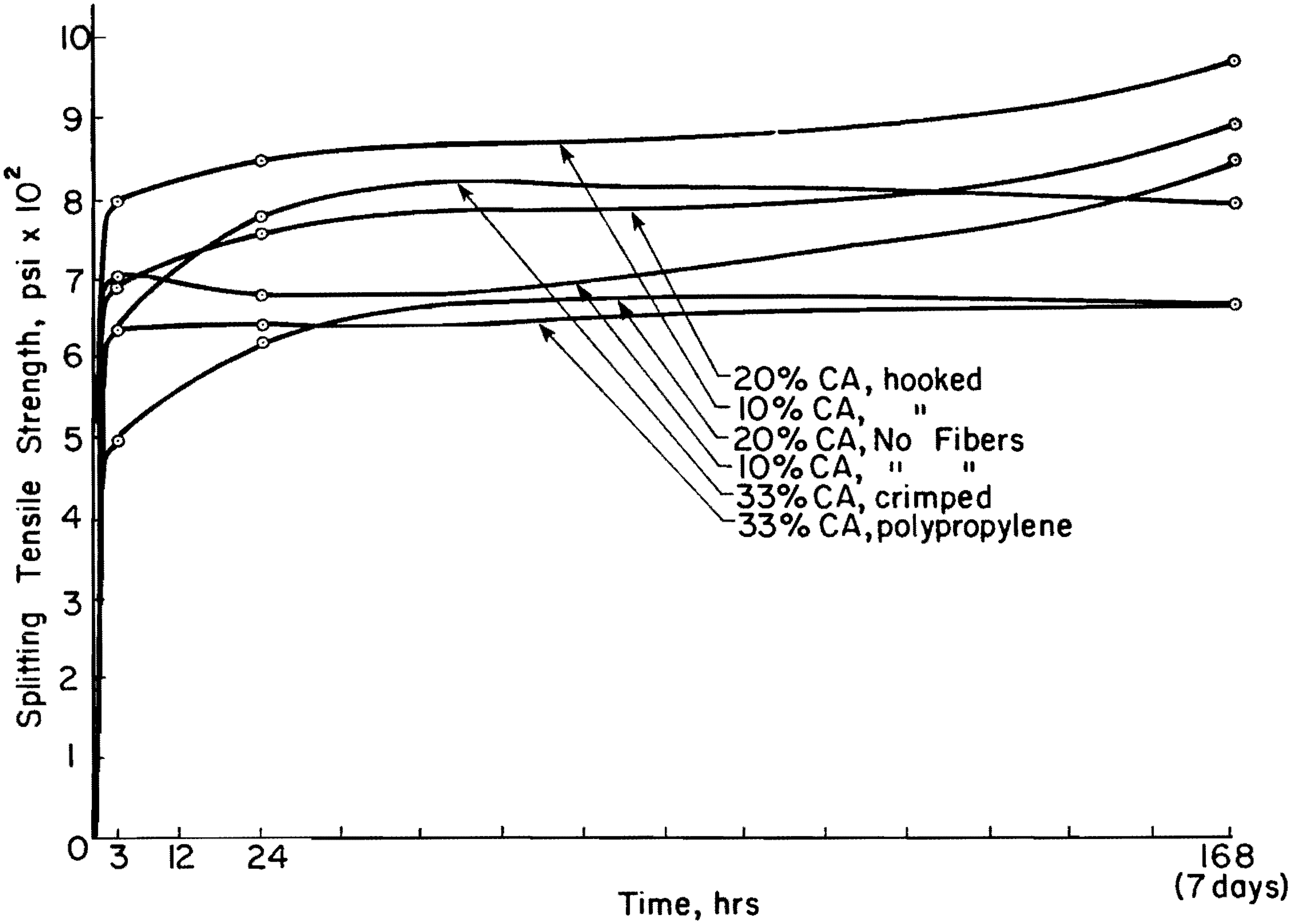

Fig. 6.20. Set-45 Splitting Tensile Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

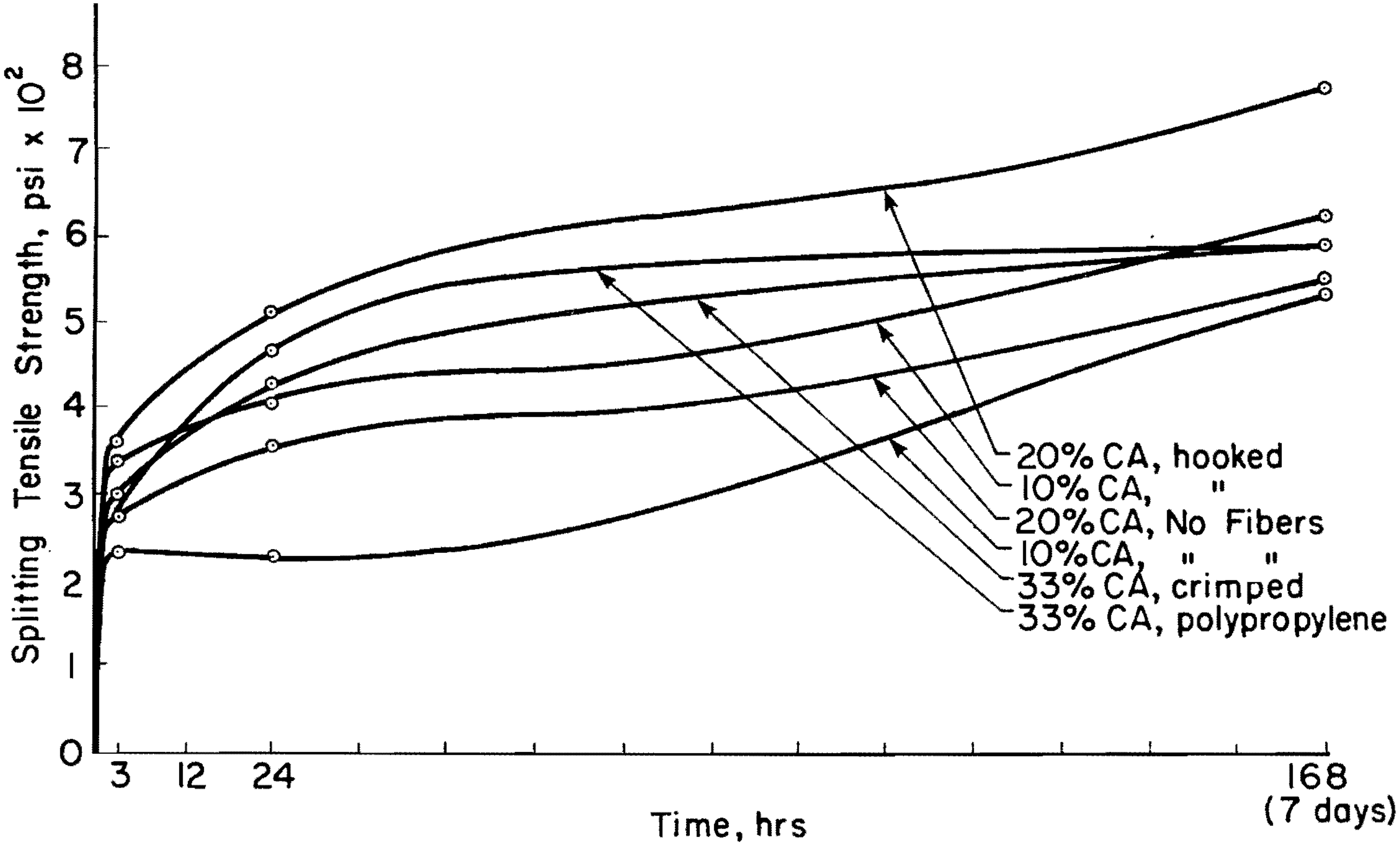

Fig. 6.21. GHP Splitting Tensile Strength as a Function of Time: Varied CA ratio, Hooked Fiber Content = 85 lb/yd^3

Table 6.4 Splitting Tensile Strength Results

Material	C.A. Ratio %	Fiber Content $lb/yd^3(kg/m^3)$	Fiber Type	Area Under Load-Deflection Curve and Relative Toughness					
				3 hour		24 hour		7 day	
				Area	R. Toughness	Area	R. Toughness	Area	R. Toughness
Duracal	10	0	-	14	1.0	24	1.0	33	1.0
	10	85 (50.4)	hooked	107	7.6	214	8.9	107	3.2
	20	0	-	13	1.0	30	1.0	26	1.0
	20	85 (50.4)	hooked	73	5.6	106	3.5	126	4.8
	33	0	-	12	1.0	28	1.0	24	1.0
	33	85 (50.4)	hooked	41	3.4	93	3.3	159	6.6
	33	75 (44.5)	hooked	40	3.3	78	2.8	113	4.7
	33	65 (38.6)	hooked	56	4.7	103	3.7	194	8.1
	33	85 (50.4)	crimped	55	4.6	112	4.0	124	5.2
	33	1.6 (0.95)	polypropylene	47	3.9	57	2.0	75	3.1
Set-45	10	0	-	55	1.0	54	1.0	64	1.0
	10	85 (50.4)	hooked	184	3.3	206	3.8	237	3.7
	20	0	-	27	1.0	49	1.0	57	1.0
	20	85 (50.4)	hooked	169	6.3	179	3.7	183	3.2
	33	0	-	24	1.0	27	1.0	30	1.0
	33	85 (50.4)	hooked	89	3.7	142	5.3	134	4.5
	33	75 (44.5)	hooked	129	5.4	131	4.9	133	4.4
	33	65 (38.6)	hooked	111	4.6	108	4.0	137	4.6
	33	85 (50.4)	crimped	87	3.6	124	4.6	122	4.1
	33	1.6 (0.95)	polypropylene	55	2.3	52	1.9	78	2.6

When the STS values are compared with the corresponding flexural strengths of the three rapid-setting materials (Figs. 6.10, 6.11, and 6.12), there is little or no agreement in terms of which CA ratio mix has the highest or lowest values for both types of tests. The overall difference between STS and flexural strength values for similar mix designs is small for the most part, with the exception that the 10 and 20 percent CA ratio STS values are always a good deal higher than the flexural strength values for the same mix designs.

6.8 Length Change vs Fiber Content and Type

Length change vs. time curves for Duracal, Set-45, and GHP with varied fiber content and a CA ratio of 33 percent are shown in Figs. 6.22, 6.23, and 6.24. The curves shown are based on a fourth order least squares fit. As with the previous data given in this report, the results of the various fiber content mixes did not follow any particular order from highest to lowest when comparing different materials.

Figure 6.22 shows the length change of the Duracal mixes. The 85 lb per cu yd (50.4 kg per cu meter) and no fiber mixes showed a significant expansion at an early age, which is largely due to the gypsum content of Duracal. The length change of all Duracal mixes had either leveled off or even began to increase (expand) after 100 days.

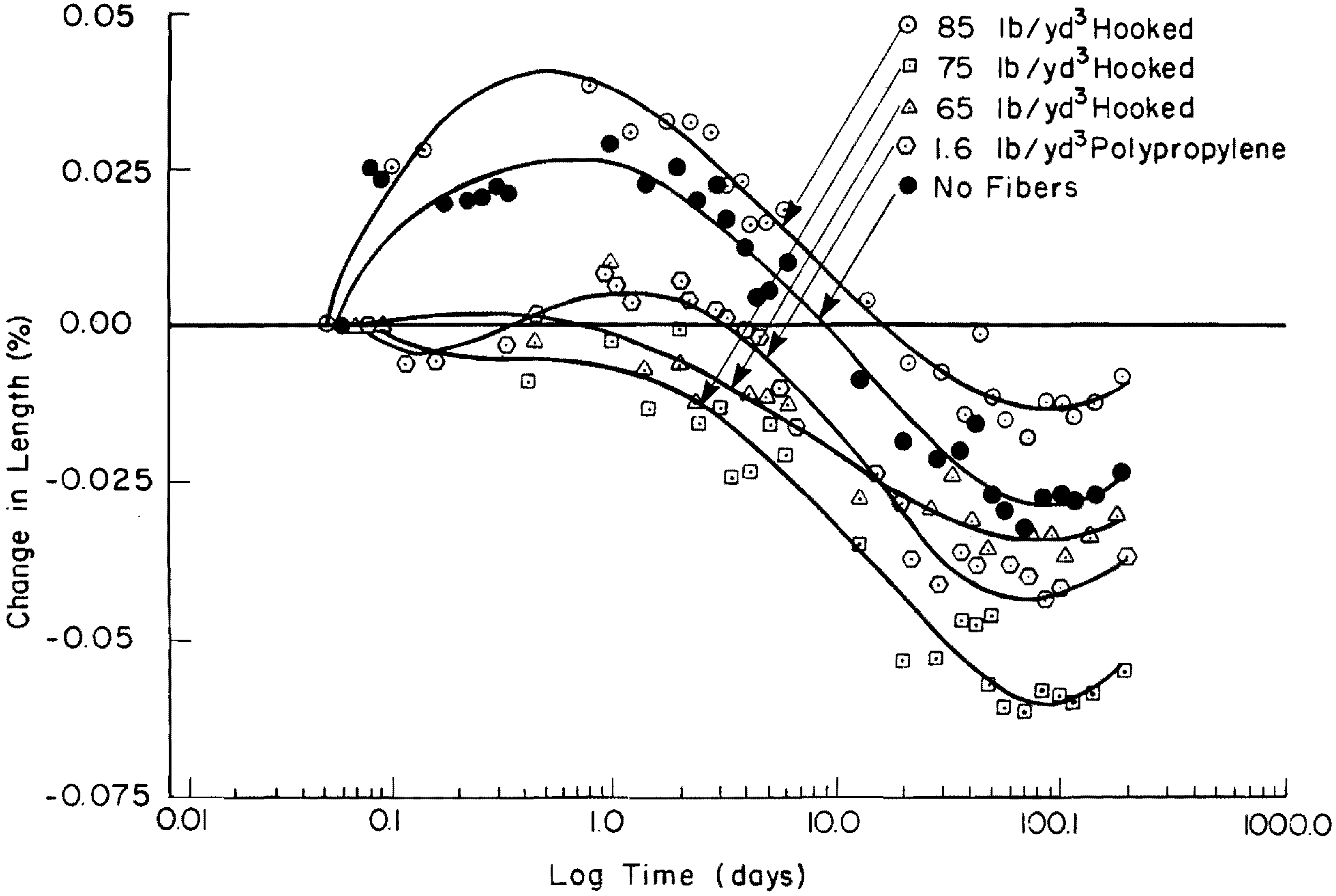

Fig. 6.22. Duracal Length Change as a Function of Time: Varied Fiber Content, CA ratio = 33%

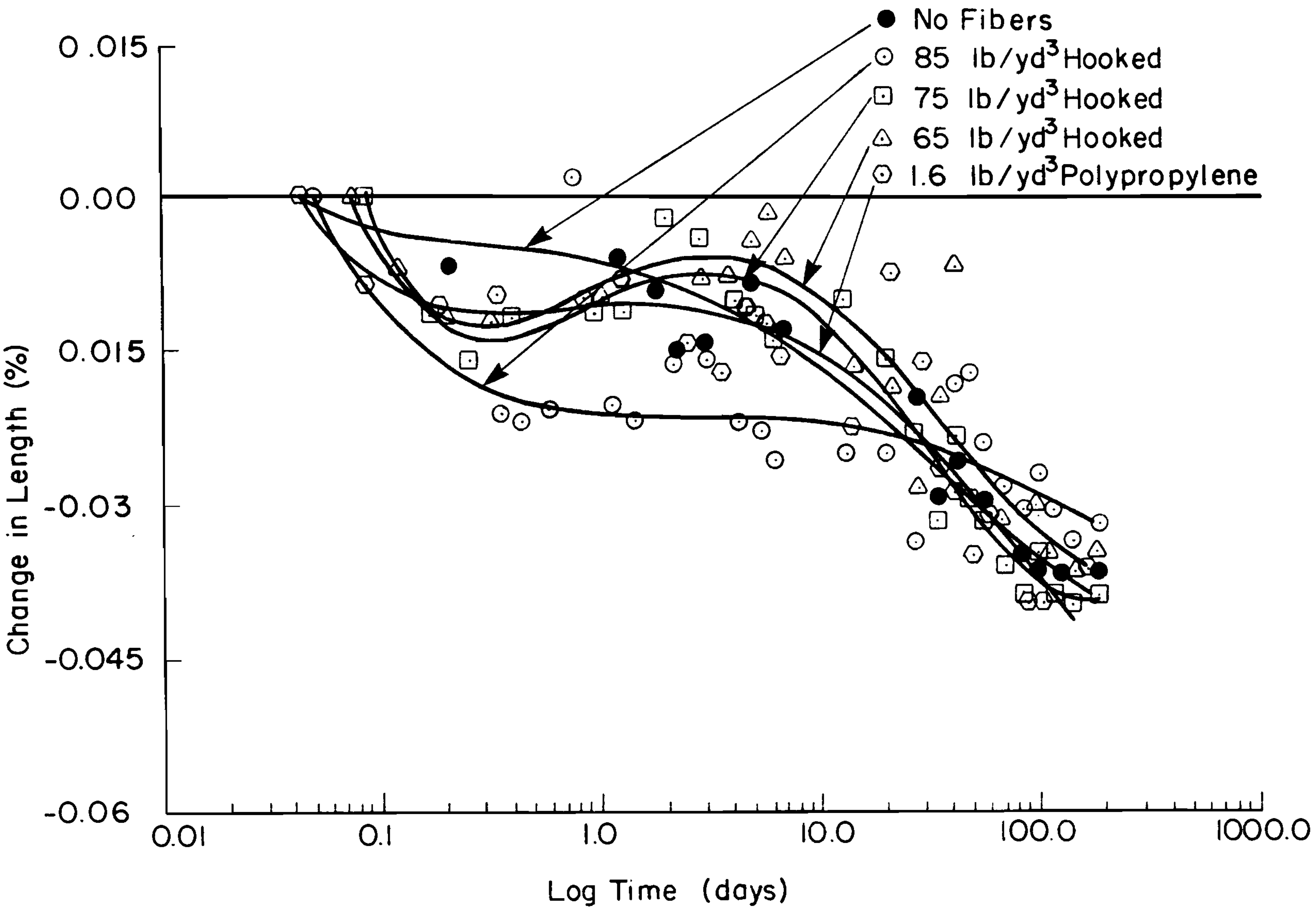

Fig. 6.23. Set-45 Length Change as a Function of Time: Varied Fiber Content, CA ratio = 33%

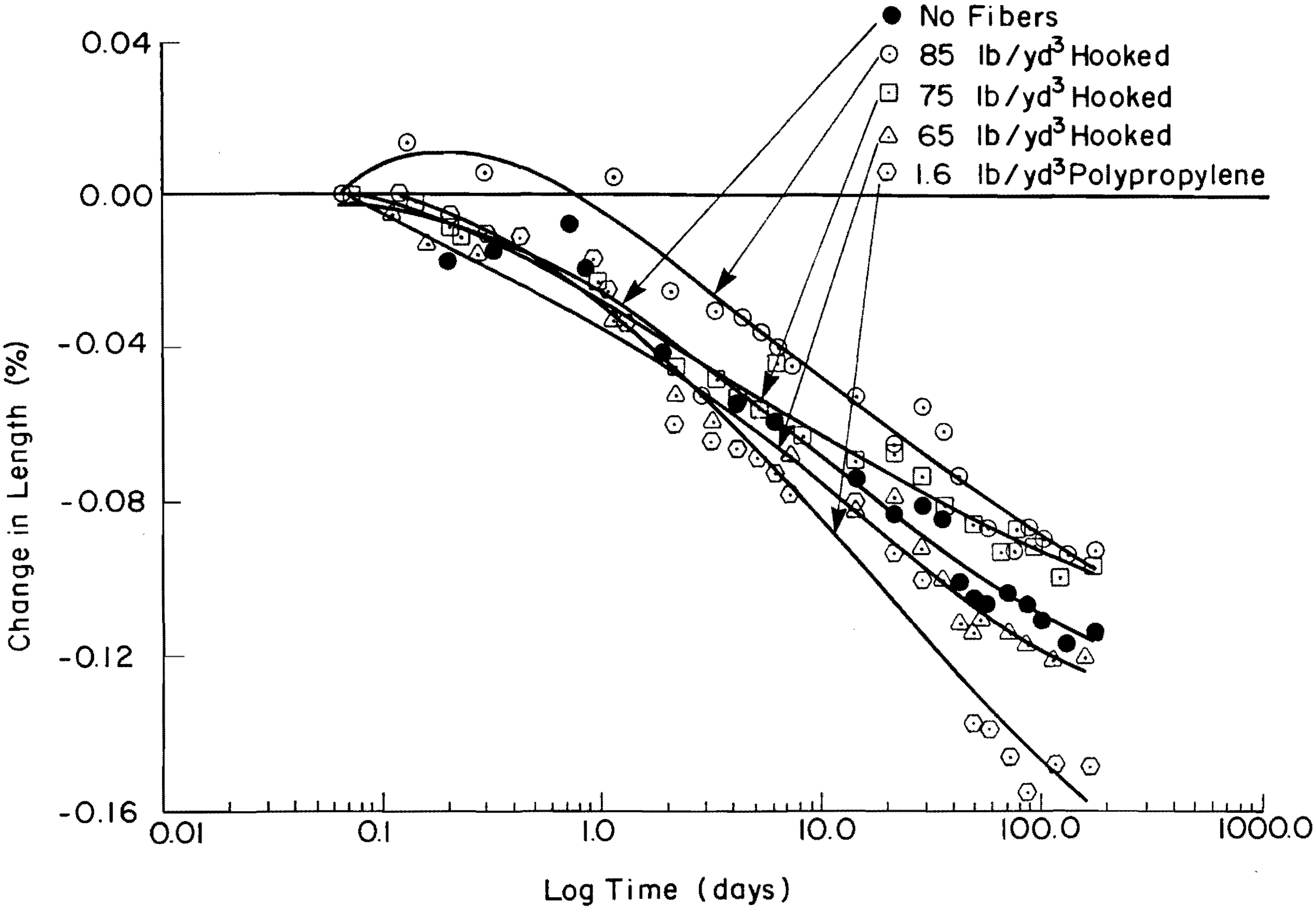

Fig. 6.24. GHP Length Change as a Function of Time: Varied Fiber Content, CA ratio = 33%

Set-45 length change results are shown in Fig. 6.23. All of the mixes have values falling in a very close range, with a maximum change in length of 0.036 percent at 100 days. Data scatter for the Set-45 mixes is more pronounced than that for the Duracal or GHP mixes.

Length change results for the GHP mixes are shown in Fig. 6.24. The 85 lb per cu yd (50.4 kg per cu meter) mix showed a slight expansion at an early age, while all other mixes had an immediate shrinkage. The maximum change in length for GHP mixes was 2 1/2 times that of Duracal and 3 1/2 times that of Set-45.

CHAPTER 7
FIELD REPAIRS

7.1 Introduction

In order to determine the best methods for the mixing, placing, and finishing of the three rapid-setting candidate materials, previous Project 311 work included the completion of field repairs in or near Waco, Amarillo, Dallas, and Houston from September 28 through December 8, 1983. These field repairs are described in CTR Report 311-4, Laboratory and Field Evaluation of Rapid-Setting Materials Used for Repair of Concrete Pavements. Most of the repairs, with the exception of several full depth repairs in Dallas, were made without fiber reinforced material. In order to better evaluate the field performance of fiber reinforced rapid-setting materials, several field repairs were made near Paris, Texas. Because of previous poor results with GHP field repairs, only Duracal and cold weather Set-45 were used in the Paris repairs. (Cold weather Set-45 was used due to a delivery error by the manufacturer. The hot weather formula had originally been ordered.)

7.2 Paris

The Paris district, in response to a Project 311 questionnaire sent to all TSDHPT districts[3], had reported no previous use of rapid-setting repair materials or accelerated PCC. Repairs that had previously been made on the district's limited amount of PCC pavement used truck compacted cold mix asphalt.

The Paris field repairs were made on May 23, 1984. Two full depth punchouts were repaired in the north bound outside lane of State Highway 271, and a spalled area was repaired in the west bound outside lane of State Highway 82.

The Paris district supplied the required labor, equipment, tools, water, and aggregates. Project 311 personnel provided the rapid-setting materials and fibers. A 3/8-in. (9.5 mm) maximum size silicious gravel was used as coarse aggregate for the Duracal and Set-45 mixes and a silicious sand was used as fine aggregate for the Duracal mix. Fibers used were uncollated 1.18-in. (30 mm) x 0.0197-in. (0.5 mm) Dramix hooked steel fibers. An approximate fiber content of 85 lb per cu yd (50.4 kg per cu meter) was used. Mix proportions used are shown in Table 7.1.

A 2-cu ft (0.057-m^3) mortar mixer, shown in Fig. 7.1, was used to mix the materials. The water, aggregates, and fibers (when used) were placed in the mixer and mixed prior to the addition of the rapid-setting material.

Compaction of the full depth repairs was accomplished by rodding each lift of material. Finishing of both the full depth and spall repairs was done by slightly overfilling the repair area and then screeding excess material to grade with the surrounding pavement. No trowling or other final finishing method was used.

Table 7.1 Field Repair Proportions

Brand	Prepackaged Material lb (kg)	C.A. lb (kg)	F.A. lb (kg)	Water gal(liter)	Fibers lb(kg)
Duracal	50(22.7)	50(22.7)	50(22.7)	1.38(5.22)	3.0(1.36)
Duracal	50(22.7)	50(22.7)	50(22.7)	1.38(5.22)	0
Set-45	50(22.7)	25(11.4)	a	0.5(1.89)	1.5(0.68)
Set-45	50(22.7)	25(11.4)	a	0.5(1.89)	0

[a] F.A. included in prepackaged material.

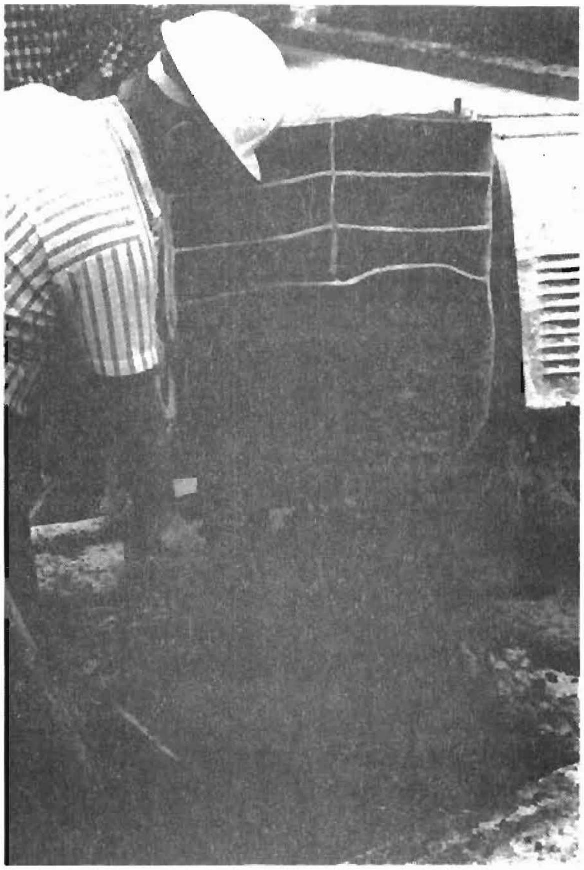

Fig. 7.1. Mortar Mixer Used for Paris Repairs

7.2.1 Full Depth Repairs

Fig. 7.2 shows the location of the two full depth repairs made. The repair areas were prepared by making a approximate 2-in. (25.4-mm) deep saw cut around the damaged concrete and then breaking out the old concrete with a backhoe mounted jackhammer. Figs. 7.3 and 7.4 show the sawing and breaking out of the repair areas. To simplify removal of the old concrete, both the longitudinal and transverse steel was cut and later spliced back together. The edges of the old concrete and the reinforcement were sandblasted to remove any remaining debris. Both the Duracal and Set-45 repairs were divided into two sections so that fiber reinforced and non-reinforced materials could be placed side by side in order to get similar wearing conditions. Fig. 7.5 shows a full depth punchout ready for placing of the repair material.

7.2.1.1 Set-45

The Set-45 repair was made from 10:15 to 11:45 A.M. The approximate weather conditions at the time of this repair were: 1) ambient temperature of 80°F (27°C); 2) 10 mph (16 km/hr) wind; and 3) 50 percent R.H.

Fig. 7.6 shows a sketch of the Set-45 repair, with existing reinforcement and cracks noted. Figs. 7.7 and 7.8 show respectively the repair area before and after the material was placed and finished. When the fiber reinforced half (first half) of the Set-45 repair was being finished, the material set

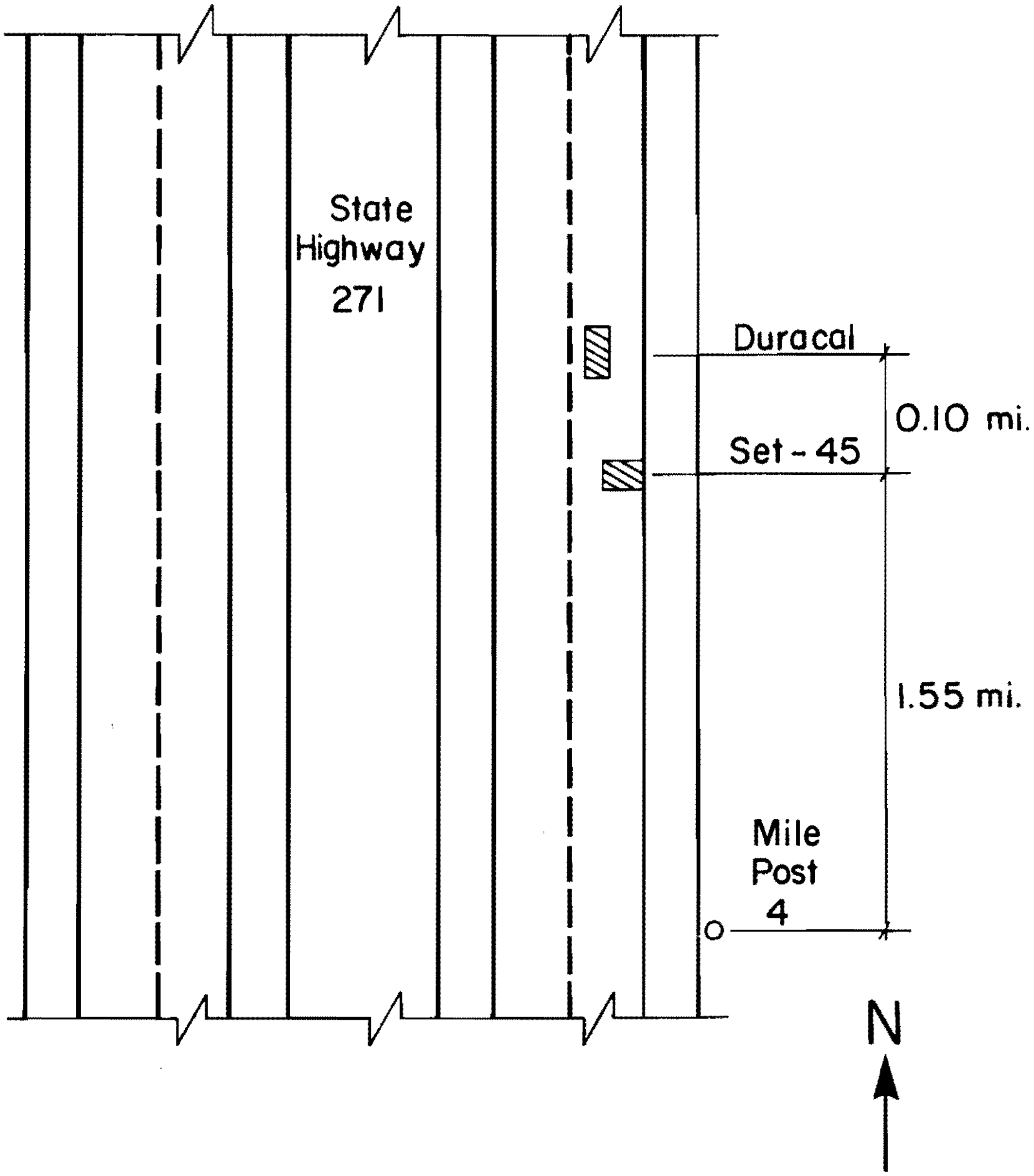

Fig. 7.2. Location of Paris Full Depth Repairs

Fig. 7.3. Sawing of Full Depth Repair

Fig. 7.4. Jackhammering Full Depth Repair

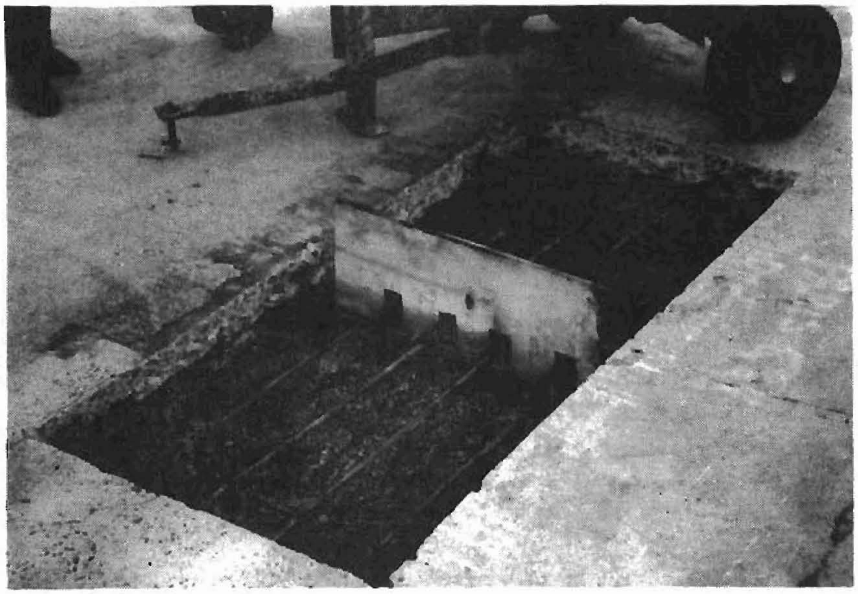

Fig. 7.5. Full Depth Punchout
Ready for Repair Material

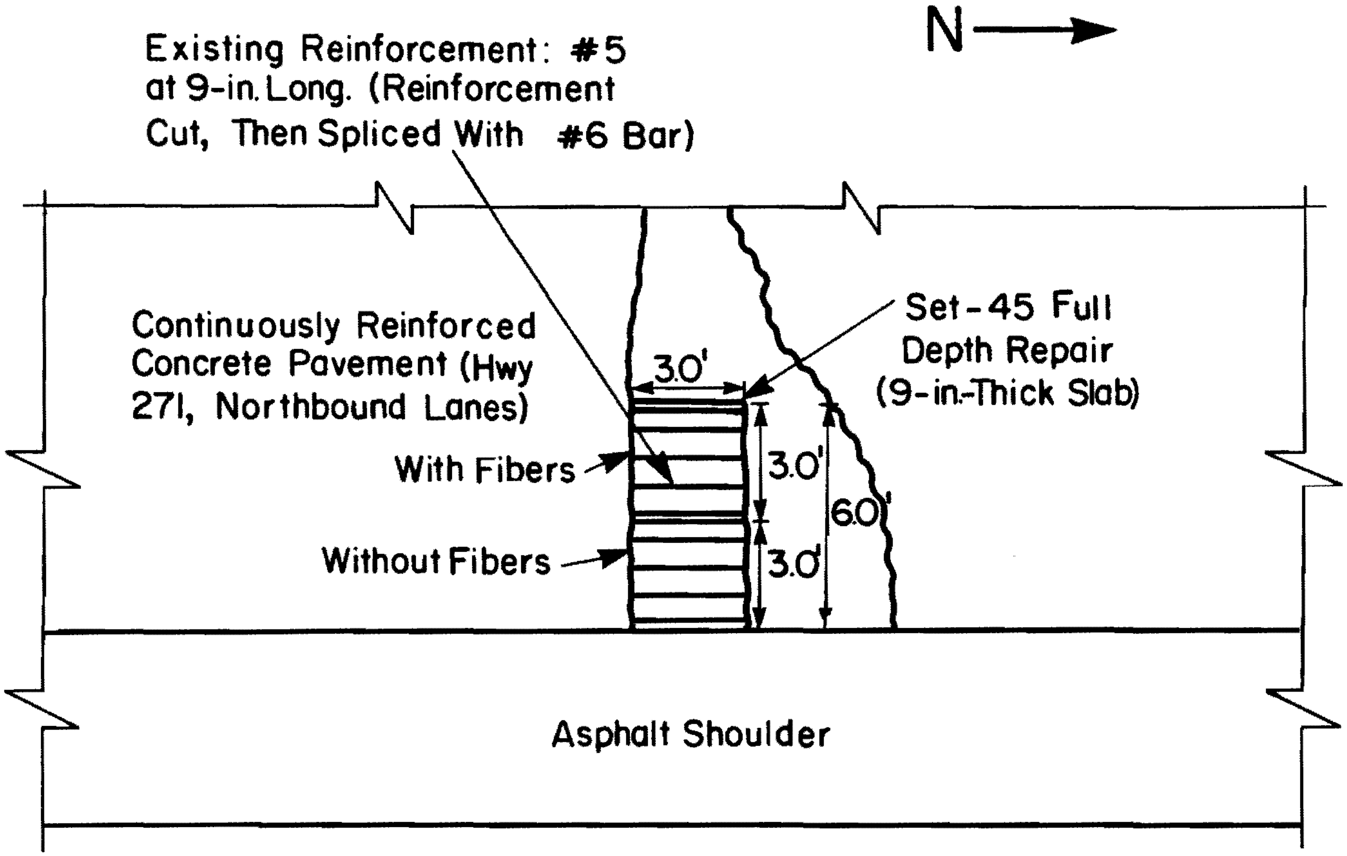

Fig. 7.6. Sketch of Set-45 Full Depth Repair

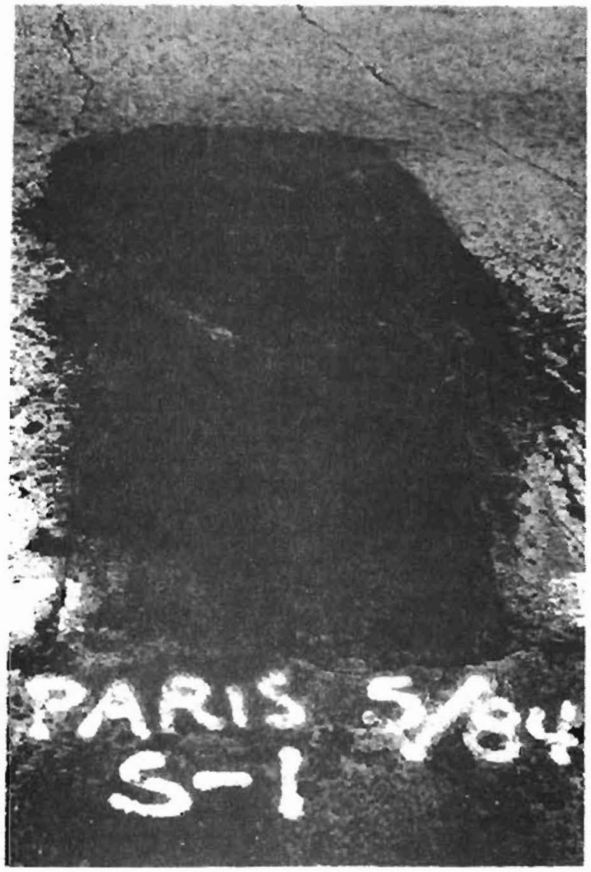

Fig. 7.7. Set-45 Repair Area Before Repair

Fig. 7.8. Completed Set-45 Full Depth Repair

extremely fast and left a unsatisfactory finish. In order to correct this, the top 2-in. (50.8-mm) of the partial repair was removed with a 30-lb (13.6-kg) jackhammer. After the no fiber material was placed in the second half of the repair, a non fiber Set-45 mix with a small amount of coarse aggregate was used as a slurry coat over both sections of the repair to provide a smooth finish.

7.2.1.2 Duracal

The Duracal repair was made from 1:30 to 2:15 P.M. The approximate weather conditions at the time of this repair were: 1) ambient temperature of 85°F (29°C); 2) 10 mph (16 km/hr) wind; and 3) 60 percent R.H.

Fig. 7.9 shows a sketch of the Duracal repair. Figs. 7.10 and 7.11 show respectively the repair area before and immediately after the Duracal was placed. The use of extremely saturated fine and coarse aggregates required a decrease in the amount of mixing water used in the Duracal mixes.

7.2.2 Spall Repair

Fig. 7.12 shows the location of the spall repair and Fig. 7.13 shows the spall area before the repair. The unreinforced PCC pavement at this location had a joint spacing of 15 ft. (4572 mm), and there were spalled areas at many of the joints. Set-45 was used as a mortar mix at the manufacturer's recommended proportions.

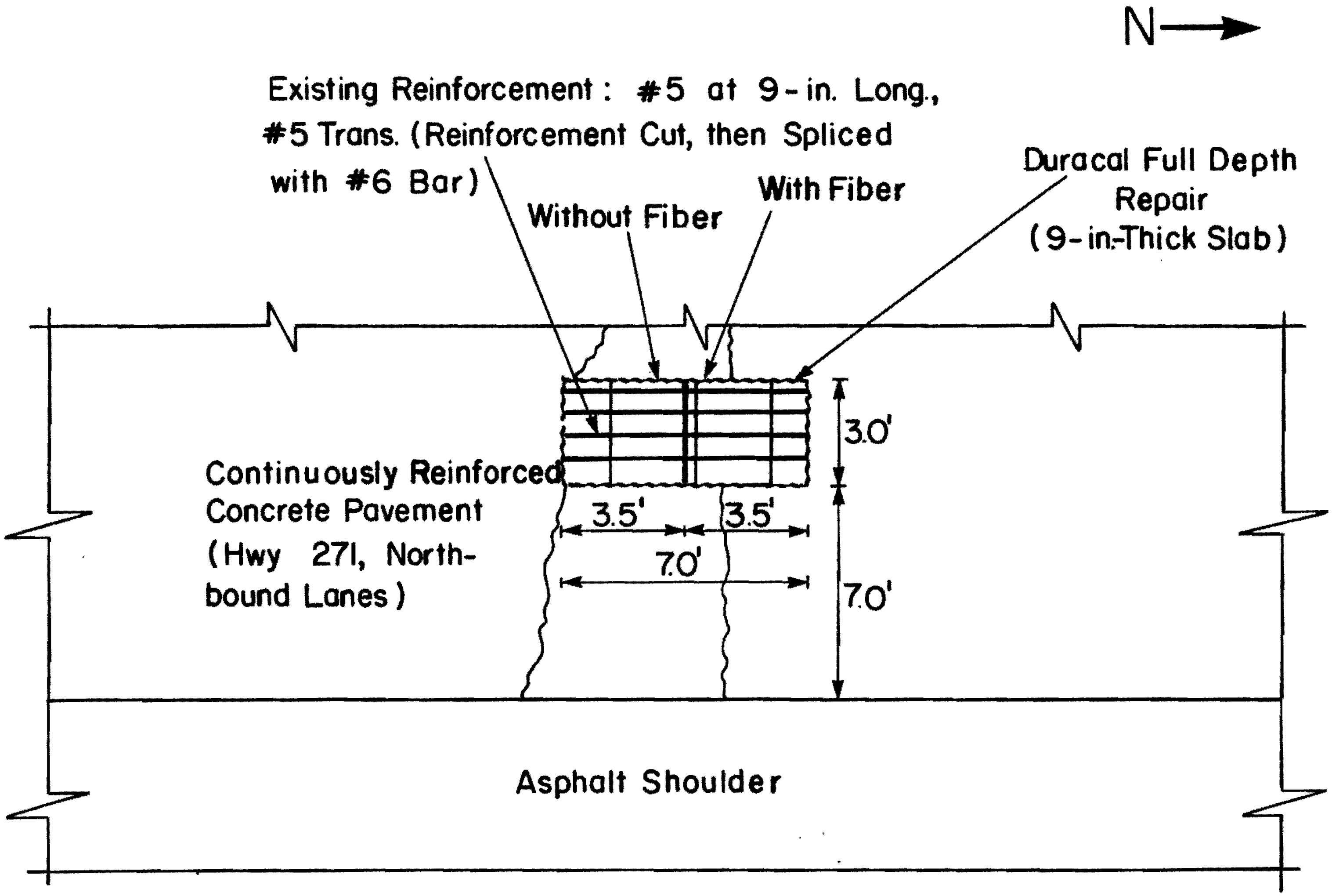

Fig. 7.9. Sketch of Duracal Full Depth Repair

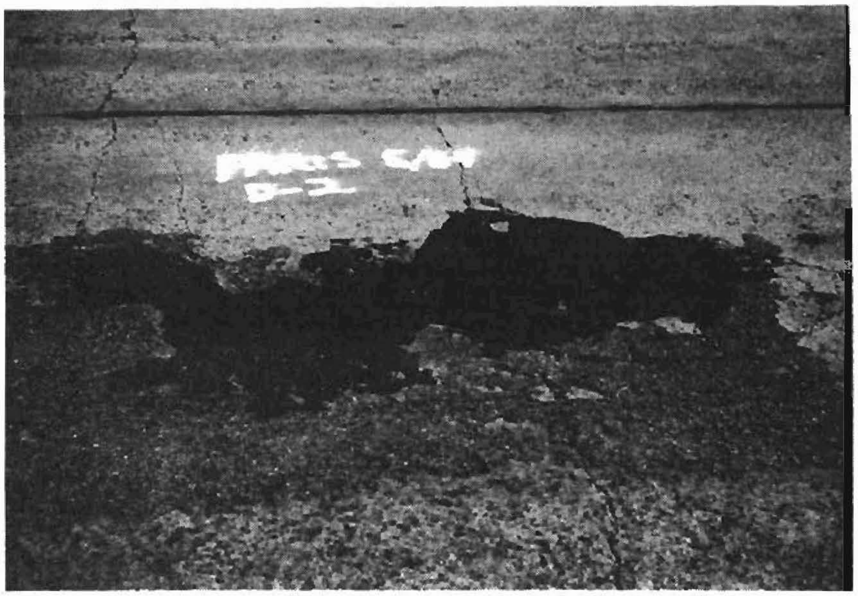

Fig. 7.10. Duracal Repair Area Before Repair

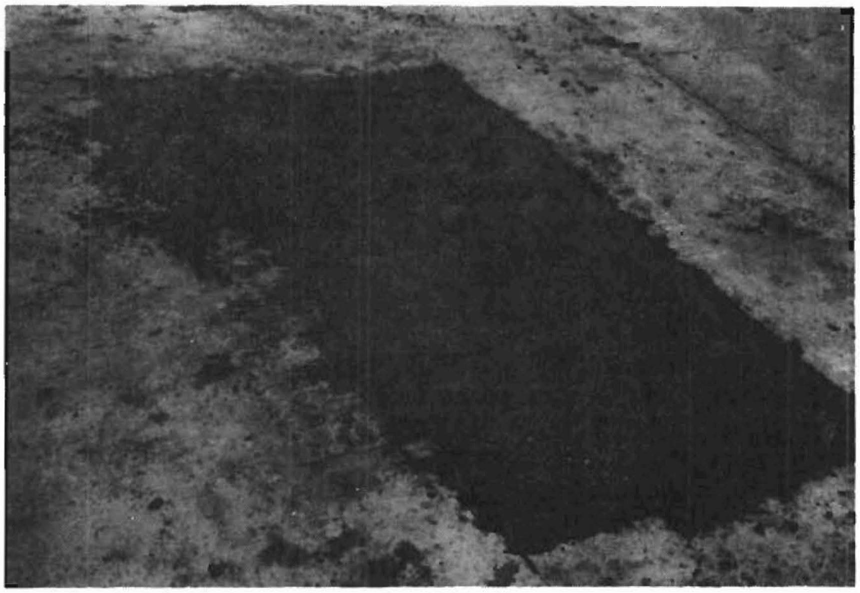

Fig. 7.11. Completed Duracal Full Depth Repair

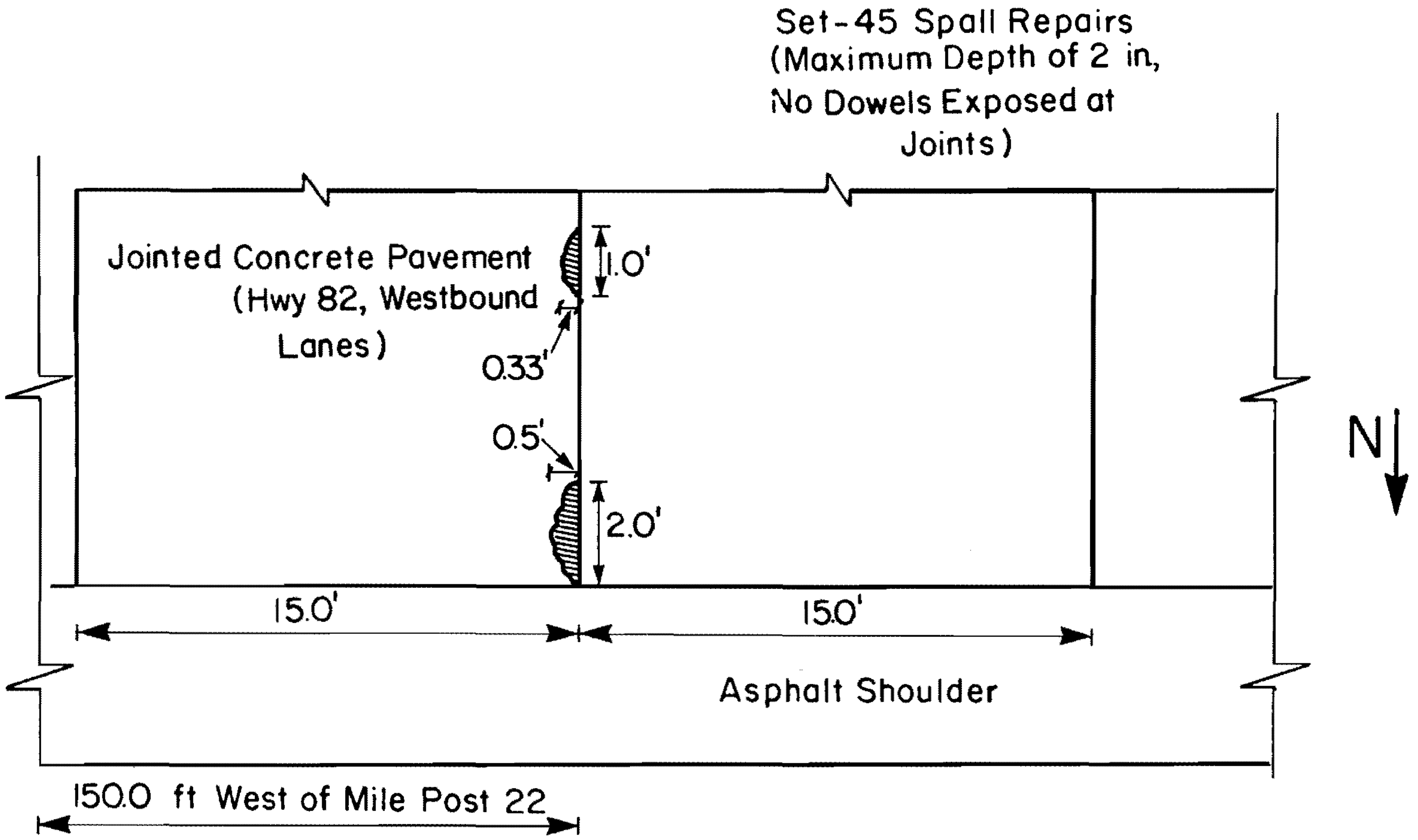

Fig. 7.12. Location of Set-45 Spall Repair

Fig. 7.13. Spall Area Before Repair

The damaged concrete was removed with a 30-lb (13.6-kg) jackhammer, and the exposed concrete was sandblasted to roughen and clean the surface. A strip of roofing felt was placed at the intersection of the repair and the joint to preserve the action of the joint. Fig. 7.14 shows the spalled area ready for placement of Set-45, while Fig. 7.15 shows the completed repair.

7.2.3 Field Specimens

Compression cylinder and flexural beam specimens were made for both the Duracal and Set-45 full depth repairs and were tested at 48 hours. Three specimens were cast for each half of each repair. (Fiber and non fiber.) Table 7.2 shows the results of the tests.

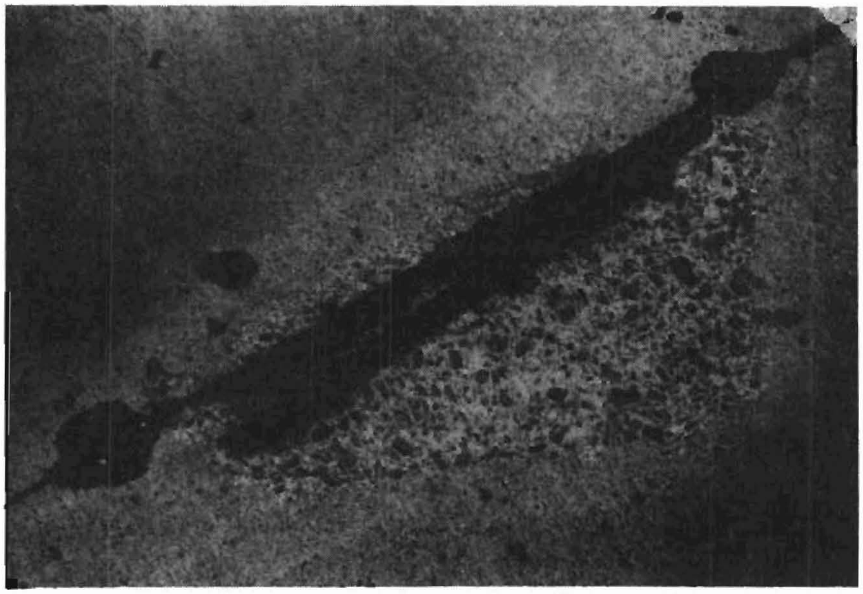

Fig. 7.14. Spall Area Ready for Repair Material

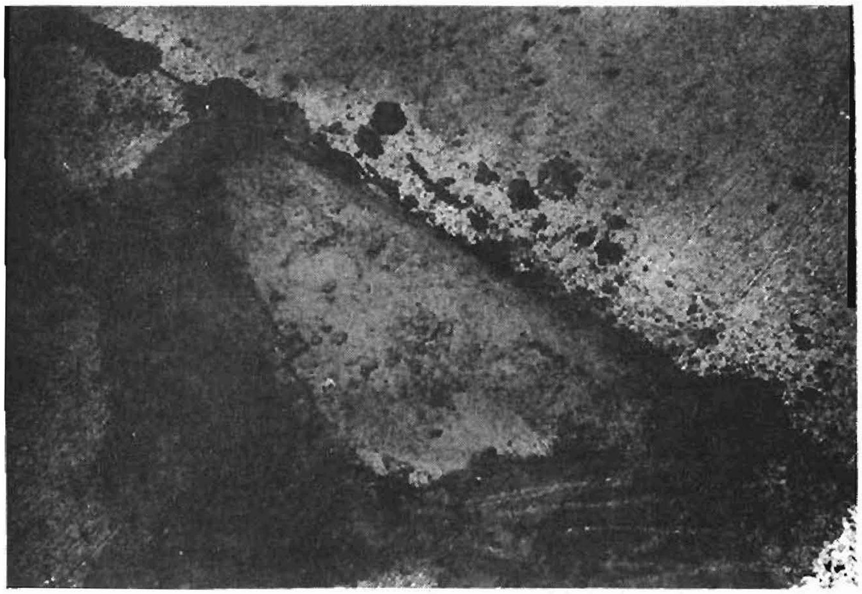

Fig. 7.15. Completed Spall Repair

Table 7.2 Field Specimen Test Results

Material	Fiber Content lb/yd^3(kg/m^3)	Compressive Strength at 48 hours Psi(MPa)	Flexural Strength at 48 hours Psi(MPa)
Set-45	0	4160(28.6)	480(3.30)
Set-45	85(50.4)	5460(37.6)	690(4.75)
Duracal	0	3140(21.6)	540(3.72)
Duracal	85(50.4)	3500(24.1)	790(5.44)

CHAPTER 8
FIBER REINFORCED MATERIAL COSTS

Although the cost of repair material may only be a small part of the total repair cost, material cost can be the deciding factor when choosing among several similar patching materials. Table 8.1 shows the relative costs of the rapid-setting materials with and without fibers. All costs are for aggregate extended mixes with a CA ratio of 33 percent and are current as of October 1984. Costs of Set-45 and GHP, the two most costly materials, are only increased 1 to 7 percent when fibers are added, while Duracal costs are increased 4 to 17 percent.

Table 8.1 Relative Cost of Fiber Reinforced Materials

Material[a]	Relative Cost (RC)[b]						
	No Fibers	Hooked (Dramix) 85 lb/yd^3 @ $0.50/lb		Crimped (Xorex) 85 lb/yd^3 @ $0.32/lb		Polypropylene (Forta Fibre) 1.6 lb/yd^3 @ $5.63/lb	
	RC	RC	% increase	RC	% increase	RC	% increase
Duracal	1.0	1.17	17	1.11	11	1.04	4
Set-45 (Hot & cold)	3.94	4.11	4	4.05	3	3.98	1
GHP	2.55	2.72	7	2.66	4	2.58	1

[a] Aggregate extended mix (C.A. ratio = 33%)

[b] 1 cu yd of Duracal = $253.8

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary

Because of higher than expected traffic volume and loads, a large amount of PCC pavement has surpassed its design life. The need is high for rapid-setting patching materials which are durable, easy to place, and cost effective. The addition of fiber reinforcement to rapid-setting materials is a cost effective and easy way to improve some of the materials' properties.

Research Study 311, "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges," was originated to select candidate rapid-setting materials which were then subjected to extensive laboratory tests. The candidate materials, which include Duracal, Set-45, and Gilco Highway Patch (GHP), were used to make field repairs in various TSDHPT districts so that the proper methods for mixing, placing, and finishing of the materials could be demonstrated to highway maintenance personnel. The selection of the candidate materials and the tests performed on these materials are described in previous Research Study 311 reports.

This report presents the results of laboratory tests on the fiber reinforced candidate materials, along with the results of field repairs made in Paris, Texas with fiber reinforced and non-reinforced materials.

Laboratory test results presented in this report include the following: 1) compressive strength; 2) flexural strength; 3) relative toughness; 4) length change of air dried specimens; and 5) splitting tensile strength. Tests were performed according to ASTM standards which were slightly modified.

The relative toughness (RT) of a material, as defined in this report, is the ratio of the absorbed energy of a fiber reinforced material to the absorbed energy of a non-reinforced material. It is calculated by taking the area under a fiber reinforced beam's flexural load-deflection curve and dividing it by the area under a nonreinforced beam's flexural load-deflection curve.

Test variables in laboratory tests include fiber content and coarse aggregate (CA) ratio. Three different types of fibers, two made of steel and one made of polypropylene, were used in these tests. The CA ratio of the mixes was varied at 10, 20, and 33 percent.

Field repairs using fiber reinforced and non-reinforced Duracal and Set-45 were made in Paris, Texas on May 23, 1984. Two full depth repairs, both with sections of fiber reinforced and non-reinforced materials, and a spall repair using Set-45 as a mortar mix were completed.

9.2 Conclusions

After reviewing the fiber reinforced laboratory and field test results, the following conclusions can be made:

1) The compressive strength of the rapid-setting materials did not vary significantly for different fiber contents. This was expected, since a compression cylinder will generally fail between zones of restrained and constrained compression. This mode of failure does not allow the fibers to contribute any significant strength to the concrete.

2) The compressive strength of the three materials did not vary significantly when the CA ratio was changed. This is consistent with Smith's results[4], and points out that the rapid-setting materials can be extended with aggregate and made more cost effective without decreasing their compressive strengths.

3) When the fiber content and type was varied in flexural specimens, it was observed that the addition of fibers can increase the flexural strength of the materials a nominal amount. The optimal rate of application for the increase of flexural strength, however, cannot be clearly derived from the results because of the scattering of results for similar mixes with different materials.

4) The flexural strength of the materials with varied CA ratios was typically highest with the 10 and 20 percent CA ratio mixes with fibers. The difference in strength between the 10, 20, and 33 percent mixes was not large enough, however, to eliminate the use of the 33 percent mix. As with the compressive strength of the materials, the higher percentage CA mixes can be used to make the materials more economic, while not significantly affecting

their flexural strengths.

5) All of the fiber reinforced mixes had RT values larger than one. The largest increases came when hooked and crimped steel fibers were used. Virtually all of the steel fiber mixes had RT values higher than three. The optimum fiber rate of application for the increase of RT appears to be 85 lb per cu yd (50.4 kg per cu meter) with either the hooked or crimped fibers. This fiber rate does not always give the highest 3 and 24 hour RT values, but the 3 and 24 hour values that they do give are typically four or more times that of a material without fibers. This is judged to be sufficient.

6) The RT of the materials changed significantly when the CA ratio was varied, but this change was not consistent from one material to another. The 10 and 20 percent mixes gave some of the higher RT values, but it is doubtful if these high values are really needed. The 10 percent mixes for all three materials showed a decrease in their RT values between 24 hours and 7 days. The decreasing trend between these two points is believed to be due to one or more stray data points and does not lead to any definite conclusions about the strength of the 10 percent mixes. The 33 percent mixes consistently had RT values of 3 or more and, obviously, will give the lowest unit cost for each material. For these reasons, it is judged that the 33 percent CA ratio design is the best compromise mix.

7) The splitting tensile strength results proved to be more consistent than the flexural strength results only in the sense that the mixes without fibers usually gave the lowest splitting tensile strengths.

8) The maximum drying shrinkage at 100 days for all Duracal mixes was 0.06 percent, while the maximum drying shrinkage at 100 days for the Set-45 and GHP mixes was 0.036 and 0.155 percent, respectively. The addition of fibers did little to help change the shrinkage or expansion of the material. GHP was the only material for which shrinkage was a major concern. The large amount of shrinkage in the GHP specimens is probably due to the fact that the water content had to be increased 15 to 20 percent over that recommended by the manufacturer in order to get a workable mix.

9) A mortar type mixer will mix the rapid-setting materials quicker and more evenly than a drum type mixer for the small quantities used in this study.

10) The addition of fibers to the rapid-setting materials does not appreciably change the workability of the materials. Uncollated (loose) fibers, however, need to be added to the rotating mixer slowly in order to prevent them from clumping.

11) The cost of the fiber reinforced materials is one to seventeen percent higher than materials without fibers. This is an insignificant increase in cost when the increased toughness (which contributes to increased pavement life) due to the fibers is taken into consideration. The extra cost of the fibers also

tion. The extra cost of the fibers also appears to be trivial when the total cost of the repair (materials, labor, equipment) is taken into account.

9.3 Recommendations

From the test results and conclusions given in this report, the following is recommended:

1) Duracal, Set-45, and GHP should be extended with 3/8-in (9.5-mm) maximum size gravel when used for partial (at least 4 in (102 mm)) or full depth repairs. A coarse aggregate ratio of 33 percent is recommended.

2) When making spall repairs, the rapid-setting materials should be used as a mortar mix to insure a good bond between the old pavement and the repair material.

3) Hooked, uncollated Dramix fibers (or similar hooked fiber) with a length of 1.18 in (30-mm) should be added to the rapid-setting materials when used for partial or full depth repairs. A rate of 85 lb per cu yd of concrete is recommended.

9.4 Continuing Research

Although a large quantity of research on rapid-setting materials has been completed, there is a need for continuing research in the following areas:

1) Over the span of Project 311, the candidate materials lacked consistency in properties from bag to bag and from lot to lot. Some manufacturers claim that they now have their products under more

stringent quality control measures, while other manufacturers claim to have improved (or at least changed) the formulations of their products. For these reasons, the materials should be tested periodically to insure that they continue to meet the consumer's requirements.

2) As previously recommended by Smith[5], the use of a continuous batching device, such as the Concrete Mobile, to make larger repairs with rapid-setting materials still needs to be investigated.

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