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16. Abstract

Many materials are available for rapid repair of portland cement concrete. This report describes research which was undertaken to (1) investigate test procedures to evaluate rapid-setting repair materials and (2) test selected materials. Report 311-1, "Results of a Survey on the Use of Rapid-Setting Repair Materials," summarizes the results of an initial survey which identified rapid-setting repair materials used in Texas and other states and summarized the properties and characteristics deemed most important. This study examined a wide range of test procedures for evaluating rapid-setting repair materials, including compressive strength, modulus of elasticity, flexural strength, set time, flow, shear bond, flexural bond, and sand blast abrasion. For some properties more than one test procedure was used. Three materials were used in the testing program: modified portland cement (Duracal), magnesium phosphate (Set-45), and magnesium polyphosphate (Neco-crete).

The tests which appear to be most applicable to evaluating rapid-setting materials are cylinder compression, flexural strength, Gilmore needle set time, and shear bond. The magnesium phosphate developed the most rapid strength gains and highest compressive and flexural bond strength and exhibited the most reasonable set times. The magnesium polyphosphate had the highest modulus of elasticity and the highest flexural strength. The modified portland cement had the highest direct shear bond strength.

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LABORATORY TESTS ON SELECTED RAPID-SETTING REPAIR MATERIALS

by

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Research Report Number 311-2

Evaluation of Fast-Setting Repair Materials
for Concrete Pavements and Bridges

Research Project 3-9-82-311

conducted for

Texas
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
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

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PREFACE

The research program reported was carefully coordinated with the State Department of Highways and Public Transportation Advisory Committee, consisting of George Randolph (D-9), chairman; Ralph Banks (D-18), and Gerald Peck (D-8). Their advice and suggestions were extremely important to the work plan which has been developed.

The assistance of others is gratefully acknowledged: David Macadam and Kevin Smith, graduate research assistants; David Whitney and Tom Phillips, technicians; James Stewart, machinist; Nancy Zett, administrative secretary; and Gloria Clay, clerk-typist.

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ABSTRACT

Many materials are available for rapid repair of portland cement concrete. This report describes research which was undertaken to (1) investigate test procedures to evaluate rapid-setting repair materials and (2) test selected materials. Report 311-1, "Results of a Survey on the Use of Rapid-Setting Repair Materials," summarizes the results of an initial survey which identified rapid-setting repair materials used in Texas and other states and summarized the properties and characteristics deemed most important. This study examined a wide range of test procedures for evaluating rapid-setting repair materials, including compressive strength, modulus of elasticity, flexural strength, set time, flow, shear bond, flexural bond, and sand blast abrasion. For some properties more than one test procedure was used. Three materials were used in the testing program: modified portland cement (Duracal), magnesium phosphate (Set-45), and magnesium polyphosphate (Neco-crete).

The tests which appear to be most applicable to evaluating rapid-setting materials are cylinder compression, flexural strength, Gilmore needle set time, and shear bond. The magnesium phosphate developed the most rapid strength gains and highest compressive and flexural bond strength and exhibited the most reasonable set times. The magnesium polyphosphate had the highest modulus of elasticity and the highest flexural strength. The modified portland cement had the highest direct shear bond strength.

SUMMARY

Test methods for evaluating rapid-setting repair materials for portland cement concrete were investigated. The methods included compression strength, modulus of elasticity, flexural strength, set time, flow shear bond, flexural bond, and sand blast abrasion. Compression strength, flexural strength, Gilmore needle set time, and shear bond strength appear to be the most feasible properties for identifying candidate materials. Three materials were used in this evaluation: magnesium phosphate, magnesium polyphosphate, and modified portland cement. The magnesium phosphate generally had the most desirable properties.

IMPLEMENTATION

The results of this study will permit rapid-setting repair materials for portland cement concrete to be evaluated in a more systematic manner. Districts were surveyed to obtain their experience with available materials and to identify the most important properties and characteristics. The laboratory test program used materials identified in the survey. The evaluation methods investigated will be useful to D-9 and District laboratories for identifying candidate materials. Test results on several of the most widely used materials will be of direct benefit. This study includes a field phase which will provide performance data. These data may permit the identification of the best laboratory test for predicting performance. Until the study is complete, full implementation cannot be recommended.

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CHAPTER 1

INTRODUCTION

1.1 Background

Rapid setting repair materials for portland cement pavements and bridge decks are in great demand. The high traffic volumes and the advancing age of many pavements and bridges have created serious maintenance problems for state highway forces.

A wide range of repair materials is available (1,2,3).* The materials have been categorized as: 1) portland cement, 2) other chemical-setting cements, 3) thermosetting materials, 4) thermoplastics, 5) calcium sulfate, 6) bituminous materials, 7) composites, and 8) additives used to alter mix characteristics.

Many different brands of materials are available, and considerable variation in properties is likely for each category from brand to brand. There is considerable variation in cost per unit volume, and the final inplace cost must take into account the ratio of binder to aggregate. Some materials are designed for temporary repairs, and others are designed for permanent repairs. Some are to be used in limited ambient temperature ranges, and some cannot be used in wet weather. Some can be used at feathered edges, but most require a chipped or saw-cut boundary.

There is a pressing need for information on which to base selection of rapid setting materials for different applications. However, there is a serious lack of reliable information from manufacturers and users. Mechanical and durability properties, when available from the manufacturer, are often given without reference

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*Numbers in parentheses refer to references included at the end of this report.

to the test method. There is no standard evaluation method for rapid setting repair materials. The fact that new products are continually being introduced and old ones are modified makes the evaluation and selection more difficult. There has been a paucity of performance information from users.

1.2 Summary of Previous Research

Research Study 311, Evaluation of Rapid-Setting Repair Materials, was begun in September 1981 with the following objectives: 1) identify candidate materials, 2) evaluate selected materials in laboratory, 3) determine optimum placement methods, 4) test materials and methods in the field, and 5) disseminate results. Results from phase one of this research were reported in Research Report 311-1, "Results of a Survey on the Use of Rapid-Setting Repair Materials" ( ).

In Research Report 020 ("Rapid Setting Cement Mortars for Concrete Repair")(5) , results of tests performed by the Texas State Department of Highways and Public Transportation Materials and Tests Division on 19 rapid setting materials are described. Specifications for evaluating magnesia phosphate mortars and rapid setting cement mortars have been developed.

All of the State Department of Highways and Public Transportation Districts in Texas were surveyed to determine their experience and evaluation of rapid setting reapir materials. Quantities of each repair material were made on the basis of types of repair, cost, climatic condition, durability, bond to concrete, and appearance. Considerable variation was noted for the 27 materials reported.

Other selected states were surveyed to determine their current experience. Six of the eight states responding listed specific materials that were currently being used. Three states provided an evaluation similar to that provided by the State Department of Highways and Public Transportation Districts.

The State Department of Highways and Public Transportation Districts provided a priority order for characteristics and mechanical properties. Setting time, performance (durability), and working time were ranked as the top three characteristics, while bond strength to concrete, flexural strength, and shrinkage were rated as the top three mechanical properties.

1.3 Scope of Report

From phase one of this study four of the most promising rapid-setting repair materials were identified. These materials were Duracal, Set-45, Neco-crete, and Gilco Rapid Patch. An array of tests was then performed on these products to identify the most useful tests for the evaluation of rapid-setting materials. The list of proposed tests included two types of compression tests, a test for modulus of elasticity, a flexural test, three set time tests, a flow test, an abrasion test, three bond tests, a shrinkage test, a test for coefficient of thermal expansion, and a freeze-thaw test.

CHAPTER 2

MATERIALS TESTED

2.1 Introduction

After the preliminary evaluation of rapid setting materials was completed, four materials were selected to be tested. These were Duracal, Set-45, Neco-crete, and Gilco Rapid Patch. The mixes were all designed according to the manufacturers' recommendations. It should be noted that all of the materials but the Neco-crete are recommended for temporary patching.

In the tests, two types of mixes were used, depending upon specimen size and test characteristics. The mixes used were a mortar mix and an aggregate mix. Table 2.1 shows the typical mortar mix proportions, while Table 2.2 exhibits the aggregate mix proportions. Some of the products are packaged neat (cement only), but most of the products are packaged as a rapid setting mortar (fine aggregate included).

Two basic differences in mix design considerations relate to curing technique and the liquid that is used to activate the cement. Some products required a moist cure while others specified an air cure. In regard to liquid, most of the materials tested used water as an activator, but one material called for addition of its own liquid activator.

The type of aggregate employed had to satisfy the manufacturers' recommendation. The fine aggregate used was bagged all-purpose sand with a fineness modulus of 2.8 and a moisture content at SSD of 2 percent. A 3/8-in. (9.5-mm) maximum size pea gravel was used as the coarse aggregate. These aggregates were used for all the mixes, including the portland cement concrete (PCC) specimens used in the bond tests.

TABLE 2.1 MORTAR MIX PROPORTIONS

	MATERIAL			
INGREDIENTS	DURACAL	GILCO RAPID PATCH	NECO-CRETE	SET-45
Packaged Material (lb)	50.0	55.0	50.0	50.0
(kg)	22.7	24.9	22.7	22.7
Fine Aggregate (lb)	50.0	----	----	----
(kg)	22.7	----	----	----
Liquid (gal)	1.5	1.0	1.0	0.5
(liter)	5.68	3.79	3.79	1.89

TABLE 2.2 AGGREGATE MIX PROPORTIONS

	MATERIAL				
INGREDIENTS	DURACAL	GILCO RAPID PATCH	NECO-CRETE	SET-45	PCC
Packaged Material (lb)	50.0	55.0	50.0	50.0	50.0
(kg)	22.7	24.9	22.7	22.7	22.7
Fine Aggregate (lb)	50.0	----	----	----	139.4
(kg)	22.7	----	----	----	63.2
Coarse Aggregate (lb)	50.0	30.0	18.0	30.0	96.2
(kg)	22.7	13.6	8.2	13.6	43.5
Liquid (gal)	1.75	1.0	1.0	0.5	0.74
(liter)	6.62	3.75	3.75	1.89	2.80

2.2 Duracal

The Duracal product is a modified portland cement. It is the only material tested that is packaged neat. Because of this, sand has to be added to obtain a mortar. The manufacturer of Duracal recommends that the material be cured at 95 percent R.H., 72°F (22°C), to achieve maximum strengths. Two mixing proportions are published by Duracal; the one used was printed on the bag. The other proportions are printed in their brochure, revised 1977, and require the addition of one-fourth gallon more water for both the mortar and aggregate mix. The manufacturer also produces a Duracal "AG" which has a slower set time.

2.3 Set-45

Set-45 is a magnesium phosphate packaged as mortar. It is water activated and was cured at ambient laboratory conditions (72°F or 22°C, 50 percent R.H.). A Set-45 Hot Weather mix is also available.

2.4 Neco-crete

This material is a magnesium polyphosphate. It is packaged as a mortar and comes with its own liquid activator. Due to a very short set time, the liquid activator was chilled to 50°F (10°C) to facilitate its placement into the molds. This was found to have very little effect on the resulting strengths. The Neco-crete product was cured at ambient laboratory conditions. The use of Neco-crete for testing was discontinued about halfway through the tests. This was done because the liquid activator was no longer reacting properly with the dry mix. It should be noted that as the Neco-crete reacts, a pungent ammonia odor is released which makes it unpleasant to use.

2.5 Gilco Rapid Patch

Gilco Rapid Patch is a modified portland cement material. It is packaged as a mortar, uses water as an activator, and is moist cured (95 percent R.H., 72°F or 22°C). Testing of this product was discontinued after the mortar cube compression test because it became unavailable from the manufacturer.

2.6 Portland Cement Concrete

Type III cement was used in the mix of the PCC specimens. They were cured for 28 days at 95 percent R.H. and 72°F (22°C). An aggregate mix was used for all PCC bond specimens.

CHAPTER 3

EXPERIMENTAL TEST PROCEDURES

Numerous tests were proposed to obtain strength, durability, and material property data for rapid setting materials. The tests were generally conducted in accordance with ASTM standard testing procedures. Some tests were modified slightly to make them more applicable to the rapid setting nature of the products. Other testing procedures were adapted from previous research at The University of Texas or devised using sound engineering judgement. Unless otherwise noted, all tests were run at ambient laboratory conditions, approximately 72°F (22°C) and 50 percent R.H. At the time of writing, three of the proposed tests had not been completed. This was due to the unavailability of testing apparatus. The three pending tests were length change, coefficient of thermal expansion, and freeze-thaw.

3.1 Compressive Strength

3.1.1 Mortar Cubes

The mortar cube compressive strength test was run according to ASTM C109-80, "Compressive Strength of Hydraulic Cement Mortars." The specimens were cast in 2-in. x 2-in. (50.8-mm x 50.8-mm) steel molds and tested at ages of one hour, three hours, 24 hours, and seven days. Specimens were loaded at a uniform rate of 10,000 lb (44.48 kN)/min. Mortar mixes were used for all tests.

3.1.2 Cylinders

Compression cylinders were made and tested according to ASTM C39-80, "Compressive Strength of Cylindrical Concrete Specimens."

The specimens used 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 one hour, three hours, 24 hours, seven days, and at the time that the peak exothermic temperature occurred. All specimens were capped to provide a smooth loading surface. Slight modifications were made to the compaction techniques called for in the specification. The cylinders were placed in two lifts and rodded thirty times per lift. A vibrating table was also used to insure adequate compaction. The loading rate used for the cylinders was 15,000 lb (66.72 kN)/min. Aggregate mixes were used for these tests.

3.2 Modulus of Elasticity

The test for modulus of elasticity was performed as stated in ASTM C469-65, "Static Modulus of Elasticity of Concrete in Compression." A compressometer was attached to the seven-day compression cylinder, as shown in Fig. 3.1. The compressometer had two diametrically placed dial gauges for reading vertical deflection of the specimen under compression. Readings of the dial gauge were recorded every 2,000 lb (8.9 kN) until ultimate strength was reached.

3.3 Flexural Strength

The guidelines used to obtain the flexural strength of the materials was 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 prisms were tested using third point loading. The apparatus consisted of a loading block and a bearing plate that provided concentrated loads of the third points of a 6-in. (152.4-mm) span. The loading block was centered in the beam, and a uniform loading rate of 150 lb (667.2 kN)/min was applied. The beams were tested at one hour, three hours, and 24 hours. All of the beams were cast using an aggregate mix.

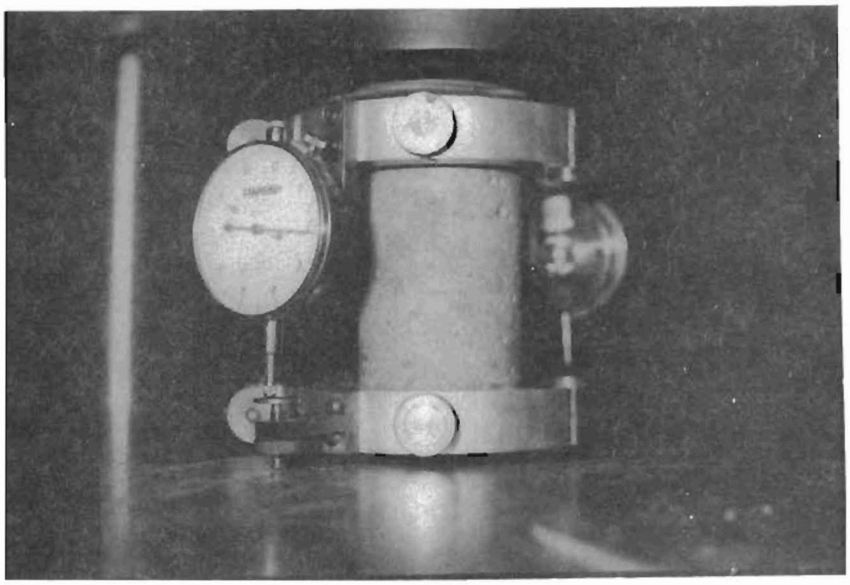

Figure 3.1 Compressometer Used in Determining Modulus of Elasticity

3.4 Set Time

3.4.1 Gilmore Needle

The Glmore needle test for set time was performed according to ASTM C266-77, "Time of Setting of Hydraulic Cement by Gilmore Needles." Figure 3.2 shows a photograph of the Gilmore needle apparatus. The specimen used was a mortar pat, 3 in. (76.2 mm) in diameter and 1/2 in. (12.7 mm) in thickness.

3.4.2 Penetration Resistance

The penetration resistance set time test was performed according to ASTM C403-80, "Time of Setting of Concrete Mixtures by Penetration Resistance." The penetrometer is shown in Fig. 3.3. A mortar mix was used for this test and the container used was a 6 in. (152.4 mm) diameter cylinder, 6 in. (152.4 mm) long.

3.4.3 Peak Exotherm

A third means used to estimate set time is a measurement of peak exothermic temperature. A thermocouple was used to measure the temperature of the material at the center of a 3-in. x 6-in. (76.2-mm x 152.4-mm) specimen in a cardboard cylinder. The mix used for this test was the aggregate concrete mix.

3.5 Flow

An attempt was made to measure the flow characteristics of the materials by using ASTM C124-71, "Flow of Portland Cement Concrete by Use of a Flow Table." This test was tried using both mortar and aggregate mixes.

3.6 Shear Bond

3.6.1 Direct Shear Bond

For the direct shear bond test, 5-in. x 5-in. x 1-in. (127-mm x 127-mm x 25.4-mm) specimens of PCC were cast and cured. A 1/2-in. (12.7-mm) thick layer of rapid setting material was then cast against

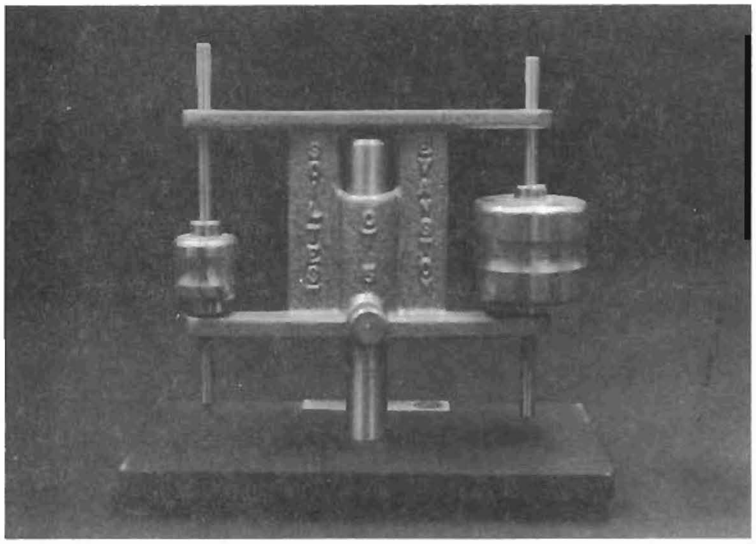

Figure 3.2 Gillmore Needle Apparatus

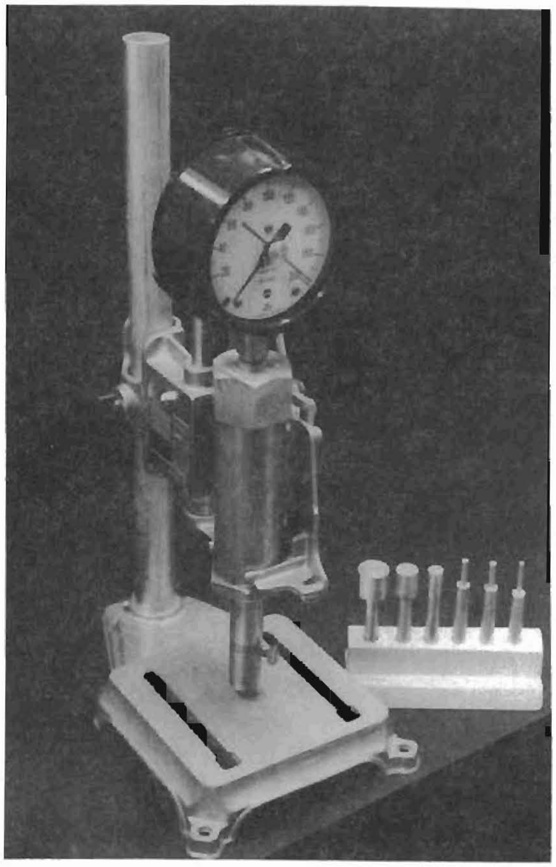

Figure 3.3 Penetrometer Used for Penetration Resistance Set Time Test

the trowelled surface of the PCC plates. A vertical force was then applied through a steel bar on the edge of the rapid setting material portion of the plate. A second bar was placed under the PCC portion of the plate to act as a support (Fig. 3.4).

Two types of bonding surfaces were examined, wet and dry. For the wet case, the PCC portions of the specimens were soaked in water for at least two hours before casting. In both cases, the bonding surfaces were dampened with water or liquid activator immediately before casting. Mortar mixes of rapid setting materials were used.

3.6.2 Flexural Shear Bond

The first step in the procedure to run the flexural shear bond was to cast 2-in. x 1-in. x 12-in. (50.8-mm x 25.4-mm x 304.8-mm) PCC prisms with a trowelled top surface. These were placed in the 2-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 304.8-mm) steel molds and a 1-in. (25.4-mm) layer of rapid setting material was cast on top of them. The beams were then broken utilizing third point loading. Figure 3.5 exhibits the test set-up.

Wet and dry bonding surfaces were used, with the procedures for obtaining the wet bonding surface being similar to those used in the Direct Shear Bond test. The bond surfaces were again dampened with water or liquid activator before placement. The aggregate mixes were used for this test.

3.7 Flexural Bond

Flexural bond was investigated by casting 2-in. x 2-in. x 12-in. (50.8-mm x 50.8-mm x 304.8-mm) PCC beams. These beams were then cured and broken in flexure in the middle. The prisms were placed back in the beam molds where rapid setting material was cast against the broken face. The beams were then broken in third point loading, as seen in Fig. 3.6. A wet and dry bonding surface was used with the bond surface being dampened as before. The aggregate mixes were used in this test.

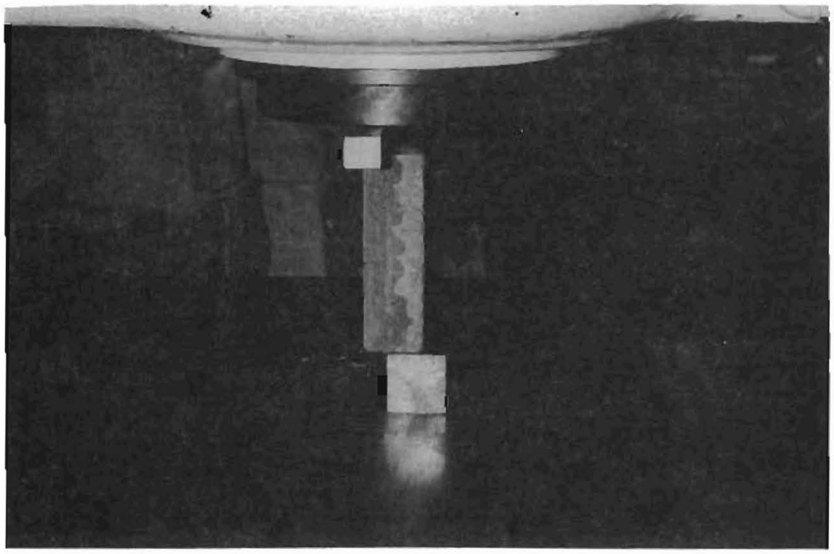

Figure 3.4 Test Set Up for Direct
Shear Bond Test

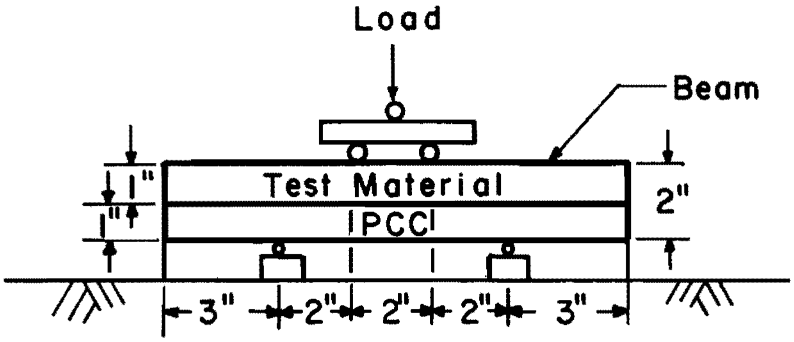

Figure 3.5 Loading Arrangement for Flexural Shear Bond Test

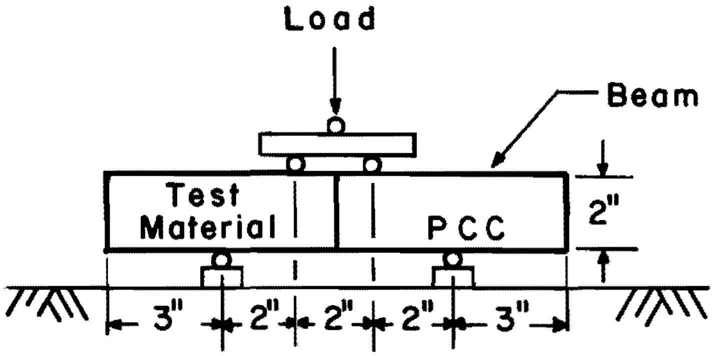

Figure 3.6 Loading Arrangement for Flexural Bond Test

3.8 Sand Blast Abrasion

The test for abrasion resistance was carried out according to ASTM C418-76, "Abrasion Resistance of Concrete by Sandblasting." The specimens used were the 5-in. x 5-in. x 1/2-in. (127-mm x 127-mm x 12.7-mm) rapid setting material plates that had been sheared off in the Direct Shear Bond test. These were cured for seven days.

CHAPTER 4

EXPERIMENTAL TEST RESULTS

The experimental tests outlined in the previous chapter were performed using at least two and as many as four rapid setting materials. The purpose of the tests was both to evaluate the selected materials and to select a series of tests to provide a basis for rapid setting material evaluation. Following is an analysis of the experimental tests presented in Chapter Three.

4.1 Compression Strength

4.1.1 Mortar Cubes

Compressive strengths of all four materials were found using the mortar cubes. The results are tabulated in Table 4.1 and plotted in Fig. 4.1. The products with the most rapid strength gain were also the products with the highest ultimate strengths. These materials are Set-45 and Gilco Rapid Patch.

As can be seen in Fig. 4.1, the most appreciable strength gain of the rapid setting materials occurred in the first 24 hours. Only in the Duracal was there more than a 15 percent increase in strength beyond the 24-hour period (Table 4.2).

4.1.2 Cylinders

Three materials, Duracal, Neco-crete, and Set-45, were evaluated by compressive strength tests. The compressive strength versus time results are illustrated in Table 4.3 and Fig. 4.2. By examining the correlation between Fig. 4.1 (mortar cube compressive strengths) and Fig. 4.2 (cylinder compressive strengths), it can be seen that the

TABLE 4.1 COMPRESSIVE STRENGTH OF MORTAR CUBES

MATERIAL	CURING TIME	AVERAGE COMPRESSIVE STRENGTH (psi)	(MPa)
DURACAL	1 hr	760	5.26
	3 hr	1650	11.40
	24 hr	3100	21.37
	7 days	4160	28.67
GILCO RAPID PATCH	1 hr	3250	22.44
	3 hr	4520	31.13
	24 hr	4970	34.22
	7 days	5370	37.00
NECO-CRETE	1 hr	1780	12.26
	3 hr	2190	15.09
	24 hr	3460	23.87
	7 days	3480	23.99
SET-45	1 hr	3400	23.44
	3 hr	4660	32.14
	24 hr	4920	33.90
	7 days	5600	38.61

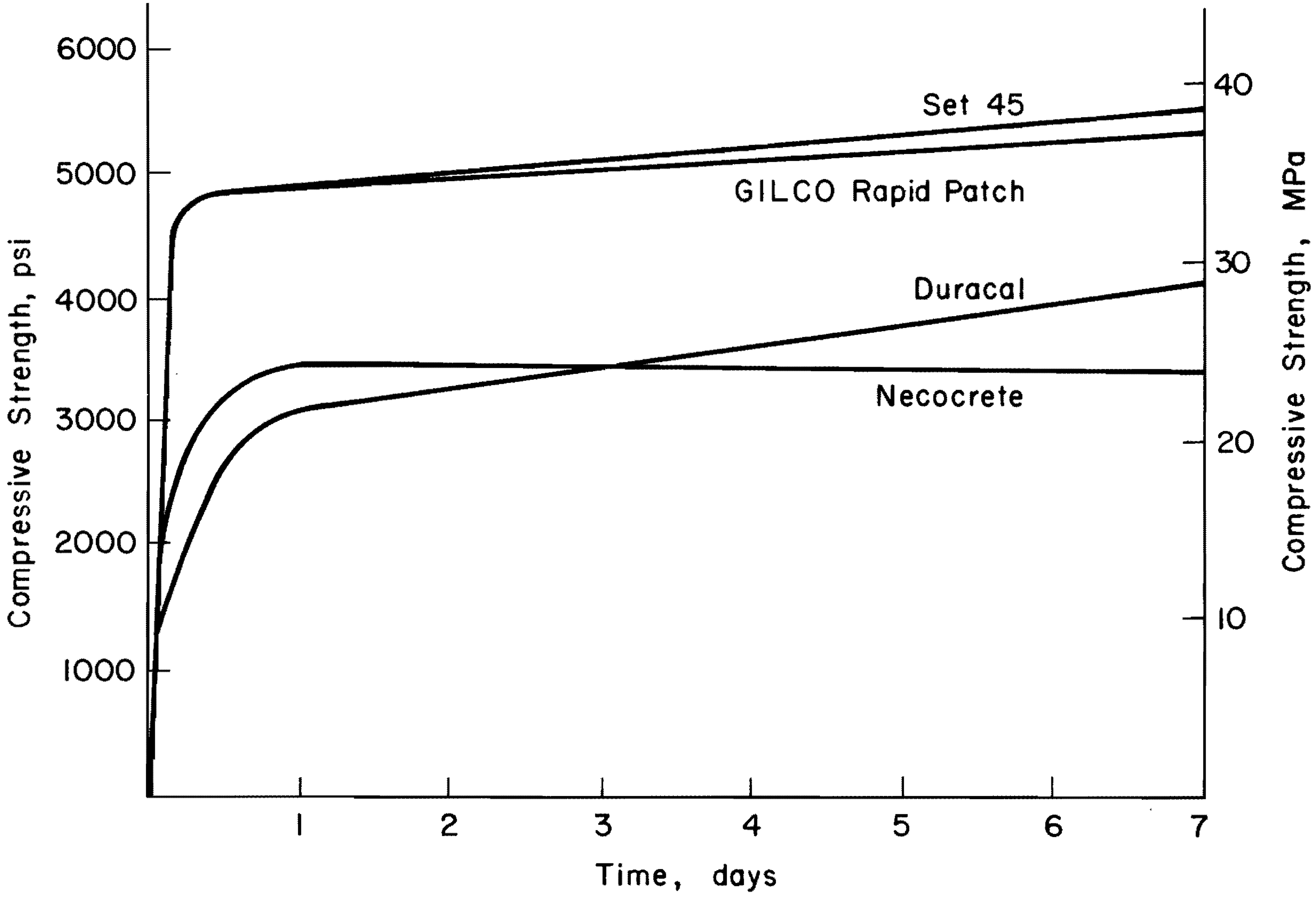

Figure 4.1 Compression of 2-in. x 2-in. Mortar Cubes

TABLE 4.2 COMPRESSIVE STRENGTH AS A PERCENTAGE OF 24 HOUR MORTAR CUBE COMPRESSIVE STRENGTH

MATERIAL	CURING TIME	COMPRESSIVE STRENGTH (psi)	24 HOUR COMPRESSIVE STRENGTH (percent)
DURACAL	1 hr	760	24.6
	3 hr	1650	53.3
	24 hr	3100	100.0
	7 days	4160	134.2
GILCO RAPID PATCH	1 hr	3250	65.5
	3 hr	4250	90.9
	24 hr	4970	100.0
	7 days	5370	108.1
NECO-CRETE	1 hr	1780	51.4
	3 hr	2190	63.2
	24 hr	3460	100.0
	7 days	3480	100.5
SET-45	1 hr	3400	69.1
	3 hr	4660	94.7
	24 hr	4920	100.0
	7 days	5600	113.8

TABLE 4.3 COMPRESSIVE STRENGTH OF CYLINDERS*

MATERIAL	CURING TIME	AVERAGE COMPRESSIVE STRENGTH (psi)	(MPa)
DURACAL	1 hr	320	2.23
	80 min	1290	8.88
	3 hr	1410	9.71
	24 hr	2860	19.75
	7 days	4000	27.60
NECO-CRETE	18 min	1550	10.70
	1 hr	2540	17.48
	3 hr	2910	20.06
	24 hr	3580	24.71
	7 days	3730	25.72
SET-45	30 min	2760	19.05
	1 hr	4150	28.65
	3 hr	4690	32.35
	24 hr	4870	33.59
	7 days	5230	36.04

*The expected values for full size (6-in. dia. x 12-in. lg) cylinders would be lower. These values were deemed adequate for comparative purposes and therefore were not adjusted.

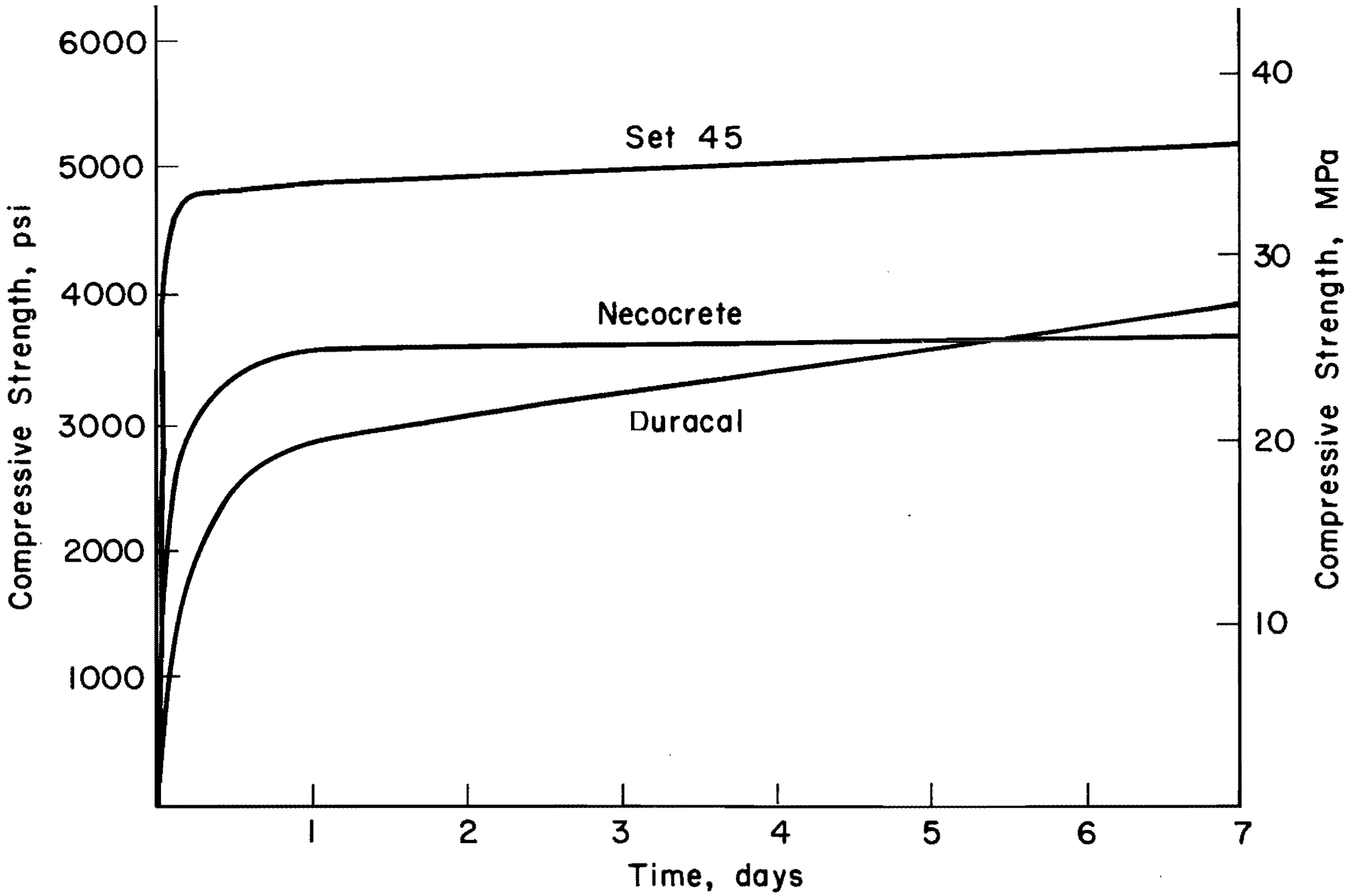

Figure 4.2 Compression of 3-in. x 6-in. Cylinders

mortar cubes and cylinders gave similar compressive strength results. Again the Set-45 material has the most rapid strength gain and highest ultimate strength. A one-hour ultimate compressive strength of 4154 psi (28.6 MPa) was reached by Set-45, with 5227 psi (36.0 MPa) being reached after seven days.

4.2 Modulus of Elasticity

The modulus of elasticity was measured from seven-day compression cylinders. Typical stress-strain curves for each material are shown in Figs. 4.3, 4.4, and 4.5. The modulus of elasticity was calculated by the equation

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon - 0.0005} \qquad (7.1)$$

where

E = the secant modulus of elasticity in psi (MPa),
σ_1 = the stress corresponding to a longitudinal strain of 50 μin./in. in psi (MPa)
σ_2 = the stress corresponding to 40 percent of ultimate load in psi (MPa),
ε_2 = the longitudinal strain produced by stress σ_2 in in./in. (mm/mm).

The modulus of elasticity was measured on three specimens for each material. Table 4.4 exhibits the average modulus of elasticity values and ultimate strength for each material. It can be seen that these rapid setting materials have a substantially lower modulus of elasticity than that of PCC.

4.3 Flexural Strength

The flexural strength was found for the same three products as the cylinder compression tests. Since the major strength gains of the rapid setting materials were found to occur in the first 24 hours, a seven-day flexural strength test was not performed. The results of the flexural strength test are exhibited in Fig. 4.6 and Table 4.5.

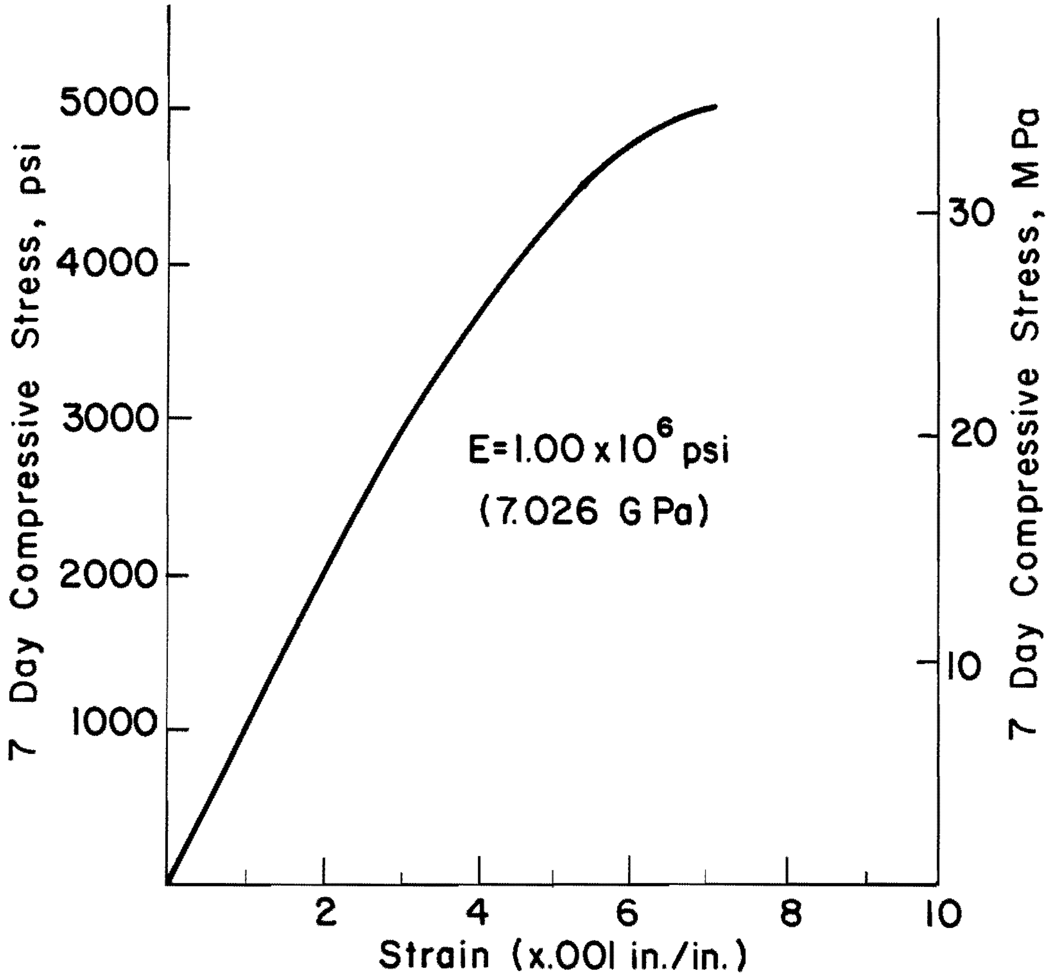

Figure 4.3 Typical Stress-Strain Relationship for Duracal

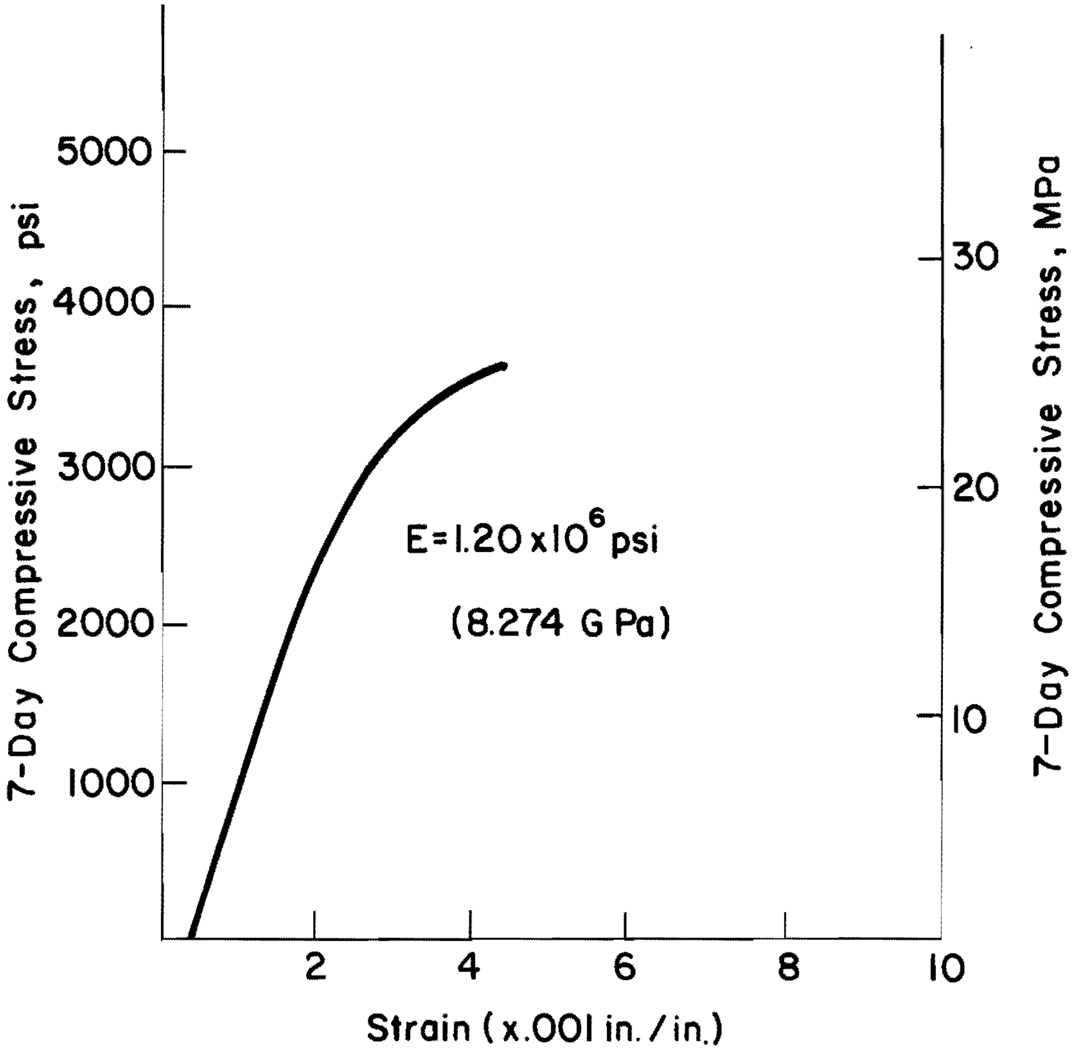

Figure 4.4 Typical Stress-Strain Relationship for Neco-crete

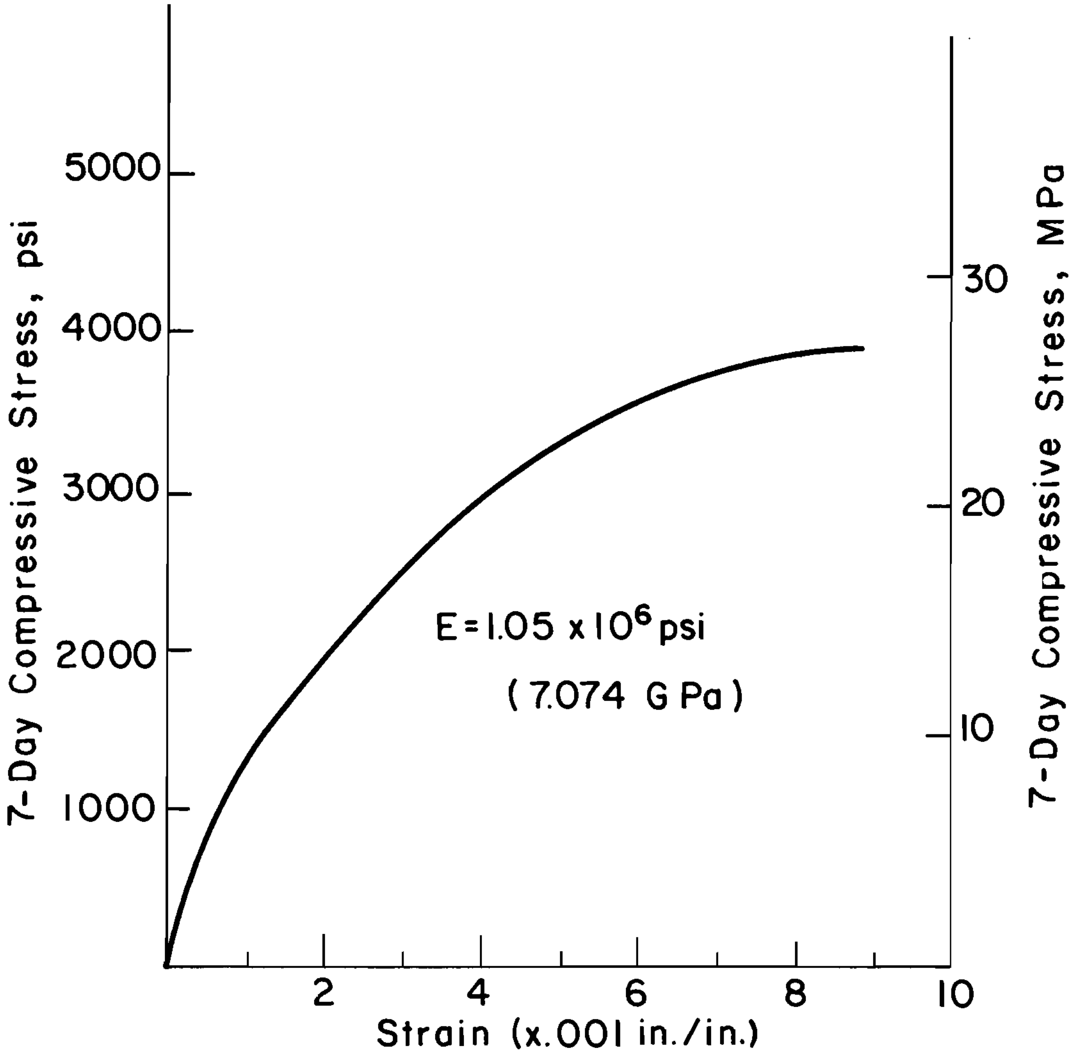

Figure 4.5 Typical Stress-Strain Relationship for Set-45

TABLE 4.4 MODULUS OF ELASTICITY OF SEVEN DAY CYLINDERS

MATERIAL	AVERAGE 7 DAY COMPRESSIVE STRENGTH (psi)	AVERAGE MODULUS OF ELASTICITY (1×10^6 psi)	(GPa)
DURACAL	4000	1.00	6.826
NECO-CRETE	3730	1.35	9.446
SET-45	523	0.95	6.619

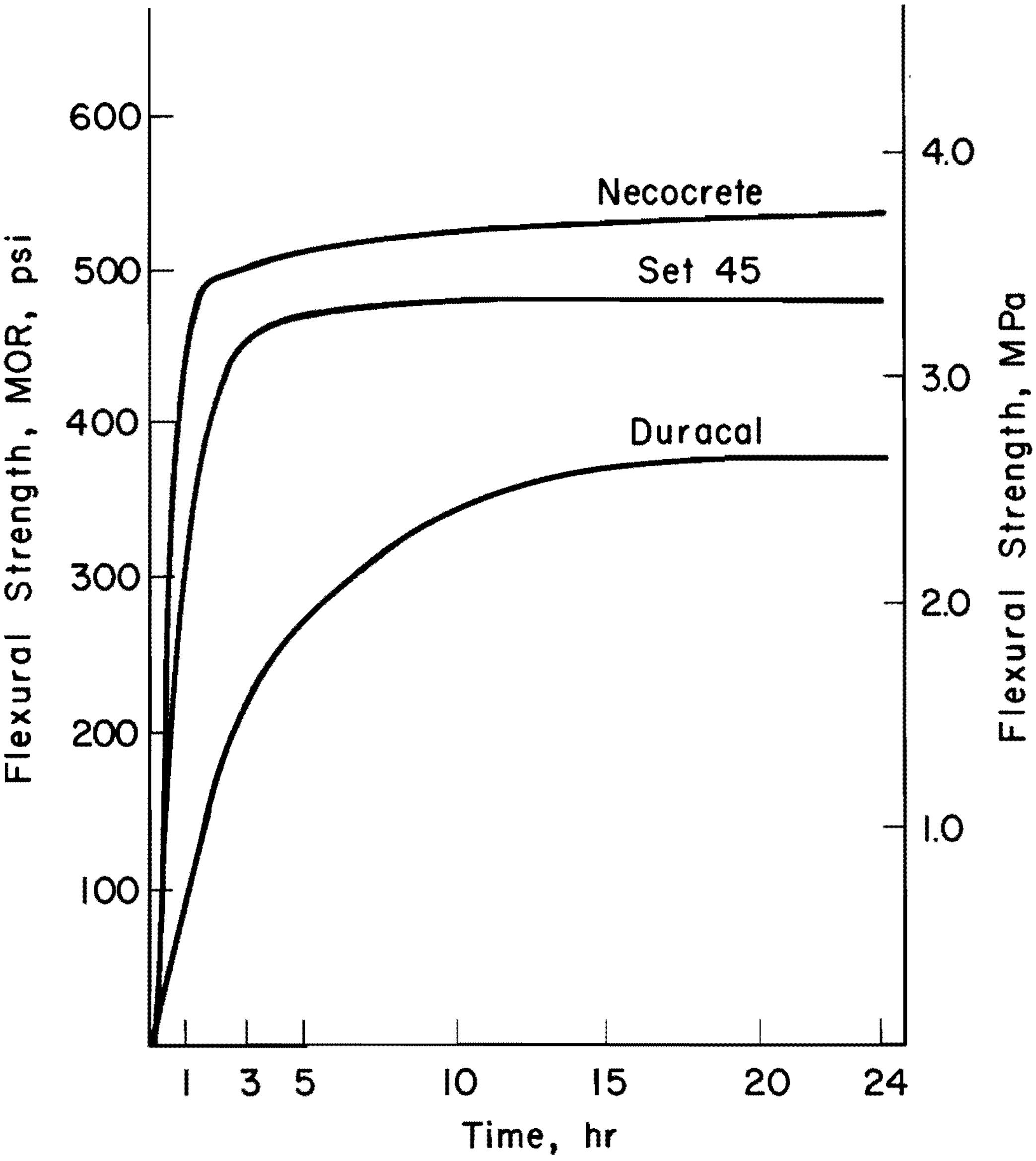

Figure 4.6 Flexural Strength of 2-in. x 2-in. x 6-in. Beams

TABLE 4.5 FLEXURAL STRENGTH

MATERIAL	CURING TIME	AVERAGE FLEXURAL STRENGTH (psi)	(MPa)
DURACAL	1 hr	115	0.80
	3 hr	230	1.59
	24 hr	385	2.66
NECO-CRETE	1 hr	480	3.33
	3 hr	505	3.50
	24 hr	540	3.72
SET-45	1 hr	385	2.65
	3 hr	460	3.16
	24 hr	485	3.35

They show that the Neco-crete material has a higher flexural strength than the other two products. The 24-hour ultimate flexural strength of Neco-crete was found to be 540 psi (3.7 MPa).

4.4 Set Time

4.4.1 Gilmore Needle

The Gilmore needle set time test was performed on Duracal, Neco-crete, and Set-45. Intial set times ranged from four minutes to 41 minutes with final set times in the range of five minutes to 48 minutes. The Neco-crete had the fastest set times, and the Duracal had the slowest. The set times for both of these materials seem inappropriate for rapid setting material. The results of the Gilmore needle test are given in Table 4.6.

4.4.2 Penetration Resistance

The penetrometer was the second device used to measure the set time of the rapid setting materials. The results were similar to those given by the Gilmore needle. The Set-45 product had the most practical set time. Table 4.7 exhibits the results of this set time test. The penetrometer was awkward to work with.

4.4.3 Peak Exotherm

A graph plotting time versus the exothermic temperature of a rapid setting material (Fig. 4.7) was the third means used to measure set time. Since the exothermic temperature is directly related to the hydration-reaction process, the peak exotherm can be used as an indication of when the material has its most rapid strength gain. This phenomenon was noticed during the testing of the compression cylinders. In all three materials, there were noticeable strength increases from the first to second to third cylinders that were broken at the peak exotherm. It should be noted that the initial and final sets as measured by the Gilmore needle occurred earlier than the time of peak exotherm.

TABLE 4.6 GILMORE NEEDLE SET TIME

MATERIAL	AVERAGE SET TIME INITIAL (min)	FINAL (min)
DURACAL	41	48
NECO-CRETE	4	5
SET-45	13	15

TABLE 4.7 PENETRATION RESISTANCE SET TIME

	AVERAGE SET TIME	
MATERIAL	INITIAL (min)	FINAL (min)
DURACAL	35	38.5
NECO-CRETE	7.5	8.5
SET-45	11.5	12.5

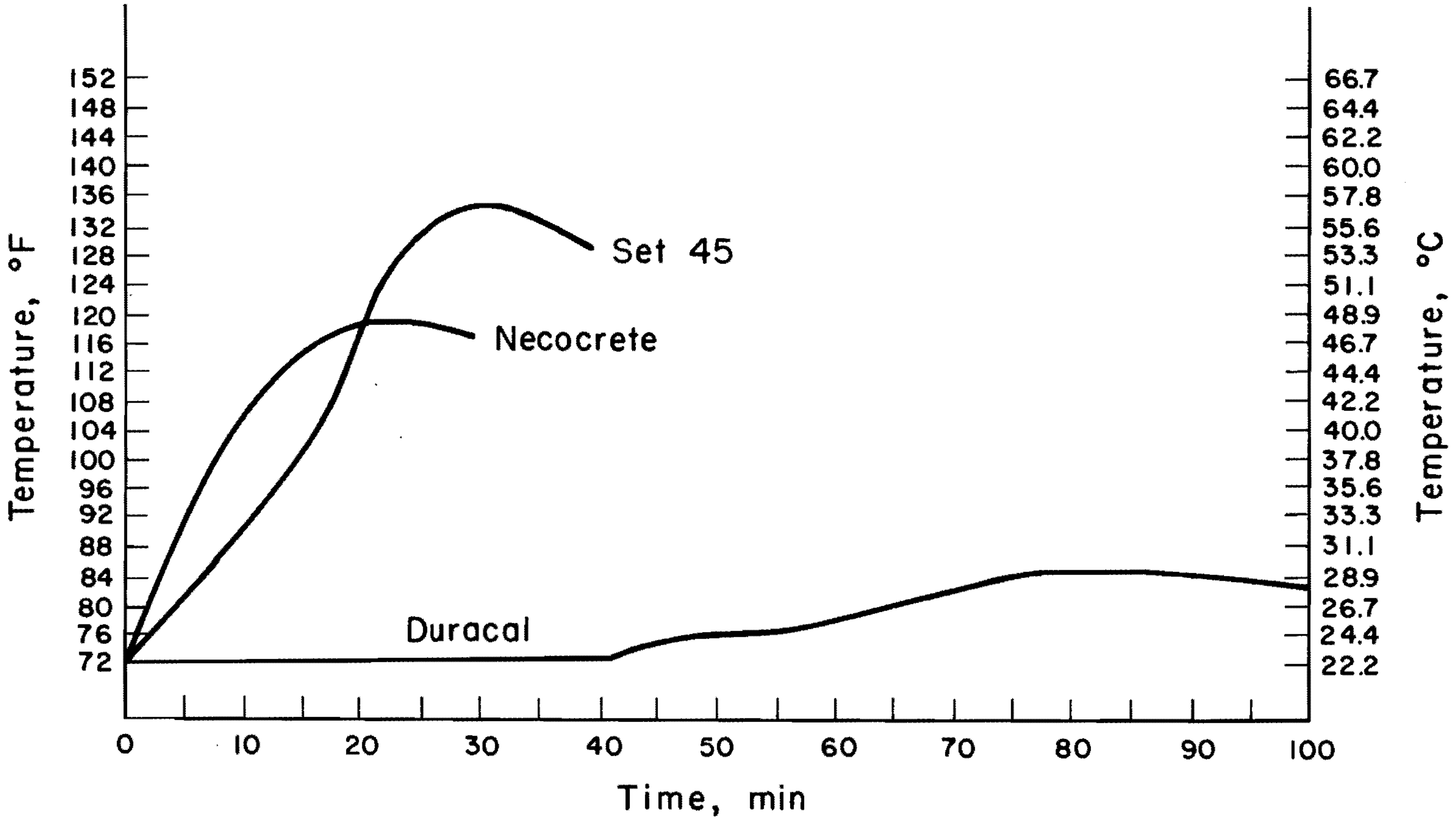

Figure 4.7 Time versus Exothermic Temperature Relationships

4.5 Flow

The flow test was used in an attempt to measure the workability of the rapid setting materials. Due to the varying viscous characteristics of the products and because of its impractical nature, the flow test was abandoned. The amount of working time available for these materials was found to correlate with the Gilmore needle set time test. From laboratory experience it was discovered that the materials were still workable up to 80 percent of the Gilmore needle initial set time.

4.6 Shear Bond

4.6.1 Direct Shear Bond

The direct shear bond test was performed using Duracal and Set-45. The direct shear bond stress was found by dividing the load by the cross-sectional area of the plate, which was 25 in.^{2} (161.3 cm^2). Also recorded was the percent of rapid setting material area still bonded to the PCC. Ideally the failure plane would occur completely within the PCC. The results of the direct shear bond are provided in Table 4.8. It was observed that for all the testing ages, Duracal had a higher bond strength than Set-45, and, in all cases, the dry bonds outperformed the wet ones. Another observation that was made was that the percentage of bonded material left on the concrete was low for the Duracal (in one case, the concrete stayed bonded to the Duracal, such that a negative bonding percentage was recorded) and consistently higher for the Set-45. Figure 4.8 exhibits a specimen with approximately a 50 percent bond failure.

4.6.2 Flexural Shear Bond

The purpose of the flexural shear bond test was to achieve a shear failure in the beam, as shown in Fig. 4.9. The test was run on the Duracal and Set-45 at one hour. All of the specimens displayed a flexural failure, as seen in Fig. 4.10. There appears to be no possibility of getting a shear failure with this type of test. For this reason, the flexural shear bond test was terminated.

TABLE 4.8 DIRECT SHEAR BOND

MATERIAL	CURING TIME	BONDING SURFACE	AVERAGE SHEAR BOND STRENGTH (psi)	AVERAGE SHEAR BOND STRENGTH (MPa)	AVERAGE APPROX. PERCENT STILL BONDED TO CONCRETE
DURACAL	1 hr	dry	103	0.71	2
		wet	97	0.69	10
	3 hr	dry	135	0.93	0
		wet	119	0.82	0
	24 hr	dry	161	1.11	-2
		wet	120	0.82	0
SET-45	1 hr	dry	62	0.43	0
		wet	41	0.28	75
	3 hr	dry	134	0.92	40
		wet	85	0.59	60
	24 hr	dry	146	1.01	5
		wet	101	0.70	80

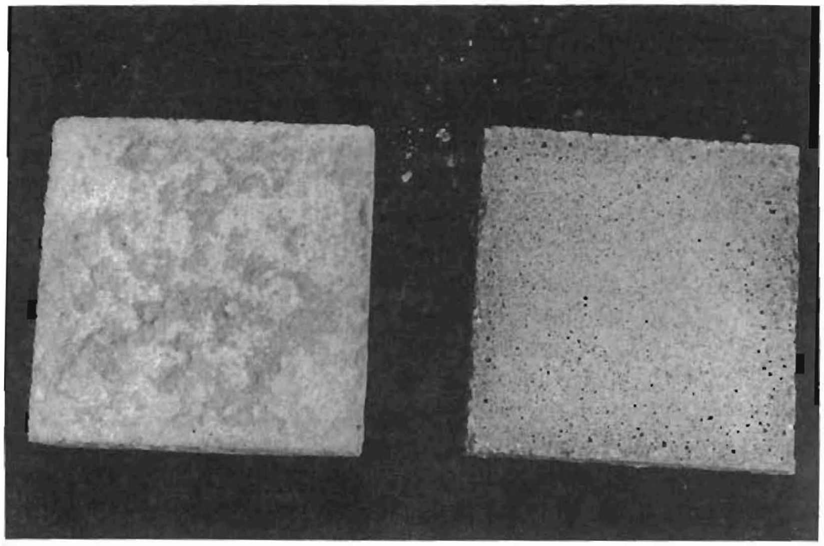

Figure 4.8 Shear Bond Specimen with Approximately 50 Percent of the Material Still Bonded to the Concrete

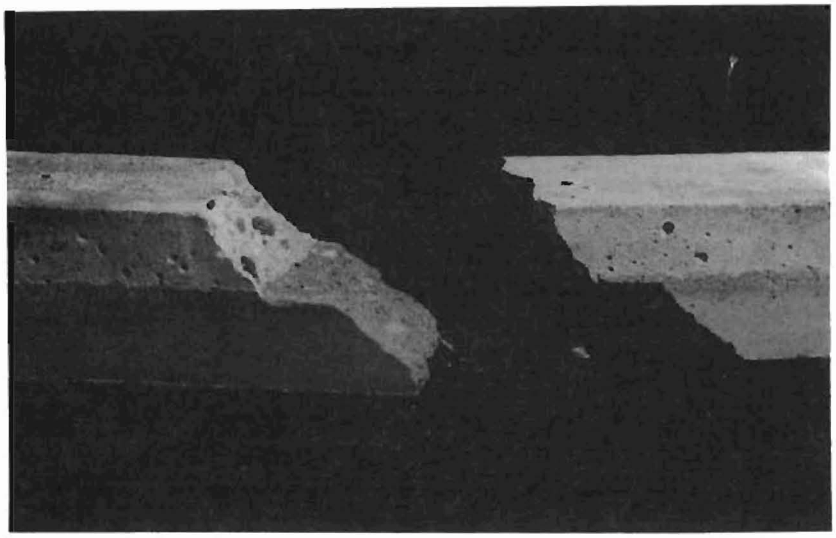

Figure 4.9 Flexural Shear Bond Specimen
with Controlled Shear Failure

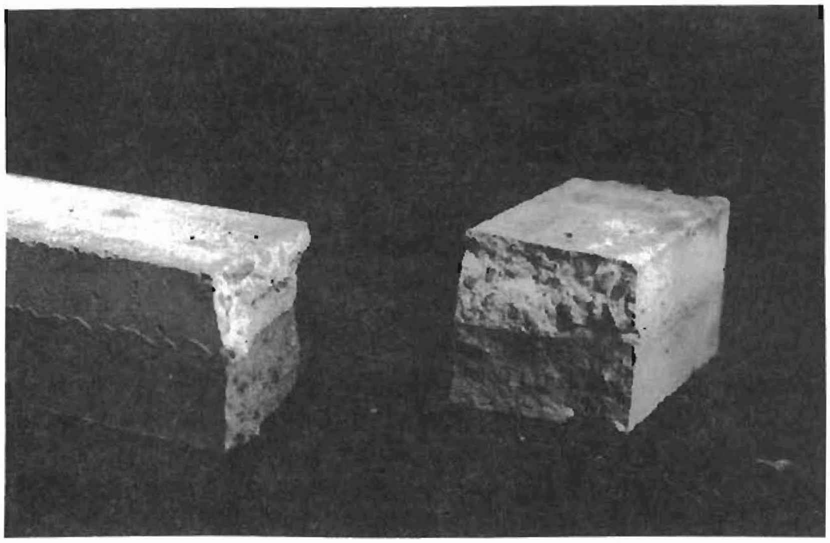

Figure 4.10 Flexural Shear Bond Specimen
with Flexural Failure

4.7 Flexural Bond

The flexural bond test was run on the Duracal and Set-45. The bond was converted to a flexural bond strength by standard bending formulas. Also recorded during this test was the location of the failure plane. For all testing ages, the Set-45 outperformed the Duracal, and the dry bonds outperformed the wet ones (Table 4.9). A slight inconsistency arose concerning the Duracal's bonding properties. In the case of the direct shear bond test, the percentage of bonded material left on the concrete was low. For the flexural bond tests, most of the failures occurred in the Duracal, as opposed at the bond surface. The only explanation that could account for this is the low flexure strength (Fig. 4.6) of the Duracal material. A specimen which failed in the repair material is shown in Fig. 4.11. Figure 4.12 illustrates a bond failure at the bond interface.

4.8 Sandblast Abrasion

The sandblast abrasion test was run on Duracal and Set-45. The test results are summarized in Table 4.10. They show that the Set-45 had approximately 50 percent more abrasion loss than the Duracal. Figure 4.13 shows a specimen after it had been abraded.

TABLE 4.9 FLEXURAL SHEAR BOND

MATERIAL	CURING TIME	BONDING SURFACE	AVERAGE FLEXURAL BOND STRENGTH (psi)	(MPa)	PREDOMINANT FAILURE PLANE
DURACAL	1 hr	dry	135	0.94	Material
		wet	95	0.65	Material
	3 hr	dry	190	1.31	Material
		wet	160	1.09	Bond Interface
	24 hr	dry	375	2.59	Material
		wet	240	1.66	Bond Interface
SET-45	1 hr	dry	210	1.44	Material
		wet	175	1.20	Bond Interface
	3 hr	dry	360	2.47	Material
		wet	175	1.20	Bond Interface
	24 hr	dry	380	2.61	Bond Interface
		wet	295	2.04	Bond Interface

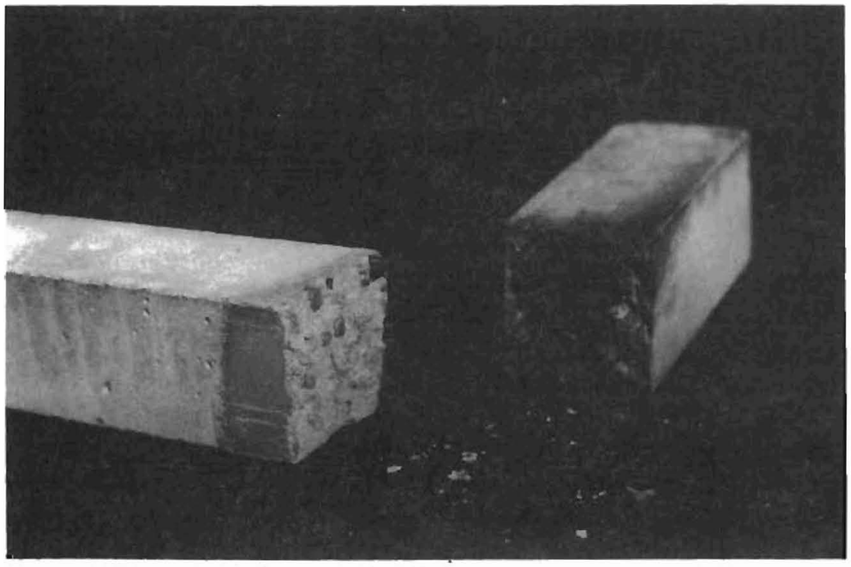

Figure 4.11 Flexural Bond Specimen with the Failure Plane in the Rapid Setting Material

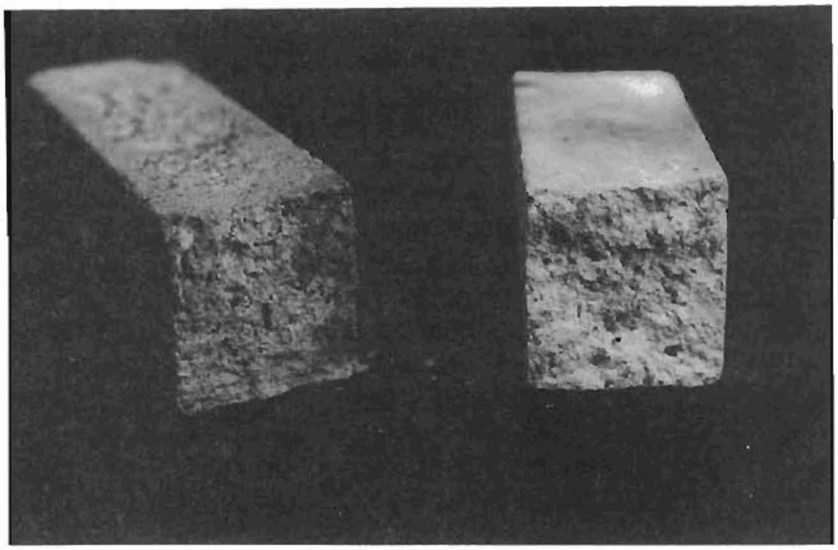

Figure 4.12 Flexural Bond Specimen with the Failure Plane at the Bond Interface

TABLE 4.10 SAND BLAST ABRASION COEFFICIENTS

MATERIAL	AVERAGE ABRASION COEFFICIENT (cm^3/cm^2)
DURACAL	0.117
SET-45	0.164

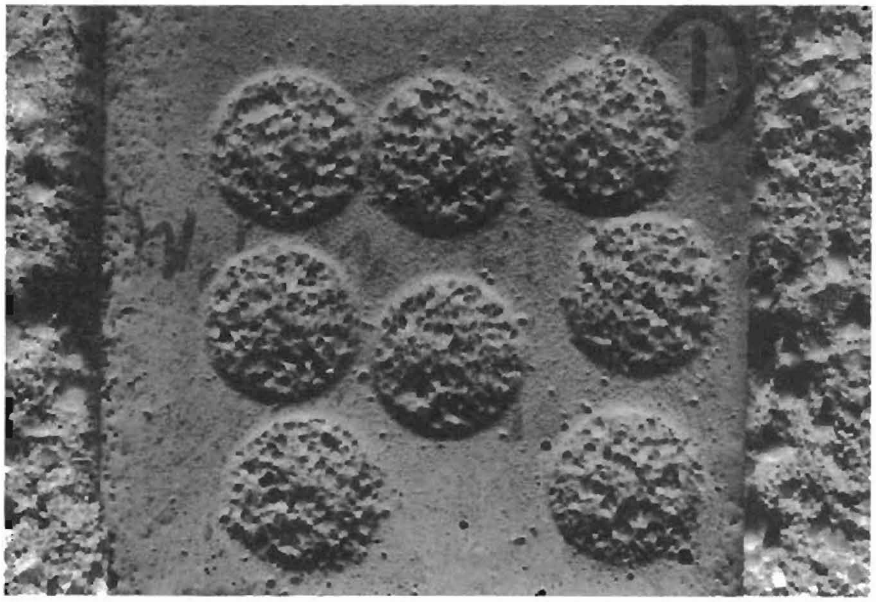

Figure 4.13 Sandblast Abrasion Specimen

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

There is an urgent need for dependable rapid setting materials for the repair of concrete pavements and bridge decks. Many types and brands are currently available, but the selection of an appropriate material is complicated by the lack of reliable data from manufacturers and users. There is no standard evaluation procedure for these materials.

This report summarizes the evaluation of certain selected materials that were chosen by the Texas State Department of Highways and Public Transportation. The preliminary data that were gained from the surveys and previous testing were used to develop a series of tests to run on the rapid setting materials.

Four materials were selected for testing, Duracal, Gilco Rapid Patch, Neco-crete, and Set-45. The materials have varying chemical compositions and properties. Only two of the materials were available for use throughout the full array of tests.

The proposed list of tests included two types of compression tests, a test for modulus of elasticity, a flexural test, three set time tests, a flow test, an abrasion test, three bond tests, a shrinkage test, a test for coefficient of thermal expansion, and a freeze-thaw test. All but the final three tests were completed and are reported herein. The tests were all run in compliance with ASTM standards, with as few modifications made as possible. Some of the tests, e.g., bond tests, were developed at The University of Texas and were run in accordance with good engineering practice.

5.2 Conclusions

Based upon the surveys and experimental results, the following conclusions can be made:

1) The Set-45 product exhibited the most rapid strength gains and highest ultimate strengths in compression. It achieved 94.7 percent of its 24-hour compressive strength in three hours. The Set-45 had a 24-hour compressive strength of 4870 psi (33.59 MPa) compared to 3580 psi (24.71 MPa) for Neco-crete and 2860 psi (19.75 MPa) for Duracal.

2) Neco-crete had the highest modulus of elasticity of the rapid setting materials. The average seven-day modulus of elasticity was 1.35×10^6 psi (9.446 GPa) for Neco-crete, as compared to values of approximately 1×10^6 psi (6.826 GPa) for Duracal and Set-45.

3) In flexure, Neco-crete had higher values than the two other materials tested. The 24-hour modulus of rupture for Neco-crete was 540 psi (3.72 MPa), for Set-45 was 485 psi (3.35 MPa), and for Duracal was 385 psi (2.667 MPa).

4) The Set-45 exhibited the most practical set times for a rapid setting material under these laboratory conditions. The initial Gilmore needle set time was thirteen minutes for Set-45, as opposed to 41 minutes for Duracal and four minutes for Neco-crete. The final set times were one to seven minutes after the initial one.

5) The Duracal exhibited higher values than the Set-45 in the direct shear bond test, while the Set-45 exhibited higher values than the Duracal in the flexural bond test. In both tests, the dry bonding surface gave higher results than the wet one.

6) The Duracal is more abrasion resistant than the Set-45.

7) As a result of the testing done so far, the Set-45 product seems to be the most promising.

8) Of the tests already run, the cylinder compression test, flexural test, Gilmore needle set time, and shear bond test appear to be the most applicable to the nature of rapid setting materials.

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