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16. Abstract

This study was an evaluation of variations in the mixing energy and variations in the quantity of concrete mixed for rapid setting repair materials. The normal mixing energy of the one-cubic-foot drum mixer produced concrete with higher compressive and flexural strengths more consistently than concrete prepared at the alternate speeds. Rapid-setting concrete mixed at a quantity of two-thirds cubic foot obtained the highest compressive and flexural strengths for the majority of the tests. Tests on silica fume concrete are also presented but did not indicate that the combination of silica fume and portland cement could increase concrete strengths rapidly.

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LABORATORY EVALUATION OF MIXING METHODS FOR
RAPID-SETTING REPAIR MATERIALS

by

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Research Report Number 311-6

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November 1984

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

Thanks are extended to the numerous employees of the Texas Department of Highways and Public Transportation for their cooperation throughout this research. The assistance given by David Whitney, Dean Malkemus, Nancy Zett, Rose Rung, Sue Sweeney, Donna Williams and the entire Center for Transportation Research staff was invaluable and greatly appreciated. A special thanks is extended to Mark Temple for his assistance in the organization and implementation, as well as his participation in the laboratory testing program.

ABSTRACT

This study was an evaluation of variations in the mixing energy and variations in the quantity of concrete mixed for rapid setting repair materials. The normal mixing energy of the one-cubic foot drum mixer produced concrete with higher compressive and flexural strengths more consistently than concrete prepared at the alternate speeds. Rapid-setting concrete mixed at a quantity of two-thirds cubic foot obtained the highest compressive and flexural strengths for the majority of the tests. Tests on silica fume concrete are also presented but did not indicate that the combination of silica fume and portland cement could increase concrete strengths rapidly.

SUMMARY

The objectives of this study were to determine the optimum percentage of a mixer's capacity that should be filled with concrete during the mixing procedure and to determine if mixing concrete at speeds other than the recommended speed would be more beneficial than mixing concrete at the normal speed. Also, limited tests were performed on concrete containing silica fume to determine if accelerated strength gain would result by the addition of small amounts of silica fume.

The rapid-setting materials were tested using procedures that were investigated in earlier phases of project 311. Results containing compressive strength vs time and flexural strength vs time were obtained from the tests. These results indicated that concrete batches prepared at two-thirds of the mixer's capacity produced the highest strengths. There was not any trend in the results to substantiate decreasing or increasing the mixing speed from the normal mixing speed. The addition of silica fume produced concrete with lower strengths as greater amounts of silica fume were added.

IMPLEMENTATION

The primary objectives of this study were to determine the optimum percentage of a drum mixer's capacity that should be filled with concrete during mixing procedures and to determine if mixing concrete at speeds other than the normal speed would be more beneficial. This study indicates that concrete prepared at approximately two-thirds of the mixer's capacity produced the highest results. Neither of the alternate speeds tested indicated that consistently stronger concrete could be obtained by either decreasing or increasing the mixing speed.

Tests on silica fume indicated that at three days the portland cement concrete composed of the smallest amount of silica fume had the highest strengths. These results can be implemented by district maintenance personnel to more effectively produce rapid-setting concretes for repair.

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CHAPTER 1
INTRODUCTION

1.1 Background

In Texas, highway maintenance personnel are faced with a continuing task of repairing deteriorating portland cement concrete (PCC) roadways and bridges. Many methods and materials are available for repairs, and there are several factors to consider when deciding which of these materials and methods are most advantageous for the particular repair. These factors include: 1) cost and availability of labor, equipment, and materials; 2) repair durability; 3) time delays to motorists; 4) safety hazards to motorists and repair crews. Rapid-setting materials, that gain strength quickly, enabling traffic lanes to reopen within a few hours after placing are greatly needed.

The rapid-setting materials presently available include: 1) type III PCC with set accelerator and additional admixtures; (Class K concrete) 2) chemical setting cements; 3) thermosetting materials; 4) calcium sulphate materials; and 5) bituminous materials. Materials costs, workability, mechanical properties, and overall performance vary from category to category and from brand to brand.

Research Study 311, "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges," was conducted for the Texas State Department of Highways and Public Transportation from September 1981 until August 1984. The objectives of the study were: 1) identify candidate materials based on D-9 evaluation tests and a survey of districts and other states; 2) perform laboratory tests on candidate materials; 3) determine optimum mixing, placing, and finishing methods; 4) make field repairs in different districts using candidate materials; 5) disseminate results. Results of the survey of districts and states and data from laboratory tests performed at 72°F were presented in Survey of and Evaluation Methods for Rapid-Setting Materials by George P. Beer (1). Tests performed at 40°F and 110°F plus the results of field repairs made in Waco, Amarillo, Dallas, and Houston were presented in Laboratory and Field Evaluation of Rapid-Setting Materials by Kevin G. Smith (2). This report presents results of additional laboratory work considering changes in the energy of the mixer and amount of concrete mixed in the mixer.

1.2 Scope of Report

The scope of this report presents results of laboratory work considering changes in the energy of the mixer, changes in the amount of concrete mixed in the mixer, and effects of the addition of silica fume to portland cement concrete.

CHAPTER 2
MATERIALS TESTED

2.1 Introduction to Materials Tested

Four candidate rapid-setting materials were selected. They were Duracal™[a], Set-45™, Gilco Highway Patch™, and silica fume. Manufacturer's recommendations for mixing were followed except for Gilco Highway Patch where various amounts of water had to be added for proper mixing to take place and to improve workability to a degree where the concrete could be placed. An aggregate mix containing binder, fine aggregate (sand), and coarse aggregate was used in laboratory tests.

A 3/8-in. maximum size siliceous Colorado River gravel was the coarse aggregate used in the tests. The fine aggregate used was a siliceous sand. The fine aggregate was only needed for the Duracal mix. Set-45 and Gilco Highway Patch are packaged with sand and binder premixed.

All materials are water-activated. The mixer capacity was approximately one cubic foot. All specimens were air-cured at laboratory conditions at approximately 72°F and 50 percent relative humidity.

2.2 Packaged Materials

2.2.1 Duracal

Duracal, produced by United States Gypsum, is composed of portland cement and gypsum (calcium sulphate) and is water-activated.

The manufacturer's recommendations and limitations for Duracal include: 1) use at a temperature above 32°F; 2) provide a two-in. vertical saw cut along patch perimeter; 3) moisten patch prior to placing Duracal; 4) mix materials until lump free, but not more than five minutes; 5) use a curing compound on hot, windy days to prevent

[a]Trademark symbols are not used in subsequent mentions of brand names.

plastic shrinkage cracking; and 6) open repair to traffic one hour after set.

2.2.2 Set-45

Set-45 by Set Products, is composed of magnesia-phosphate powder and fine aggregate and is water activated. The manufacturer requires that: 1) use a 1/2-in. minimum saw cut patch perimeter, 2) use a mortar type mixer, 3) the repair depth must be greater than 1/2 in., 4) reduce water to compensate for damp aggregate, 5) place mix into patch from one side to the other, not in lifts, 6) warm materials must be used for cold weather, 7) air cure with no curing compound, 8) there is a better bond to dry surface.

2.2.3 Gilco Highway Patch

Gilco Highway Patch (GHP) produced by Gifford-Hill, is a modified portland cement. GHP is water-activated. The manufacturer recommends: 1) the use of a mortar type mixer, 2) square patch edges by jack hammering or saw-cutting a minimum of 1-in. deep (no feathered edges), 3) neat material should be used for repairs less than 3 in. deep, 4) dampen patch area, but remove excess moisture with rags or compressed air just prior to patching, 5) mix materials two to three minutes, 6) consider moisture content of coarse aggregate when determining total water quantity.

2.3 Silica Fume

Silica fume is a by-product resulting from the reduction of high purity quartz with a coal in electric arc furnaces in the manufacture of ferro-silicon and silicon metal. The fume is used as a partial replacement for portland cement in the composition of portland cement concrete. Silica fume, which is composed of more than 90 percent silicon dioxide, consists of very fine spherical particles that are collected by filtering the gases escaping from the furnaces.

Silica fume may replace up to 30 percent of portland cement, but an increase in water demand may be observed to obtain the required slump of concrete. The relative density of typical silica fume is approximately 2.2 as compared with about 3.1 for normal portland cement.

There are several problems associated with the use of silica fume. These problems are: 1) there is limited availability of silica fume in some areas since silica fume is still regarded as a waste product and is not marketed for use in concrete; 2) silica fume presents handling problems because of its extreme fineness; 3) silica fume may pose a health hazard; and 4) the importance of silica fume has increased within the last three years, thus the price has risen substantially in that time.

2.4 Aggregates

An aggregate mix containing binder, coarse aggregate, and fine aggregate was used in all of the tests. All aggregates were oven dried prior to batching of materials.

2.4.1 Coarse Aggregate

The coarse aggregate used in all tests, was a 3/8-in. maximum size siliceous Colorado River gravel from Capitol Aggregates. Coarse aggregate was required in the mixing of the three rapid setting materials and the batches containing silica fume.

2.4.2 Fine Aggregate

A siliceous sand was the fine aggregate used in the tests. Fine aggregate was needed only for the Duracal mixes and batches containing silica fume. Set-45 and GHP are packaged with fine aggregate and binder premixed.

CHAPTER 3
EVALUATION TESTS

Beer and Smith evaluated rapid-setting materials using several different tests (1,2). These tests included: 1) mortar cube compressive strength; 2) cylinder compressive strength; 3) modulus of elasticity; 4) flexural strength; 5) Gilmore needle set time; 6) penetration tration resistance set time; 7) peak exotherm; 8) flow; 9) direct shear; 10) flexural shear bond; 11) flexural bond; 12) sand blast abrasion; 13) length change; 14) coefficient of thermal expansion, and 15) freeze--thaw resistance. For this report, the compressive strength of cylinders and the flexural strength of beams were tested.

Slight modifications of ASTM test methods were needed for some rapid-setting materials. These modifications included: 1) thinly covering contact surfaces of metal molds with a heavy lubricating grease (oil was not adequate for magnesia phosphate materials), and 2) air curing all specimens. Air curing seemed to be more appropriate since rapid setting materials differ greatly from conventional PCC.

3.1 Compressive Strength

Compressive strength was determined using cylinders, in accordance with ASTM C 39-81, compressive strength of cylindrical concrete specimens. The molds used to form specimens were disposable, wax-coated cardboard molds. The cylinders used were three in. in diameter by six in. Cylinders were capped with a sulphur compound to provide a smooth loading surface. The cylinders were loaded at a rate of 20,000 lbs. per minute until failure. The stress was calculated by dividing the average failure load of the cylinders by the cross-sectional area of 7.069 sq in.

The cylinders were tested at four different times after pouring. The first test was in one hour for Set-45 and Duracal. Gilco Highway Patch was tested in two hours because the concrete did not set until that length of time had expired. Additional tests for the three materials were made at three hours, 24 hours, and seven days.

3.2 Flexural Strength

Tests for flexural strength were run according to ASTM C78-75, flexural strength of concrete (using a simply supported beam with third point loading). Beam specimens were cast in two-in. by two-in. by twelve-in. metal molds. Equal concentrated loads were applied at the third point. The total load on the beam was applied at a rate of 300 lbs. per minute. The ultimate moment (M) of the beam is between the two loading points and is given by:

$$M = R \times 2 \text{ inches}$$

where $R = 1/2$ of the total load, P

Thus $$M = \frac{P}{2} \times 2 = P$$

The extreme fiber stress (f_t) is given by:

$$f_t = M/S$$

where

$$S = \text{section modulus} = 2 \text{ in.} \times (2 \text{ in.})^2 /6$$
$$S = 1.33 \text{ in.}^3$$

Thus

$$f_t = 0.75 \times P$$

The stress of the extreme fibers was increased at a rate of 225 psi/minute.

CHAPTER 4
TEST VARIABLES

4.1 Constants in Mixes

For each of the three candidate materials, several parts of the batching procedure were held constant. This was to insure consistent results between different mixing speeds, different batch volumes, and between different brands.

Foremost in the procedure for each material the ratio of binder to coarse and fine aggregate (for Duracal) and to water was not varied except for adding additional water to GHP to make the mix workable. Secondly, the time of mixing was held constant at two minutes. All batches of concrete were mixed in the same gravity type mixer. Since the tests were performed indoors in a laboratory, the environment of the mixing and curing was constant.

4.2 Changes in the Energy of the Mixer

Tests were performed for rapid-setting concrete mixed at three speeds. The speeds were at 19, 22, and 30 drum revolutions per minute. Twenty-two revolutions per minute was the normal speed of the mixer. The speed of the mixer was altered mechanically by changing the size of the pulley which was connected to the motor shaft. The minimum and maximum pulley sizes were used by taking into account the space limitations of the system. Nineteen revolutions will be referred to as the slow speed and 30 revolutions as the fast speed.

4.3 Varying the Volume of the Batch

The rapid-setting concrete was mixed in volumes from one-third cu ft to one cu ft. The volumes tested were one-third cu ft, two-thirds cu ft, and one cu ft. The various volumes of the concrete batches were produced for all three mixing speeds.

4.4 Variations of Silica Fume in PCC

Portland cement concrete was prepared in approximately 1/2 cu ft batches. Silica fume was used in each of these mixes to partially replace portland cement. Silica fume replaced portland cement by 30, 25, and 20 percent in the three batches that were prepared. The effects of mixing speed and volume were not investigated in the tests on silica fume concrete. The percentage of portland cement replaced in the mixes was by a slurry that was composed of 50 percent silica fume.

CHAPTER 5

MIXING AND PLACING PROCEDURE OF MATERIALS

The mixing procedures of each material were held constant throughout all of the batches. This chapter explains the batching and placing procedure for each of the materials and gives the quantities of binder, aggregate, and water used to produce the rapid-setting concrete. The batching proportions are listed in Table 5.1.

5.1 Duracal

Duracal was the only neat material (sand not included) of the three concretes tested. After thoroughly cleaning the mixer, all of the water was added to the gravity type mixer. Only one-half of the fine aggregate and one-half of the coarse aggregates were added at this stage. The mixer power was turned on and the water and aggregates were mixed for one minute. Next, all of the binder was added followed by the remaining aggregates and mixed for two minutes. After two minutes the concrete was poured into a container and placed.

5.2 Set-45

Set-45 was prepackaged containing both the binder and the sand. All of the water and all of the coarse aggregate were put into the mixer and mixed for approximately one minute. At this time all of the Set-45 was added, the mixer turned on one side and the materials were mixed for two minutes and poured into a container and placed.

5.3 Gilco Highway Patch

Gilco Highway Patch was prepackaged containing both binder and sand. The GHP was put into a small container and mixed by hand to help insure that the binder and sand were proportioned well. Some settling could occur during shipping causing the blend in each bag to be non-uniform. This procedure was also done for the Set-45.

Table 5.1 Mix Proportions

Brand	Packaged Material lb (kg)	Fine Aggregate lb (kg)	Coarse Aggregate lb (kg)	Water gal (liter)
Duracal	50.0 (22.7)	50.0 (22.7)	50.0 (22.7)	1.75 (6.62)
Set-45	50.0 (22.7)	a	30.0 (13.6)	0.5 (1.89)
Gilco Highway Patch	55.0 (24.9)	a	30.0 (13.6)	0.5 (1.89)
Portland Cement Concrete	21.0 (9.5)	48.0 (21.8)	72.0 (32.7)	1.17 (4.46)

[a]Fine aggregate included in packaged material

To mix the materials all of the water and coarse aggregate were placed in the mixer and mixed for approximately one minute. The amount of water originally put into the mixer was the amount recommended by the manufacturer. After one minute of mixing, the Gilco Highway Patch was added, the mixer was turned on one side and these materials were mixed for two minutes and placed.

A problem developed with the GHP mix in that by using only the quantity of water recommended by the manufacturer the mix that was produced was extremely dry and completely unworkable. The concrete that was produced was in large lumps and could not be placed into cylinder and beam molds. To make the concrete workable varying amounts of water were added to the mix after the binder was added to insure workability of the concrete. The amount of extra water added ranged from three percent to 25 percent above the standard amount.

5.4 Silica Fume

The concrete composed of silica fume and portland cement was prepared as follows: 1) one-half of the coarse aggregate, sand and binder were placed into the drum mixer; 2) all of the silica fume was added; 3) the mixer was started and about 40 percent of the water was added; 4) the remainder of the aggregates and binder were added; 5) the mixer was turned onto one side to help in mixing the materials; 6) the remaining water was slowly added until the mix was made workable; and 7) the mix was poured into a container and placed.

5.5 Placing the Concrete

After mixing the materials for two minutes the mixer was stopped. The wet concrete was then poured into a container and taken to the molds. Water was immediately placed into the mixer to insure that none of the material set in the mixer.

5.5.1 Cylinders

Each cylinder was filled to approximately one-half of the cylinder's total volume with the concrete. This layer of concrete was rodded 15 times with a small piece of steel rebar. The cylinder was then filled to almost capacity. The top layer of concrete was then rodded 15 times. When rodding the top layer, only the top layer was rodded; thus the rebar was not allowed to disturb the bottom layer.

After two layers were put into the cylinder and rodded, the cylinder was filled to capacity. To remove air bubbles in the mix, a small trowel was used to tap the side of the cylinder repeatedly around the entire cylinder. The excess concrete on top of the cylinder was screeded off by the trowel to make a relatively level surface. Additional water was never added during placing.

5.5.2 Beams

To place concrete into the 2-in. x 2-in. x 12-in. beam molds, each beam mold was filled to approximately one-half of the total beam volume. This layer of concrete was rodded 15 times with the rebar. The beam was then filled to capacity with concrete. The sides of the beam molds were then tapped vigorously for several seconds to vibrate the concrete to remove air bubbles from the mix. The excess concrete on top of the beams was screeded off with the small trowel to make a smooth level surface, that would make the beam square. Water was never added during placing of the concrete.

5.5.3 Comparison of Placing Materials

Duracal was always workable using the mix prescribed by the manufacturer. Set-45 was workable at the mix used, but was slightly more difficult to get smooth finishes on tops of cylinders and beams. Some cylinders did set before they were properly finished and had to be repoured.

Gilco Highway Patch was quite difficult to work with unless at least 15 percent more water was added. Some specimens were placed using less than 15 percent extra water but did not look as good as those placed with additional water.

CHAPTER 6

TEST RESULTS

6.1 Compressive Strength vs Energy Variations in Mixer

The compressive strength of concrete cylinders as a function of time was evaluated using the candidate materials. Each material was mixed at one-third cu ft, two-thirds cu ft, and one cu ft. This section is divided into results for the three volumes.

6.1.1 Mixes Using One-Third of a Cubic Foot

Figure 6.1 shows compressive strength vs time curves for materials mixed at various speeds for one-third cu ft batches. For Set-45 the highest strengths were given by the batch mixed at normal speed. Duracal had uniform results with the exception that the seven day strength of the mix at slow speed was 15 percent lower than the strengtns at the other two speeds. The normal mixing speed of GHP produced the highest strengths at each time tests were made.

In comparison of materials, Set-45 recorded the highest early strengths. Duracal was consistently stronger at seven days. GHP had the poorest results throughout the testing period.

6.1.2 Mixes Using Two-Thirds of a Cubic Foot

Figure 6.2 displays the compressive strength vs time curves for two-thirds cu ft batches mixed at various speeds. For all of the materials, the mixes prepared at the normal speed gave the highest strength during the entire testing period. The alternate mixes of Set-45 and GHP had strengths that were at least 20 percent lower than the mixes made at normal speed. The results for Duracal were more consistent, with only a five to seven percent variation in strength.

In comparison of materials, Set-45 had much higher strengths for the first 24 hours. After three hours Set-45 showed very little strength gain, but the Duracal strength kept increasing to where in

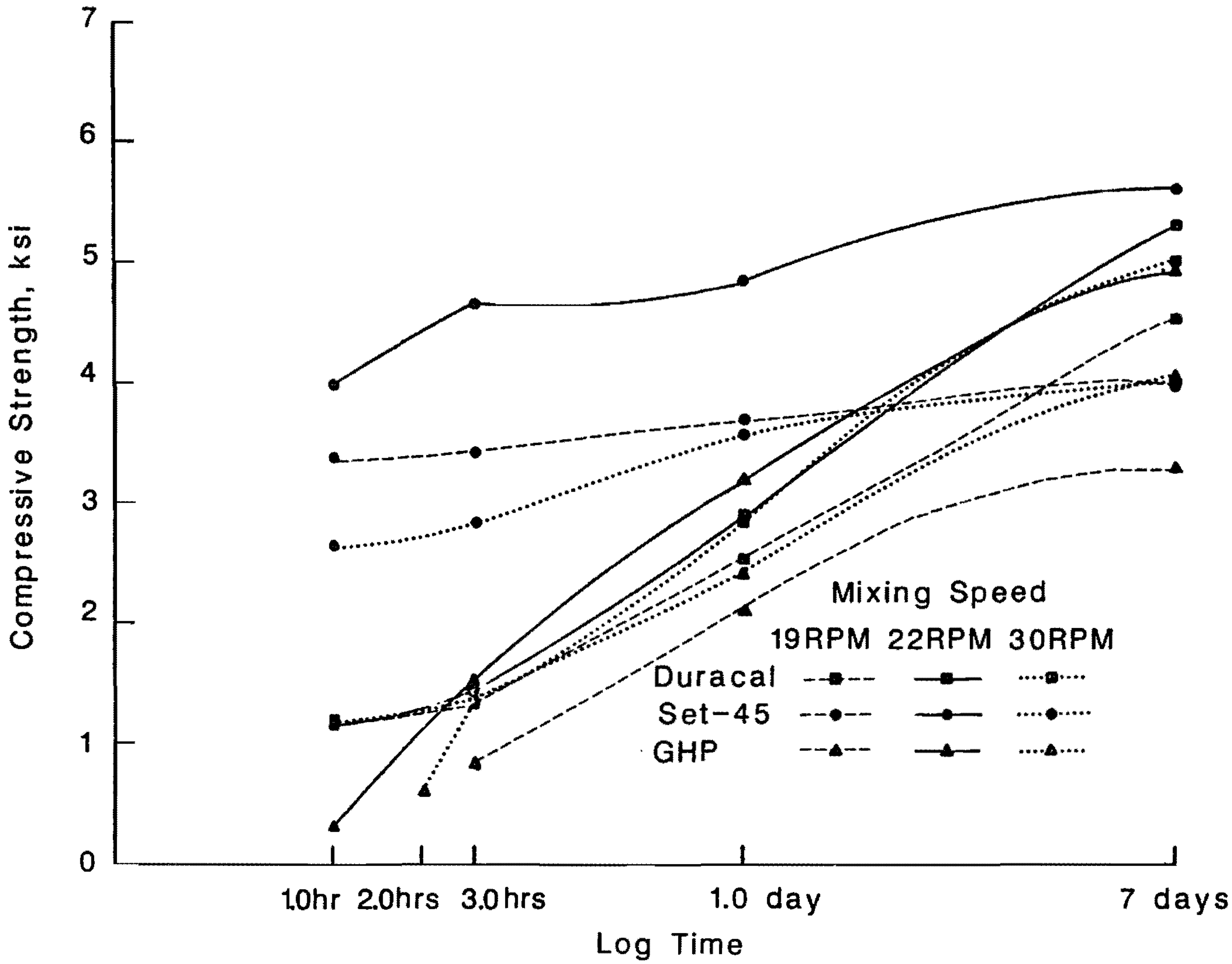

Fig. 6.1 Compressive Strength vs Time for One-Third of a Cubic Foot Mixes with Varying Mixing Speeds.

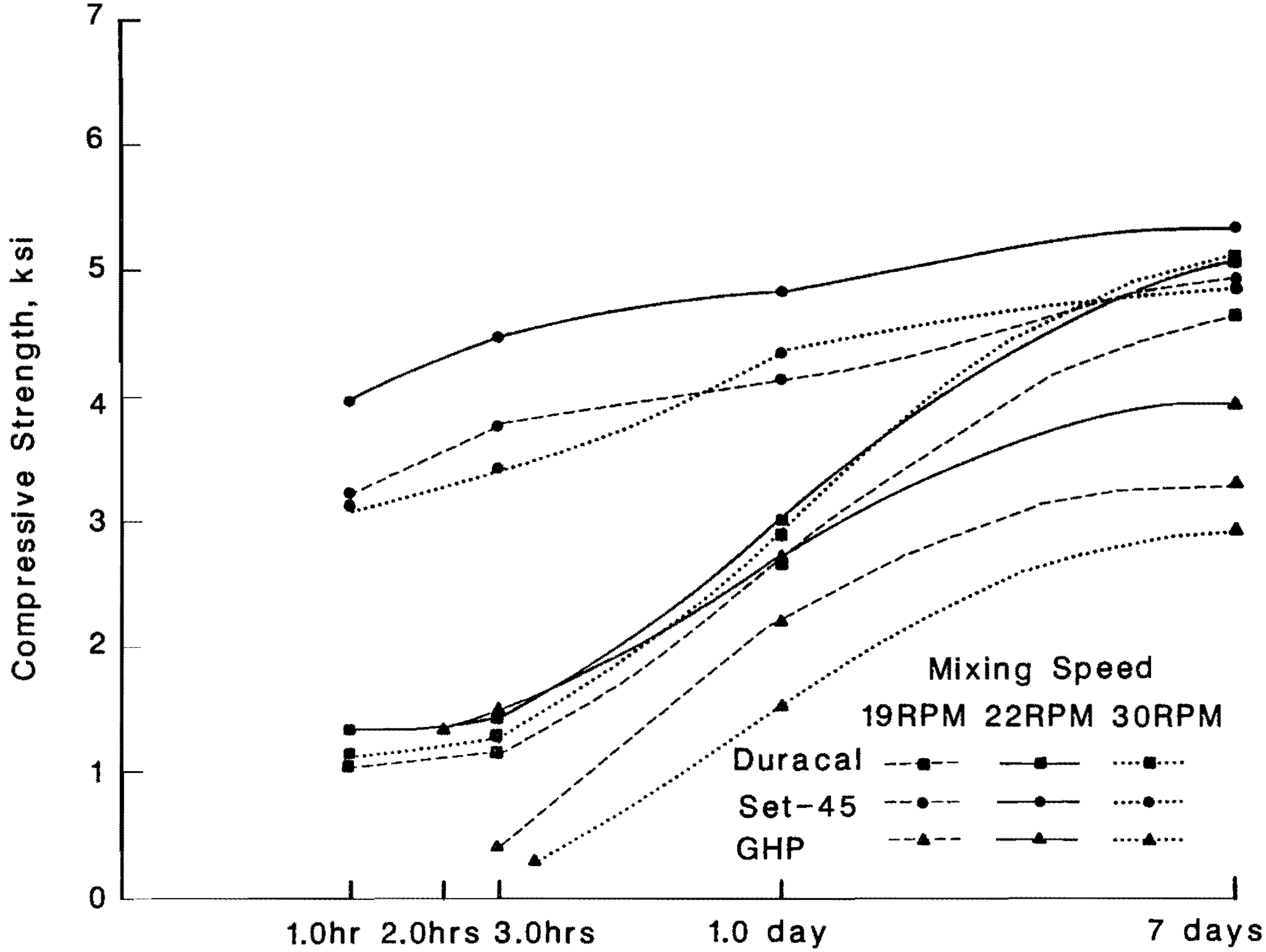

Fig. 6.2 Compressive Strength vs Time for Two-Thirds of a Cubic Foot Mixes with Varying Mixing Speeds.

seven days the strengths of Duracal and Set-45 were in the same range. GHP tested the lowest of the three materials for nearly every case.

6.1.3 Mixes Using One Cubic Foot

Figure 6.3 exhibits the compressive strengths as a function of time for materials mixed at various speeds of one cu ft batches. For Set-45, the mix at slower speeds produced slightly higher early strengths, but the normal and fast mixing speeds produced mixes displaying the highest strengths at seven days. Duracal had very uniform results with negligible variations in strength throughout the tests, except at seven days. The batch at normal speed for GHP obtained the highest strengths for the testing period.

In comparison of materials, Set-45 was much stronger for the first three hours and 15 percent stronger at 24 hours. Again, Set-45 gained little strength after 24 hours while Duracal kept increasing in strength and at seven days Duracal was ten to 15 percent stronger than Set-45. GHP was the weakest throughout seven days, except for the mix at normal speed which had comparable strength to Set-45 at seven days.

6.2 Compressive Strength vs Quantity in Mixer

The compressive strength of cylinders as a function of time was evaluated for the three materials by varying the quantity of material in the mixer. Each material was mixed at one-third cu ft, two-thirds cu ft, and one cu ft and at speeds of 19 RPM (slow), 22 RPM (Normal), and 30 RPM (Fast). This section is divided into results of the three speeds.

6.2.1 Compressive Strength for Batches Mixed at 19 RPM

Figure 6.4 illustrates the compressive strength vs time for changes in the quantity of material in the mixer for batches mixed at 19 RPM. For Set-45 two-thirds cu ft gave the highest strengths at all times with the one cu ft mix performing very poorly. The low strengths for the one cubic foot mix could be attributed to the poor mixing action for the large batch. Since the mixer was almost completely

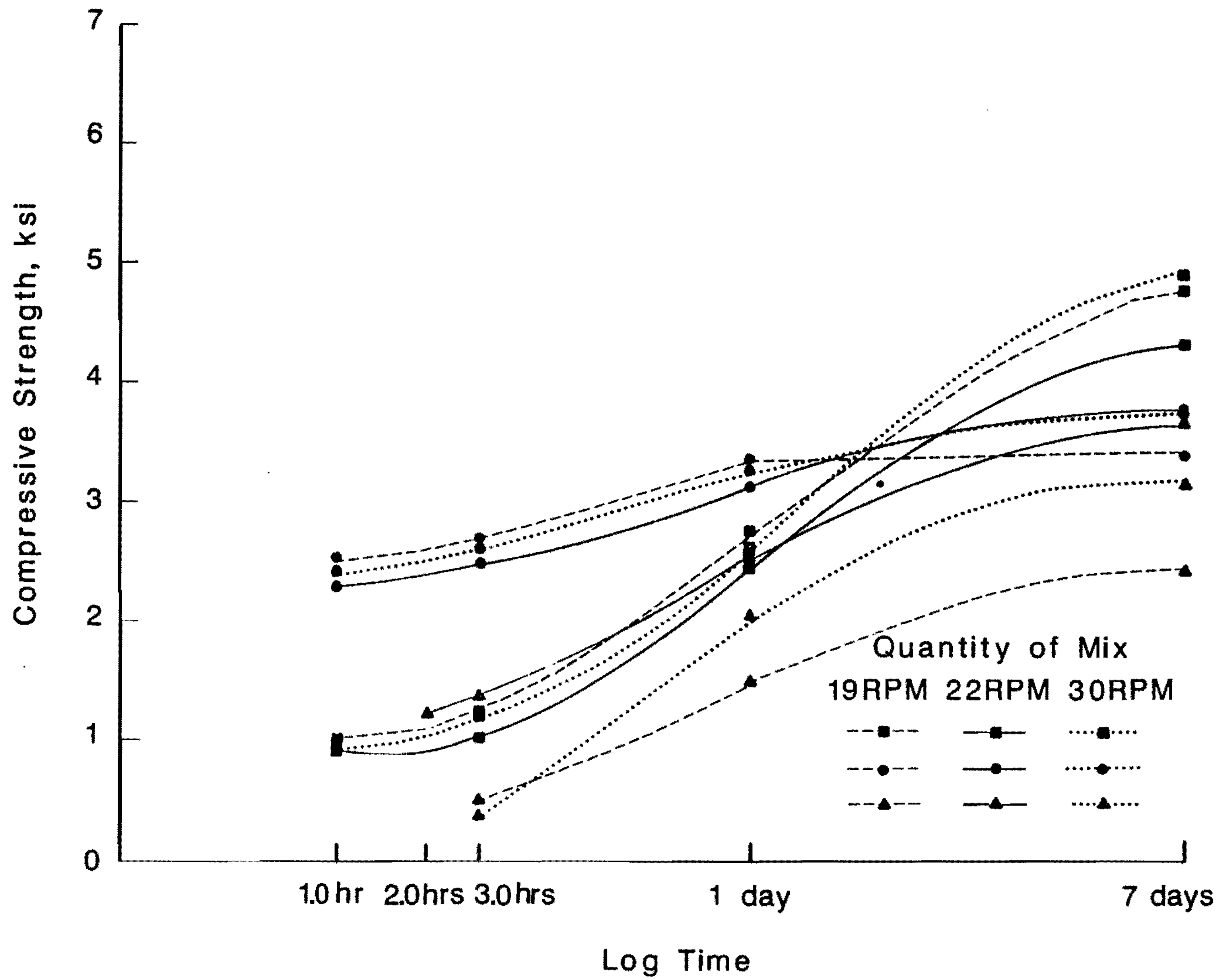

Fig. 6.3 Compressive Strength vs Time for One Cubic Foot Mixes with Varying Mixing Speeds.

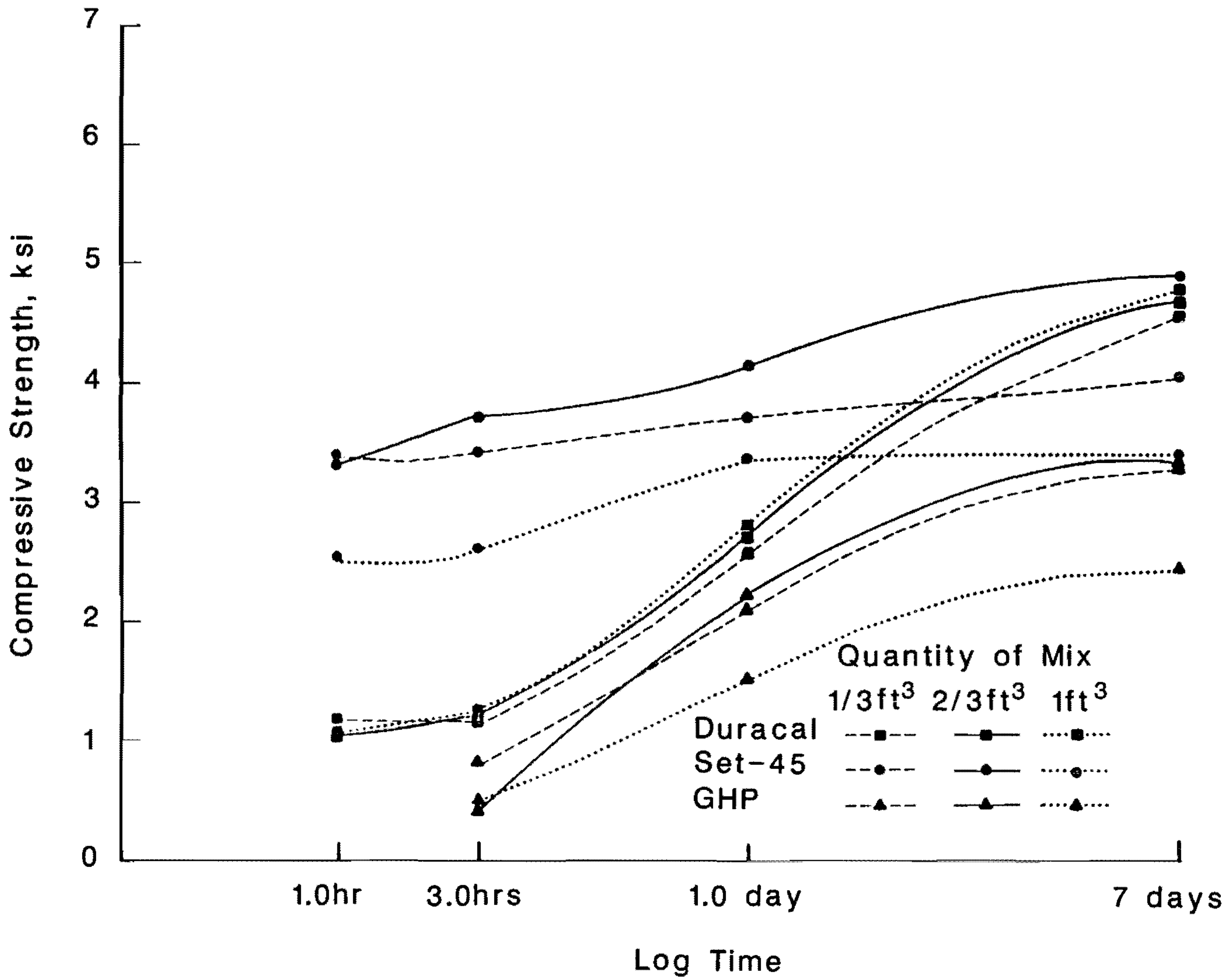

Fig. 6.4 Compressive Strength vs Time for Batches Mixed at 19 RPM with Varying Quantities of Mix.

filled with material, the coarse aggregate, binder, and water were not thoroughly mixed together as well as the smaller mixes. Duracal again displayed very consistent strengths with only small variations at seven days. The two smaller batch sizes of GHP gave strengths that were 10 to 30 percent higher than strengths of the one cu ft batch.

The early strengths of Set-45 were the highest of the materials. With only the exception of Set-45 mixed at two-thirds cu ft, Duracal had the highest seven day strengths. During the entire testing procedure GHP had strengths below those of Set-45 and Duracal.

6.2.2 Batches Mixed at 22 RPM (Normal Speed)

The compressive strength vs time curves for changes in the quantity of the batch mixed at 22 RPM, are shown in Fig. 6.5. The two smaller batches of Set-45 performed equally, but the one-cubic-foot mix could only achieve strengths of 60 percent of the smaller batches. The strengths for Duracal were uniform for 24 hours but at seven days one-third cu ft batches gave the highest strengths. The strengths for two-thirds cu ft batches were approximately five percent less than strengths for one-third cu ft batches at seven days. At seven days one cu ft produced strengths that were 20 percent below the strengths of the one-third cu ft batch. The one-third cu ft mix of GHP displayed much higher strengths than the larger mixes, throughout the tests.

In comparison between materials, Set-45 had strengths three to four times as great as Duracal and GHP after three hours. With the exception of the one cu ft batch of Set-45, at 24 hours, Set-45 had strengths 40 percent more than GHP and Duracal. Gilco Highway Patch and Duracal produced strengths that were in the same approximate range for the first 24 hours. The results at seven days were scattered from 3700 psi to 5600 psi. Set-45 had the highest strengths, with Duracal in the 4000 to 5000 psi range and GHP displaying the lowest strengths.

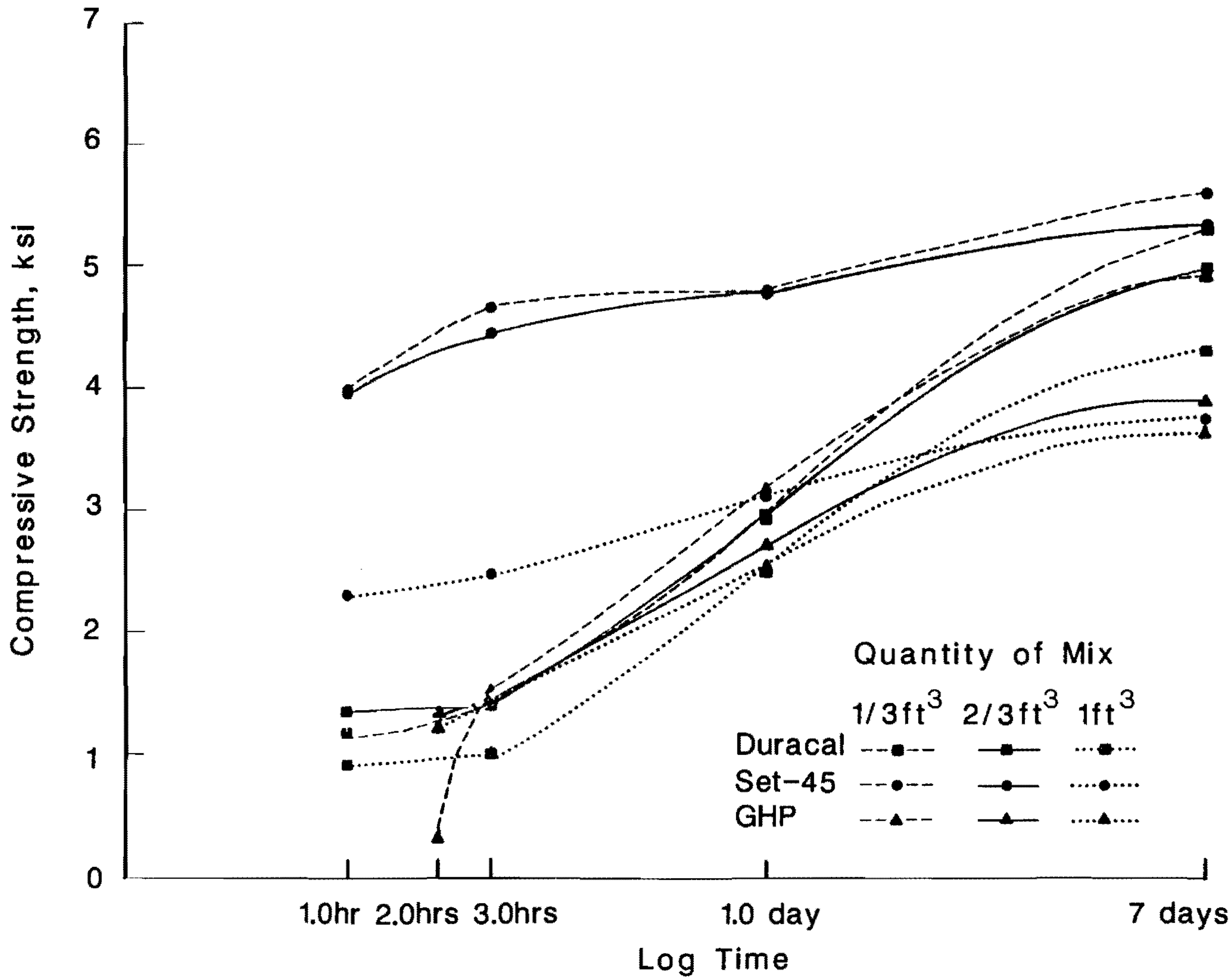

Fig. 6.5 Compressive Strength vs Time for Batches Mixed at 22 RPM with Varying Quantities of Mix.

6.2.3 Concrete Mixed at 30 RPM

Figure 6.6 shows the compressive strength vs time for changes in the quantity of material mixed at 30 RPM. For tests run at one and three hours of Set-45, the batch of two-thirds cu ft had strengths approximately ten percent above strengths of the other mixes. By 24 hours and through seven days the strength of the two-thirds cu ft mix was 20 to 25 percent above the other two mixes. Duracal had very uniform results for the seven day testing period. The strengths for Duracal were always within a range of 200 psi to 400 psi at each test time. The smallest batch of GHP produced the highest strengths of the three mixes throughout the testing period. The early strengths of the two-thirds cu ft mix were about ten percent below the one cu ft mix and the seven day strength was approximately 20 percent lower than the one cu ft mix. Results that were usually 20 percent lower than the one-third cu ft mix were displayed by the one cu ft mix.

In comparison of materials, Set-45 again had the highest strengths for the first 24 hours. The strengths at one and three hours were two to three times as great as the strengths for GHP and Duracal. Set-45 however, followed a trend of not gaining much strength after 24 hours and leveled off. Duracal gained strength rapidly after three hours and by seven days, Duracal had the highest strengths at about 5000 psi. Gilco Highway Patch displayed the lowest results at three hours and 24 hours. The one-third cu ft batch of GHP was in the same range as Set-45 at seven days while the other two mixes produced the lowest of any readings.

6.3 Flexural Strength vs Energy Variation in the Mixer

The flexural strength of beams as a function of time was evaluated for the candidate materials with respect to variations of the amount of energy used to mix the concrete. Each material was mixed at 19 RPM, 22 RPM, and 30 RPM. Also, batch sizes were made of one-third cu ft, two-thirds cu ft, and one cu ft. From the combinations made from the different batch sizes and mixing speeds, the beams were cast

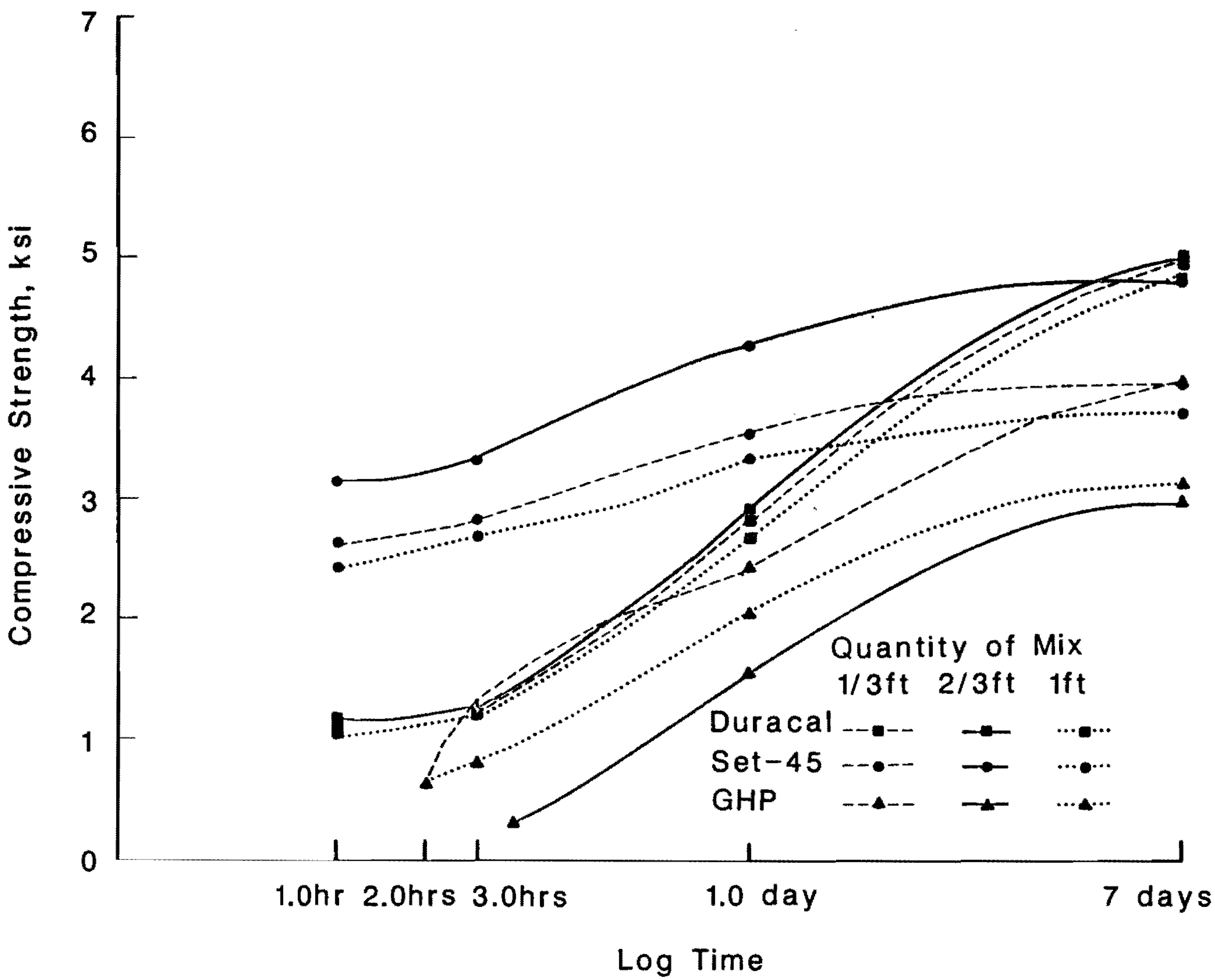

Fig. 6.6 Compressive Strength vs Time for Batches Mixed at 30 RPM with Varying Quantities of Mix.

and tested at three hours, 24 hours, and seven days. This section gives the results of the flexure test and is divided into results of the three volumes that were prepared.

6.3.1 Mixes Using One-Third of a Cubic Foot

Figure 6.7 shows the flexural strength vs time curves for materials mixed at various speeds for one-third cu ft volumes of concrete. The highest strengths of Set-45 were by concrete mixed at 19 RPM (slow). At three hours, Set-45 prepared at the two faster speeds was about 18 percent lower than the concrete made at 19 RPM. Throughout the test concrete mixed at 30 RPM was about 80 psi below concrete mixed at 19 RPM. The strength of concrete mixed at normal speeds at 24 hours was 150 psi below the strength of the slow speed mix, but by seven days, their strengths were almost equal.

Duracal had the highest early strengths with the concrete mixed at the slow rate. At 24 hours, the normal and fast speeds produced slightly stronger concrete than the slow rate of mixing. At seven days the fast rate of mixing produced concrete 35 psi stronger than that mixed at the slow speed. The normal rate of mixing for GHP produced the highest strengths for the first 24 hours. By seven days the high speed of mixing produced concrete with the highest strength.

In comparison of materials, Set-45 usually produced the highest strengths in three hours with Duracal having the lowest strengths. At 24 hours all materials had strengths above 450 psi, but the results were scattered. GHP and Duracal produced the strongest concrete at seven days.

6.3.2 Mixes Using Two-Thirds of a Cubic Foot

Figure 6.8 illustrates flexural strength vs time curves for energy variations of concrete mixed at two-thirds cu ft. At three hours all of the Set-45 mixes had strengths over 500 psi and the strengths were within 25 psi of each other. Concrete mixed at normal speed gained strength slightly faster than the alternate mixes and obtained the highest strengths at 24 hours and seven days. For Duracal

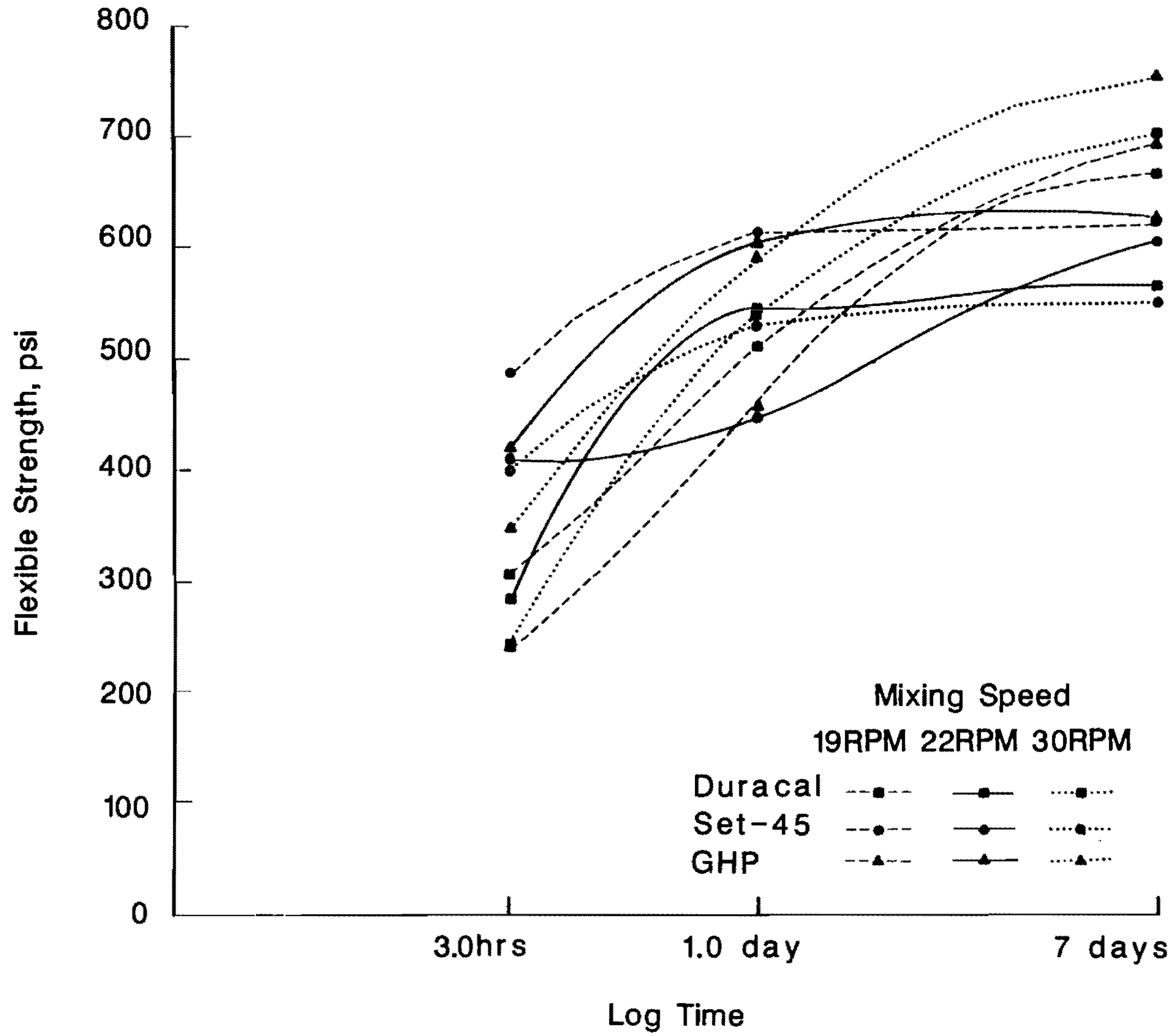

Fig. 6.7 Flexural Strength vs Time for One-Third of a Cubic Foot Mixes with Varying Mixing Speeds.

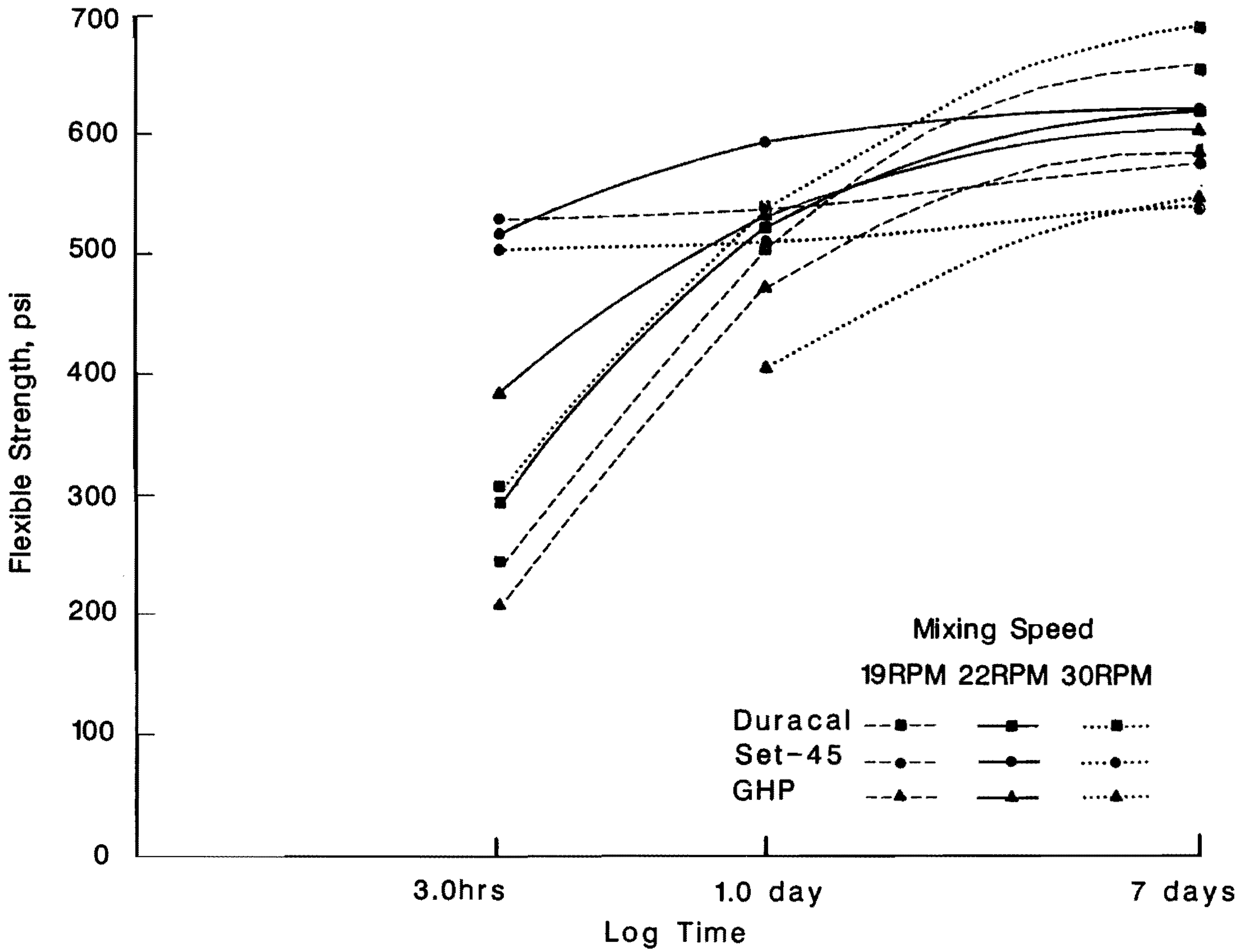

Fig. 6.8 Flexural Strength vs Time for Two-Thirds of a Cubic Foot Mixes with Varying Mixing Speeds.

the batch prepared at the fast rate of mixing had slightly higher strengths throughout the test, even though all of the Duracal curves were with 30 to 80 psi of one another.

Gilco Highway Patch produced results at the normal rate of mixing that were the highest throughout the testing period. The batch produced at slow mixing speed was significantly lower in strength at three hours, yet at seven days only 20 psi below the strength of concrete mixed at normal speed. The batch produced at the fast rate of mixing was much lower in strength than the two batches mixed at slower speeds.

In comparison of materials, Set-45 again had much higher strengths at three hours, but by 24 hours all of the materials had results scattered within the same testing range. Duracal produced the highest strengths at seven days.

6.3.3 Mixes Using One Cubic Foot

Figure 6.9 displays the flexural strength vs time curves for one cubic foot batches mixed at various speeds. The normal mixing speed of Set-45 produced the highest strengths throughout the testing period even though the fast rate of mixing produced seven day strengths that were the same. At three hours, the three Duracal mixes produced concrete of the same strength. The normal speed mix had slightly higher strengths at 24 hours, yet the mix produced at the slowest rate of mixing had a slightly higher seven-day strength. The mix produced at the fast speed was significantly lower at seven days.

The normal mixing speed of GHP gave the highest strength for the testing week, which were usually 50 to 100 psi higher than results from concrete mixed at fast speeds. The batch produced at the slow rate of mixing was much lower in strength than the other two mixes.

In comparison of materials, Set-45 again had the highest early strengths and by 24 hours all of the materials had strengths that were scattered in a very close range. By seven days Duracal and GHP had obtained the highest strengths. Both Duracal and GHP had their seven day strengths scattered within 125 psi of each other, with the exceptio of the slow speed mix of GHP.

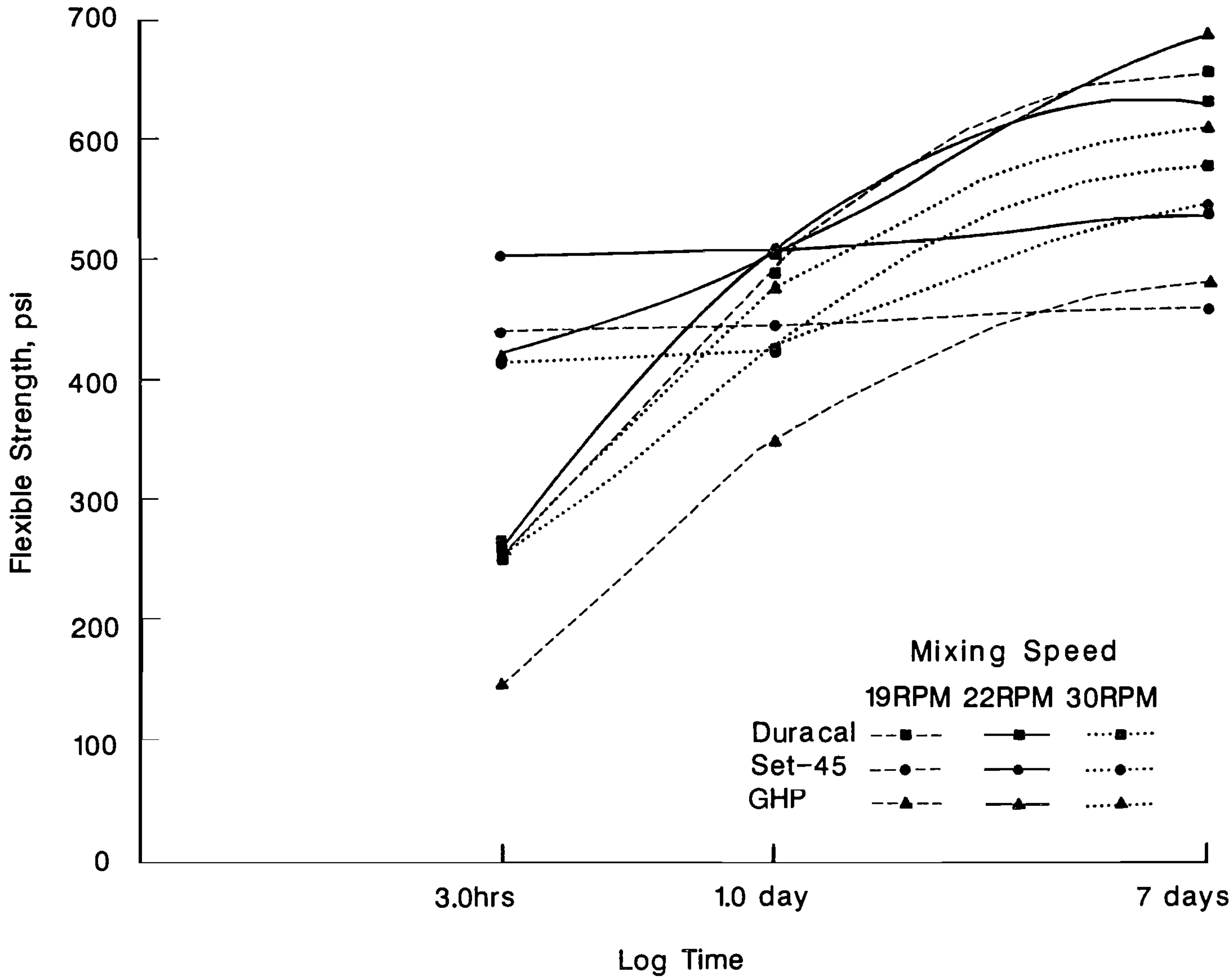

Fig. 6.9 Flexural Strength vs Time for One Cubic Foot Mixes with Varying Mixing Speeds.

6.4 Flexural Strength vs Quantity of Material in Mixer

The flexural strength of beams as a function of time was evaluated for the three materials by varying the quantity of material in the mixer. The quantities were one-third cu ft, two-thirds cu ft, and one cu ft and the material was mixed at speeds of 19 RPM, 22 RPM, and 30 RPM. This section discusses the results of the flexural tests and the results are divided into subsections of mixes produced at 19 RPM, 22 RPM, and 30 RPM.

6.4.1 Batches Mixed at 19 RPM

Figure 6.10 shows the flexural strength of concrete vs time curves for changes in the quantity of batch size mixed at 19 RPM. The highest three-hour strength of Set-45 was recorded by the batch mixed of two-thirds cu ft. The one-third cu ft batch produced concrete that was about 70 psi stronger at 24 hours than the two-thirds cu ft batch and at seven days the strength for the one-third cu ft mix was about 40 psi stronger than the two-thirds cu ft mix. The one cubic foot mix had results that were considerably less than the other two mixes. Again, this could be attributed to the problem of mixing a large quantity of material in the gravity type mixer combined with the slower mixing action. The materials were not easily mixed in with the water.

For Duracal, the batch of one-third cu ft had a three hour strength about 50 psi greater than the other two mixes. At 24 hours, the strengths were all within 30 psi of each other, with one-third cu ft and two-thirds cu ft showing the higher strengths. At seven days, very little difference in strengths was recorded with the one-third cu ft batch having strengths only ten psi more than the two-thirds cu ft batch. These strengths were all greater than 650 psi.

The one-third cu ft and two-thirds cu ft batches of GHP had comparable strengths for 24 hours with the one-third cu ft mix displaying a 20 psi higher strength at 24 hours. At seven days the one-third cu ft mix strength was approximately 100 psi higher than any of the other mixes. The one cu ft mix showed the same problem of having considerably lower strengths throughout the testing week. The same

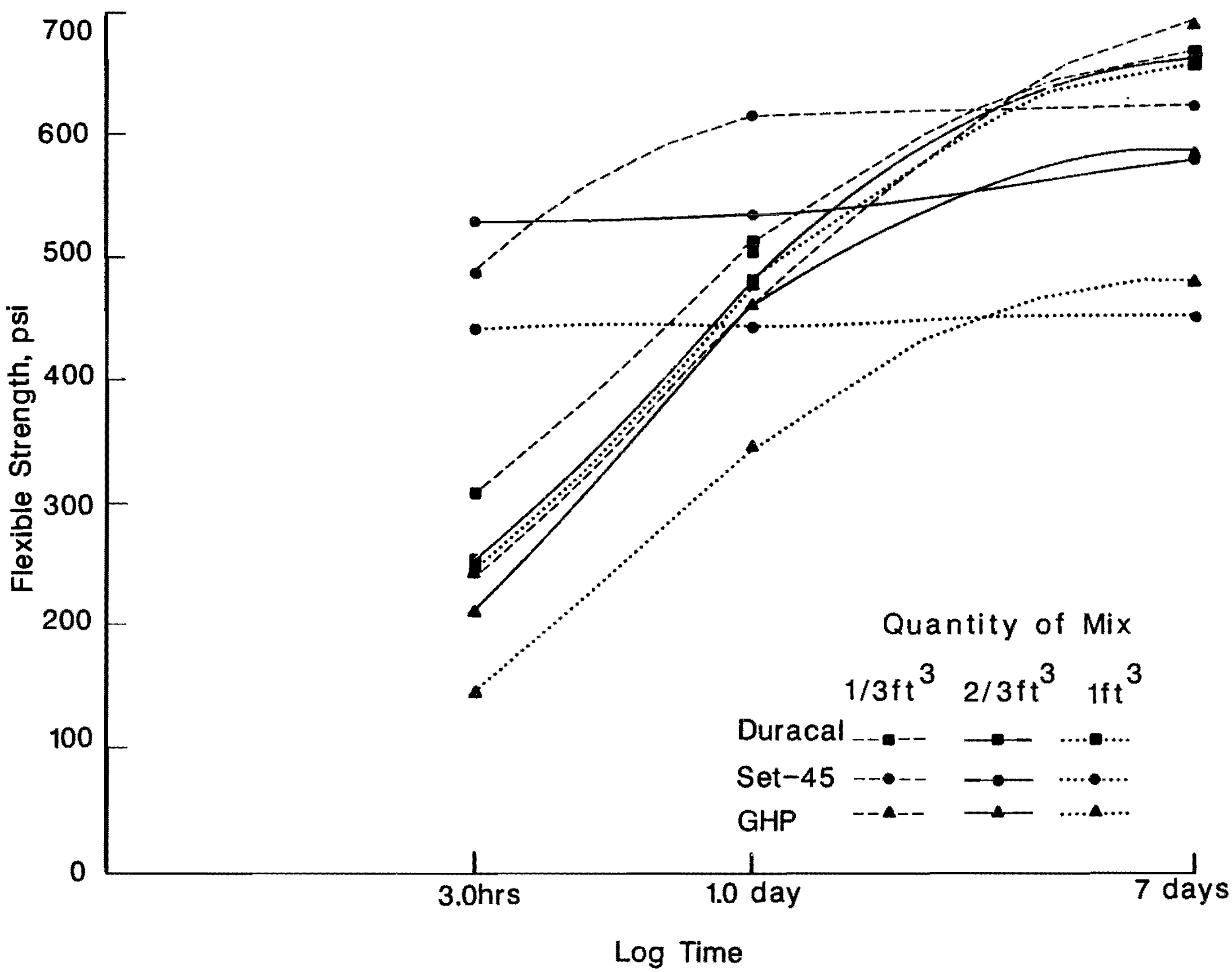

Fig. 6.10 Flexural Strength vs Time for Batches Mixed at 19 RPM with Varying Quantities of Mix.

mixing difficulties were observed with GHP as were seen with Set-45: there was too much material in the mixer to allow the dry binder to reach the water in the lower part of the mixer, in the first few seconds after mixing had begun. Thus, after two minutes of mixing the materials were not as uniformly mixed as the smaller quantities.

In comparison of materials, Set-45 again had considerably higher strengths at three hours. Duracal's flexural strength was far below strengths of Set-45 and slightly above the strengths of GHP. Two of the 24-hour strengths for Set-45 were still the highest results. The results of Duracal and GHP at 24 hours were within 40 psi, with only one exception and these results were approximately 50 to 110 psi below the highest strength of Set-45. The seven-day strength of the one-third cu ft batch of GHP recorded the highest strength of 685 psi followed by all of the Duracal mixes approximately 25 psi lower. The one cu ft mixes of GHP and Set-45 had strengths considerably lower at seven days than the rest of the mixes.

6.4.2 Concrete Mixed at Normal Speed (22 RPM)

Figure 6.11 exhibits the flexural strength vs time curves for changes in the quantity of batch size mixed at the normal speed of the mixer (22 RPM). Set-45 mixed at two-thirds cu ft displayed slightly higher strengths at three hours than the cu ft mix and at 24 hours the two-thirds cu ft mix was still slightly greater than the one cu ft mix in strength. The one-third cu ft mix had much lower early strengths than the larger mixes but by seven days all of the mixes were within 15 psi of each other. The mix using two-thirds cu ft had the highest strength of the three mixes.

The results for Duracal were not as uniform as had been observed in other tests. The three hour strengths for the two-thirds cu ft batch of Duracal were slightly higher than the strengths for the one-third cu ft mix, but by 24 hours the strength for the one-third cu ft batch was 25 psi stronger than the strength of the two-thirds cu ft batch. The strength of the one cu ft mix was approximately 40 psi less than the smaller batches during the early stages of the tests. At seven days

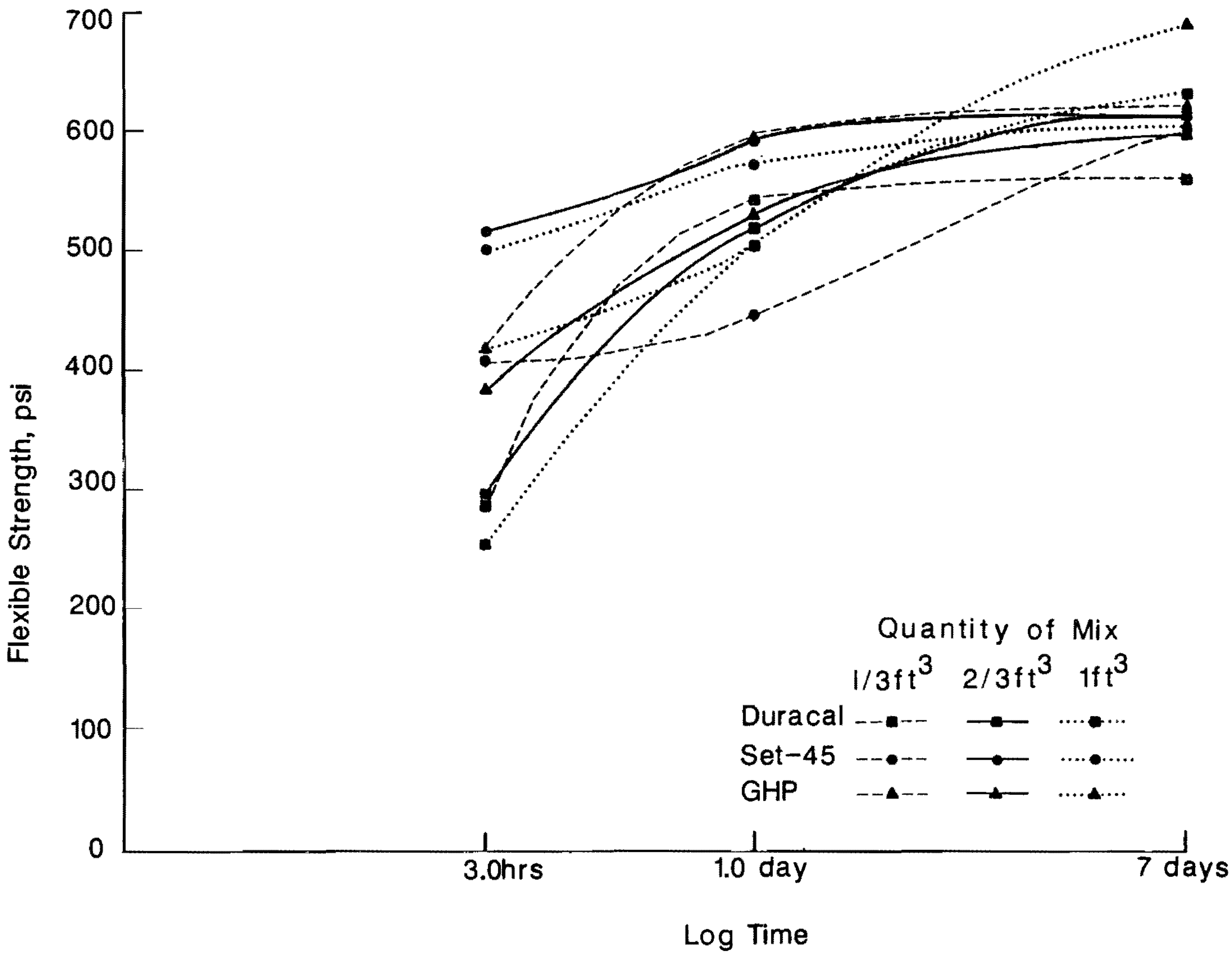

Fig. 6.11 Flexural Strength vs Time for Batches Mixed at 22 RPM with Varying Quantities of Mix.

though the one cu ft batch produced the highest strength which was 15 psi higher than the strength of the two-thirds cu ft batch. The batch of one-third cu ft had the lowest seven-day strength.

The strengths for the mixes of GHP were very scattered and non-uniform. The one-third cu ft and one cu ft mixes obtained the highest early strengths. The one-third cu ft batch also had the highest strength the following day while the one cu ft mix was 95 psi below the strength of the one-third cu ft mix. At seven days the one cu ft mix displayed a strength 65 psi more than the strength of the one-third cu ft batch. The two-thirds cu ft^{-3} batch of GHP did not cure sufficiently in three hours to permit strengths to be measured when the beams were tested. However, the other materials did develop strength in three hours.

When the strengths of all the materials were evaluated, Set-45 had the highest initial strength but GHP was within 100 psi and Duracal within 250 psi. After 24 hours with the exception of one Set-45 mix all of the results were within 100 psi of each other. Set-45 and GHP had mixes at the top of that range. After seven days all of the results were within 40 psi except for GHP mixes at one cu ft which recorded the highest reading and the one-third cu ft mix of Duracal which had the lowest reading.

6.4.3 Concrete Mixed at 30 RPM

Figure 6.12 illustrates the flexural strength vs time curves for changes in the quantity of batch size mixed at a rate of 30 RPM, which was the fastest mixing speed. The batch of two-thirds cu ft of Set-45 had the highest early strength, yet by 24 hours, the strengths of the one-third cu ft and two-thirds cu ft mixes were comparable in magnitude. At seven days all of the strengths were very close in magnitude.

The highest early strength for Duracal was obtained by the batch of two-thirds cu ft, which at that point was considerably higher than the other mixes. By 24 hours, though the strengths for the one-third cu ft and two-thirds cu ft mixes were the same. The seven-day

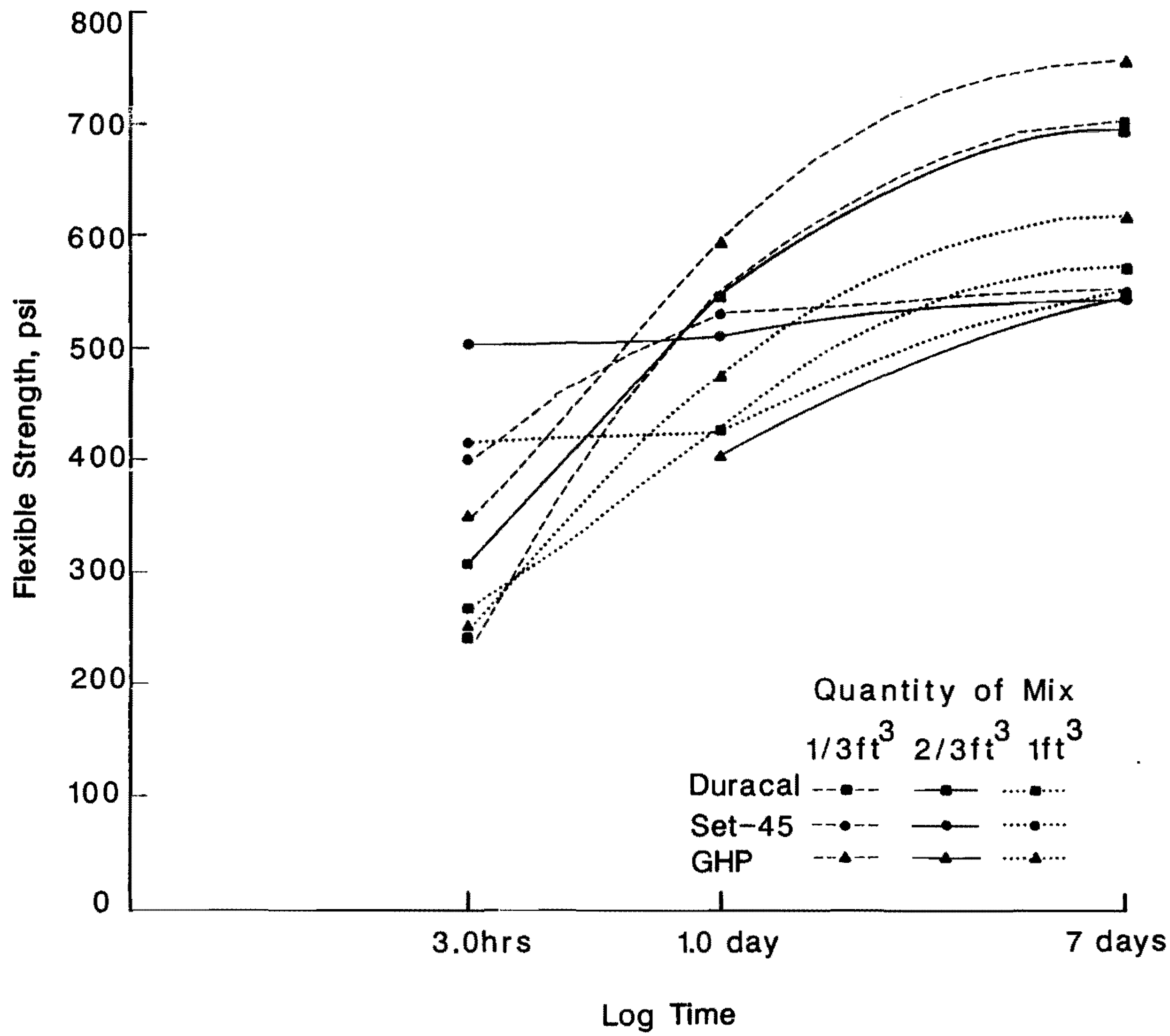

Fig. 6.12 Flexural Strength vs Time for Batches Mixed at 30 RPM with Varying Quantities of Mix.

strengths for each of the two smaller batches were over 690 psi and there was only a six psi difference between them. The strengths for the one cu ft mix were consistently 100 psi or more lower than the smaller mixes after 24 hours.

The batch of one-third cu ft of GHP produced the highest results throughout the testing period. At three hours the one-third cu ft batch was nearly 100 psi stronger than the one cu ft batch and by seven days the strength was over 200 psi stronger than strengths exhibited by the larger batches.

In comparison of materials, Set-45 again had the highest early strength. At 24 hours the strengths of the three materials were scattered throughout a 200 psi range. One mix of GHP had the highest strength, while one mix of Duracal was within 30 psi. At seven days the one-third cu ft batch of GHP displayed the highest strength, followed by the two smallest batches of Duracal. Set-45 gained very little strength after the first day, so those strengths fell at the lower end of the seven-day range of flexural strengths.

6.5 Compression Tests of Silica Fume

Figure 6.13 shows the compressive strength vs time curves of silica fume concrete. Throughout the test week, the concrete with 20 percent silica fume had the highest strengths and the concrete using 25 percent silica fume obtained strengths within four percent of the 20 percent mix. Concrete with 30 percent silica fume had the lowest results at all times. The mixes using 20 and 25 percent silica fume had strengths below 1000 psi in one day. At three days, strengths of 2300 psi were obtained by the 20 and 25 percent mixes and at one week the strengths were above 3400 psi.

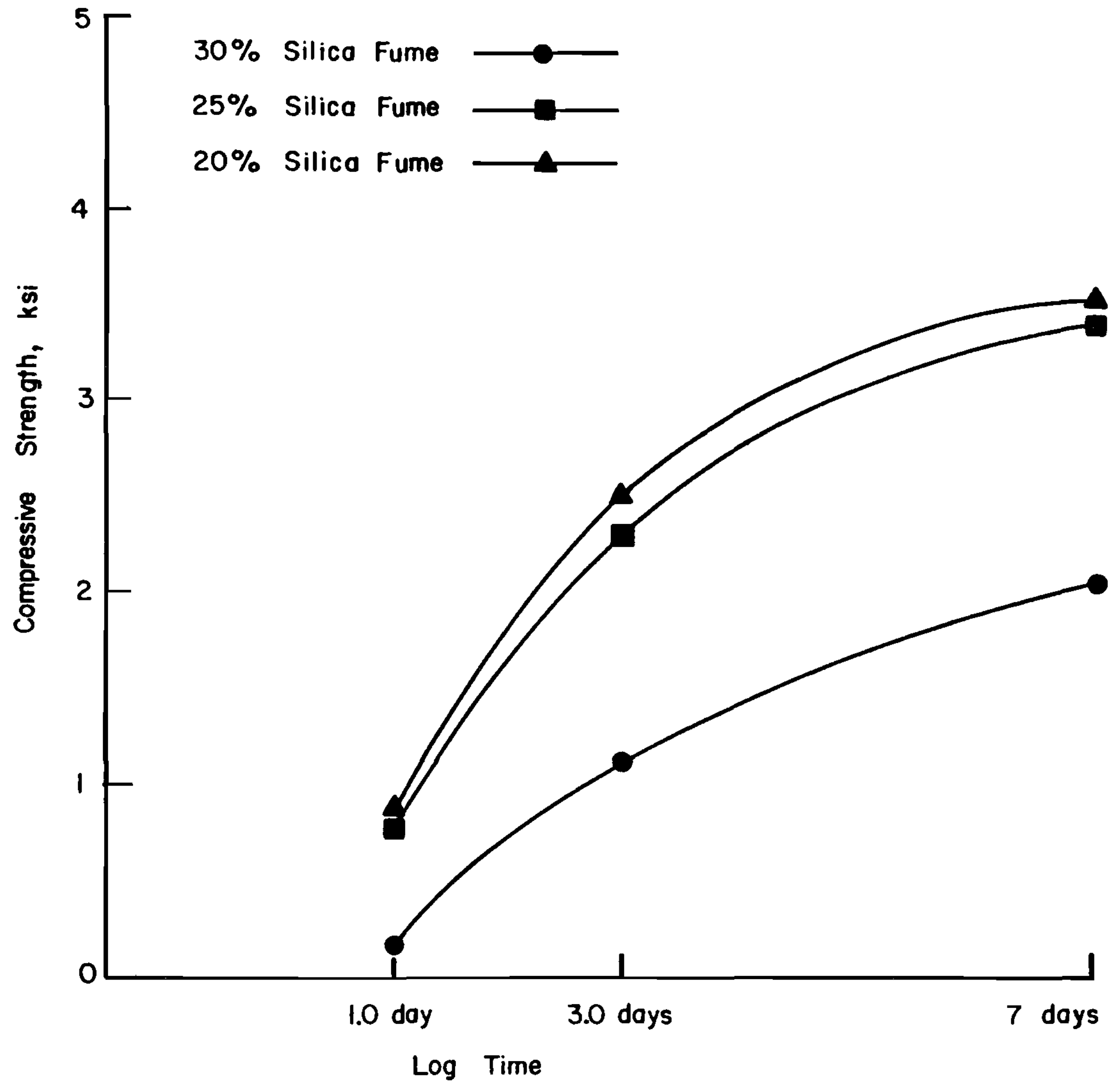

Fig. 6.13 Compressive Strength vs Time for Silica Fume Concrete.

CHAPTER 7
SOURCES AND COSTS OF MATERIALS

The prices and sources for Duracal, Set-45, and Gilco Highway Patch are listed below. These prices were given in August 1984 and are subject to change at any time. The supplier should be contacted for up-to-date prices and availability of materials.

7.1 Materials

Product and Source	Price per pound Amount (lb)	Price
1. Duracal (50 lb package, neat)	50-2000	0.21
David Hawn Lumber Company	2000+	0.19
(214) 946-8123		
2. Set-45 (50 lb package, Hot	50-5000	0.40
and Cold Weather formulations,	5000-20000	0.35
cement- F.A. mixture)	20000-40000	0.33
Master Builders	40000+	0.28
(512) 442-0025		
3. Gilco Highway Patch	50+	0.27
(55 lb package, cement-		
F.A. mixture)		
Shepler's Equipment Co.		
(713) 799-1150		

CHAPTER 8
SUMMARY AND CONCLUSIONS

8.1 Summary

Rapid-setting repair materials are very useful to reduce lane closure time for the repair of deteriorating highways. By using materials that set quickly and gain strength rapidly, traffic lanes may be reopened within three hours after placing, thus easing time delays and traffic congestion to motorists. There are many different types of products and brands of materials available to repair roadways and bridges. For any particular repair there are several factors to evaluate when considering what product to use to make a successful repair. Material costs, mechanical properties, workability, and availability may differ greatly from material to material making the choice of material a difficult one.

Research Study 311, "Evaluation of Fast-Setting Repair Materials for Concrete Pavements and Bridges," was conducted for the State Department of Highways and Public Transportation from September 1981 through August 1984. The objectives of the study were: 1) identify candidate materials based on D-9 evaluation tests and a survey of districts and other states; 2) perform laboratory tests on candidate materials; 3) determine optimum mixing, placing, and finishing methods; 4) make field repairs in different districts using candidate materials; 5) disseminate results. Results of the Survey of Districts and States and data from laboratory tests performed at 72°F were presented in Survey of and Evaluation Methods for Rapid-Setting Materials (1). Tests performed at 40°F and 110°F and the results of field repairs made in four cities were presented in Laboratory and Field Evaluation of Rapid-Setting Materials (2).

This report presents results of additional laboratory work evaluating three rapid-setting cements while considering changes in the mixing energy and volume of concrete in the mixer. The three materials tested were Duracal, Gilco Highway Patch, and Set-45.

Results presented in this report include: 1) evaluation of compressive strength vs time for materials mixed at different rates of speed; 2) evaluation of compressive strength vs time for materials mixed at varying quantities of total material placed in the mixer; 3) evaluation of flexural strength vs time for rapid-setting concrete prepared at different rates of mixing speeds; 4) evaluation of flexural strength vs time for concrete mixed at varing amounts of total material placed in mixer.

All specimens were placed and cured at temperatures and relative humidities of 72°F and 50 percent respectively.

Limited laboratory tests were also performed on the rapid-setting ability and accelerated strength gains when combining silica fume and portland cement in various ratios.

8.2 Conclusions

1) The compressive strengths of batches prepared at 22 RPM were consistently the highest of the batches by the three mixing speeds, while mixed at any volume.

2) Set-45 always obtained the highest compressive strengths during the first 24 hours for the materials evaluated with varying mixing speeds while the mixing volumes were held constant. By seven days Duracal was as strong or stronger than Set-45, while Gilco Highway Patch always had the lowest strengths.

3) Compressive strengths for all materials mixed at 67 percent capacity of the mixer usually were the highest while mixing speeds were kept constant at either 19 RPM, 22 RPM, or 30 RPM.

4) The compressive strengths for all materials mixed at 100 percent capacity of the mixer displayed the lowest results at most mixing speeds.

5) For materials mixed with varying mixing capacities while the mixing speed was held constant, Set-45 always obtained the highest compressive strengths during the first 24 hours. Duracal had the highest seven day compressive strengths for concrete mixed at 19 RPM

and 30 RPM, while Set-45 had the highest seven-day strengths for material mixed at 22 RPM.

6) For Gilco Highway Patch, the normal mixing speed attained the highest flexural strength for each mixing volume. For Duracal and Set-45, there was not a definite trend of which mixing speed produced the highest flexural strength for a constant mixing volume.

7) The flexural strength of Set-45 was the highest during the first 24 hours for materials evaluated with the same mixing volume. Duracal and GHP exhibited the highest seven-day strengths for materials evaluated using the same mixing volume.

8) The flexural strength of materials prepared at quantities of 33 percent capacity and 67 percent capacity was consistently higher than the strengths of 100 percent capacity mixes.

9) For materials mixed with varying mixing capacities while the mixing speed was held constant, Set-45 had the highest flexural strengths during the first 24 hours, while Gilco Highway Patch consistently had the highest strengths after seven days.

10) The combination of silica fume and portland cement concrete did not produce concrete with higher early strengths than Set-45, Duracal, and Gilco Highway Patch.

8.3 Recommendations

1) Rapid setting concrete should be mixed at 67 percent capacity of the mixer.

2) Mixing concrete at 100 percent of the mixer capacity should be avoided.

REFERENCES

1. Beer, George P., "Survey of and Evaluation Methods for Rapid-Setting Materials," Center for Transportation Research Report 311-1, The University of Texas at Austin, December, 1982.
2. Smith, Kevin G., "Laboratory and Field Evaluation of Rapid-Setting Materials," Center for Transportation Research Report 311-4, The University of Texas at Austin, January 1984.