R 613

Technical Report

MIX DESIGNS FOR FAST-FIX 1 CONCRETE

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Technical Report R-613

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by

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ABSTRACT

The purpose of this investigation was to obtain information required for the use of Fast-Fix 1 concrete as a structural material. In particular, the effects of concrete mix design parameters and aging were investigated to determine if varying them would permit attaining compressive strengths in excess of 2,500 psi without the use of retarding agents. In addition, splitting tensile strength and compressive stress—strain relations were determined for standard control cylinders. Results indicated that for concretes with an age of 1 hour, compressive strengths up to 3,300 psi can be achieved by proper selection of constituents. Attempts to attain higher compressive strengths resulted in unworkably short set times and exorbitant cement contents. The age of the concrete did not alter its compressive strength within the limits tested. Recommendations are presented in the form of design curves which enable one to design a mix for a specified compressive strength and set time.

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INTRODUCTION

Objective

The overall objective of this investigation was to obtain information required for the use of Fast-Fix concrete as a structural material. The influence of the mix design parameters on the strength is discussed, and various properties required for the structural design are presented.

Specifically, the major objectives of this investigation were:

1. To achieve Fast-Fix concrete strength in excess of 2,500 psi from a mix design yielding practical set times. The following variables were considered:

    a. Sand-to-total-aggregate ratio

    b. Water-cement ratio

    c. Aggregate-to-cement ratio

2. To investigate the variation of compressive strength with age

3. To determine the splitting tensile strength

4. To determine the stress–strain relation of the Fast-Fix concrete in compression

Background

Fast-Fix concrete is a mixture of Fast-Fix cement, fine aggregate, coarse aggregate, and water. The use of Fast-Fix cement makes it possible for concrete to gain essentially full strength in a relatively short time (less than 30 minutes). When properly designed, Fast-Fix concrete has a buttermilk consistency (approximately 10-inch slump) and a set time of about 12 minutes. The set time is defined as the interval between the addition of water to the "dry" constituents and the hardening of the concrete to a state in which it can no longer be shaped by a steel trowel.

Fast-Fix cement was originally developed by the Air Force with the intention of producing a fast setting, high early strength concrete that would enable the rapid repair of bomb-damaged runways. Laboratory investigations[1] resulted in the development of a cement blend consisting of calcium sulfate hemihydrate (a type of gypsum), portland cement, and a dispersing agent called TF-4. This blend is manufactured by The Western Company[2] under the trade name Fast-Fix 1 cement. Having decided upon the cement blend, the Air Force has published a series of reports[3,4,5] on the utilization of Fast-Fix cement and Fast-Fix concrete for rapid repair of runways. The proposed mix proportions for Fast-Fix concrete were (by weight) four parts Fast-Fix cement, three parts sand, and nine parts crushed rock; the water-cement ratio was taken as 35%, with the aggregates containing 2% moisture.[2,3,5] This mixture has a set time of about 11 minutes and provides a 30-minute compressive strength of 1,700 psi.[5]

However, to be of structural quality, concrete must have a compressive strength of 2,500 psi or higher.[6,7] Since the mix designs for Fast-Fix concrete recommended in the available literature[2,3,5] yield strengths lower than this minimum, a mix design providing compressive strengths in excess of 2,500 psi was necessary to justify proceeding with the study of the structural properties of reinforced, Fast-Fix concrete structural members. To be of a practical value, this mix design should also provide a reasonable value for set time.

Scope and Approach

To achieve the foregoing objectives, batches of two different volumes were used:

1. Small-volume batches (0.06 ft^3) were adopted mainly for rigid laboratory control when the study was focused on the effect of various mix-design parameters on compressive strength at one hour and set time. All test cylinders made of this batch size were 3 x 6 inches. Parameters studied were:

   a. Sand-to-total-aggregate ratio (0.25, 0.60, and 1.0)

   b. Water-cement ratio (0.26 to 0.48 by weight)

   c. Aggregate-to-cement ratio (1, 1.5, 3, and 4)

2. Information gained from testing cylinders of the small-volume batches was used in the design of batches of larger volume (3 ft^3); 6 x 12-inch control cylinders were used for:

   a. Determining the splitting tensile strength

   b. Determining compressive stress—strain relations

   c. Comparing the compressive strength of the 6 x 12-inch cylinders with that of 3 x 6-inch cylinders cast from the same batch

3. Both large- and small-volume batches were used for:

   a. Determining whether batch volume has any effect on compressive strength and set time

   b. Investigating the effect of concrete age on compressive strength

EXPERIMENTAL WORK

Materials

The following materials were used in the small- and large-volume batches.

Fast-Fix 1 Cement. Fast-Fix 1 cement is composed of approximately 94.5% alpha gypsum, 5.0% portland cement, and 0.5% TF-4, a dispersing agent. For this test series, 50 bags of Fast-Fix 1 cement were obtained; the cement was manufactured by The Western Company and packaged in 100-pound bags. No additives to Fast-Fix 1 cement were used throughout this investigation.

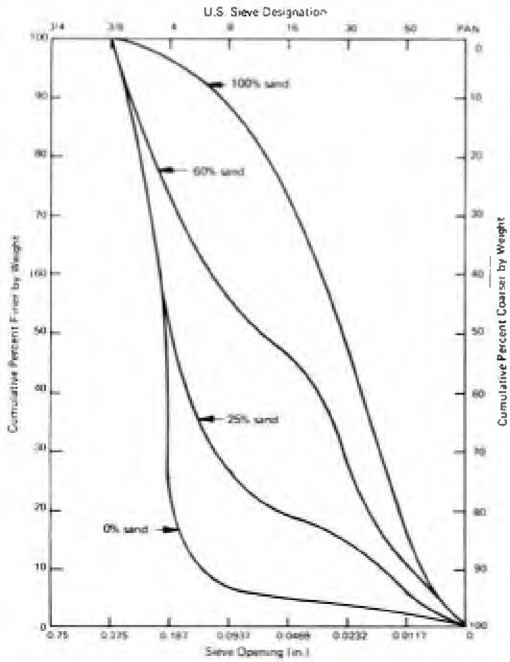
Sand. Sand was obtained locally from the Santa Clara River Basin. A cumulative gradation curve is shown in Figure 1.

Crushed Gravel. The crushed gravel, which was also obtained from the Santa Clara River Basin, had a maximum size of 3/8 inch; a cumulative gradation curve is shown in Figure 1. In order to simulate field conditions, the crushed gravel was used as delivered; that is, no attempt was made to wash it.

Water. Water was obtained from the Port Hueneme Municipal Water Department.

Fabrication

The procedures for mixing, pouring, and preparing for testing the control cylinders were similar for concrete of both small- and large-volume batches. Sand and crushed gravel were checked for moisture content on each casting day. The amount of mixing water was modified on the assumption that a saturated surface-dry condition corresponds to a total moisture of 1% above the oven-dry condition.



(Aggregate = Sand + Crushed Gravel)

Figure 1. Sieve analysis of various percentages of sand to total aggregate.

After the appropriate weights of sand and crushed gravel were mixed for 1-1/2 minutes, the designed weight of Fast-Fix 1 cement was added and the total dry ingredients were mixed for an additional 1-1/2 minutes. To these dry ingredients, the whole amount of water required was added as fast as possible, and mixing continued for exactly 3 more minutes.

The concrete was then poured in the cylindrical steel molds, which had already been cleaned and oiled. The concrete of the small-volume batches was vibrated by placing the steel molds on a Syntron Vibration Table. Hand-held internal mechanical vibrators were used for the concrete of the large-volume batches. The top surface of the concrete cylinders was carefully finished with a steel trowel; set time was recorded when hand troweling could no longer shape the concrete. Fifteen minutes after the concrete set, the cylindrical molds were removed and the control cylinders were allowed to air cure until test time. Due to time limitation, standard caps were not made for the control cylinders; however, cardboard disks were used to distribute stresses as evenly as possible during compressive tests.

Mixing and Testing Equipment

The small-volume batches (0.06 ft^3) were mixed in a 5-quart-capacity Hobart Mixer. This mixer together with other facilities of the Model Laboratory of NCEL are shown in Figure 2. Larger volume batches were mixed with a 6-ft^3-capacity mixer shown in Figure 3 along with cylinder forms and slump test equipment. A close view of a typical slump test is shown in Figure 4.

Figure 2. Laboratory mixing facilities.

Figure 3. Out-of-doors mixing facilities.

Figure 4. Typical slump test.

A 120,000-pound-capacity universal testing machine was used for testing all the 3 x 6-inch cylinders of the small-volume batches. Cylinders of both sizes (3 x 6 inch and 6 x 12 inch) of the large-volume batches were tested in a 400,000-pound-capacity universal testing machine. The stressing rate for compression tests was 34 psi/sec, and for splitting tensile tests was 110 psi/min; these stressing rates conform with the ASTM specifications,[8] namely, ASTM C 39-66 and ASTM C 496-66 respectively. A microformer-actuated compressometer (Figure 5) was used to obtain the load—deformation curves for the 6 x 12-inch cylinders under compression.

TEST RESULTS

General

Results of the testing program are given in Tables 1, 2, and 3. Table 1 lists results of tests for small-volume batches conducted on 3 x 6-inch cylinders under rigid laboratory control to investigate the effects of mix proportions.

Table 2 lists results of tests for larger volume batches conducted on 6 x 12-inch cylinders out-of-doors to investigate splitting tensile strength, stress–strain relations, and effect of batch volume. Table 3 lists results of tests conducted both in the laboratory and out-of-doors to determine the effect of cylinder size and age of concrete on compressive strength.

Factors Affecting Strength

In the ensuing discussion it will become evident that set time is an important parameter for Fast-Fix cement; consequently, set time along with compressive strength will be presented whenever applicable. A full discussion of the importance of set time will be given following the test results.

Sand-to-Total-Aggregate Ratio. Laboratory tests revealed that decreasing the sand-to-total-aggregate ratio (without varying the other factors) yielded higher compressive strengths, but was accompanied by a serious drop in set time and workability. This was attributed to the high water absorption capacity of silt- and clay-size particles found in the unwashed crushed gravel. Since this report is intended for use in the field, where it is common practice to use crushed aggregate as is, it was decided that in lieu of washing the crushed gravel, it would be more meaningful and practical to determine optimum sand percentage by varying the amount of mixing water for each sand percentage. Thus, the amount of water was varied to obtain a nominal set time of 8 minutes. In particular, sand-to-total-aggregate ratios of 0.25, 0.60, and 1.0 were each investigated with varying amounts of mixing water while the aggregate-to-cement ratio was held constant at 3.0. Compressive strengths for the various mixes with an 8-minute set time are shown in Figure 6. The cumulative gradation curve for each of the aggregate combinations is shown in Figure 1. Figure 6 illustrates that compressive strength does not vary significantly with respect to the sand percentage within the limits tested. Since the sand-to-total-aggregate ratio of 0.60 indicated the best result, this value was chosen as optimum and held constant throughout the remainder of the testing program.

Water-Cement Ratio. To investigate the effect of water-cement ratio on compressive strength, four proportions of aggregate-to-cement were selected, and each one was held constant while net mixing water was varied. In particular, proportions of aggregate to cement of 4.0, 3.0, 1.5, and 1.0 were individually investigated with varying amounts of water. Figure 7 gives compressive strength and set time versus water-cement ratio for the aggregate-to-cement ratios of 4.0, 3.0, 1.5, and 1.0. It is clear that decreasing the water-cement ratio increased the compressive strength but decreased set time.

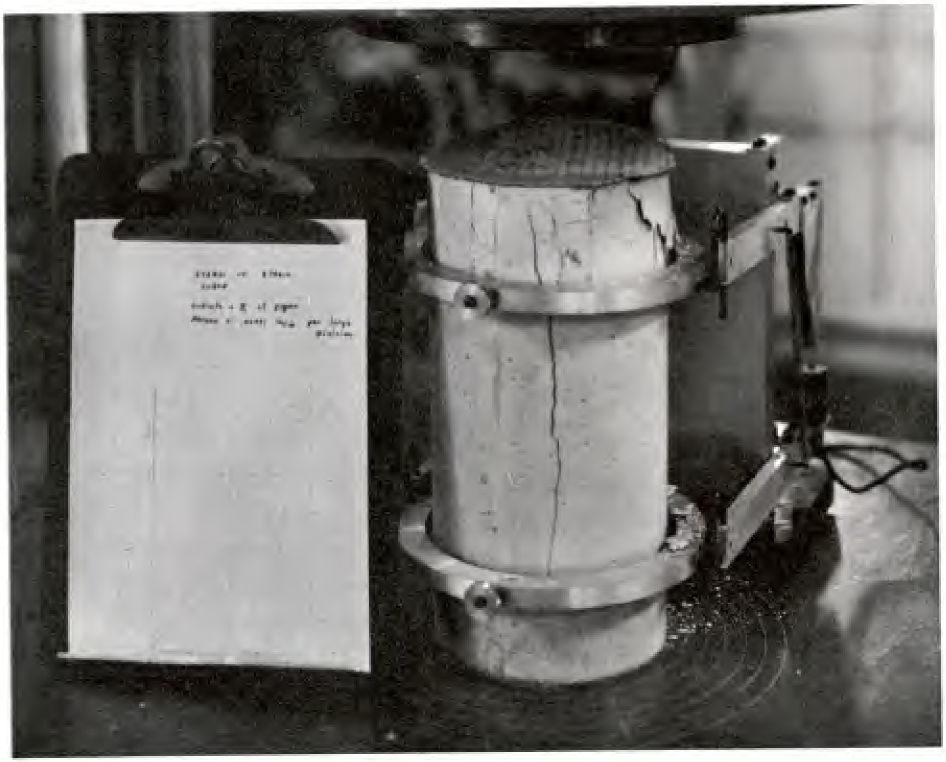
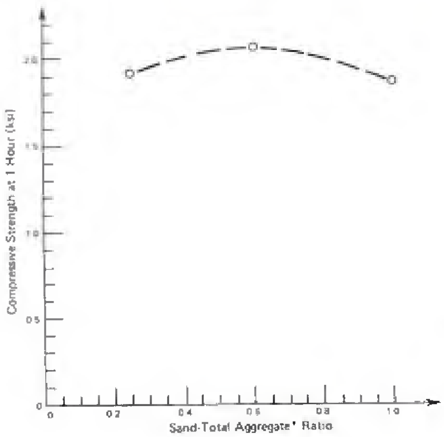


Figure 5. Typical compressive test with compressometer.



* Total aggregate = sand plus crushed gravel

Figure 6. Compressive strength versus aggregate gradation based on a set time of 8 minutes and aggregate-to-cement ratio of 3 (constant dry proportions).

Aggregate-to-Cement Ratio.

Inherent in the test series for investigating the effects of water-cement ratio are the effects of aggregate-to-cement ratio on compressive strength and set time. For a simpler representation of the effects of aggregate-to-cement ratio, the four graphs of Figure 7 are grouped in one graph shown in Figure 8. The general trend is: for a given water-cement ratio, a decrease of aggregate-to-cement ratio increased both set time and compressive strength.

Table 1. Design Data and Test Results for Small-Volume Batches (3 x 6-inch cylinders)

Batch No.	Dry Proportions (by weight)* Cement:Sand:Gravel	Cement (sacks/yd^3)**	Water-Cement Ratio (by weight)	Water (gal/sack)	Set Time (min)	f'_c at 1 Hr (psi)
S1	1.00:0.75:2.25	8.75	0.330	3.96	5-1/2	2,400
S2	1.00:0.75:2.25	8.48	0.460	5.52	9	1,500
S3	1.00:0.75:2.25	8.46	0.470	5.64	9-1/2	1,215
S4	1.00:3.00:0.0	8.67	0.362	4.34	6	1,875
S5	1.00:3.00:0.0	8.64	0.377	4.53	8-1/2	1,790
S6	1.00:2.40:1.60	7.00	0.408	4.90	9-1/2	1,623
S7	1.00:2.40:1.60	6.97	0.433	5.20	10-1/2	1,602
S8	1.00:2.40:1.60	6.87	0.511	6.13	11-1/2	1,482
S9	1.00:2.40:1.60	6.83	0.543	6.52	17	1,023
S10	1.00:2.40:1.60	6.78	0.574	6.89	19-1/2	962
S11	1.00:1.78:1.19	8.72	0.362	4.35	6	2,160
S12	1.00:1.78:1.19	8.70	0.377	4.53	8	2,100
S13	1.00:1.78:1.19	8.63	0.410	4.92	10	2,060
S14	1.00:1.78:1.19	8.60	0.432	5.19	11	1,710
S15	1.00:0.90:0.60	13.6	0.275	3.30	6-1/2	3,147
S16	1.00:0.90:0.60	13.5	0.292	3.51	9	2,713
S17	1.00:0.90:0.60	13.4	0.312	3.75	10	2,486
S18	1.00:0.90:0.60	13.3	0.345	4.14	15	2,015
S19	1.00:0.60:0.40	16.7	0.270	3.24	8	3,352
S20	1.00:0.60:0.40	16.7	0.270	3.24	8	3,221
S21	1.00:0.60:0.40	16.6	0.284	3.41	10	3,200
S22	1.00:0.60:0.40	16.4	0.297	3.57	12	2,815
S23	1.00:0.60:0.40	16.1	0.347	4.17	16	2,295

* Weights of aggregates are those at the saturated surface-dry condition.

** Each sack of Fast-Fix cement weighs 100 pounds; concrete weighs 140 lb/ft^3.

Table 2. Design Data and Test Results for Large-Volume Batches (6 x 12-inch cylinders)

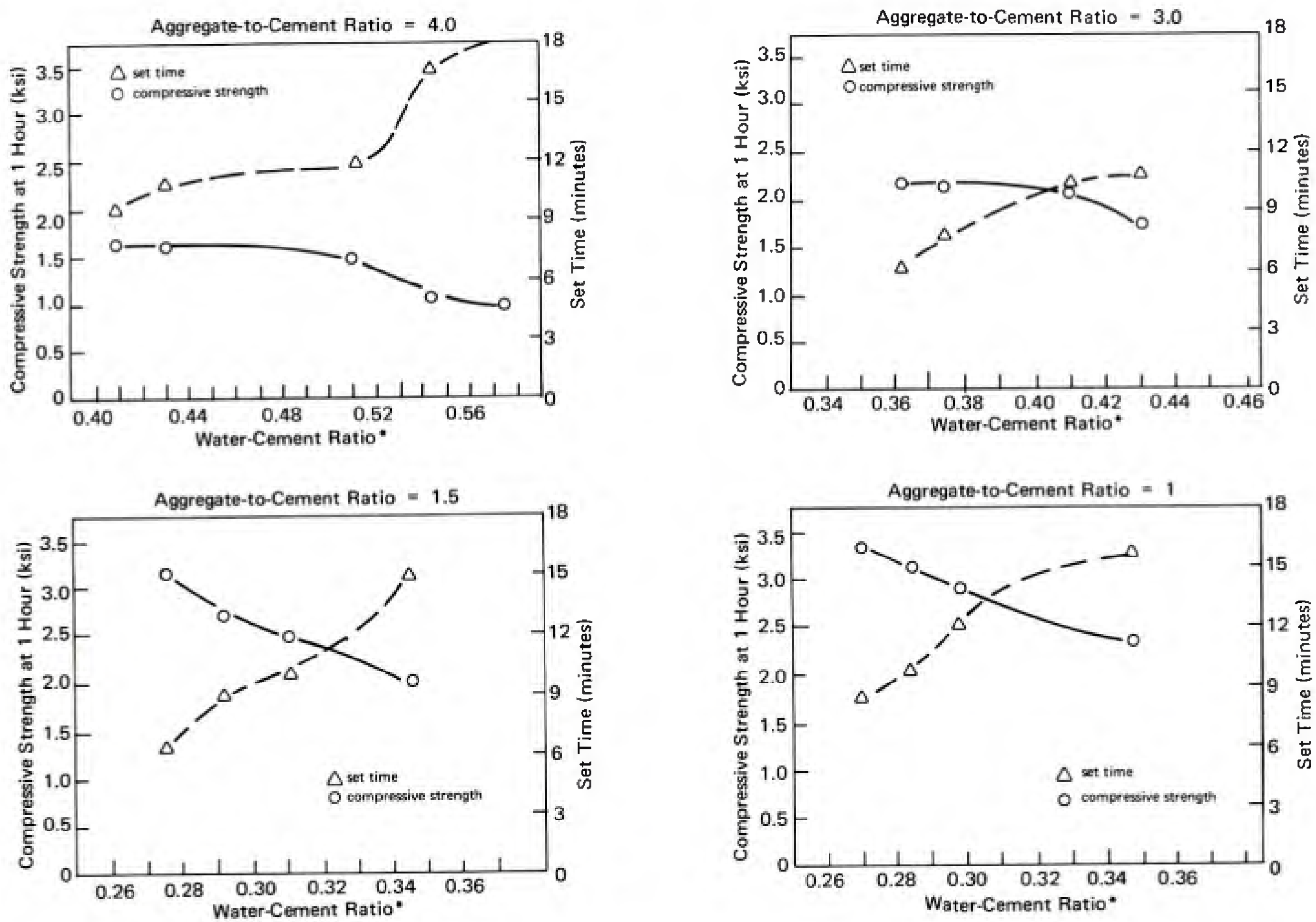
Mix	Batch No.	Dry Proportions (by weight) Cement:Sand:Gravel	Cement (sacks/yd^3)	Water-Cement Ratio (by weight)	Water (gal/sack)	Slump (in.)	Set Time (min)	Average Weight of Cylinder (lb)	f'_c (psi)		f_{sp} (psi)
									1 Hr	2 Hr	
1	L1	1.00:1.78:1.19	8.75	0.395	4.74	10-1/2	12	27.9	1,981	1,964	209
	L2	1.00:1.78:1.19	8.75	0.392	4.70	10-3/4	12	28.0	1,892	1,732	202
	L3	1.00:1.78:1.19	8.75	0.400	4.80	10-1/2	11	28.0	1,952	—	212
	L4	1.00:1.78:1.19	8.75	0.393	4.72	10	11	28.0	2,032	1,875	208
	L5	1.00:1.78:1.19	8.75	0.399	4.78	10-1/2	12	28.0	2,220	2,240	214
	L6	1.00:1.78:1.19	8.75	0.398	4.77	10-1/4	12-1/2	28.0	1,925	1,810	210
	L7	1.00:1.78:1.19	8.75	0.397	4.76	10-1/2	11	27.6	2,250	2,094	219
2	L8	1.00:0.67:0.44	15.4	0.299	3.59	10-3/4	12	27.0	2,985	3,030	264
	L9	1.00:0.67:0.44	15.4	0.298	3.58	10-3/4	14	27.0	2,760	3,078	275
	L10	1.00:0.68:0.45	15.0	0.309	3.71	11-1/2	12	26.5	2,760	2,766	250
	L11	1.00:0.67:0.44	15.4	0.299	3.59	11	16-1/2	27.0	2,709	2,771	264
	L12	1.00:0.67:0.44	15.4	0.298	3.58	11	13	26.9	2,778	3,198	257
	L13	1.00:0.67:0.44	15.4	0.298	3.58	11-1/4	14	27.0	3,066	3,088	271
	L14	1.00:0.67:0.44	15.4	0.298	3.58	11	13-1/2	26.8	2,945	2,920	244

Table 3. Variation of Compressive Strength With Age and Cylinder Size

Batch No.	Cylinder Size (in.)	Dry Proportion (by weight) Cement:Sand:Gravel	Water-Cement Ratio (by weight)	Set Time (min)	Compressive Strength at Given Age Beyond Time of Setting— (psi)												
					15 Min	30 Min	45 Min	1 Hr	2 Hr	6 Hr	1 Day	2 Day	3 Day	4 Day	5 Day	6 Day	7 Day
M1*	6 x 12	1.00:0.67:0.44	0.304	13	2,830 2,880	2,160 2,420	2,850 3,180	2,470 2,630									
	3 x 6				2,730 3,040	2,800 2,550	2,860 2,330	2,940 2,680									
M2*	6 x 12	1.00:1.79:1.20	0.407	12				1,950 1,860	1,750 1,850	1,955 1,760	1,885 1,900						1,910 2,110
M3**	3 x 6	1.00:1.79:1.20	0.403	8				2,336 2,506				2,405 2,590				2,260 2,690	
M4**	3 x 6	1.00:0.67:0.44	0.297	12				2,970 3,132						3,140 3,390	2,980 3,340		

* Mixing conducted out-of-doors.

** Mixing conducted in laboratory with small Blakeslee Mixer.



* By weight.

Figure 7. Relation between water-cement ratio and compressive strength for different cement-to-aggregate ratios.

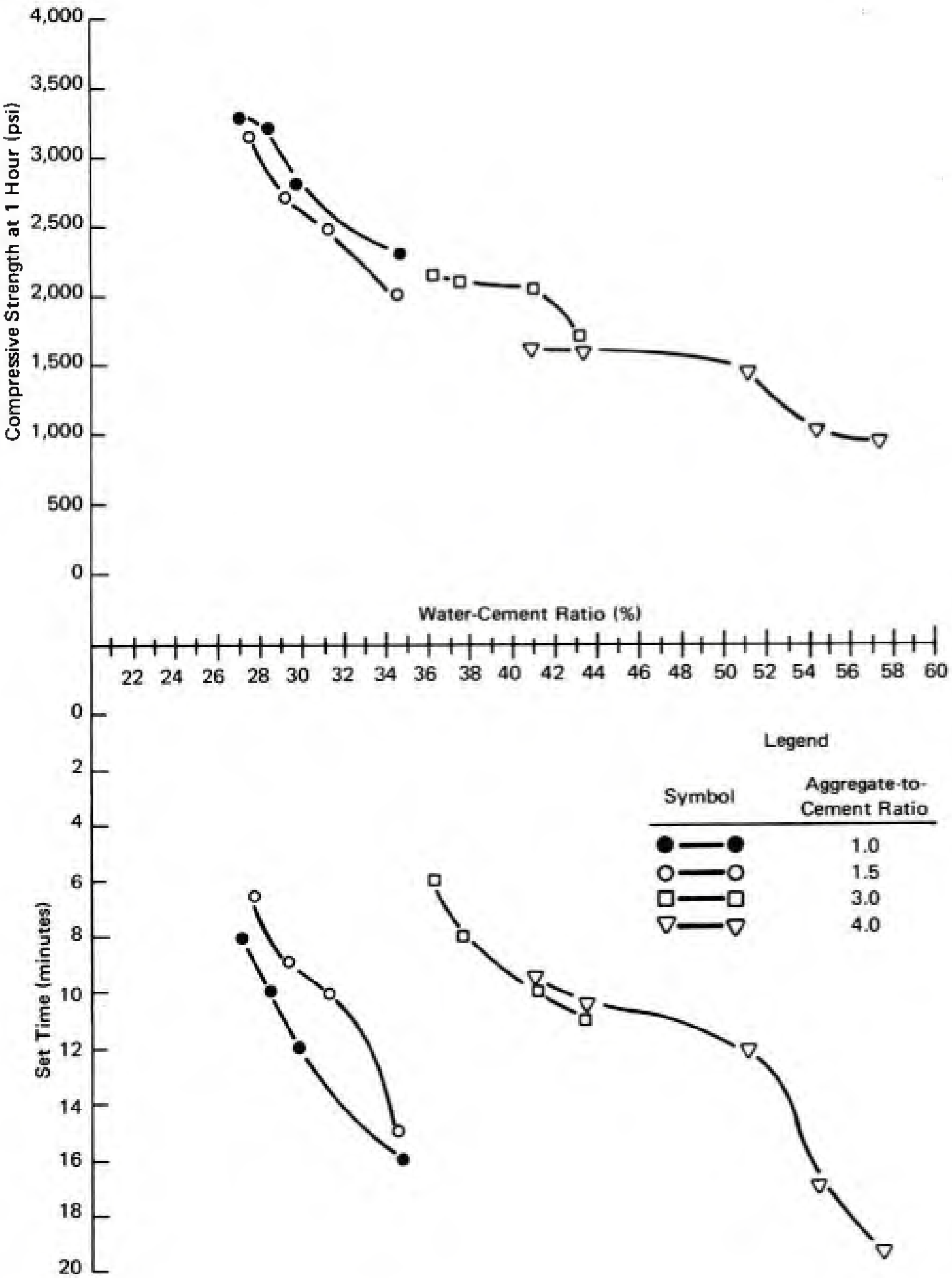


Figure 8. Compressive strength and set time versus water-cement ratio for various aggregate-to-cement ratios.

Batch Volume. In order to study the effect of batch volume (which includes the influence of equipment and techniques) on compressive strength and set time, 14 large-volume batches (3 ft^3) were designed, using the information gained from the small-volume batches as a guide. These 14 batches represented two mix designs with nominal compressive strengths of 2,000 psi and 3,000 psi. The characteristics of these two mixes are as follows:

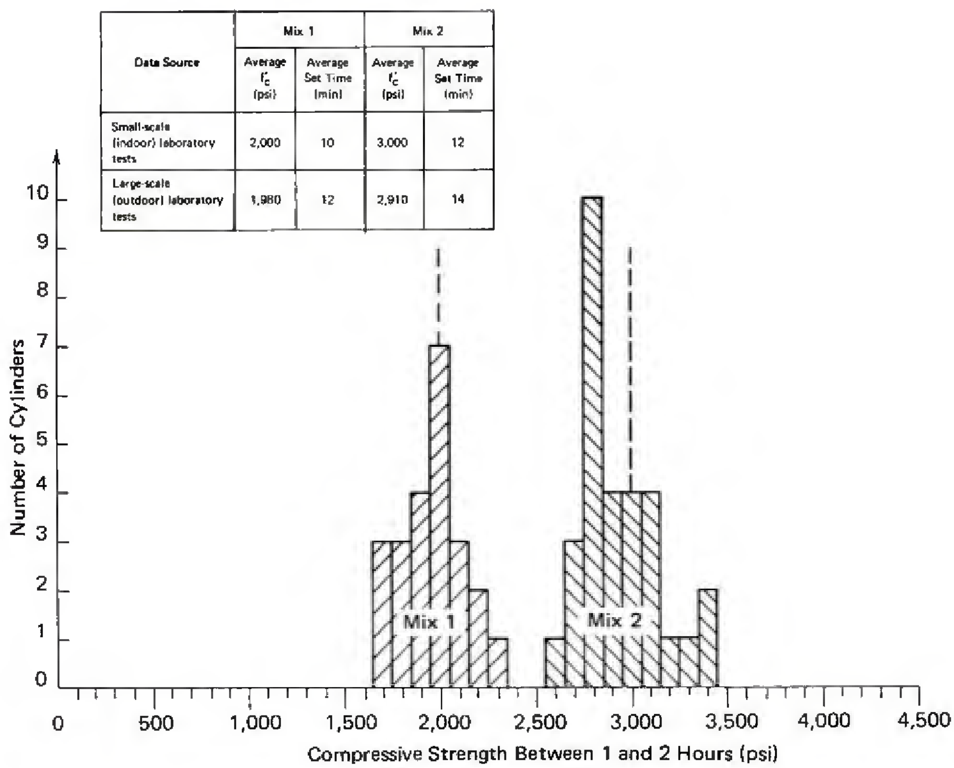
	Mix 1	Mix 2
Nominal compressive strength (psi)	2,000	3,000
Expected set time (minutes)	10	12
Sand-to-total-aggregate ratio	0.6	0.6
Aggregate-to-cement ratio	3.00	1.11
Water-cement ratio	0.397	0.298

The compressive strengths for Mix 1 and Mix 2 averaged 1,980 psi and 2,910 psi, which are very close to the anticipated nominal values tabulated above. Figure 9 shows the frequency distribution of the individual compressive tests for Mix 1 and Mix 2 and gives an indication of predictability of the compressive strength. The set times for Mix 1 and Mix 2 averaged 12 minutes and 14 minutes respectively.

It may be concluded that the batch volume had no significant effect on compressive strength; however, the set time tended to increase for the larger-volume batches. Extrapolation for increase in set time for batches larger than 3 ft^3 should not be assumed without further study.

Cylinder Size. To investigate the effects of cylinder size on compressive strength, eight 6 x 12-inch and eight 3 x 6-inch cylinders were cast from the same batch and tested alternately in pairs of one large and one small cylinder. The results of these paired compressive tests are shown in Figure 10. It is seen that neither cylinder is predominantly favored with a higher compressive strength. The ratio of the average compressive strength for the small-size cylinders to that for the large-size cylinders is 1.02.

Age. To investigate the variation of concrete with age, four batches representing Mix 1 and Mix 2 were used. Two cylinders from each batch were tested at 1 hour and the remaining cylinders of each batch were tested in pairs at predetermined ages.



Data Source	Mix 1		Mix 2	
	Average f'_c (psi)	Average Set Time (min)	Average f'_c (psi)	Average Set Time (min)
Small-scale (indoor) laboratory tests	2,000	10	3,000	12
Large-scale (outdoor) laboratory tests	1,980	12	2,910	14

Figure 9. Statistical representation of number of tested cylinders versus compressive strength for Mix 1 and Mix 2 from large-volume batches.

Figure 11 gives the variation with age for the ratio of the concrete compressive strength at a given time relative to that at 1 hour. These results show that compressive strength remains relatively constant for ages of concrete ranging from 15 minutes up to 7 days.

Splitting Tensile Strength

Split cylinder tests were conducted on 6 x 12-inch cylinders cast from seven batches of Mix 1 and Mix 2. For each batch, six cylinders were tested in the following sequence: (1) two compressive tests (at 1 hour from time of setting), (2) two split cylinder tests, and (3) two compressive tests. The relationship between average splitting tensile strength and average compressive strength for each test series is shown in Figure 12. Included in Figure 12 is an empirical relation[9] that gives the relation between the splitting tensile strength, f_{sp}, and the compressive strength, f'_c, for concrete made of portland cement.

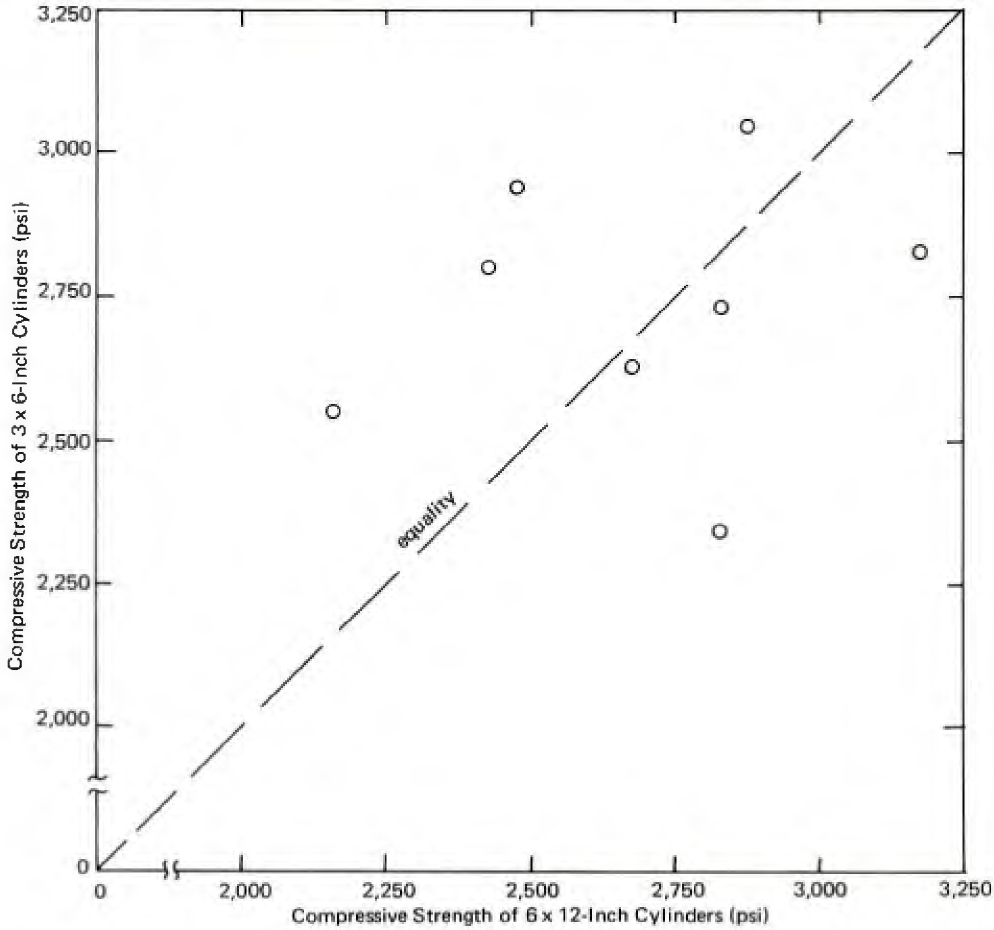
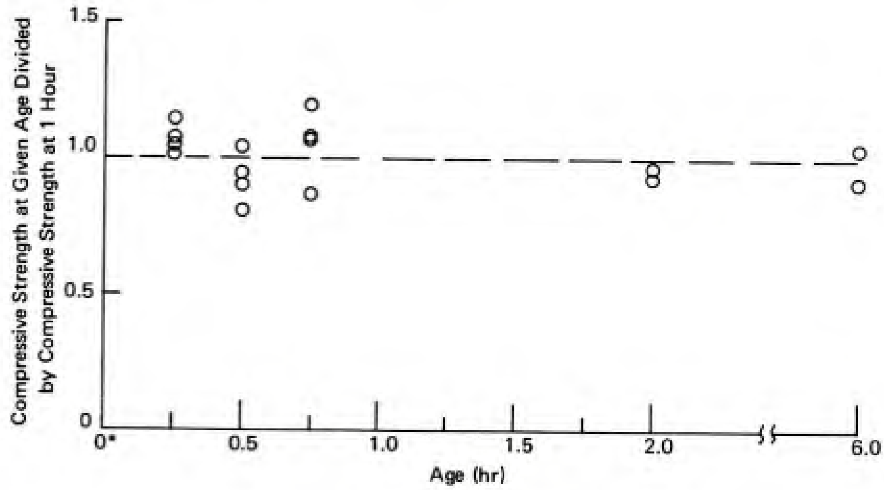


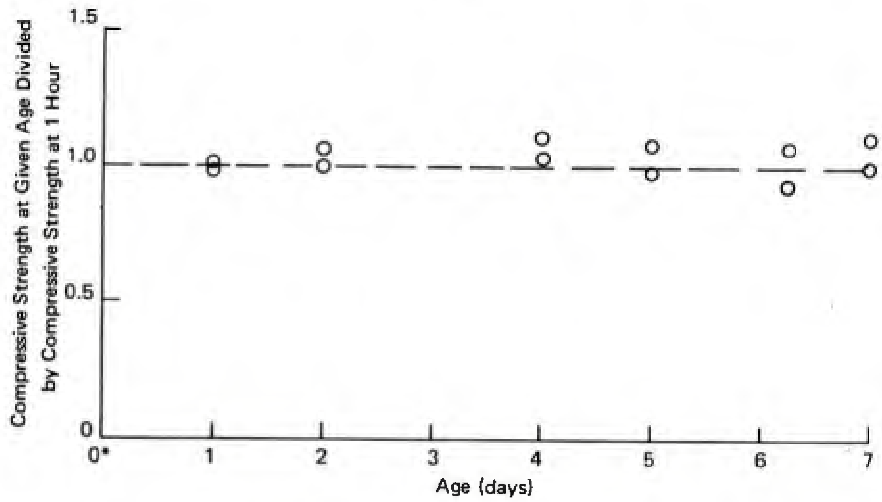
Figure 10. Comparison of compressive strength of standard (6 x 12 inch) cylinders with that of smaller (3 x 6 inch) cylinders.

For all data points shown in Figure 12, the average splitting tensile strength is 9.7% of the average compressive strength. The splitting tensile strength may be linearly approximated by $f_{sp} = 0.054 f'_c + 104$ when f'_c is equal to or between 2,000 psi and 3,000 psi.

Stress–Strain Relations in Compression

Load–deformation curves were obtained from test cylinders cast from 10 large-volume batches representing both Mix 1 and Mix 2. Typical stress–strain curves for control-cylinder tests of both mixes are shown in Figure 13. Included in Figure 13 are the respective initial moduli of both test cylinders, and in tabular form are shown the secant moduli at 1/3 f'_c, 1/2 f'_c, and 9/10 f'_c. Figures 14 through 17 show the relationships between compressive strength and both initial tangent modulus and secant modulus at various stress levels, namely, 1/3 f'_c, 1/2 f'_c, and 9/10 f'_c. For comparison and reference, each graph contains the curve representing the equation $E_c = 33 w^{1.5}\sqrt{f'_c}$, which is the expression for the modulus recommended by the ACI Code[6] for portland concrete. It is interesting to note that the scatter of data points for each of the four graphs does not show an increasing trend of modulus proportional to $\sqrt{f'_c}$, but rather the moduli remain almost constant as shown in the table of Figure 14.





* Age = 0 at time of setting

Figure 11. Variation of compressive strength with age.

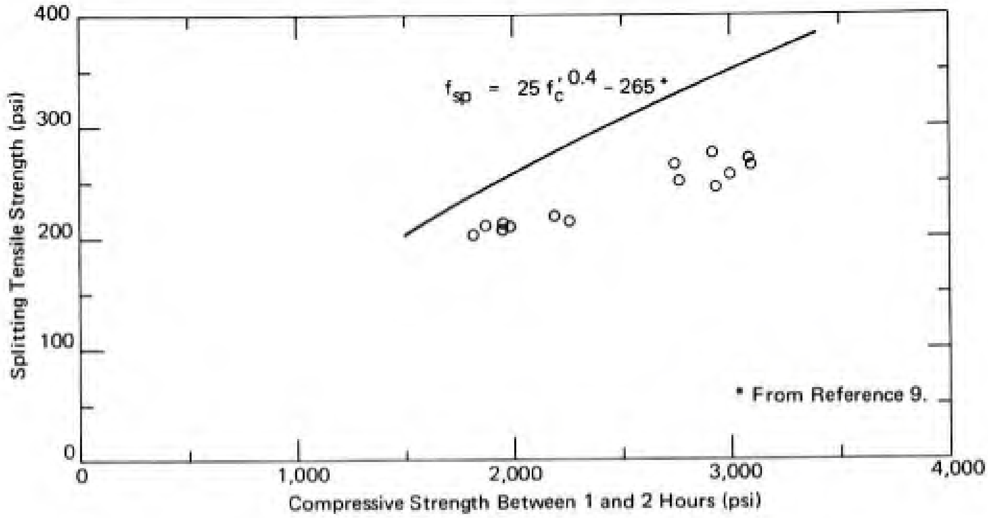
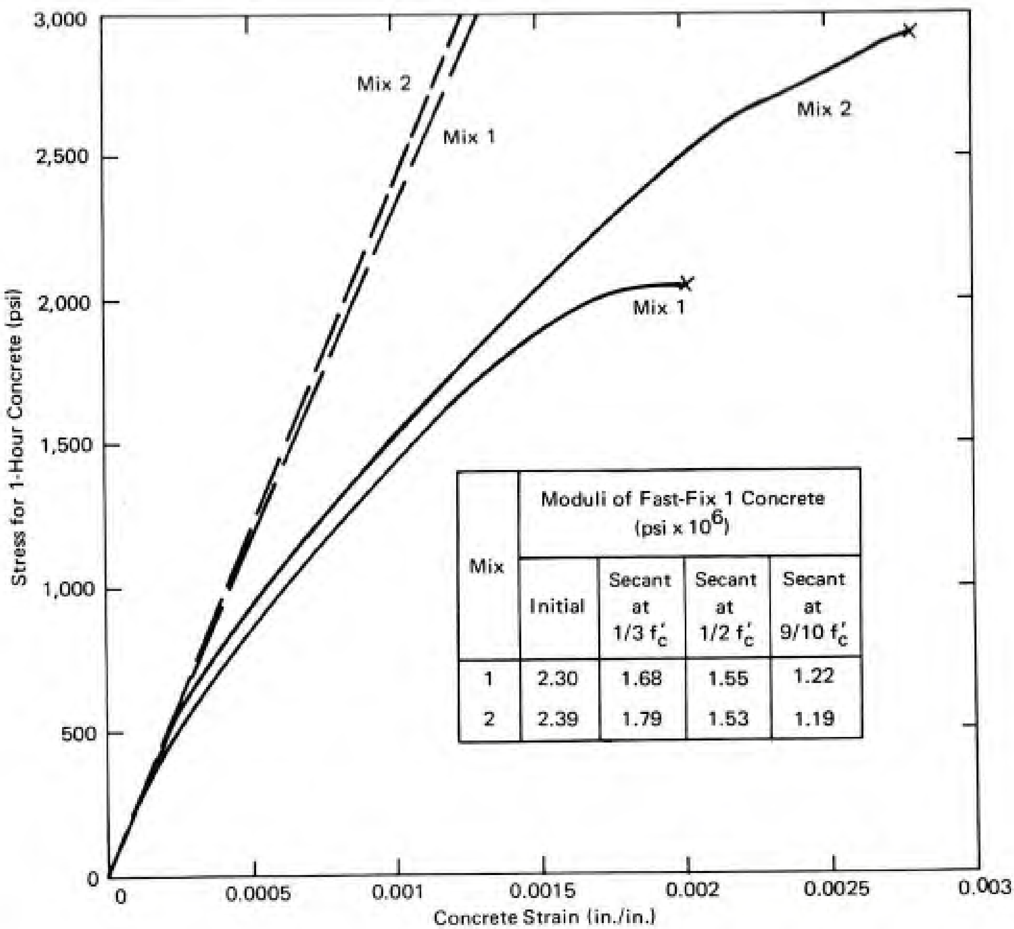
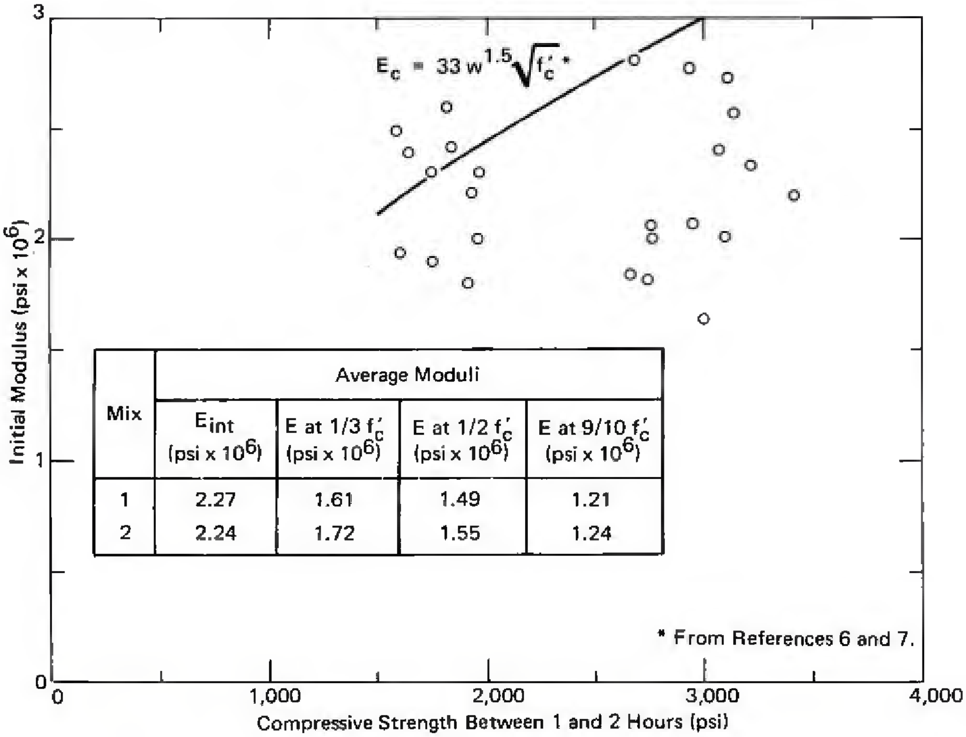


Figure 12. Splitting tensile strength versus compressive strength.



Mix	Moduli of Fast-Fix 1 Concrete (psi x 10^6)			
	Initial	Secant at 1/3 f_c'	Secant at 1/2 f_c'	Secant at 9/10 f_c'
1	2.30	1.68	1.55	1.22
2	2.39	1.79	1.53	1.19

Figure 13. Typical stress–strain curves for Mix 1 and Mix 2.



Mix	Average Moduli			
	E_{int} (psi x 10^6)	E at 1/3 f'_c (psi x 10^6)	E at 1/2 f'_c (psi x 10^6)	E at 9/10 f'_c (psi x 10^6)
1	2.27	1.61	1.49	1.21
2	2.24	1.72	1.55	1.24

Figure 14. Initial modulus versus compressive strength.

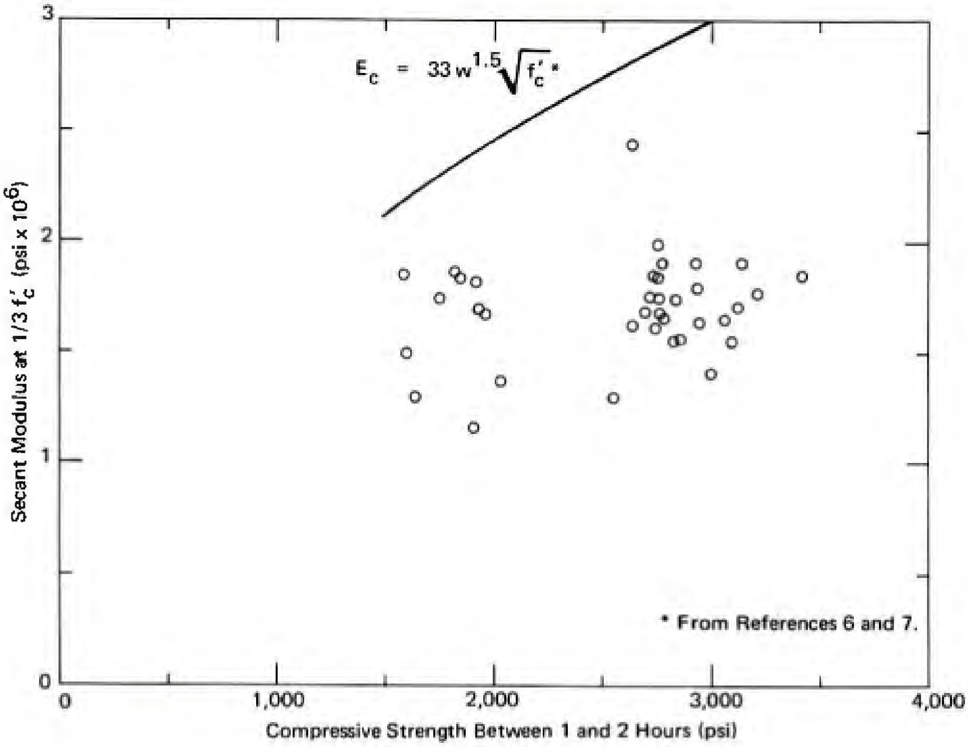


Figure 15. Secant modulus at 1/3 f'_c versus compressive strength.

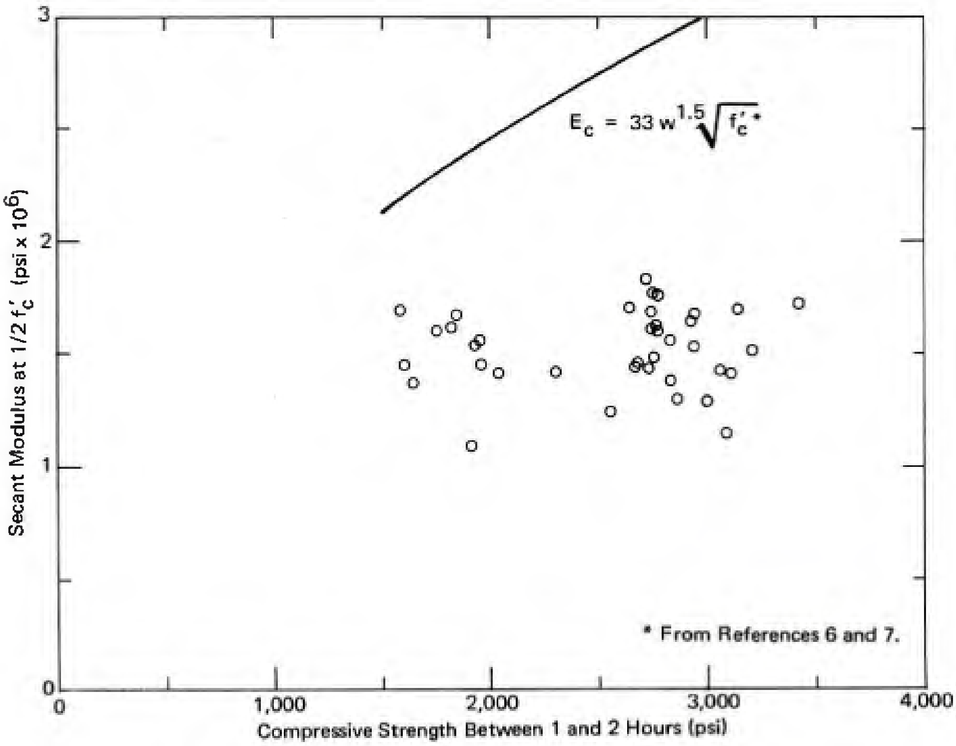


Figure 16. Secant modulus at 1/2 f'_c versus compressive strength.

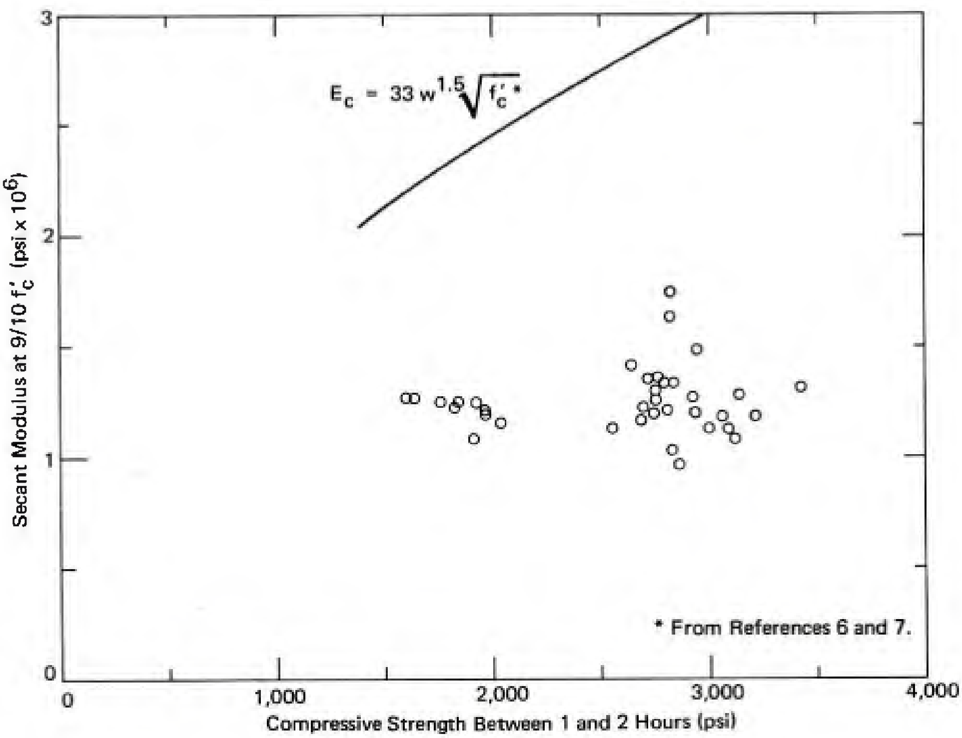


Figure 17. Secant modulus at 9/10 f'_c versus compressive strength.

Figure 18 gives strain (ϵ_o) at maximum stress as a function of f_c' for each cylinder test. In addition, an empirical curve for the strain at maximum stress versus f_c' is shown. This curve, which was developed by Hognestad,[10] is for concrete made of portland cement.

A cursory investigation of creep response was made by step loading a standard cylinder cast from Mix 1. The loading was done in increments of 10,000 pounds with each increment held for 3 minutes. The resulting stress–strain relation is shown in Figure 19. It is apparent that viscous response is significant, and consequently any rigorous analysis for deformation should include time effects.

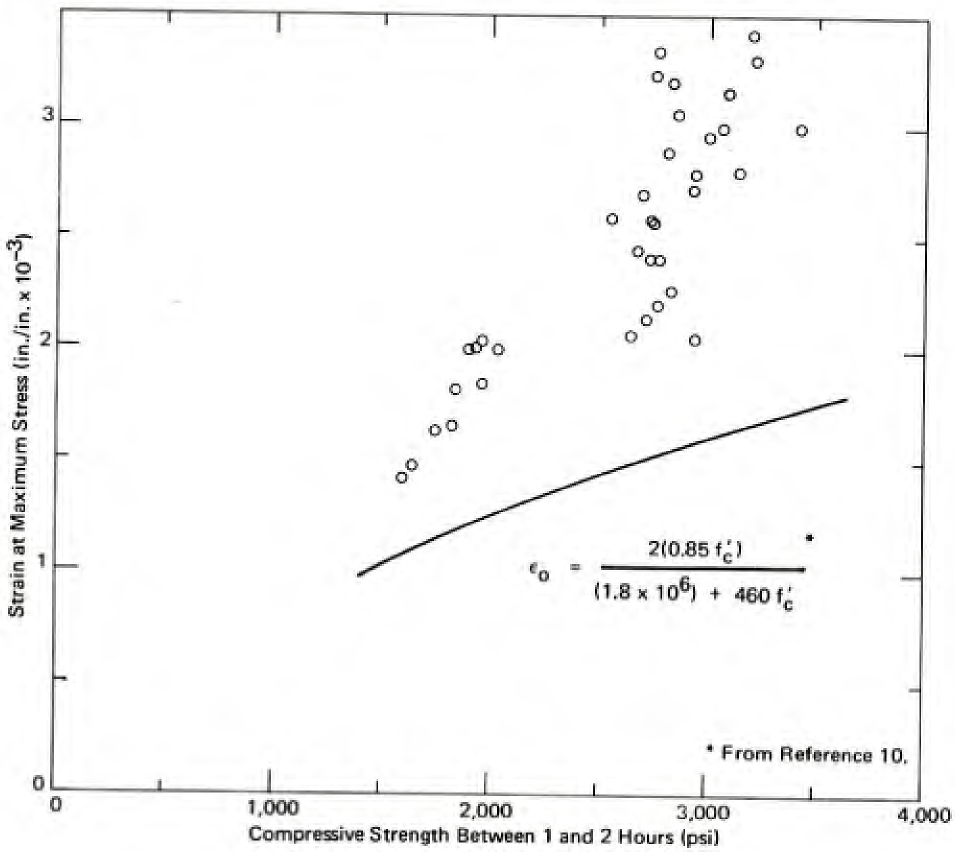


Figure 18. Strain at maximum stress versus compressive strength.

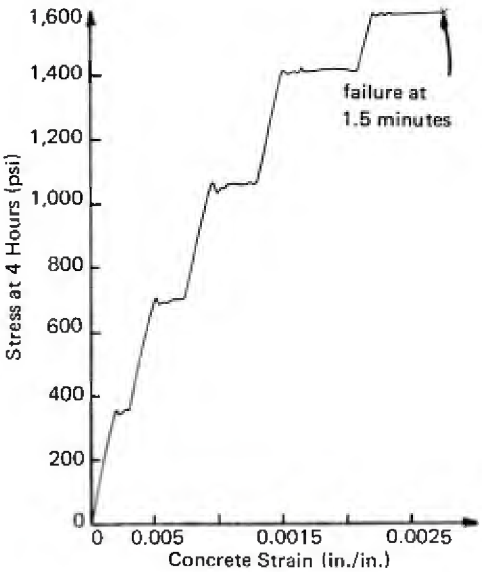


Figure 19. Effect of step load input on stress–strain relation for a 6 x 12-inch cylinder of Mix 1. (Each load plateau was held for 3 minutes.)

DISCUSSION

As mentioned earlier, set time is an important parameter when mix designs of concrete made of Fast-Fix 1 cement are considered, as evidenced from the trends shown in Figures 7 and 8. These graphs indicate that both set time and compressive strength can be increased by decreasing the aggregate-to-cement ratio while holding the water-cement ratio constant. This may be desirable in that it affords a means of increasing compressive strength without the worry of the concrete setting too fast, but it is economically undesirable because of the increased cement content.

The graphs also indicate that compressive strength may be increased by decreasing the water-cement ratio and holding the aggregate-to-cement ratio constant. This procedure is economically desirable in that compressive strength is increased without an exorbitant increase of cement content; however, set time decreases substantially. Thus, even though this procedure for increasing compressive strength yields a more economical mix than the first method, it has a practical limitation in that the concrete may set before pouring is finished and the job will be a complete loss.

From the foregoing it is evident that set time must be given utmost consideration in designing mix proportions of Fast-Fix concrete. Design recommendations have been established to economically obtain mix proportions for a specified compressive strength and set time. At the present time, investigations are being conducted to develop a retarder that would increase set time without adversely affecting compressive strength. When such a retarder is perfected, additional design curves for various percentages of retarder could be constructed that would give the most economical mix proportions for a specified compressive strength and set time.

Results indicate that workability, measured in terms of slump, decreases with set time; however, once again, practical values of set time play an important role. In the opinion of the authors, 7 minutes is a practical lower limit for completing casting, since within this time, concrete must be placed, screeded, and finished in addition to cleaning the tools and mixer prior to setting of concrete. This implies that a minimum practical set time is 10 minutes because 3 minutes of wet mixing is included in the definition of set time. It is of interest to note that for all mixes with a set time greater than or equal to 10 minutes, the observed slump ranged from 10 to 11-1/2 inches. Although the slump was very high for all batches, aggregate segregation was observed only for the mixes with the higher cement content.

With this in mind, one comes to the conclusion that the choice of a mix with practical set time guarantees a high value for slump, but the choice of a mix with a value of slump of less than 7 inches does not result in a practical value of set time. Therefore, specification parameters for mix proportions using Fast-Fix cement should be set time and compressive strength, rather than slump and compressive strength as in portland cement.

FINDINGS

Within the scope of this investigation, the following appear to be valid:

1. Compressive strengths up to 3,300 psi along with a practical value for set time can be achieved by proper choice of mix proportions.

2. For a constant aggregate-to-cement ratio and constant set time, the sand-to-total-aggregate ratio has only a small effect on compressive strength. The sand-to-total-aggregate ratio yielding the best result is 0.60.

3. Decreasing water-cement ratio while holding aggregate-to-cement ratio constant increases compressive strength but decreases set time.

4. When the water-cement ratio is held constant, a decrease of the aggregate-to-cement ratio results in an increase of both compressive strength and set time.

5. Identical mix proportions for batches with volumes of 0.06 ft^3 and 3.0 ft^3 yielded cylinders of similar compressive strength, but set time was extended by 2 minutes for the batches of larger volume.

6. When control cylinders of dimensions 3 x 6 inches and 6 x 12 inches were cast from the same batch, the average compressive strength for cylinders of the two sizes differed by only 2%.

7. Age of concrete up to 7 days has practically no effect on compressive strength.

8. Splitting tensile strength averages about 10% f'_c and may be linearly approximated by $f_{sp} = 0.054 f'_c + 104$ . . . for $2{,}000 \leq f'_c \leq 3{,}000$ psi.

9. Stress–strain relations indicate that the moduli of concrete do not increase consistently with the compressive strength within the limits tested. That is, for the compressive strength between the nominal limits of 2,000 psi and 3,000 psi, the initial tangent modulus and the secant moduli measured at 1/3, 1/2, and 9/10 of the ultimate compressive strength were essentially invariant and averaged 2.25×10^6, 1.66×10^6, 1.52×10^6, and 1.22×10^6 psi, respectively.

10. Stress–strain curves indicate that Fast-Fix concrete is a nonlinear material that exhibits a significant creep response.

DESIGN RECOMMENDATIONS

The design curves in Figure 20 are intended for mixes with a yield volume in excess of 2 ft^3 and mixed in a rotating drum mixer. The density of Fast-Fix 1 concrete may be taken as 140 lb/ft^3.

The aggregate should be composed of three parts sand to two parts crushed coarse aggregate by weight; materials can be used without washing. Maximum aggregate size and gradation should be chosen by the same specifications applying to concrete made with portland cement. Weight of aggregates is to be based on saturated surface-dry condition (assumed as 1% moisture above oven-dry condition).

Use of Design Curves

Specification Parameters. To utilize the design curves, compressive strength and set time must be predetermined. Keep in mind that the lower these values are, the more economical the required mix proportion will be. To specify set time, estimate the minimum time required for placing and finishing concrete and cleaning mixer; to this add 3 minutes for wet mixing. This time interval in minutes is the desired set time.

Procedure. Enter upper graph (Figure 20) with desired compressive strength. Move horizontally to the right and intersect desired set-time curve. From this intersection move vertically downward to the abscissa and read required aggregate-to-cement ratio. Continue the vertical line into the lower graph and again intersect desired set-time curve. From this point move horizontally to the left and read required water-cement ratio.

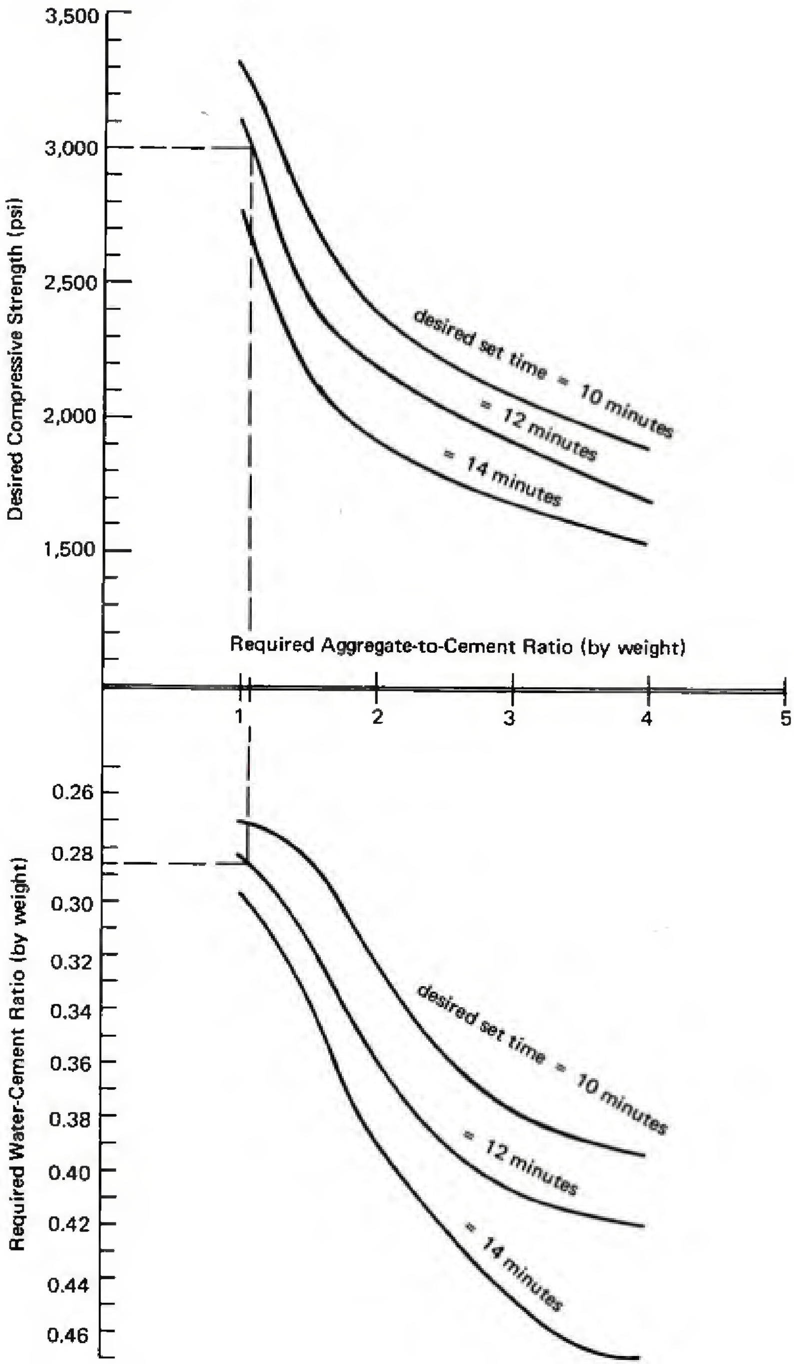


Figure 20. Design curves for Fast-Fix 1 concrete.

Corrections. The moisture content of the aggregates is based on 1% moisture above oven-dry condition. Any deviation from this must be corrected for by total water added to the mix.

Example

In this example the following are specified.

Desired compressive strength = 3,000 psi

Time estimate for casting = 9 minutes

Wet mixing time = 3 minutes

Therefore, set time = 9 + 3 = 12 minutes

Volume desired = 1.0 yd^3

With these specifications in mind, the user should proceed to determine the mix proportions from the design curves as follows:

1. From compressive strength of 3,000 psi and set-time curve labeled 12 minutes read the required aggregate-to-cement ratio (approximately 1.07).

2. Continuing vertical line into lower graph, intersect the set-time curve of 12 minutes and read the required water-cement ratio (0.286).

For 1 yd^3 of concrete at a density of 140 lb/ft^3, the total weight of ingredients = 27 x 140 = 3,780 lb. From steps 1 and 2 above, the weight of water and aggregates can be written in terms of the weight of the cement as follows:

weight of water = 0.286 x weight of cement

weight of aggregates = 1.07 x weight of cement

Therefore, the weight of cement, water, and aggregate equals (1.0 + 0.286 + 1.07) x weight of cement; this is equal to the weight calculated above (3,780 lb). Thus, the weight of cement = 3,780/(1.0 + 0.286 + 1.07) = 1,604 lb. The weight of water (net) = 0.286 x 1,604 = 459 lb. The weight of aggregate (at 1% moisture content by weight) = 1.07 x 1,604 = 1,716 lb. The weight ratio of crushed gravel to sand is 2/3; thus:

the weight of sand (at 1% moisture) = 0.6 x 1,716 = 1,030 lb

the weight of gravel (at 1% moisture) = 0.4 x 1,716 = 686 lb

To correct the weights for deviations in the moisture content from the saturated surface-dry condition for the two constituents of the aggregate, assume that the moisture content above that of the oven-dry condition were found to be as follows:

$$\text{Moisture content for sand (MCS)} = 3.0\% = 0.03$$

$$\text{Moisture content for gravel (MCG)} = 1.5\% = 0.015$$

The weights for correction are as follows:

$$\text{for sand} = (\text{MCS} - 0.01) \times \text{weight of sand (at 1\% moisture)}$$

$$= (0.03 - 0.01) \times 1{,}030 = 20.6 \text{ lb}$$

$$\text{for gravel} = (0.015 - 0.01) \times 686 = 3.4 \text{ lb}$$

Corrected weights are, therefore, as follows:

$$\text{cement} = 1{,}604 \text{ lb}$$

$$\text{sand} = 1{,}030 + 20.6 = 1{,}050.6 \text{ lb}$$

$$\text{crushed gravel} = 686 + 3.4 = 689.4 \text{ lb}$$

$$\text{water} = 459 - 20.6 - 3.4 = 435 \text{ lb}$$

Mixing Recommendations

The following mixing recommendations, which was adopted for this study, is based upon reports from and discussions with knowledgable people.

1. Prewet the mixer if it is dry and drain so that no free water is left standing.

2. Load mixer with sand and gravel and mix for 1-1/2 minutes.

3. Add Fast-Fix 1 cement and mix dry ingredients for an additional 1-1/2 minutes.

4. Add mixing water as fast as possible and mix for exactly 3 more minutes.

5. In case of mixing numerous consecutive batches, it is recommended that about 90% of the water required be introduced into the mixer along with the aggregate and mixed for about 1-1/2 minutes; this will facilitate the cleaning of the cement from the blades of the mixer. After the Fast-Fix 1 cement is added, the remaining water required is added and mixing is continued for exactly 3 more minutes. A reduction of set time for following batches as compared to the first batch can be expected. If the time interval between consecutive mixes is greater than 10 minutes, the mixer should be completely cleaned; otherwise the Fast-Fix concrete will harden in the mixer.

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S. B. Nosseir and M. G. Katona

TR-613 29 p. illus February 1969 Unclassified

1. Concrete—Rapid setting I. YF 38.536.006.01.002

The purpose of this investigation was to obtain information required for the use of Fast-Fix 1 concrete as a structural material. In particular, the effects of concrete mix design parameters and aging were investigated to determine if varying them would permit attaining compressive strengths in excess of 2,500 psi without the use of retarding agents. In addition, splitting tensile strength and compressive stress–strain relations were determined for standard control cylinders. Results indicated that for concretes with an age of 1 hour, compressive strengths up to 3,300 psi can be achieved by proper selection of constituents. Attempts to attain higher compressive strengths resulted in unworkably short set times and exorbitant cement contents. The age of the concrete did not alter its compressive strength within the limits tested. Recommendations are presented in the form of design curves which enable one to design a mix for a specified compressive strength and set time.

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13. ABSTRACT

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