THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Civil Engineering

Final Report

PHYSICAL PROPERTIES OF SAND—POLYURETHANE—POLYETHYLENE MIXTURES

Norman W. Edwards
Robert B. Harris

ORA Project 05891

under contract with:

URETHANE SALES COMPANY, INC.
LOS ANGELES, CALIFORNIA
for
DELKA RESEARCH CORPORATION

administered through:

OFFICE OF RESEARCH ADMINISTRATION ANN ARBOR

October 1963

?n m

:MR0631

This report is submitted for the exclusive use of the sponsor of this project.

The name of THE UNIVERSITY OF MICHIGAN or any of its staff shall not be used in connection with any form of publicity or advertising without the prior written approval of the Director of Research Administration.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Concluded)

INTRODUCTION

During the past few years there have been developed many uses for polyurethane compounds in the construction industry for insulation, coatings, sealants, and so forth. Some of these compounds when mixed with sand appear to have a potential as a topping for floors, paving, patching of concrete, and similar applications. The research reported herein attempts to evaluate a few of the physical properties of such mixtures.

Nine polyurethane-polyethylene compounds from four groups furnished by the sponsor were tested with the same sand and the results compared. One group, referred to as Standard or UPNT-S, consisted of three colors, black, clear, and gray. This group was a single component system which was mixed with the sand, cast and cured in open air.

A second group, referred to as Guardian or UPNT-G, was comprised of two colors, black and gray. This group was a two component system in which two compounds, "A" and "B", were mixed together in equal portions before mixing with the sand.

A third group, referred to as UPCS, contained three colors, black, clear, and gray, and required the addition of a catalyst before mixing with the sand to promote curing.

The fourth group, known as UPCM-50, was of only one color, clear, and also required a catalyst.

The sand was common mason sand obtained locally and had the following sieve analysis.

Sieve Size*	Total Per Cent Passing	Total Per Cent Retained
4	100.00	0
8	99.48	0.52
16	96.59	3.41
30	84.71	15.29
50	46.52	53.48
100	9.52	90.48
Pan	-----	100.00

Fineness Modulus = 2.63

*U.S. Standard Sieve Series

Since the potential uses for the mixtures are similar to those of concrete, the basic testing procedure was derived from the testing procedures for concrete and mortars. The testing method used is given in detail in the Appendix.

Probably the most widely used test for concrete properties is the compression test of concrete cylinders. Accordingly, compression tests on 2 inch by 4 inch cylinders were made on each mixture of compound and sand. From the results of these tests can be seen the variation in ultimate compressive stress with curing age and the comparison of the nine compounds at each stage in the curing process. Compression cylinder tests also allow for the evaluation of the modulus of elasticity, a factor of importance in paving materials. The results show the variation of this property with the ultimate compressive strength and a comparison of the average moduli for each of the nine compounds.

Natural sands contain varying amounts of water, even surface dry sands having about one per cent moisture by weight. Because of this fact, tests were made to evaluate the effect of various moisture percentages upon the compressive strength of the mixture.

Compaction is another variable which has a definite influence upon the compressive strength of materials similar to the mixtures being tested. It was necessary to control this factor during the research and a series of tests was made to determine the effect of varied compaction levels.

While the tests made used only a constant ratio of sand to liquid compound, other mixing ratios are possible and may be desirable. This factor is also reported upon in this report.

Tensile properties of concretes are seldom significant for they tend to be rather low, nevertheless, the nature of the test mixtures seemed to require some determination of the tensile property of the material. Several tests were made to study the feasibility of using the split cylinder technique for future evaluations of this property.

Aggregate variations will also produce decided variations in compressive strength in concrete. A well graded aggregate with large to fine particles will tend to give higher compressive strengths than a rather uniformly graded small aggregate. In order to establish a relationship between the mixtures being evaluated and a comparable concrete, tests were made of normal portland cement cylinders of the same size, made with the same sand as used in the test mixtures, and with a properly proportioned water—cement ratio.

COMPARATIVE TESTS

The biggest portion of this testing program was concerned with the establishment of the relationship between the curing time and the compressive strength for each of the nine mixtures as well as a comparison of the nine compounds. A sand to liquid ratio of 5 to 1 was used. For the UPCS group, 0.634 per cent catalyst was used and 0.317 per cent catalyst was used with the UPCM group. It should be noted that the mix proportions and amounts of catalyst were not chosen because they gave the highest strengths, rather they were chosen because they gave a mixture of which was of a workable consistency and remained so for a time sufficient to cast the required number of specimens.

Two different batches of each of the nine compounds were made. Eighteen specimens from each batch were cast and tested in groups of three at ages 1, 3, 5, 7, 14, and 28 days. Strain measurements were taken on one of the three specimens from each group at ages of 3, 5, 7, 14, and 28 days. All casting and testing was done in accordance with the Standard Testing Procedure which is presented in the Appendix of this report. A total of 324 specimens were cast and tested in connection with this portion of the program. The results of these tests are shown in Table I. The columns headed TEST have listed in them the average compressive strength, in pounds per square inch, of the three specimens for any given batch and the columns headed AVE contain the average of the two batches listed.

To show the effect of curing time, the compressive strength versus the specimen age has been plotted in Figs. 1-4. As a means for comparing the nine different mixtures on the basis of their compressive strengths, bar charts giving compressive strengths at 3, 7, 14, and 28 days are presented in Figs. 5-8.

As has been previously stated, strain measurements were taken on one specimen from each group of three at the ages of 3, 5, 7, 14, and 28 days. From these measurements the Secant Modulus of Elasticity was calculated according to the method described in the Standard Testing Procedure. The results of these tests are shown in Table II. In order to compare the nine different mixtures on the basis of their moduli, bar charts giving moduli at ages of 7 and 28 days are given in Figs. 9 and 10. Fig. 11 is a plot of Secant Modulus of Elasticity versus compressive strength for all tests for which the modulus was evaluated. A curve has been drawn through these points to illustrate the apparent relationship between Secant Modulus and compressive strength.

TABLE I

		Code	1 Day Test	1 Day Ave	3 Day Test	3 Day Ave	5 Day Test	5 Day Ave	7 Day Test	7 Day Ave	14 Day Test	14 Day Ave	28 Day Test	28 Day Ave
			Compressive Strength (psi)											
UPCS	Black	USB-8	455	451	496	583	607	764	718	907	1067	1139	1276	1300
		USB-14	448		670		921		1096		1210		1324	
	Clear	USC-7	433	415	567	583	842	949	813	1024	1097	1089	1060	1121
		USC-16	396		598		1055		1234		1080		1182	
	Gray	USG-6	468	428	713	717	1049	1119	1101	1206	1282	1216	1251	1252
		USG-17	388		721		1189		1311		1150		1253	
GUARDIAN	Black	GUB-11	91	91	191	245	330	380	424	446	689	772	1768	1611
		GUB-18	--		298		429		467		854		1453	
	Gray	GUG-2	82	82	366	348	536	497	681	608	713	784	1776	1594
		GUG-19	--		329		457		534		854		1412	
STANDARD	Black	SDB-13	--	--	165	202	176	244	185	234	285	387	742	655
		SDB-21	--		239		311		282		489		568	
	Clear	SDC-12	--	--	271	360	262	391	253	354	357	472	602	611
		SDC-22	--		449		521		454		586		620	
	Gray	SDG-1	--	--	343	348	430	379	453	399	345	396	879	762
		SDG-23	--		353		328		344		446		645	
UPCM-50	Clear	UMC-10	351	367	564	536	829	787	818	827	905	875	1084	1065
		UMC-15	382		508		744		835		845		1046	

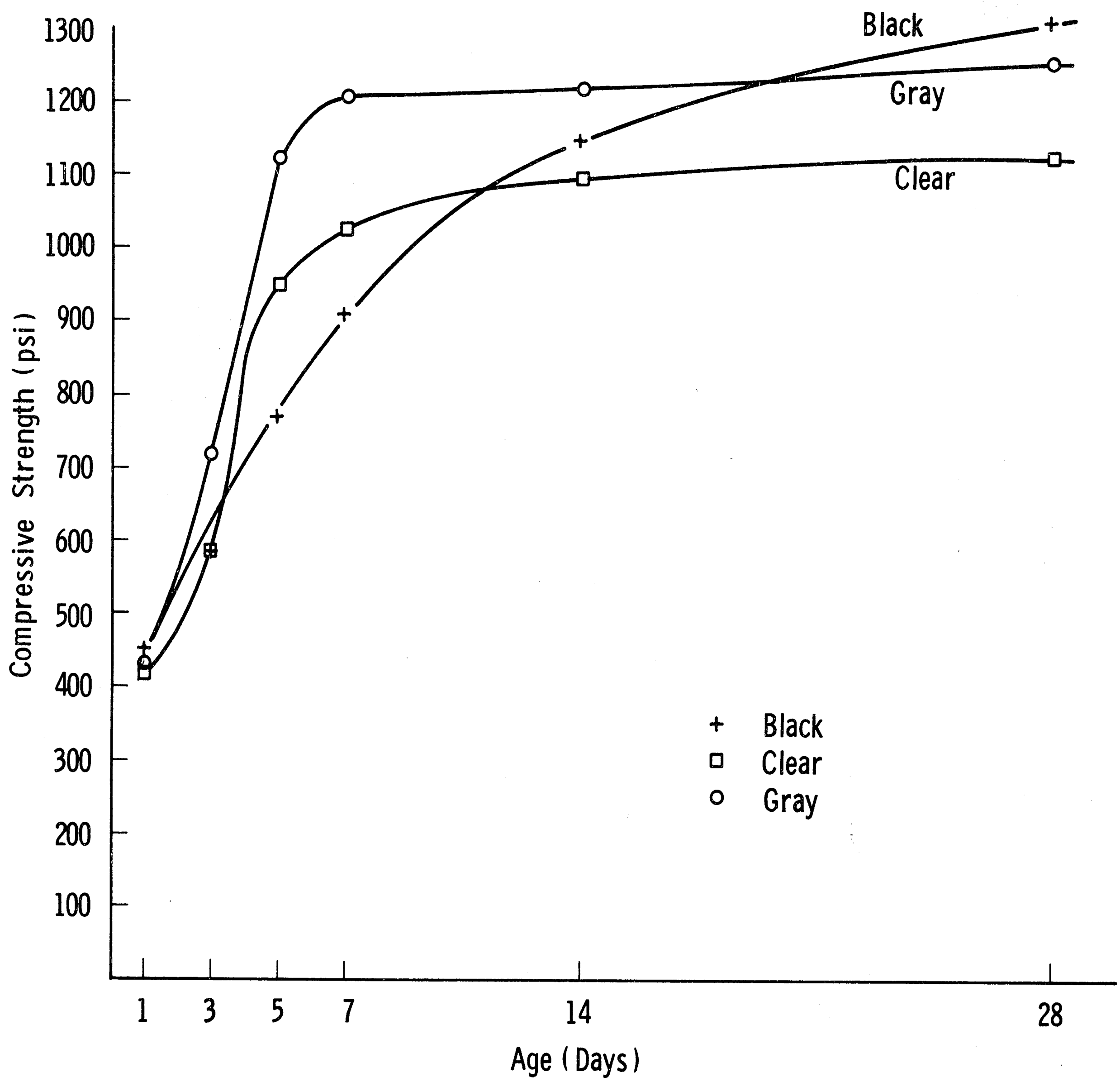

Fig. 1. Effect of Curing Time on the Ultimate Compressive Strength of UPCS—Black, Clear, and Gray mixed at a ratio of sand to liquid of 5 to 1 with 0.634 per cent catalyst.

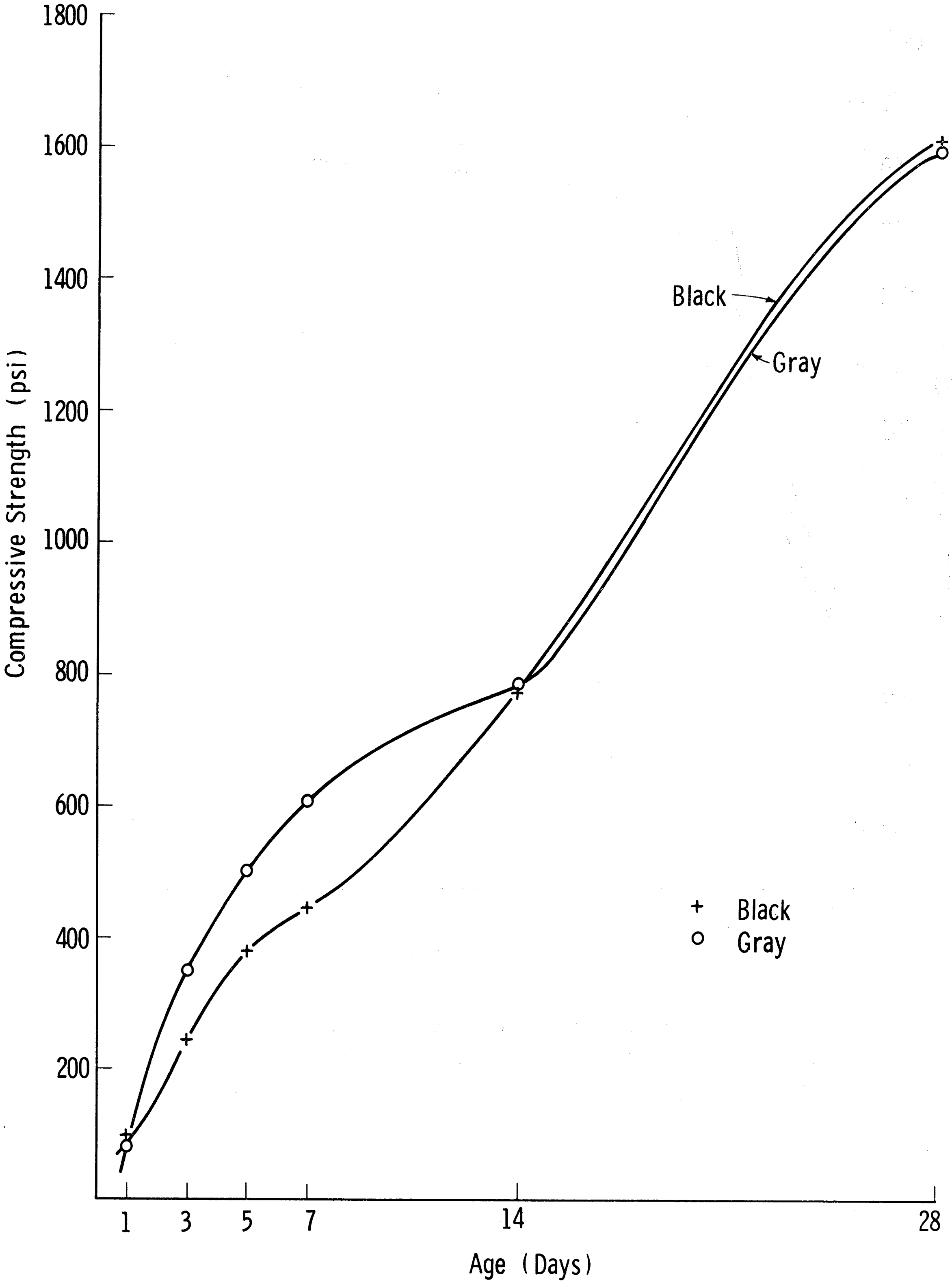

Fig. 2. Effect of Curing Time on the Ultimate Compressive Strength of Guardian—Black and Gray mixed at a ratio of sand to liquid of 5 to 1.

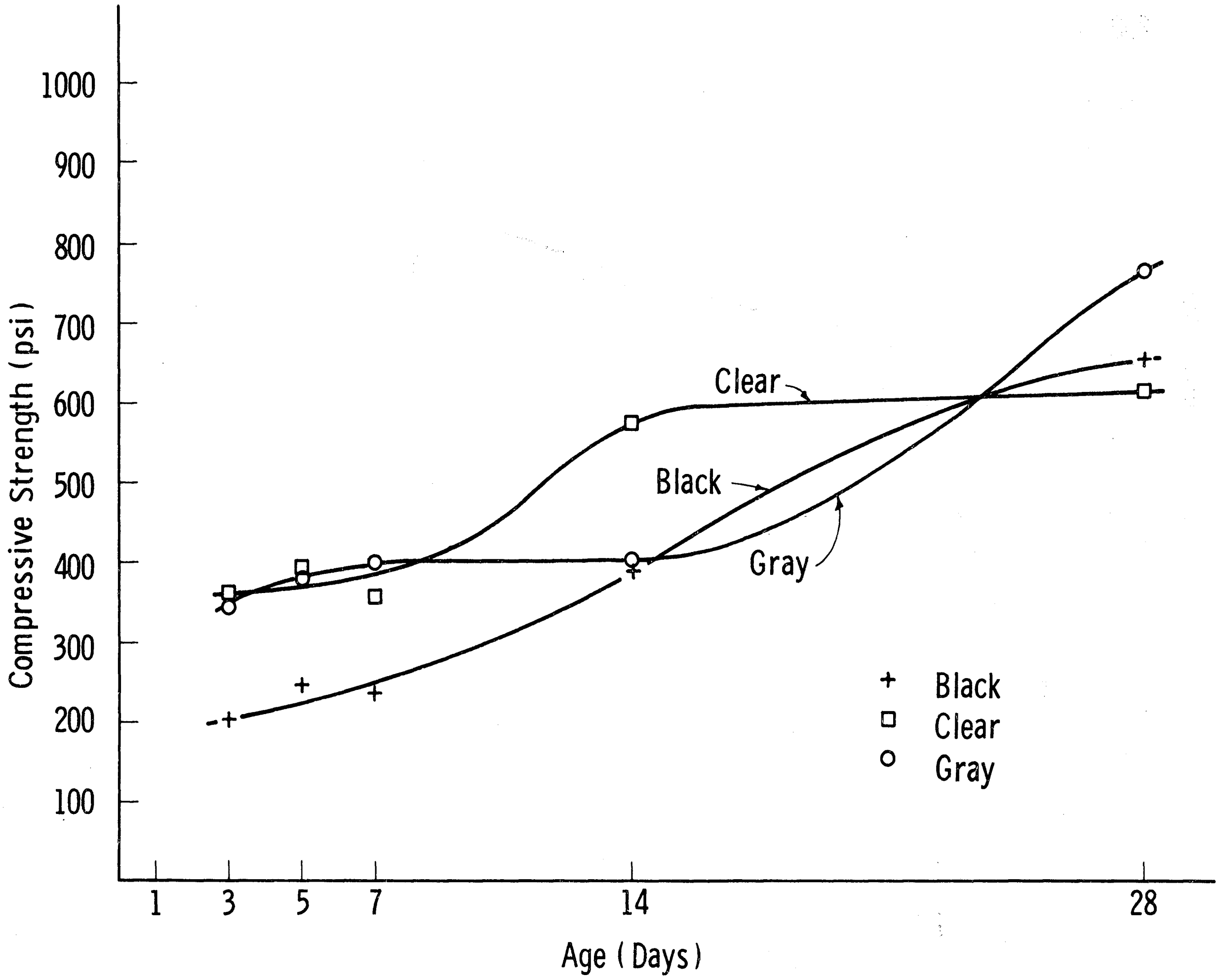

Fig. 3. Effect of Curing Time on the Ultimate Compressive Strength of Standard—Black, Clear, and Gray mixed at a ratio of sand to liquid of 5 to 1.

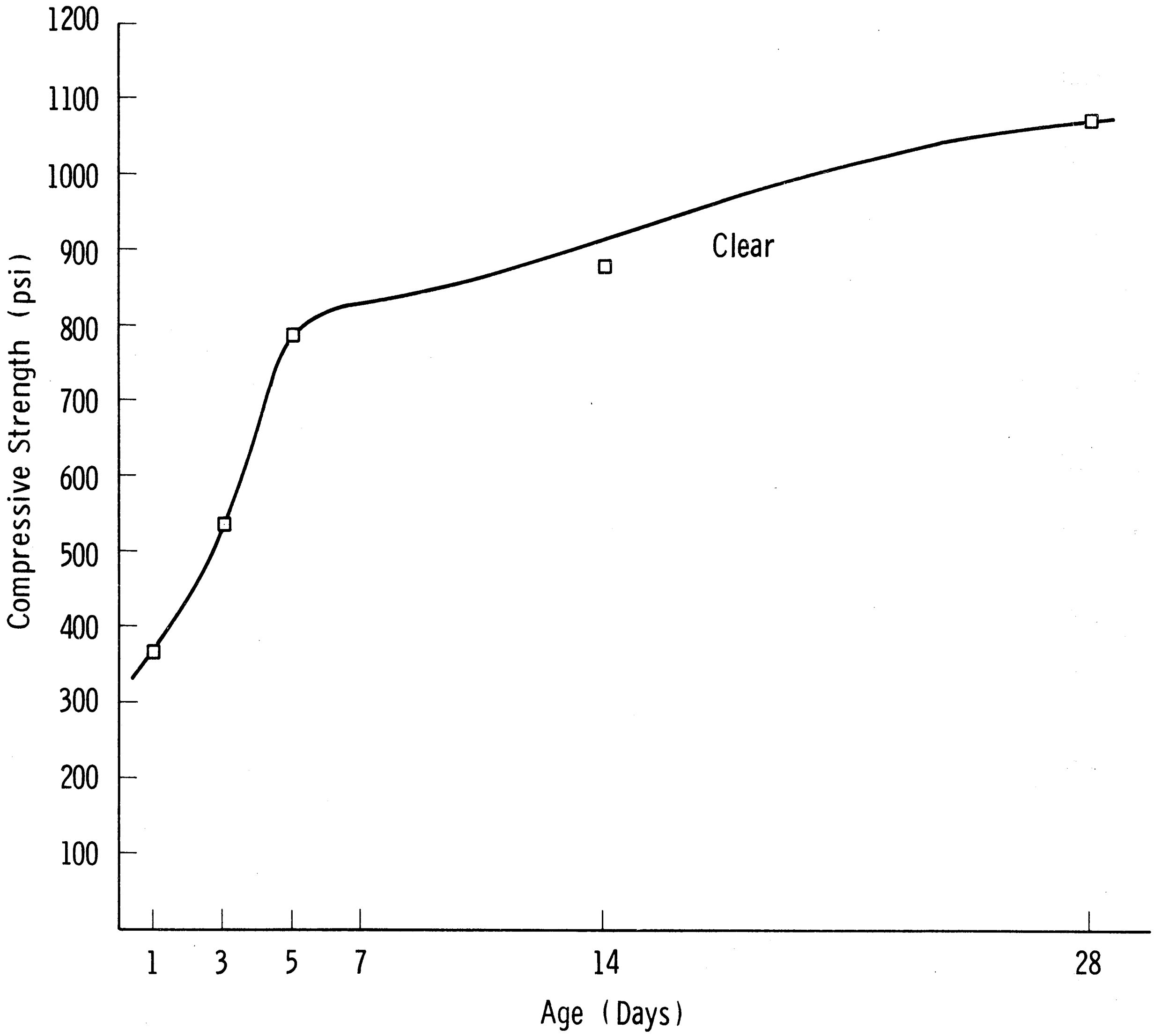

Fig. 4. Effect of Curing Time on the Ultimate Compressive Strength of UPCM—Clear mixed at a ratio of sand to liquid of 5 to 1 with 0.317 per cent catalyst.

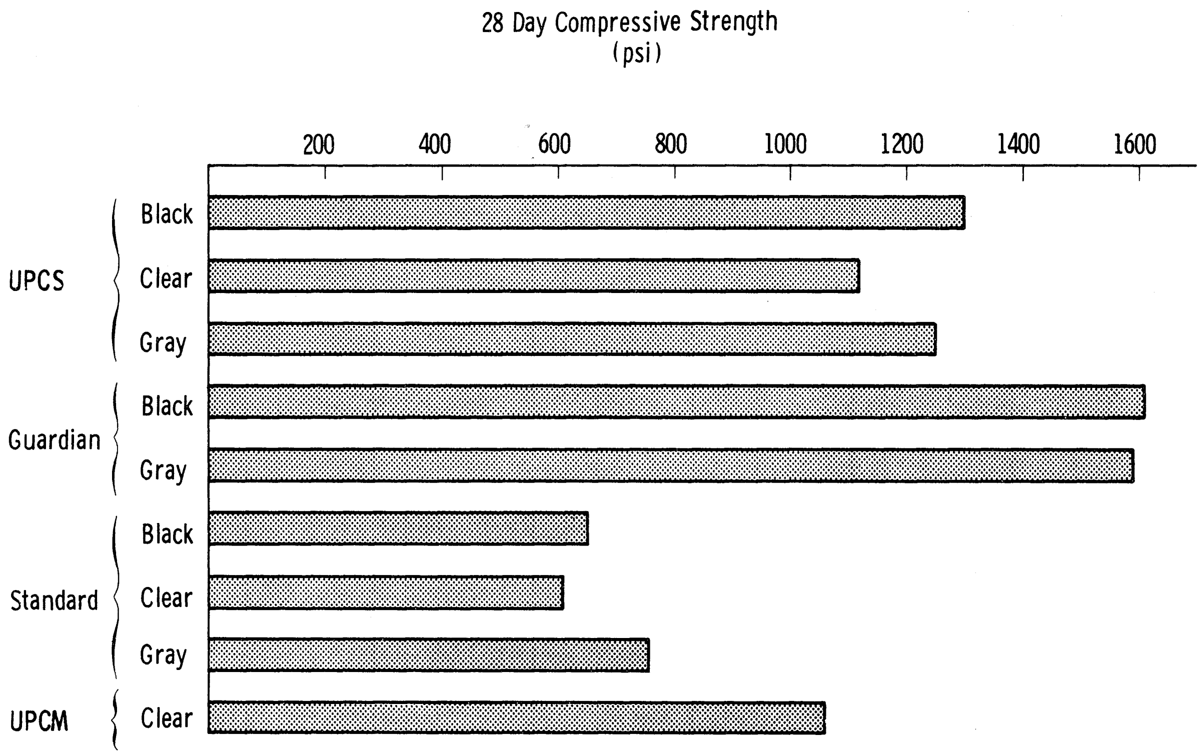

Fig. 5. Comparison of the nine different mixtures on the basis of their 28-Day Compressive Strengths.

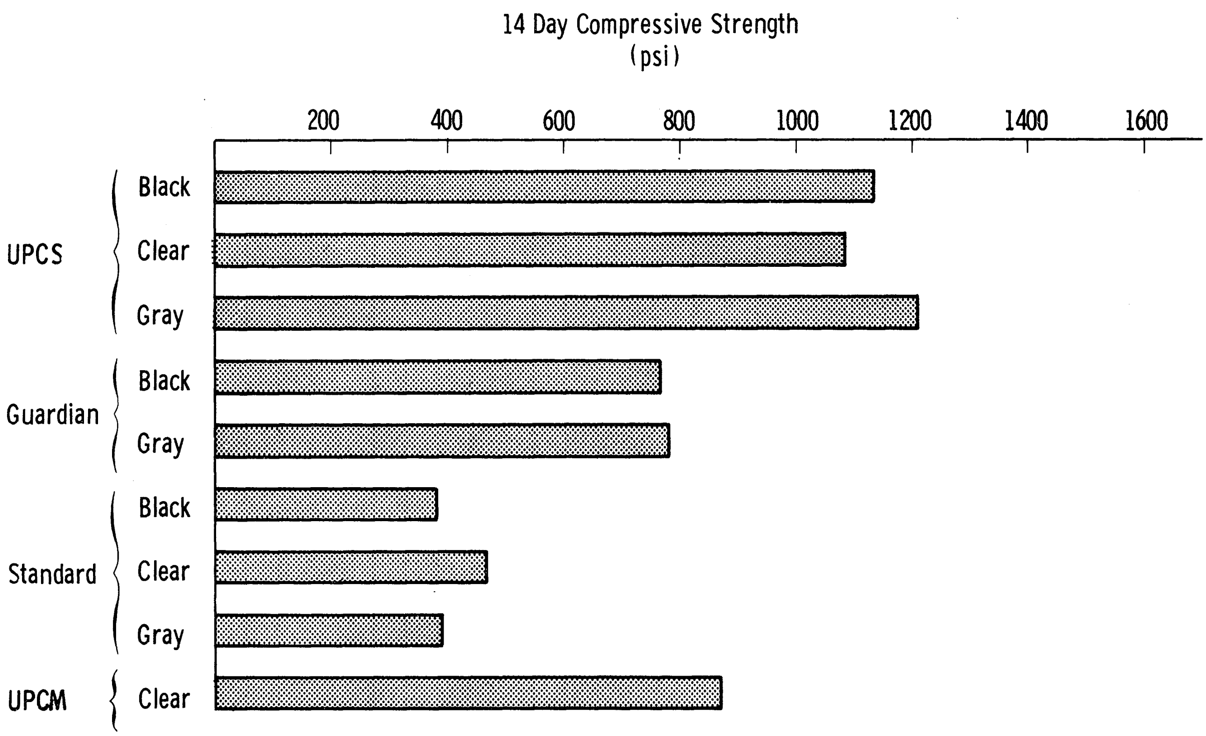

Fig. 6. Comparison of the nine different mixtures on the basis of their 14-Day Compressive Strengths.

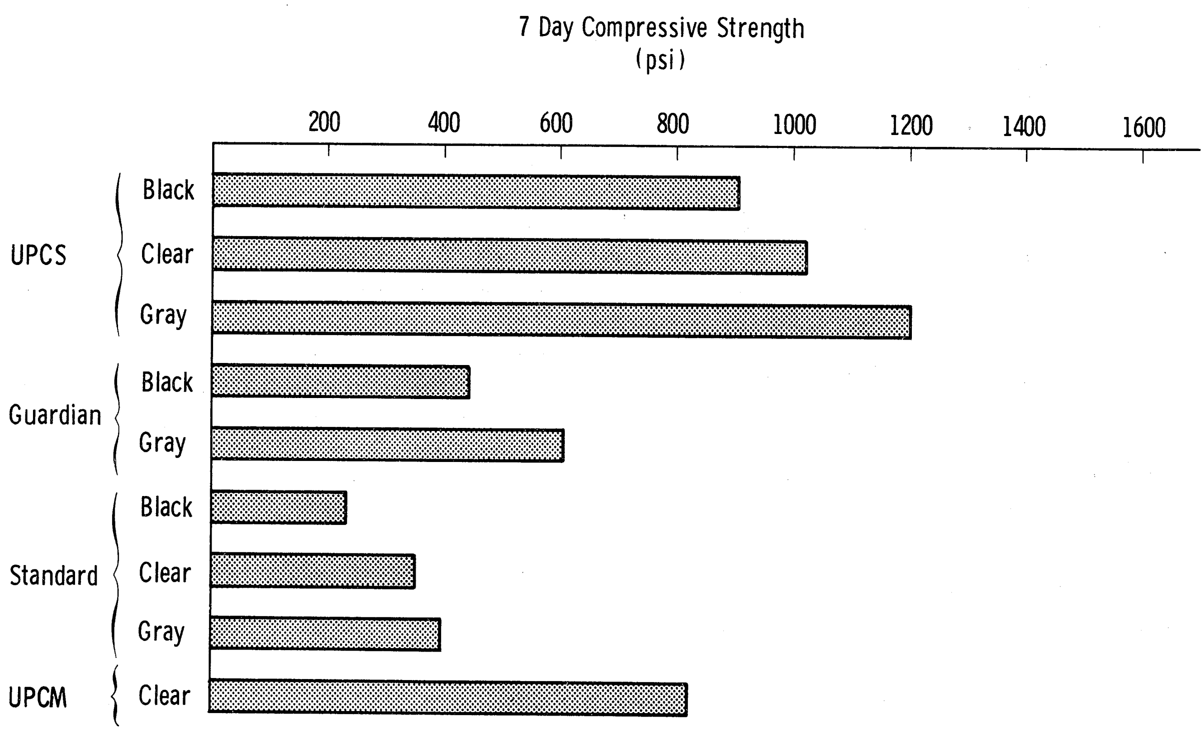

Fig. 7. Comparison of the nine different mixtures on the basis of their 7-Day Compressive Strengths.

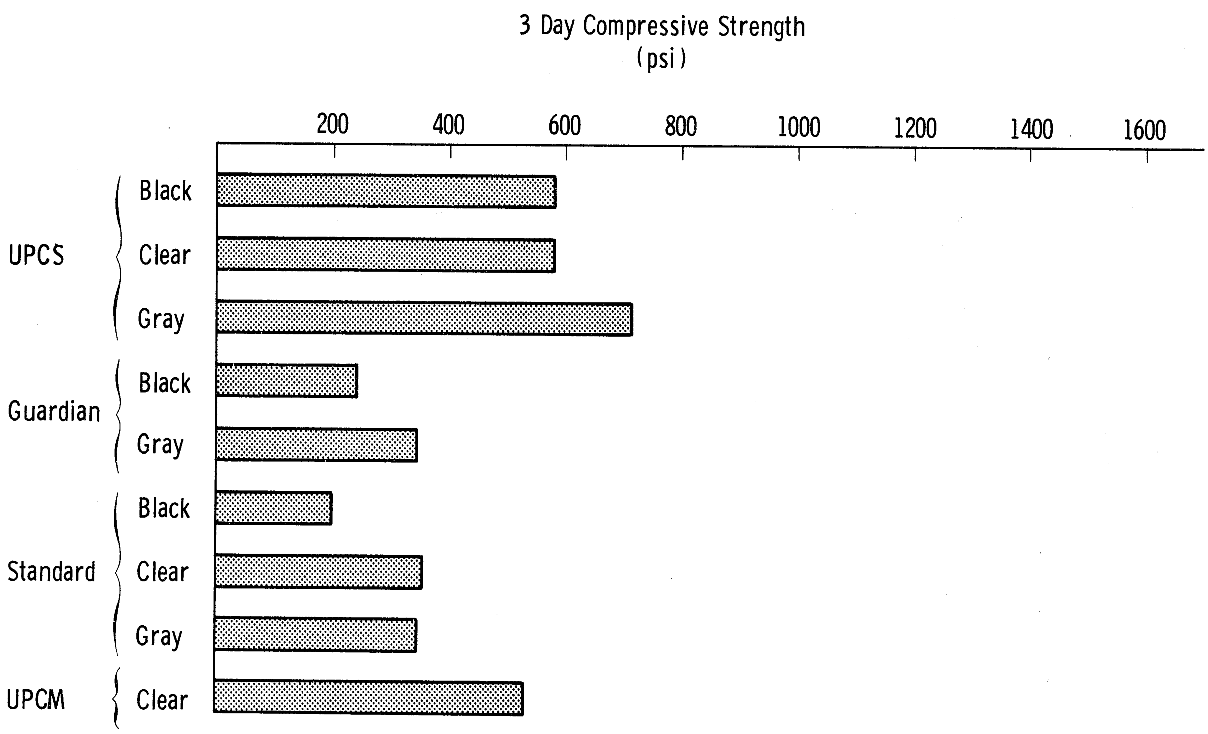

Fig. 8. Comparison of the nine different mixtures on the basis of their 3-Day Compressive Strengths.

TABLE II

		Code	Secant Modulus of Elasticity (psi)							
			5 Day		7 Day		14 Day		28 Day	
			Test	Ave	Test	Ave	Test	Ave	Test	Ave
UPCS	Black	USB-8 USB-14	34,200 62,600	48,400	45,100 62,500	53,800	60,800 78,500	69,650	65,600 105,000	85,300
	Clear	USC-7 USC-16	51,800 68,300	60,050	58,500 75,400	66,950	70,000 63,600	66,800	60,900 70,900	65,900
	Gray	USG-6 USG-17	73,100 70,800	71,950	75,300 96,400	85,850	88,400 70,500	79,450	99,800 74,700	87,250
GUARDIAN	Black	GUB-11 GUB-18	29,000 27,950	28,475	33,400 29,200	31,300	63,400 94,800	79,100	177,000 97,200	137,100
	Gray	GUG-2 GUG-19	44,300 34,700	39,500	50,300 35,600	42,950	51,500 93,800	72,650	206,000 93,750	149,875
STANDARD	Black	SDB-13 SDB-21	--- 25,950	25,950	9,580 25,300	17,440	27,400 43,500	35,450	46,800 42,200	44,500
	Clear	SDC-12 SDC-22	26,150 55,800	40,975	18,800 54,200	36,500	25,200 74,600	49,900	37,900 51,700	44,800
	Gray	SDG-1 SDG-23	--- 38,900	38,900	53,800 41,100	47,450	22,250 27,560	24,905	74,700 80,700	77,700
UPCM	Clear	UMC-10 UMC-15	46,600 35,600	41,100	44,950 46,700	45,825	46,800 56,200	51,500	71,800 61,500	66,650

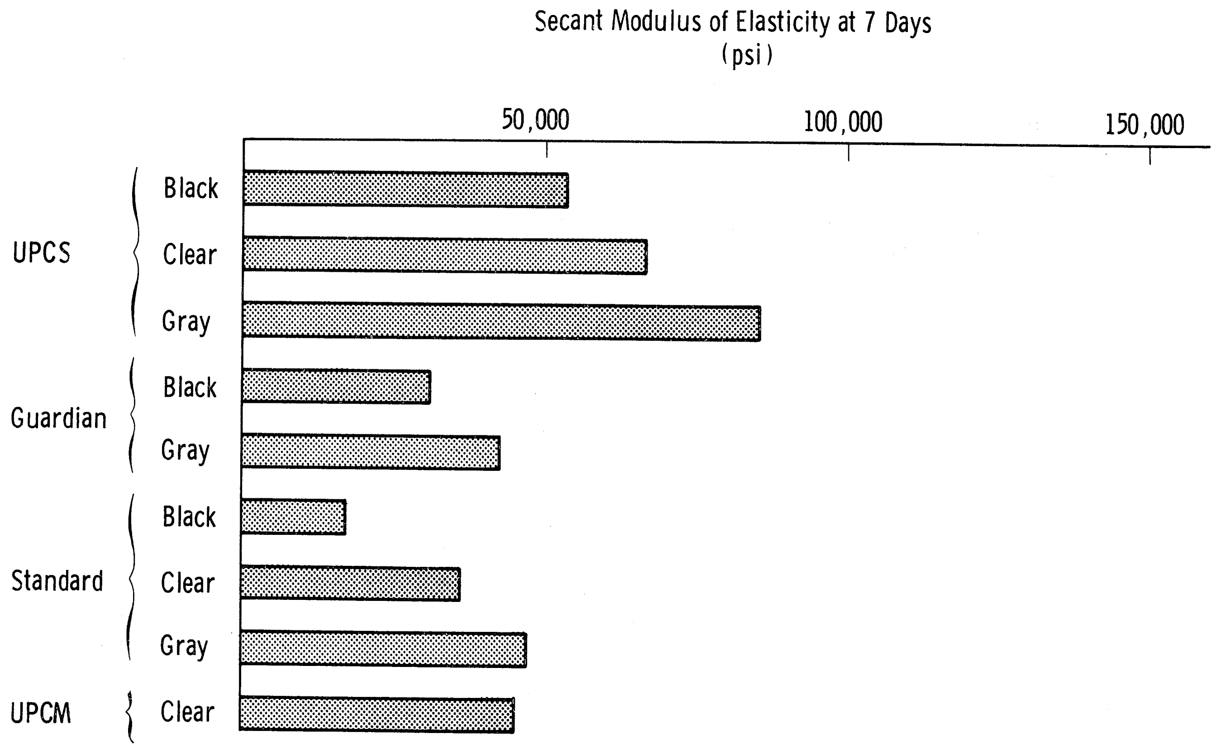

Fig. 9. Comparison of the nine different mixtures on the basis of their Secant Modulus of Elasticity measured at 7 days.

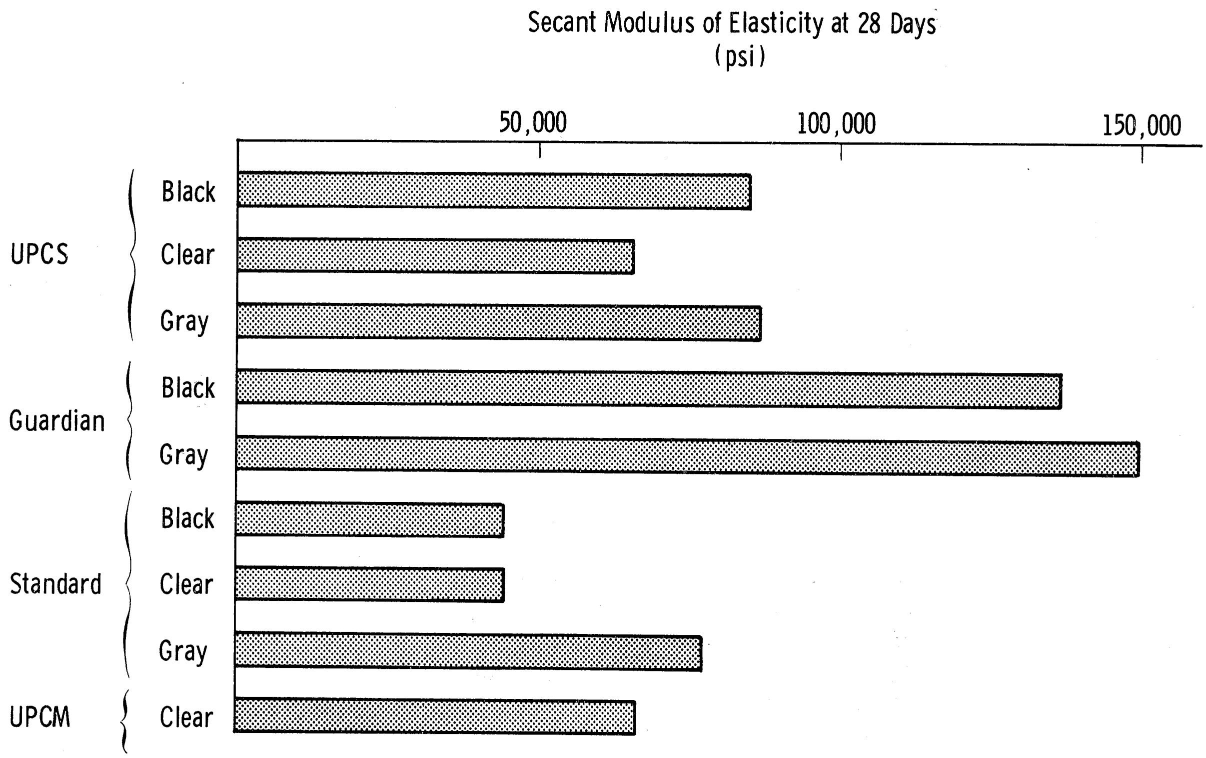

Fig. 10. Comparison of the nine different mixtures on the basis of their Secant Modulus of Elasticity measured at 28 days.

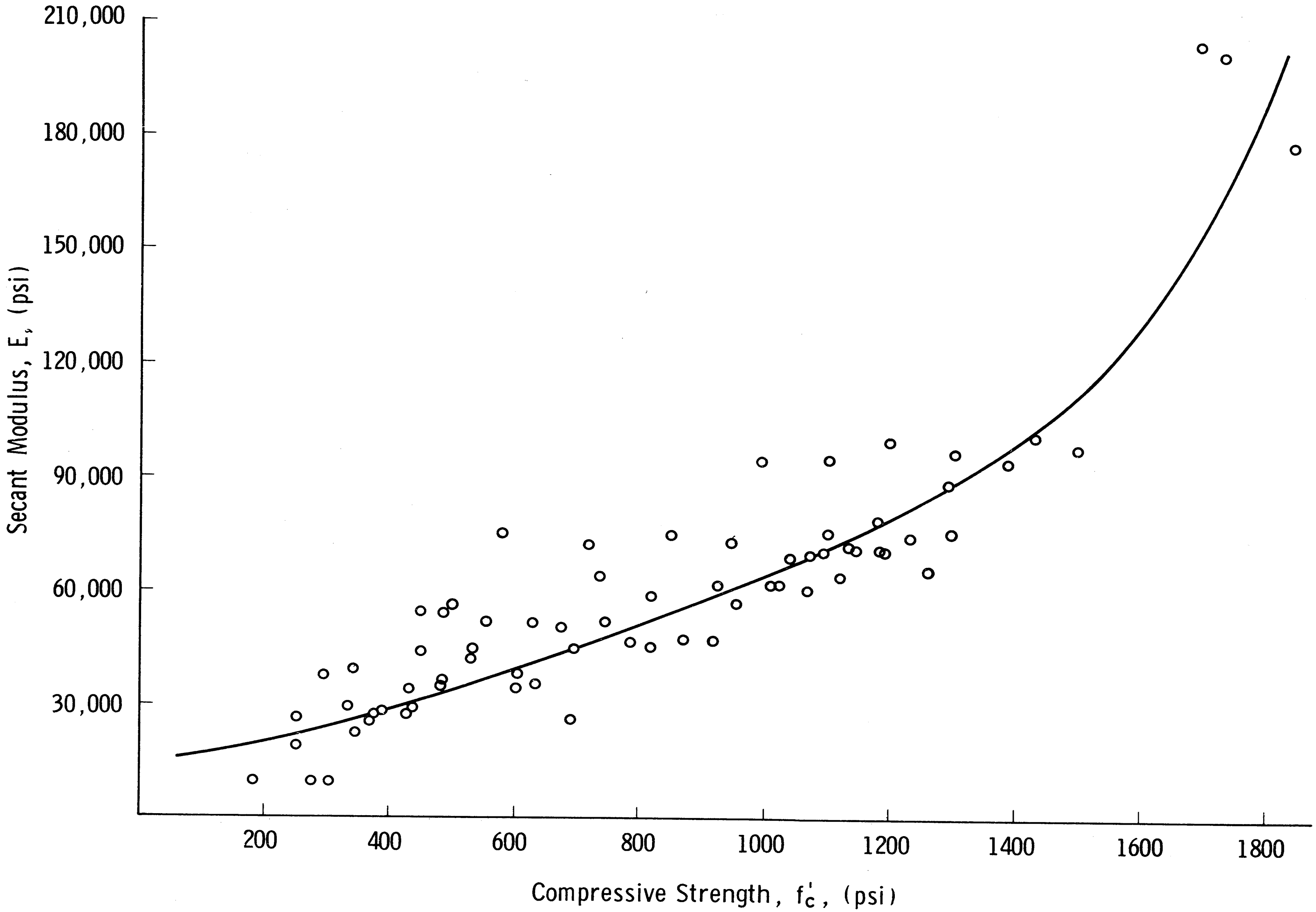

Fig. 11. Illustration of the apparent relationship between Ultimate Compressive Strength and Secant Modulus of Elasticity.

MOISTURE INFLUENCE

When sand is delivered to a job the moisture content may vary over quite a wide range. For this reason it was decided to investigate the effect the moisture content of the sand has on the compressive strength of the material.

The sand used in all experiments other than this one had been surface dried by spreading it in thin layers and exposing it to the atmosphere for a period of at least five days. Using this drying technique the moisture content is brought down to approximately 1.0 per cent ±0.2 per cent by dry weight. The sand had not been oven dried because it did not seem practicable from the standpoint of obtaining results which could be reproduced in a practical application.

UPCS—Black was used in this study. The ratio of sand to liquid used was 5 to 1 and the per cent of catalyst was 0.634. The moisture content of the dry sand was measured and found to to 1.15 per cent by dry weight. Water was added to this sand in amounts appropriate to give sands whose moisture contents were 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, and 8.0 per cent by dry weight. Three specimens were cast and tested according to the Standard Testing Procedure given in the Appendix using each of the eight above mentioned moisture contents. Table III gives the average compressive strength of the three cylinders for each moisture content used. The compressive strengths have been normalized about that compressive strength obtained for the dry sand, and Fig. 12 is a plot showing graphically the effect of the moisture content of the sand on the compressive strength of the mixture of sand and UPCS—Black.

TABLE III

Moisture Content (% of Dry Wt.)	Compressive Strength (psi)	% Normal Compressive Strength*
1.15	1370	100.0
2.0	519	37.9
3.0	269	19.6
4.0	235	17.2
5.0	193	14.1
6.0	175	12.8
7.0	155	11.3
8.0	150	11.0

*Normal Compressive Strength is that compressive strength obtained with sand containing 1.15 per cent moisture.

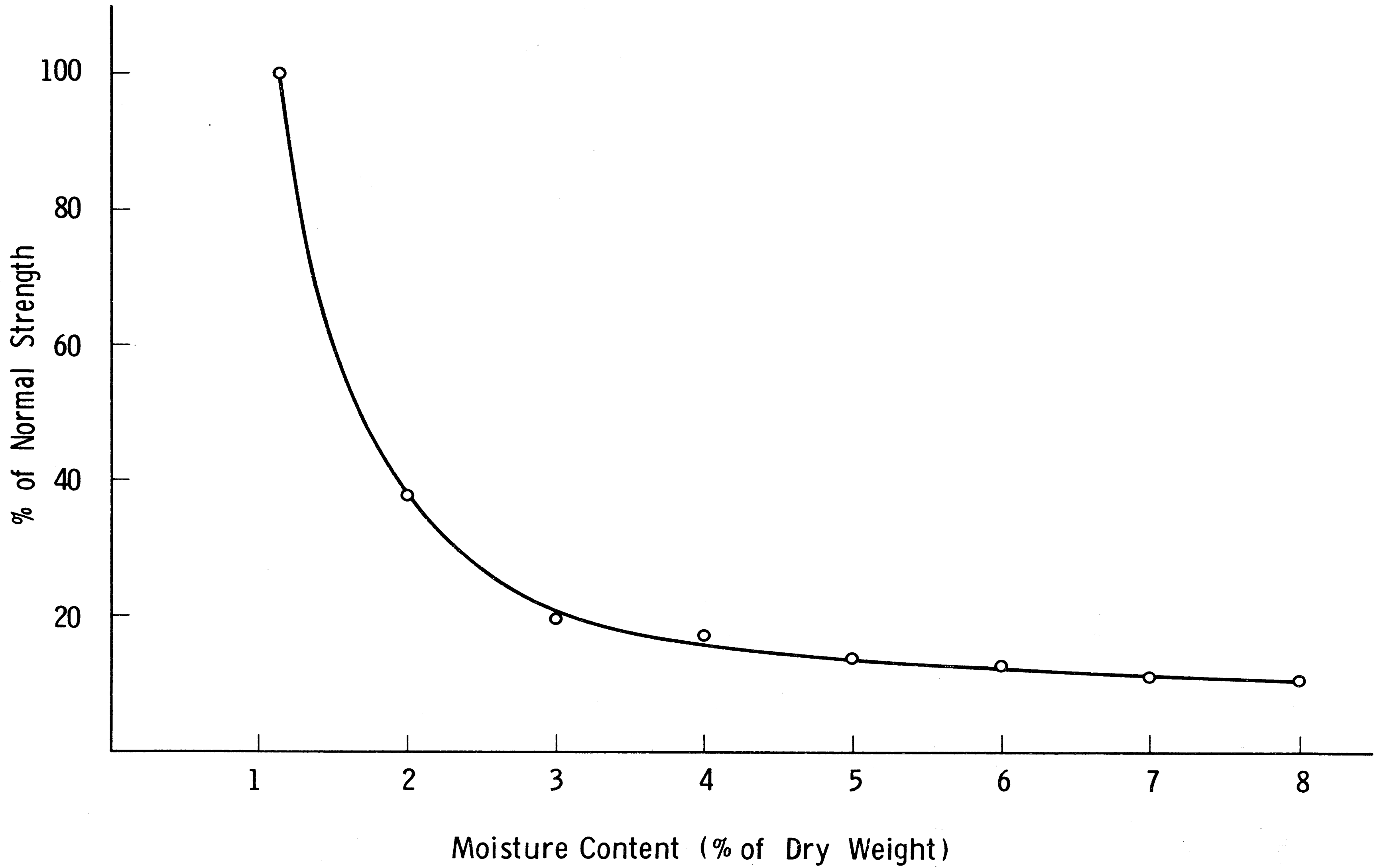

Fig. 12. Effect of moisture content of the sand on the 14-Day Compressive Strength of UPCS—Black.

INFLUENCE OF COMPACTION

The study of the compaction variable was carried out using the UPCS—Black compound. A ratio of sand to liquid compound of 5 to 1 along with a 0.634 per cent catalyst was used for these tests. Casting of the cylinders followed the standardized procedure given in the Appendix with the exception of the compacting method.

Eight degrees of compaction were used in the study. Each successive degree was obtained by decreasing the thickness of the layers of material placed in the mold while holding constant the number of blows applied to the layer with the compactor.

This procedure required that the amount of material added to the mold be known within reasonable limits. Accordingly, the mixed material was loosely placed in a small 7 inch by 7 inch wooden frame with 1 inch sides which was placed on one side of the glass mixing plate. A wooden screed was used to level the mixture.

While still in the form the mixture was cut into one inch cubes using the trowel point for cutting and the screed as a straight edge. The form was removed and each one inch cube was then lifted from the mixing plate and placed in the cylinder mold with a putty knife. Table IV shows the number of one inch cubes of the material placed per layer and compacted with 10 blows for each degree of compaction using the compactor described in the standardized procedure.

TABLE IV

	Number of 1 inch cubes compacted with 10 blows											
Degree of	Layer											
Compaction	1	2	3	4	5	6	7	8	9-15	16	17	18
0	Full Cylinder—no blows											
1	13	4*										
2	11	4	2*									
3	9	5	3*									
4	7	7	3*									
5	5	5	5	2*								
6	3	3	3	3	3	3						
7	1	1	1	1	1	1	1	1	1	1	1	1

*Top layer was limited in amount by lack of space in the form. Blow count was reduced to 5 for these layers. All forms were struck flush with the trowel after filling was complete.

Since it was necessary to identify each cylinder cast with its degree of compaction, no randomization of cylinders was possible. The unknown variable of pot life would thereby enter into the test results for any series of cylinders which were to be made. To overcome this difficulty, two series of tests were conducted, one with the cylinders cast from low degrees of compaction to high degrees and the other with the cylinders cast in reverse order. Three cylinders of each degree in each series were made and tested.

Control between the two series was obtained by casting three cylinders in each series at the same pot life and compaction. The variance of the test results at any degree of compaction was proportionally adjusted by the ratio of the averages of the control cylinders. These adjusted average strengths of cylinders of like degree of compaction were then averaged and normalized by arbitrarily dividing by the average strength at a normal degree of compaction of 3. The resulting curve shown in Fig. 13 is therefore a curve of the effects of compaction and is free of the variable of pot life. Table V below shows the average compressive strengths and the normalized values for the UPCS—Black material.

TABLE V

Degree of Compaction	Average Compressive Strength (psi)	% of Normal Compressive Strength*
0	311	27.0
1	1126	97.7
2	1161	100.9
3	1152	100.0
4	1169	101.5
5	1315	114.2
6	1343	116.6
7	1356	117.7

*Normal Compressive Strength is the average compressive strength corresponding to a degree of compaction of 3.

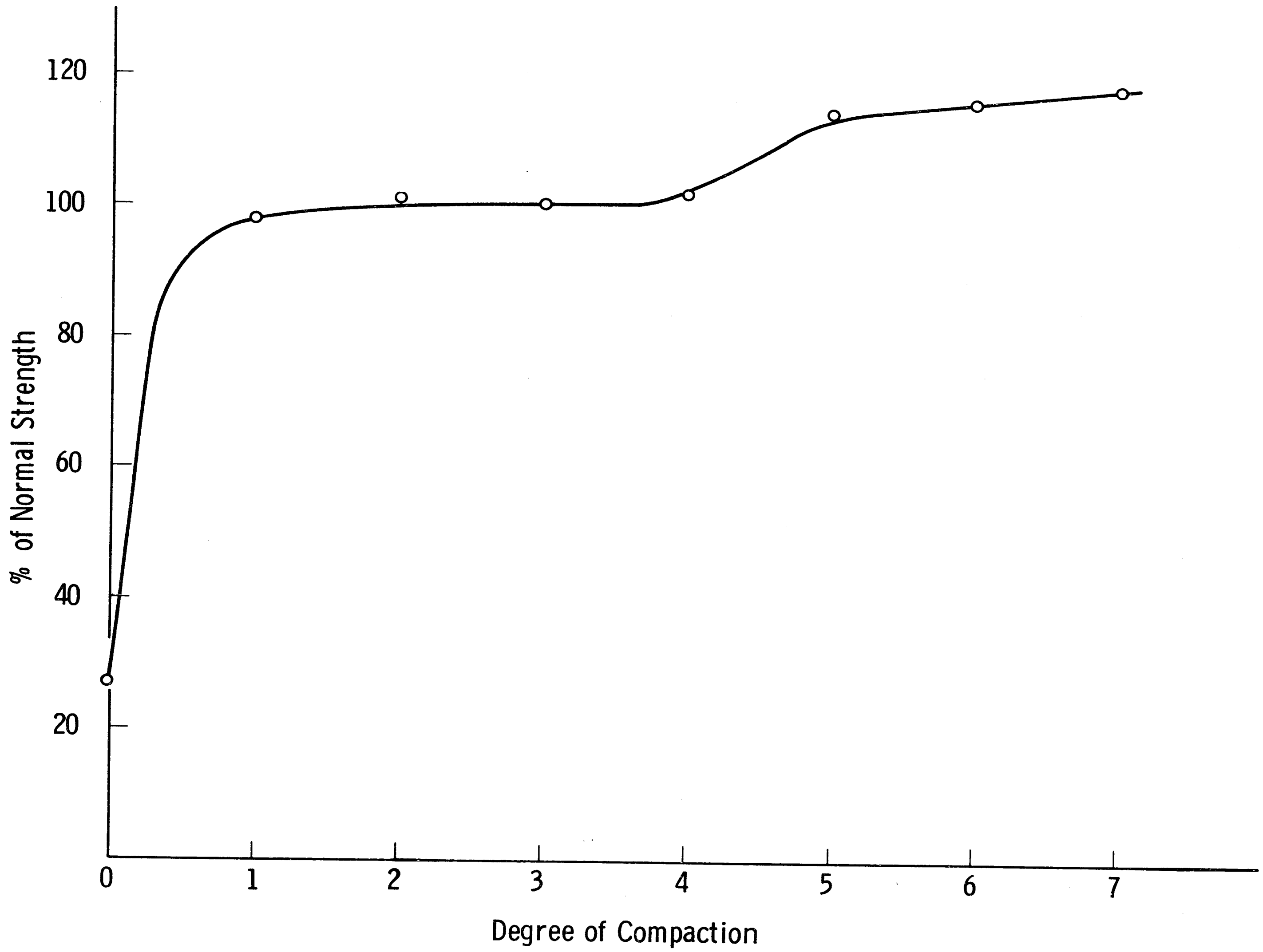

Fig. 13. Illustration of the effect of compaction on the 7-Day Compressive Strength of UPCS—Black mixed at a sand to liquid ratio of 5 to 1 with 0.634 per cent catalyst.

MIX PROPORTION EVALUATION

An extensive series of test to evaluate the effect of varying the proportions of sand and liquid compound was not carried out in this work; however, in an effort to determine just how pronounced is the effect of varying the mix proportions, a series of tests were run using UPCS—Clear. In every case the amount of catalyst used was 0.634 per cent by volume of the UPCS used.

Three specimens were cast and tested according to the Standard Testing Procedure using the mix proportions shown in Table VI. The average compressive strengths of the three cylinders are also shown in the table. These points are plotted in Fig. 14 and a curve which shows the general trend has been drawn.

TABLE VI

Ratio of Sand to UPCS	Compressive Strength (psi)	% of Normal Compressive Strength*
2.97:1	567	42.8
3.96:1	788	59.7
4.76:1	1321	100.0
5.94:1	1404	106.3
6.79:1	1386	104.8
7.93:1	1411	106.8
9.50:1	1247	94.3
11.90:1	1150	87.1

*Normal Compressive Strength is that compressive strength corresponding to a sand to liquid ratio of 4.76 to 1.

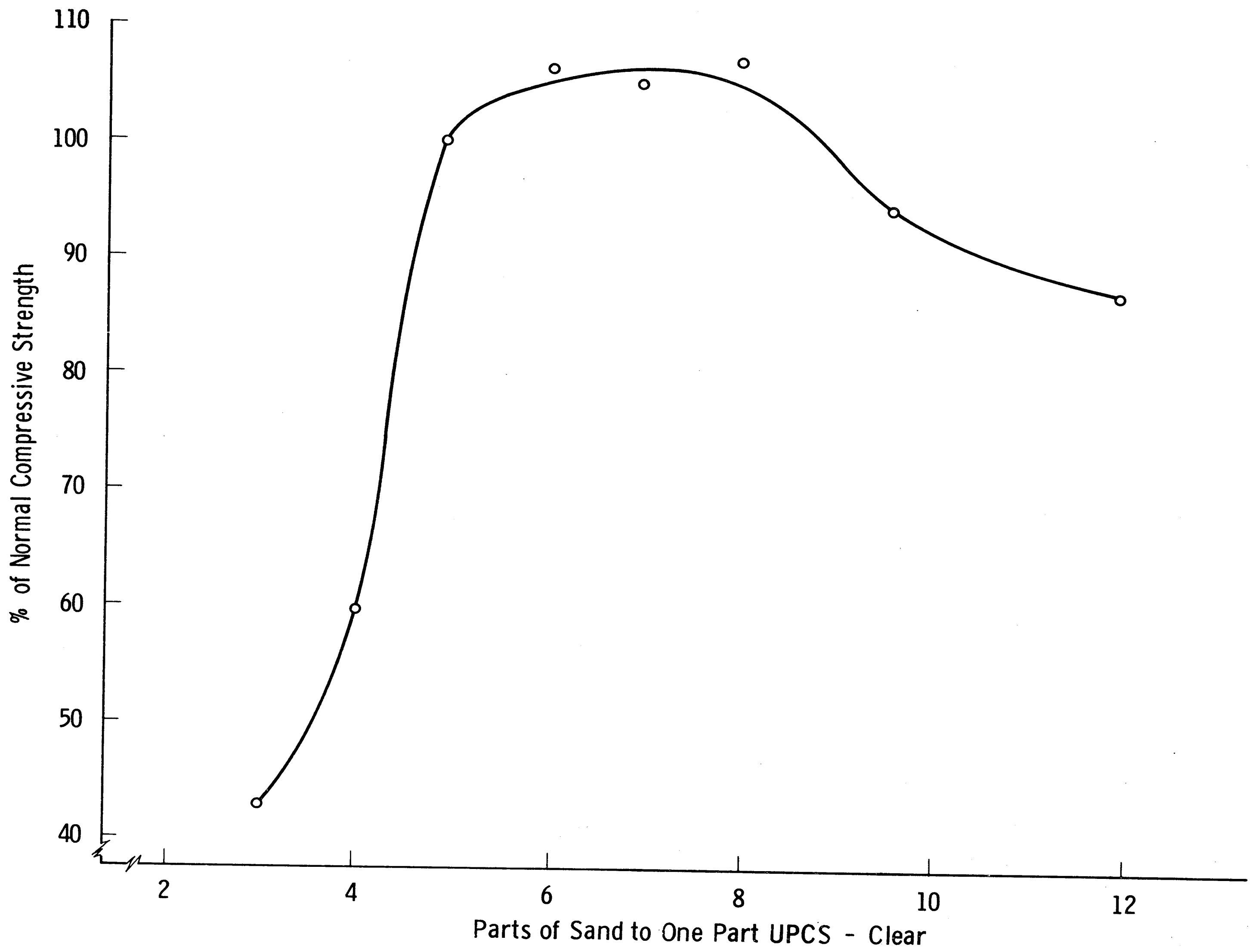

Fig. 14. Effect of varying the sand to liquid ratio on the 7-Day Compressive Strength of UPCS—Clear.

SPLIT CYLINDER TEST

In the past few years much attention has been given to the split cylinder technique for determining the tensile strength of concrete. The beam rupture test is the common method used for evaluating the tensile strength of concrete, but because of the size of the specimen required and the time needed to set up a beam test it seemed desirable to use the split cylinder method.

The test was conducted by loading the cylinder along opposite elements. Thin strips of hardboard (1/8 x 1/8 in.) were placed between the cylinder and the bearing faces of the testing machine. Upon failure the specimen actually split along the axis that extended from one bearing strip to the other. The tensile splitting strength, f_t, of the material was computed from the following equation:*

$$f_t = \frac{2}{\pi d \ell} \times P$$

where

P = load at rupture in pounds

d = diameter of the cylinder in inches

ℓ = length of cylinder in inches

f_t = tensile strength in pounds per square inch

One six cylinder set of these tests was run using a ratio of sand to UPCS—Gray of 5:1 with 0.634 per cent catalyst. The material was mixed and cast in the cylinders according to the method outlined in the Standard Testing Procedure which is presented in the Appendix of this report. Three specimens were tested at 7 days and three at 14 days. At 7 days the tensile strength was found to be 15.7 per cent of the ultimate compressive strength and at 14 days it was 17.1 per cent.

It should be mentioned that the primary reason for running this series

*Thaulow, Sven, "Tensile Splitting Test and High Strength Concrete Test Cylinders," Journal of the American Concrete Institute, Jan. 1957, Vol. 28, No. 7, p. 699.

of tests was not to determine the tensile strength of the particular material used but rather to determine whether or not the split cylinder test would be an acceptable test for determining tensile strengths of future mixtures.

CONCRETE MORTAR STANDARD

In order to establish a relationship between the material being evaluated and concrete, a series of tests were run using a normal portland cement. The sand used was the same as that used throughout this work. The test was conducted in nearly the same way as is prescribed in the Standard Testing Procedure but ASTM Designation C 109-58 (Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars) was referred to as a supplementary guide.

A total of six specimens of the concrete mortar were cast. A volume ratio of cement to sand of 1 to 2.75 was used with a water-cement ratio of 0.425 by weight. The water was introduced into the mixing container and the cement was added. These two components were mixed thoroughly and then the sand was introduced and the complete mixture was again thoroughly mixed. Once a uniform consistency was obtained the 2 inch diameter by 4 inch high cylindrical molds were half filled with the mortar. At this point the mortar was compacted into the molds by tamping 30 times with a 1/2 x 1/2 inch wooden tamper. The molds were then filled and again tamped 30 times after which the tops were finished off with a trowel.

The molds were removed after 24 hours and the specimens stored in water for 6 days. On the seventh day they were capped and tested according to Section 6 of the Standard Testing Procedure given in the Appendix.

The average 7-day compressive strength of these concrete mortar specimens was 2601 psi.

CONCLUSIONS

From the results reported here it may be concluded that the Guardian System gave the highest 28-day compressive strengths followed by UPCS, UPCM and then Standard which yielded the lowest strengths. However, compared to the UPCS and the UPCM Systems, Guardian was rather slow in curing. For example, the 7-day to 28-day strength ratio of the Guardian—Black is only 0.277, whereas the same ratio for the UPCS System is 0.914. The greatest compressive strength was obtained with Guardian—Black tested at 28 days.

The values of the Secant Modulus of Elasticity are quite low compared to the moduli of concrete. Although in some respects this is a disadvantage, it may be considered an advantage over concrete insofar as these materials' ability to withstand impact. Further, as long as these materials are not loaded past about one half their ultimate strength, they exhibit almost complete strain recovery.

The moisture in the aggregate has been shown to have a pronounced effect on the compressive strength. When the aggregate had 3 per cent moisture by dry weight, the compressive strength was only 19.6 per cent of the compressive strength obtained using aggregate having 1.15 per cent moisture. The compressive strength tends to continue to decrease as the moisture content increases above 3 per cent. Since sand is likely to have 3 or 4 per cent moisture when delivered to a job site, artificial drying of the sand would seem to be necessary.

Compaction appears to have an effect on the resulting strength of the material. The tests conducted do not show the kind or amount of compaction that is needed, but they do show that some type of field compaction is necessary.

The study has shown that there is a range of sand to liquid mix proportions which gives workable mixtures and nearly equal compressive strengths. It is believed that this range will vary with the particular compound and with the size of aggregate used. For UPCS—Clear, mixed with the sand used throughout the testing program, this range consisted of mix proportions of sand to liquid of between 4.7:1 and 7.9:1. When mix proportions either higher or lower than this range were used, the mixture lost its workability and the ultimate compressive strengths were lower.

The split cylinder test shows promise as an acceptable method of evaluating the tensile strength of the material. To be usable, the results of this type of test would have to be correlated with those of beam flexure tests.

The compressive strength of the concrete mortar, which was proportioned such that it would be similar in workability to the mixtures being tested, was approximately twice the 28-day compressive strength of the UPCS mixtures and about 1.6 times the 28-day strength of the Guardian mixtures. It is believed that this relative difference will also be present when different aggregates are used.

FUTURE STUDIES

While the studies of this report seem sufficient to compare the properties of the nine compounds when mixed with one particular aggregate, only inferences may be drawn as to the behavior of any one compound mixed with other aggregates. If one compound can be selected, its variations with the interrelated mix proportion and aggregate variables can be determined in detail. Reliability of results would require a rather extensive and controlled testing program to produce information suitable for recommendation of the particular aggregate—compound mix for any singular purpose which might be proposed.

The establishment of the behavior of the material in flexure has not been attempted here. The split-cylinder technique for determining the tensile strength should be related to the flexural tension as determined by beam tests to have significance.

It may be anticipated that temperature may have significant influences upon the material. Much work would need to be done to establish reliable data as to the effects of the casting temperature, the curing temperature, the testing temperature, and the temperatures occurring during use.

The porosity of the material mixed with varying aggregates may also be significant. An investigation of water absorbtion, the passage of gases, and similar products should be studied.

The combination of water and temperature and aging characteristics (freeze and thaw) will undoubtedly need to be evaluated before any wide spread acceptance of the product can be gained.

The effect on the material of volumetric variations, creep under load, surface hardness, shear and etc. also remain to be studied.

No doubt many of the above evaluations will be made by actual field installations and the subsequent performance of the material. Some of these factors may be more easily obtained in the laboratory. In either case a considerable amount of work still remains to be done before these materials can be used in design with complete assurance as to their field performance.

A P P E N D I X

STANDARD TESTING PROCEDURE

1. SCOPE

The testing procedure herein described is intended as a standard method for preparing and testing in compression specimens of polyurethane-polyethylene and sand as well as a method for determining the Modulus of Elasticity of the material.

2. APPARATUS

The apparatus shall consist of the following:

a. Vaseline.

b. Graduated cylinders—a 250 cc cylinder calibrated to 2 cc and a 10 cc cylinder calibrated to 0.5 cc.

c. Beakers—a 1500 ml glass beaker and a 500 ml glass beaker.

d. Glass Plate—a piece of double strength window glass approximately 2 ft. x 3 ft.

e. Trowel—a 3 in. mason's trowel.

f. Putty Knife.

g. Cylindrical Molds—brass, steel, or bronze molds 2 in. in diameter and 4 in. in height.

h. Compactor—an impact compacting device which drops a 1.1 lb. weight from a height of 18 in. (See Commentary for a description of such a device.)

i. Hydrostone.

j. Testing Machine—the testing machine shall be of the screw type and must be capable of providing the loading rate prescribed in Section 6c.

k. Dial Gage—a dial gage calibrated to 0.001 in. and a supporting stand.

3. NUMBER OF SPECIMENS

A minimum of three specimens shall be cast and tested for each testing condition or variable.

4. PREPARATION OF TEST SPECIMENS

a. Preparation of Molds—The molds shall be covered with a thin uniform coat of vaseline.

b. Proportioning and Mixing—The mixing shall be done on the glass plate. Measure out the required volume of dry sand and place this on the glass plate. Then measure out the required amount of liquid compound into a dry beaker of suitable size. When the compound being used is one which requires a catalyst this should be measured out next in the 10 cc graduated cylinder, poured into the beaker containing the liquid compound and stirred for a time sufficient to assure the complete mixing of the two components. The liquid shall be mixed with the sand in the following manner:

1. Form a pocket in the dry sand and pour one half the liquid into it.

2. Work the mixture with the trowel until no free liquid remains.

3. Form another pocket in the mixture and add the remainder of the liquid.

4. Thoroughly mix the sand-liquid mixture with the trowel until by visual inspection it is determined that a uniform consistency has been obtained.

5. Clean the beaker which contained the liquid compound with Toluene.

c. Casting the Specimens—Pat out a portion of the mixture into a layer about one inch thick with the trowel and dice into cubes approximately 1-1/2 inches on a side. With the putty knife place these cubes into the mold until it is filled to within one half inch of the top. Apply 10 blows from the compactor. Fill mold to top and apply 10 more blows from the compactor. Again fill the mold and apply 5 blows from the compactor. Add whatever amount of the mixture that is necessary to fill the mold and trowel the surface off smooth with the trowel.

d. Cleaning Equipment—All equipment shall be cleaned with Toluene Reagent immediately.

5. STRIPPING OF MOLDS

The molds shall be removed within 24 hours after casting and the specimens stored in a well ventilated place at room temperature until the testing date. Specimens shall not be stored closer than one inch from each other. Immediately after removing the molds the specimens shall be clearly identified by an appropriate code number.

6. TESTING

a. Capping—At least 3 hours before the time of testing the specimens shall be capped with Hydrostone. The caps shall provide smooth plane surfaces which are perpendicular to the axis of the specimen and parallel to each other. The caps shall be made as thin as possible.

b. Placing the Specimen—Before placing the specimen in the testing machine the bearing faces on the machine shall be wiped clean. The specimen shall be placed in the machine in a manner such that axis of the specimen is aligned with the center of thrust of the machine.

c. Rate of Loading—The load shall be applied continuously and without shock. The moving head shall travel at a rate of about 0.015 inches per minute when the machine is running idle.

d. Displacement Readings—The displacement between the moving head and the base plate of the machine shall be read from a dial gage arranged in a convenient manner. Readings shall be taken at increments sufficient to give a total of at least 15 readings.

7. CALCULATIONS

a. Ultimate Strength—The ultimate strength shall be calculated by dividing the maximum load carried in pounds by the initial cross-sectional area of the specimen in square inches.

b. Modulus of Elasticity—A curve of stress (i.e., load divided by the initial cross-sectional area) vs. unit strain (i.e., displacement reading divided by the gage length) shall be plotted. The slope of a secant drawn from the origin of the stress-strain plot to a point on the curve whose ordinate is one half the ultimate strength shall be determined and reported as the Secant Modulus of Elasticity.

COMMENTARY ON THE STANDARD TESTING PROCEDURE

1. SCOPE

Before proceeding to evaluate the four families of compounds which were supplied by the sponsor it was necessary to develop a standard method of preparing and testing specimens. Since the potential uses for the mixtures are similar to those of concrete it was decided to correlate, as closely as possible, the testing procedure with the testing procedures for concrete and mortars. It is the purpose of this commentary to explain the development of the standard test which has been set forth.

2. APPARATUS

Every item in the list of apparatus is self explanatory and easily obtainable with the exception of item h, the compactor. Upon preparing the first batch of material it was evident that some sort of compaction would be necessary in order to obtain a reasonable strength. An impact compacting device was chosen. It was also felt that the compaction would have to be carefully controlled. This was accomplished by dropping a known weight (1.1 lb.) from a known height (18 in.) a given number of times. The device used in preparing all specimens for this project is shown in Fig. 15.

3. NUMBER OF SPECIMENS

Because of the unavoidable variability in the results of tests made on materials such as these it is impossible to draw any conclusions on the basis of one test. It was therefore decided that the standard procedure would be to cast and test at least three specimens for each testing condition or variable, thereby allowing for the variability that existed within a particular batch. In order to overcome the differences which may result from the batching operation itself it also seemed advisable to require two individual batches to be mixed for each testing condition, thereby giving a total of six specimens for each testing condition or variable. Using this procedure, i.e., two batches with three specimens from each batch, any investigator should feel confident that most of the variables which arise from the batching and casting operation have been eliminated.

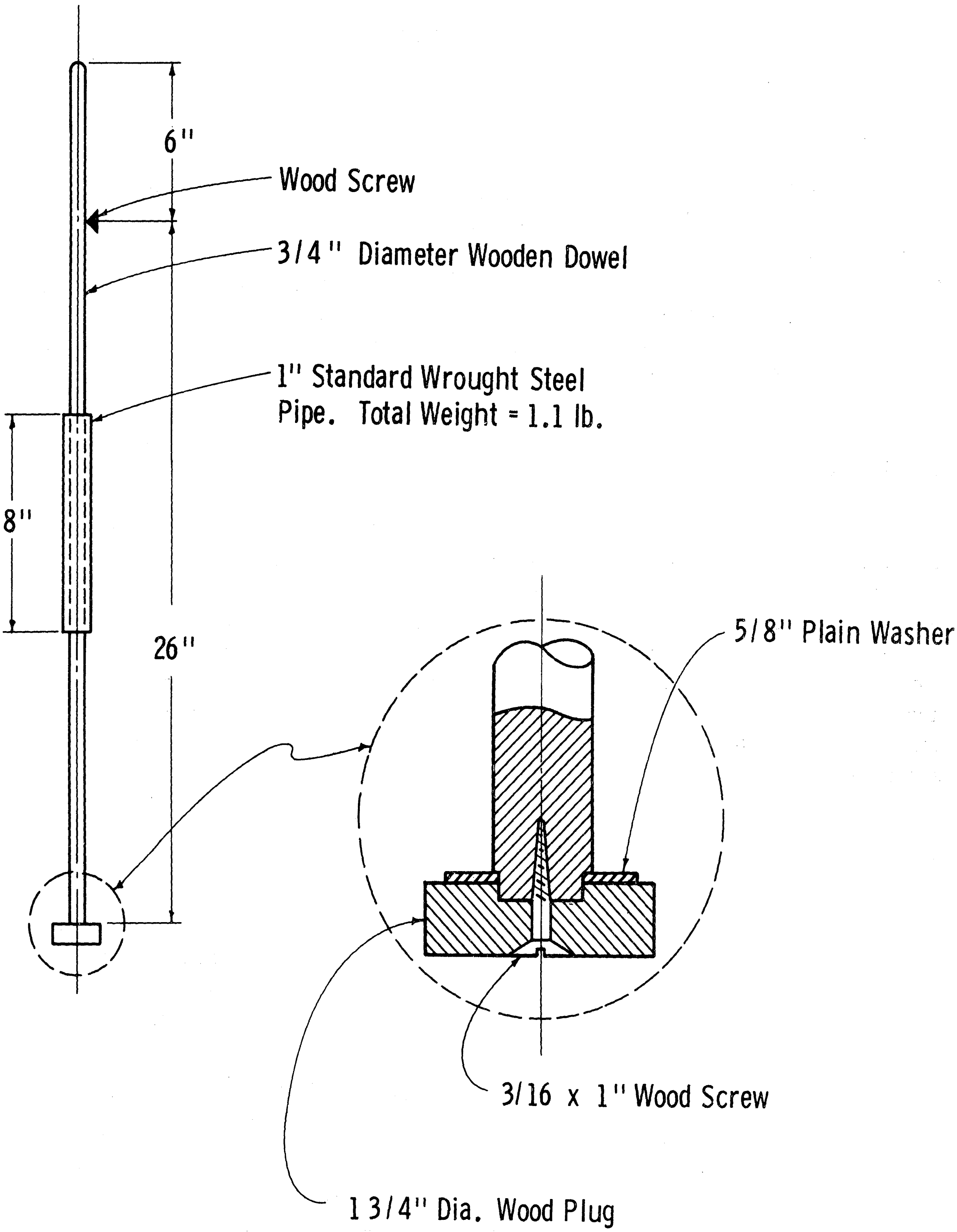

Fig. 15. An acceptable compacting device.

4. PREPARATION OF TEST SPECIMENS

a. Preparation of Molds—In casting the first specimens used in connection with this project the molds were lined with polyethylene plastic sheet. This worked very well but the process of lining the molds was a tedious and time consuming one. It was found that a thin uniform coat of vaseline applied to the molds with a cloth rag worked just as well. This seemed to have no ill effect on the specimens and enabled the molds to be stripped easily.

b. Proportioning and Mixing—A piece of double strength window glass serves very well as a mixing surface. Glass was chosen because of the ease in cleaning the plate once the batching operation is completed. The size of the plate is governed by the size of the batch. The standard size batch used was one sufficient in size to cast 19 cylinders. It was found that a 2 ft. x 3 ft. glass plate worked very well for a batch of this size.

A convenient way for determining the volume of dry loose sand needed is to multiply the total volume of molds to be filled by 1.2. This will allow for the decrease in the volume of the sand which results when the liquid is added as well as some allowance for waste.

The measurement of the liquid compound in the beaker is most easily accomplished by calibrating the beaker in advance. This may be done by measuring an equivalent volume of water with the large graduated cylinder. The water next is poured into a beaker of suitable size which is marked at the water level, emptied, and dried thoroughly. The compound may then be poured into the beaker up to the proper mark. This procedure avoids the very difficult operation of cleaning the graduated cylinder.

The measurement of the catalyst may be done directly in the small graduate since cleaning seems to be no problem. Because of the small amount of catalyst needed compared to the volume of liquid compound, it is quite essential that the mixing be thorough. A period of vigorous mixing of from two to three minutes seems to be sufficient time to insure the complete and uniform mixing of the two components.

When preparing a batch of concrete, the water is added to the dry aggregate and cement. Therefore, it is suggested that the liquid be added to the sand rather than adding the sand to the liquid. There is no prescribed method of working the mixture of sand and liquid with the trowel. Any technique may be used as long as it results in a uniform mixture. The mixing time required to obtain a consistent mixture is, of course, dependent upon the size of the batch being prepared. It was found that from ten to twelve minutes mixing time was required to mix a batch of size sufficient to cast 19 specimens.

c. Casting the Specimens—The method used in introducing the material into the molds is clearly described in the Standard Testing Procedure. The compaction prescribed was chosen because it gives a relatively well compacted specimen while consuming a minimum of time. Time becomes a factor because in some cases it is necessary to have the material in the molds within fifteen minutes after it has been mixed. For a complete discussion on the aspect of compaction, refer to the section entitled INFLUENCE OF COMPACTION of the main report.

d. Cleaning the Equipment—Once the molds have all been filled, all the equipment, including the glass mixing plate, should be cleaned with the aid of Toluene. If this is done immediately the equipment will clean up with little effort.

5. STRIPPING OF MOLDS

Because the curing process appears to be one which involves the escaping of certain vapors, it seems advisable to strip the molds as soon as possible. On the other hand, the molds cannot be removed until the material has gained sufficient strength to allow normal handling. Twenty-four hours after casting appears to be a time for stripping which meets both of these conditions.

6. TESTING

a. Before testing the specimens they must be capped. A high strength plaster of Paris (Hydrostone) was used very successfully for this. Capping can be done on either a steel or glass plate which has been carefully leveled. To insure that the caps are perpendicular to the axis of the cylinder a small square may be used to set the cylinder perpendicular to the capping plate when the cap is formed on one end. After this cap has hardened, the cylinder may be inverted for capping the other end. A small carpenter's level may be used on the first cap to make the faces of the two caps parallel.

b. Placing the Specimen—It is important that the specimen be carefully aligned with the center of thrust of the machine. This is necessary to assure that the specimen is being tested in pure compression, i.e., no bending.

c. Rate of Loading—As is stated in the Standard Testing Procedure, the load is to be applied at a constant rate. Materials which are plastic in nature creep when subjected to a sustained load. Therefore the rate at which a specimen is loaded has an effect on the results obtained. If the specimen is loaded at too fast a rate the results will be erroneous.

In order to determine a loading rate which would give representativecompressive strengths, a series of tests were run on specimens made with UPCS—Gray using different loading rates. Rates of 0.002, 0.015, 0.02, 0.1, and 0.2 inches per minute were used. Because the stress-strain relationships, as well as the ultimate strength, are effected by loading rates, the strain was also taken at each of the above mentioned rates of loading. Table VII gives the results of these tests.

TABLE VII

Loading Rate ("/min)	Modulus (psi)	Compressive Strength (psi)	% of Normal Compressive Strength*
0.002	93,200	1149	96.7
0.015	96,400	1199	100.0
0.020	106,650	1326	110.4
0.100	113,650	1503	125.3
0.200	----	1752	146.2

*Normal Compressive Strength is that Compressive Strength corresponding to a Loading Rate of 0.015 inches per minute.

Figure 16 is a plot of Compressive Strength versus Loading Rate—the compressive strength being normalized about that compressive strength corresponding to a loading rate of 0.015 inches per minute—and Fig. 17 is a plot of Secant Modulus versus Loading Rate. Since it was desirable to load as rapidly as possible and yet not produce erroneous results, a loading rate of 0.015 inches per minute was chosen. It is obvious from the two curves that this is the rate which best meets the above requirements.

d. Displacement Readings—It was first thought that strain measurements could be taken using electric resistance type strain gages; however, because of the effect of the gage cement on the material this method was not successful. The next method tried was to measure the total strain or displacement experienced by the capped specimen with the use of a dial gage. This worked very well but there was some concern about using the entire height of the capped specimen as a gage length. In order to verify this procedure the strain was measured on a specimen using the dial gage along with a mechanical gage which read strain directly from a one inch gage length, hereafter referred to as a Huggenburger Gage. Strain readings were also taken on the same specimen with an electric resistance gage. The results of this test are given in Fig. 18. The reason the Huggenburger readings do not extend over the entire range of loading is because of the large total strain encountered. Because of the agreement of the Huggenburger readings with those obtained by using the dial gage and because of the lim-

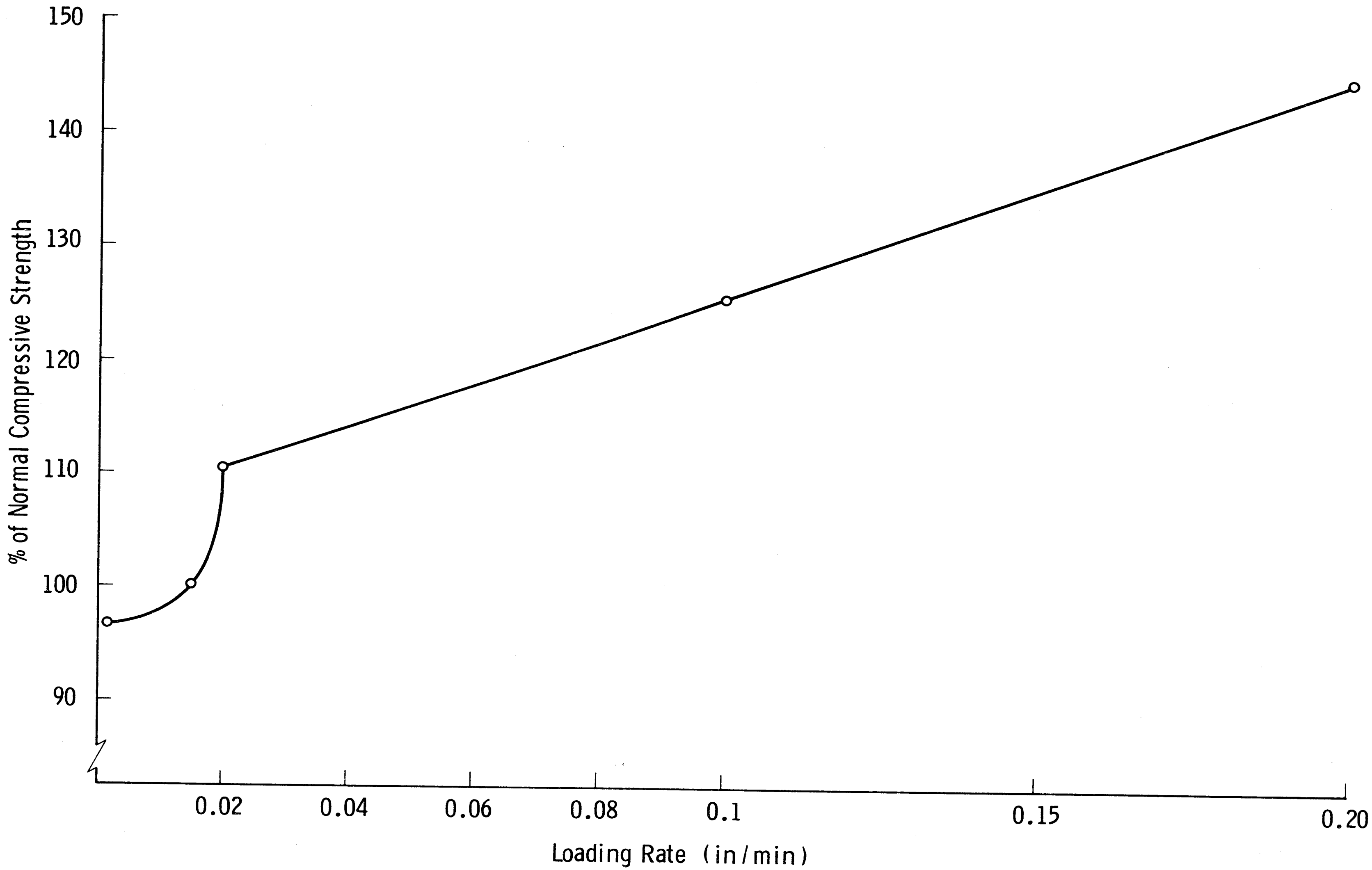

Fig. 16. Effect of Loading Rate on the 7-Day Compressive Strength of UPCS—Gray mixed at a sand to liquid ratio of 5 to 1 with 0.634 per cent catalyst.

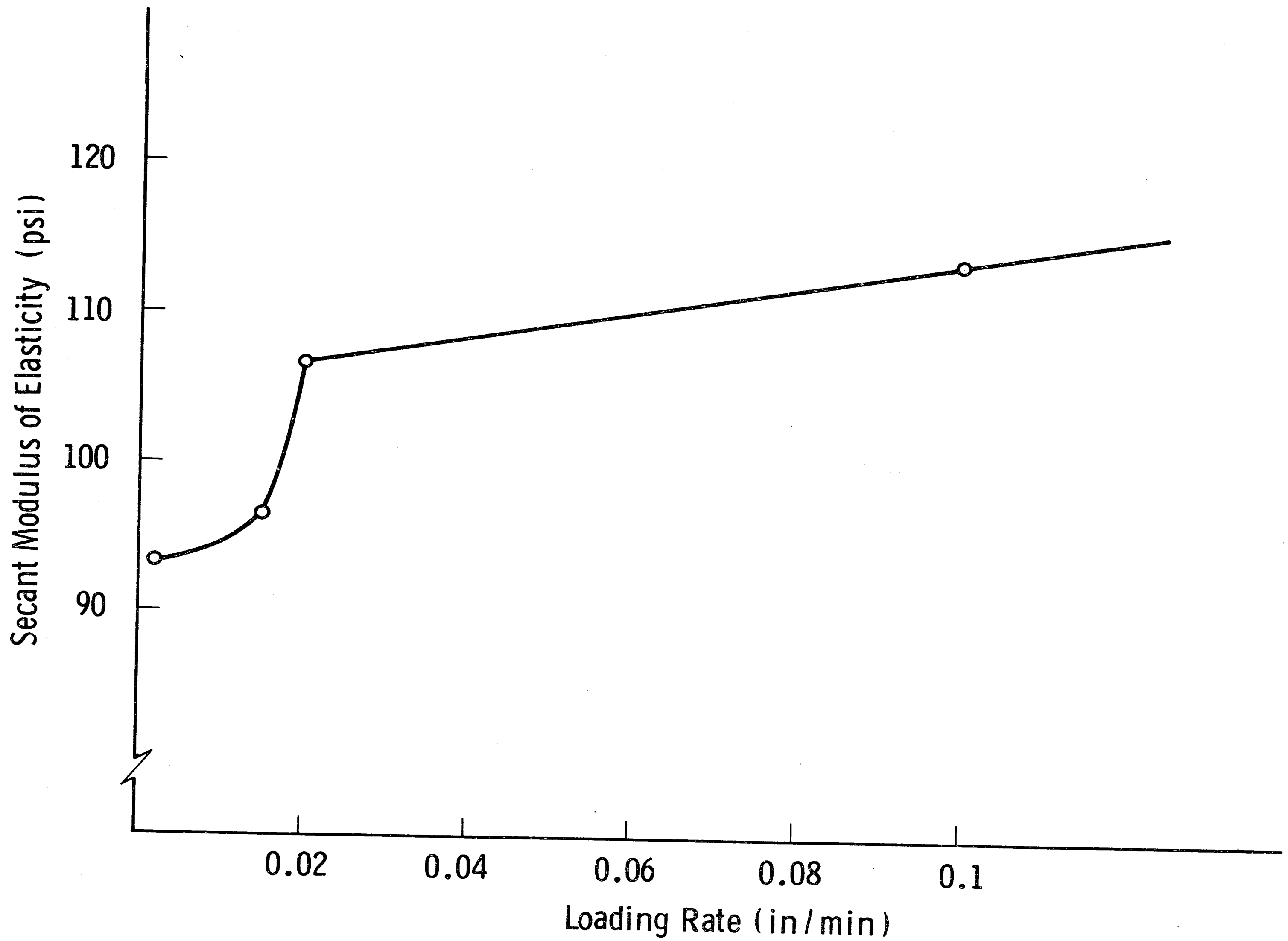

Fig. 17. Effect of Loading Rate on the Secant Modulus of Elasticity of UPCS—Gray measured at 7 days.

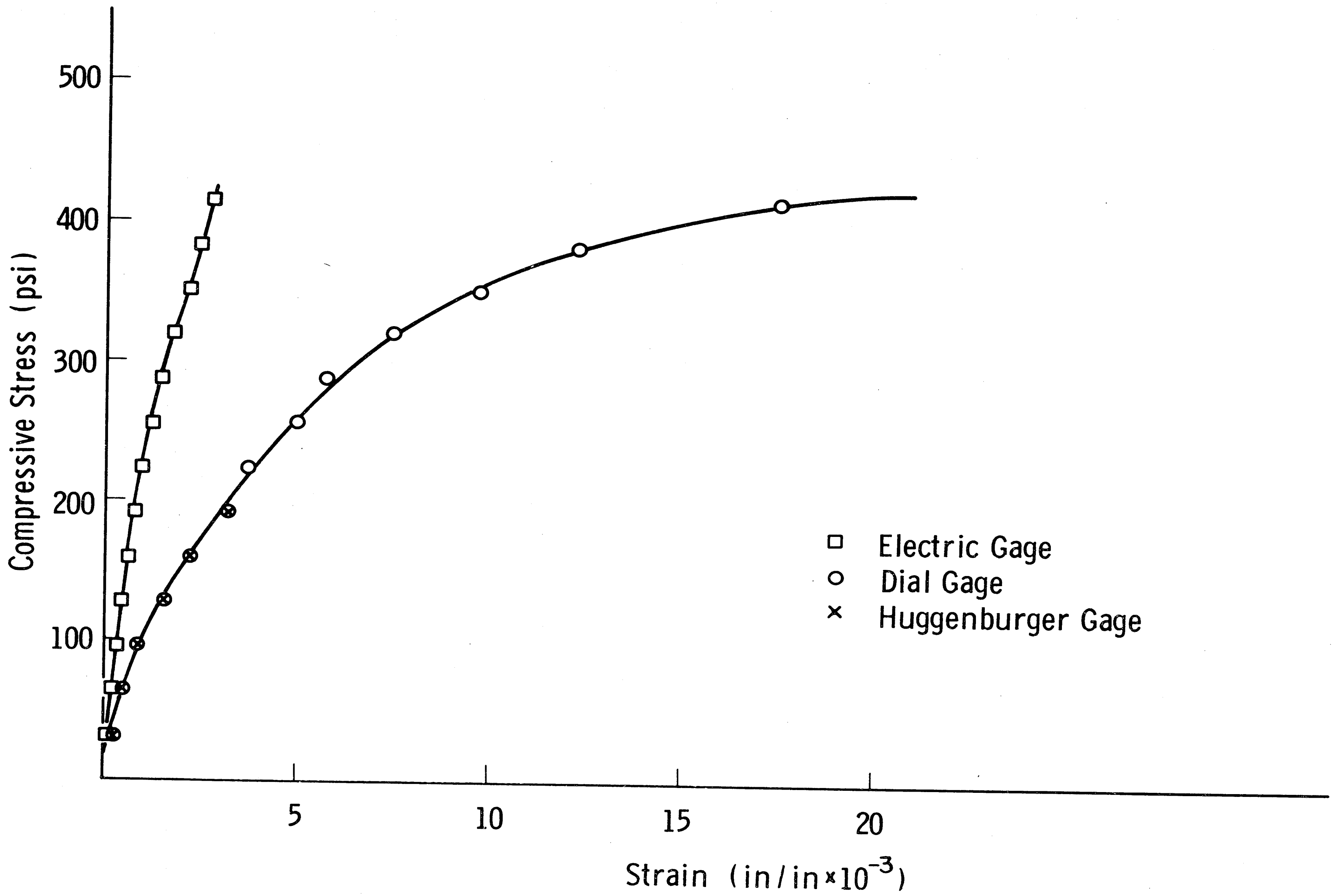

Fig. 18. Comparison of stain measurements as taken with an Electric Strain Gage, a Dial Gage and a Huggenburger Gage.

ited range of the Huggenburger Gage, the use of the dial gage has been prescribed in the Standard Testing Procedure for measuring strain.

7. CALCULATIONS

a. Ultimate Strength—The units used to express the strength of concrete are invariably pounds per square inch (psi). Accordingly, these units have been used exclusively when referring to compressive strength.

b. Modulus of Elasticity—When dealing with a material whose stress-strain plot is not linear, some criterion for expressing the Modulus of Elasticity has to be set forth. Some methods used are as follows:

1. "Initial Tangent Modulus" which is represented as the slope of a tangent to the stress-strain curve, drawn through the origin.

2. "Tangent Modulus" which is represented by the slope of a line drawn tangent to the stress-strain curve at any designated point.

3. "Secant Modulus" which is represented by the slope of a line drawn from the origin to some designated point on the curve.

The most common one used for concrete is the Secant Modulus. Therefore it was decided that the slope of a secant drawn from the origin of the stress-strain plot to a point on the curve whose ordinate is one half the ultimate strength would be used as the criterion for evaluating the Modulus of Elasticity. In order to make it clear which modulus is being used it is suggested that it be reported as the Secant Modulus of Elasticity. A sample stress-strain curve is shown in Fig. 19 with the Secant Modulus of Elasticity evaluated.

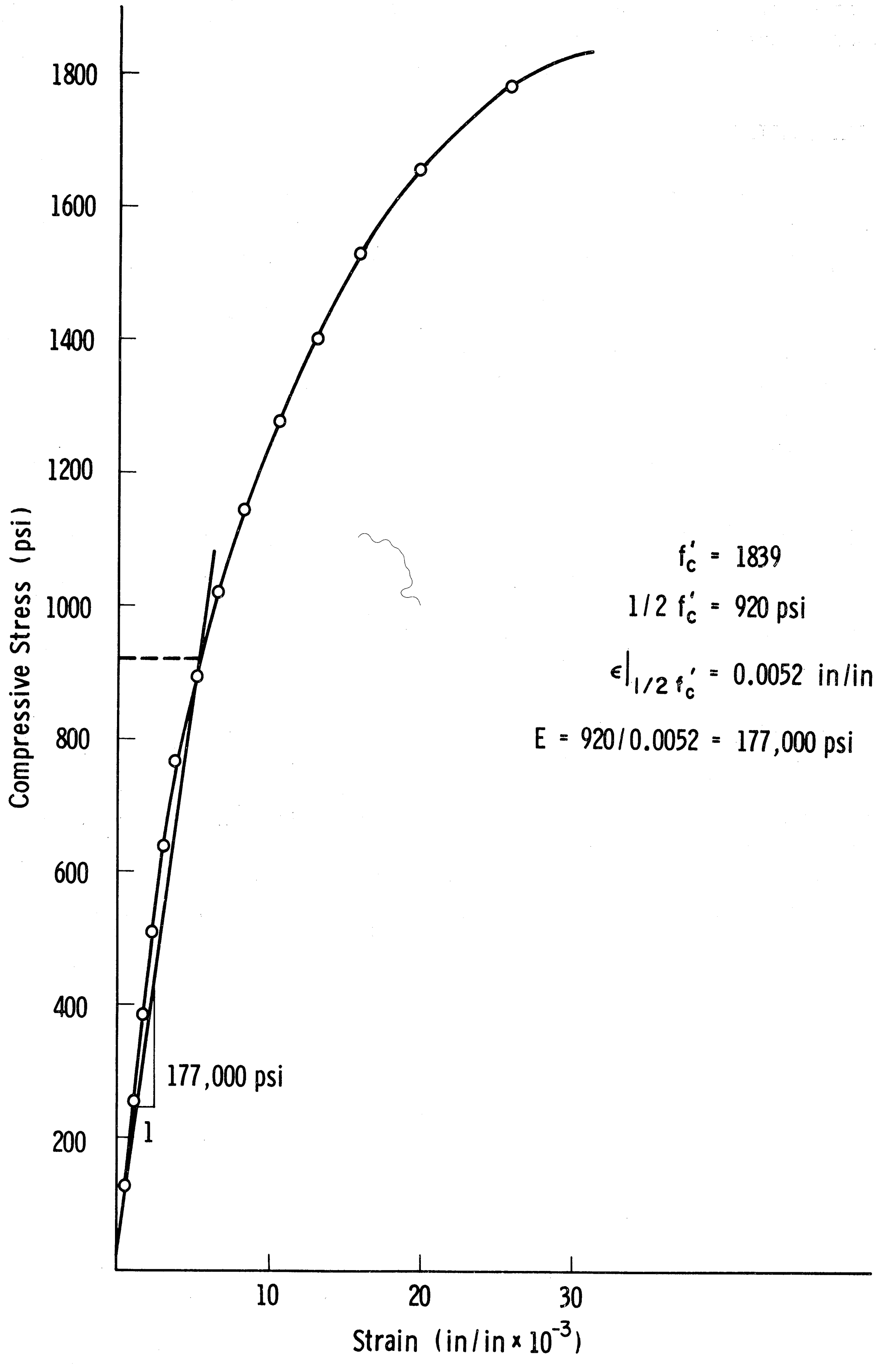

Fig. 19. Typical Stress-Strain Curve illustrating the procedure for calculating the Secant Modulus of Elasticity.