EVALUATION OF VARIOUS COARSE AGGREGATE CONCRETES

FINAL REPORT

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ABSTRACT

This study was initiated to determine the properties of concrete using three types of coarse aggregate. The coarse aggregates evaluated in this study included silicious gravel, the standard aggregate for concrete in the state, with sandstone and limestone as possible alternatives. Other variables included in this study were cement factors (5.5, 6.0 and 6.5 bags per cubic yard) and admixtures (air entraining, water reducers and super water reducers). The same fine aggregate, silicious sand, was used in all of the mixes. The properties of concrete made with each of these coarse aggregates, such as workability, strength and durability, were determined. Information was also obtained on abrasion resistance, length change, absorption, and 90 day permeability of concrete. The main objective of this study was to determine whether limestone and sandstone are suitable replacements for regular Class A gravel. The results indicated that both limestone and sandstone will provide a very suitable replacement for gravel. Improvements were also observed in durability and flexural strength when limestone and sandstone were used in the concrete. The addition of water reducing and super water reducing agents was also very beneficial in gaining high strength in all types of concrete evaluated. Due to the improved freeze-thaw resistance in gravel concrete when air entraining agents were used, its use is recommended in gravel concrete.

The information contained in this study will serve as a bench mark for any future use of concrete mix using these coarse aggregates. Mix property information will be on file.

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METRIC CONVERSION CHART

To convert U.S. Units to Metric Units (S.I.), the following conversion factors should be noted:

Multiply U.S. Units	By	To Obtain Metric Units
	LENGTH	
inches (in.)	2.5400	centimeters (cm.)
feet (ft.)	0.3048	meters (m.)
yards (yd.)	0.9144	meters (m.)
miles (mi.)	1.6090	kilometers (km.)
	AREA	
square inches (in^2)	6.4516	square centimeters (cm^2)
square feet (ft^2)	0.0929	square meters (m^2)
square yards (yd^2)	0.8361	square meters (m^2)
	VOLUME	
cubic inches (in^3)	16.3872	cubic centimeters (cm^3)
cubic feet (ft^3)	0.0283	cubic meters (m^3)
cubic feet (ft^3)	28.3162	liters (l.)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
fluid ounces (fl. oz.)	29.57	milliliters (ml.)
gallons (gal.)	3.7853	liters (l.)
	MASS (WEIGHT)	
pounds (lb.)	0.4536	kilograms (kg.)
ounces (oz.)	28.3500	grams (g.)
	PRESSURE	
pounds per square inch (p.s.i.)	0.7030	kilograms per square centimeters (kg/cm^2)
pounds per square inch (p.s.i.)	0.006894	mega pascal (MPa)
	DENSITY	
pounds per cubic yard (lb/yd^3)	0.5933	kilograms per cubic meter (kg/m^3)
bags of cement per cubic yard (cement bags/yd^3)	55.7600	kilograms per cubic meter (kg/m^3)
	TEMPERATURE	
degrees fahrenheit (°F.)	5/9 (°F.-32)	degrees celsius (°C.) or centigrade

IMPLEMENTATION

The properties of concrete using various types of coarse aggregates such as sandstone and limestone, were determined, listed and reported for the mixes prepared. The information gathered on this study serves primarily as a bench mark for any future use of concrete mixes using these coarse aggregates. It also serves as a direct comparison for like mix designs using different coarse aggregates, with additional information derived from the changes in mix variables and the sensitivity of mixes. Possible experimental sections may be evaluated in the future and further recommendations may be made if the experimental sections are approved and constructed.

INTRODUCTION

With the availability of good, strong, durable coarse aggregates decreasing in the State, developing new sources of coarse aggregates with good strength and durability properties is very desirable. The strength and durability of the aggregates should not be inferior to the present coarse aggregate in use in this State. Among the potential alternatives for new coarse aggregates are sandstones and limestone. These aggregates should also be easily obtainable and economically feasible, however, certain conditions may necessitate shipping aggregates in or using what is available.

PURPOSE AND SCOPE

It was the purpose of this project to make a complete determination of the various properties of plastic and hardened concrete, to the extent of the laboratory's capabilities, using coarse aggregates, such as sandstone and limestone. The properties of these mixes were then compared with the properties of the presently used Class A gravel concrete. This data will serve as a bench mark for any future use of concrete mix using these coarse aggregates. Mix property information will be on file.

The scope of the project was accomplished by a laboratory evaluation of a number of mix designs, totaling fifty-four, with variables including type of aggregate (gravel, sandstone and limestone), cement content (5.5, 6.0 and 6.5 sacks per cu. yd.), mix type (air, non-air) and admixture type (control, water reducer and super water reducer). Material properties determined included: compressive strength, flexural strength, splitting tensile strength, abrasion resistance, length change, time of set, resistance to freezing and thawing, scaling, 90 day permeability, absorption, slump, air content and unit weight. Evaluations were also made on the cost and the availability of these coarse aggregates.

METHODOLOGY

The first step in the methodology was to conduct a literature review on the use of various coarse aggregates in concrete, particularly sandstone and limestone. In addition, other related information was accumulated.

Upon completion of the literature review, fifty-four mix designs were prepared using the available information. The study was accomplished essentially in three phases. Phase I was the mixing and testing of concrete, using limestone coarse aggregate in the mixes; Phase II was the mixing and testing of concrete, using sandstone coarse aggregate in the mixes; and Phase III was the mixing and testing of the control concrete, using Class A gravel coarse aggregate in the mixes.

Material properties of the plastic and hardened concrete cast with these coarse aggregates were determined. During the mixing operations, the slump, air content, unit weight and the compacting factor were determined for each mix. Specimens prepared during the mixing operations were evaluated by a series of tests as listed in Table 1 below.

Table 1
List of Tests

Test	Age of Tests, Days
Compressive Strengths (ASTM C-39)	7, 28 and 200
Flexural Strengths (ASTM C-78)	7, 28 and 200
Splitting Tensile Strengths (ASTM C-496)	7, 28 and 200
Abrasion Resistance by Rotating Cutter Method (ASTM C 944)	28
Length Change of Hardened Concrete (ASTM C 157)	28, with initial reading @ 24 hrs.
Time of Set by Penetration Resistance (ASTM C 403)	-----
Resistance to Rapid Freezing and Thawing (ASTM C 666, Procedure B)	to 300 cycles
Scaling Resistance (ASTM C 672)	28
90-day Permeability Tests	90
Absorption Tests	-----

Fifty-four mix designs, as listed in Table 2 on the following page were used on this project with concrete mixed to cast 6" x 12" cylinders for strength determinations (compressive strength and splitting tensile strength, to cast 6" x 6" x 20" beams for strength determinations (flexural strength), to cast 3" x 4" x 16" beams for freeze and thaw durability and abrasion resistance, to cast molded specimens for dry shrinkage and to cast blocks for scaling tests and 90 day permeability tests. Absorption test specimens were also made and tested, along with mixtures for time of set tests.

Properties of the concrete mixes were determined, listed and reported. These included: slump, air content, unit weight, concrete temperature, and air temperature. The same fine aggregate, silicious concrete sand, of the following gradation was used in all of the mixes:

CONCRETE SAND

Sieve Size	Percent Passing (by Weight)
3/8"	100
No. 4	98
No. 16	73
No. 50	17
No. 100	1

The same coarse aggregate gradation was used for all of the mixes in this study. The coarse aggregate used in each mix included 25%, (by weight) of the materials passing the 1" sieve and retained on the 3/4" sieve; 45% from the materials passing the 3/4" sieve and retained on the 1/2" sieve and 30% of the materials passing the 1/2" sieve and retained on the No. 8 sieve. The gravel was obtained from a local pit, the limestone from Kentucky and the sandstone from Arkansas. See Table 12 in the Appendix for coarse aggregate sources. A brief geological discussion is also indicated in the Appendix on page 65.

Table 2

List of Variables and Mix Designs (coded)

Variables

Aggregates	(1) Gravel, (2) Sandstone, (3) Limestone,
Cement, sacks per cubic yd.	(4) 5.5, (5) 6.0, (6) 6.5,*
Type Mix	(7) Non-air, (8) Air,
Admixture	(9) Control***, (10) Water-reducer**, and (11) Super water-reducer**.

Mix Designs

(1)	1-4-7-9	(16)	1-6-8-9	(31)	2-6-7-9	(46)	3-5-8-9
(2)	1-4-7-10	(17)	1-6-8-10	(32)	2-6-7-10	(47)	3-5-8-10
(3)	1-4-7-11	(18)	1-6-8-11	(33)	2-6-7-11	(48)	3-5-8-11
(4)	1-4-8-9	(19)	2-4-7-9	(34)	2-6-8-9	(49)	3-6-7-9
(5)	1-4-8-10	(20)	2-4-7-10	(35)	2-6-8-10	(50)	3-6-7-10
(6)	1-4-8-11	(21)	2-4-7-11	(36)	2-6-8-11	(51)	3-6-7-11
(7)	1-5-7-9	(22)	2-4-8-9	(37)	3-4-7-9	(52)	3-6-8-9
(8)	1-5-7-10	(23)	2-4-8-10	(38)	3-4-7-10	(53)	3-6-8-10
(9)	1-5-7-11	(24)	2-4-8-11	(39)	3-4-7-11	(54)	3-6-8-11
(10)	1-5-8-9	(25)	2-5-7-9	(40)	3-4-8-9		
(11)	1-5-8-10	(26)	2-5-7-10	(41)	3-4-8-10		
(12)	1-5-8-11	(27)	2-5-7-11	(42)	3-4-8-11		
(13)	1-6-7-9	(28)	2-5-8-9	(43)	3-5-7-9		
(14)	1-6-7-10	(29)	2-5-8-10	(44)	3-5-7-10		
(15)	1-6-7-11	(30)	2-5-8-11	(45)	3-5-7-11		

* Cement content is indicated as number of cement bags (94 lbs.) per cubic yard of concrete.

** For simplicity the water reducers and super water reducers are referred as (WR) and (SWR) throughout this report.

*** The control mixes were divided into two groups of air-entrained and non-air entrained. All of the mixes with air-entraining agents were compared to air entrained control mixes and all of the mixes without air entraining were compared to control mixes without air agents.

The data obtained in this study was evaluated to determine the responses (sensitivity) within each group of mixes (made with one kind of coarse aggregate) due to changes in variables, such as admixtures or cement contents. Also, comparisons were made between like mixes from each group (i.e., same variable but a change in the kind of coarse aggregate). This is a non-statistical study, but it can be used as a bench mark or baseline study for information and comparison of results.

90 Day Permeability Test Procedure

In this test four 3" x 9" x 15" slabs for each type of coarse aggregate were constructed. These blocks were cured with wet burlap for one day, in the moist room for thirteen days and air cured in the laboratory prior to ponding for twenty-one days. After this curing period, 1" high dams were placed on top of the concrete blocks around the edge for the ponding procedure. Three blocks were continuously ponded to a depth of 1/2" with a 3% solution of sodium chloride for a period of 90 days. The other block was not ponded, but was used to determine the base-line chloride content. After the ponding period was over, the solution was removed from the blocks and they were allowed to dry. After drying the surface, the blocks were wire brushed to remove any salt crystal build up. A total of 12 samples were taken at a depth of 1/15" to 1/2" and another 12 samples were taken at a depth of 1/2" to 1" from the same four blocks. All 24 of these samples were in the form of pulverized concrete taken by a rotary hammer drilling into the blocks. The chloride content of each sample was determined.

DISCUSSION OF RESULTS

PLASTIC MIX DATA

In the gravel group series for mixes containing no air entraining admixtures, the unit weights varied from 145.6 to 148.4 lbs/ft^3 (146.4 lbs/ft^3 average). For air entrained concrete, it varied from 140 to 145.6 lbs/ft^3 with an average of 142.3. The air content for non-air entrained mixes ranged from one to three percent with an average of 2% and for air-entrained concrete it ranged from 4.2% to 5.9% with an average of 5%. The workability of gravel concrete mixes measured by slump was very much consistent in all of the concrete mixes. It varied from 3 - 4 1/2 inches with an overall average of 3 3/4 inches.

In the sandstone group, the unit weight for non-air entrained mixes ranged from 148.4 to 152.0 lbs/ft^3 with an average of 150.1 lbs/ft^3. For air-entrained sandstone concrete the ranges were from 142.4 to 147.2 lbs/ft^3 with an average of 144.0 lbs/ft^3. The air content for non air entrained concrete ranged from 0.6% to 2.4% with an average of 1.5% and 4.0% to 5.8% for mixes with air entraining agents with an average of 5%. The slump ranges for all the sandstone mixes were from 3 to 4 1/2 inches with an average slump of 3 5/8 inches.

The average unit weight for the limestone mixes were slightly higher than sandstone and gravel, the ranges were from 149.6 lbs/ft^3 to 154.4 lbs/ft^3 (average 151.5 lbs/ft^3) for non air entrained concrete and 144.4 lbs/ft^3 to 148.0 lbs/ft^3 (average 196.1 lbs/ft^3) for air entrained concrete. The air content for non-air entrained limestone concrete was somewhat lower than the other concretes. For non-air entrained concrete the air content varied from 0.7% to 2.0% with an average of 1.2% and for air-entrained limestone concrete it ranged from 4.4% to 5.1% with an average of 4.7%. The slump for non-air entrained concrete ranged from 3 inches to 4 inches, with an average of 3 3/4 inches; for air-entrained concrete, the slump varied from 3 inches to 4 1/2 inches, with an average of 3 3/4 inches.

Based on the overall data on fresh concrete, the type of coarse aggregate did not affect the slump and air content. The unit weight of plastic concrete is dependent on the specific gravity of the coarse aggregate. The SWR mixes showed an average increase of 2.6 lbs/ft^3 in the unit weight of concrete.

The temperature of all the mixes was usually about 2°F higher than the laboratory (ambient) temperature. The average temperature for concrete was 72°F while the laboratory had an average temperature of 70°F during mixing.

The plastic mix data for gravel, sandstone, concrete are indicated in Table 6 in the Appendix.

Water Cement Ratio:

For the gravel group, the adjusted water cement ratios were 0.51, 0.48, 0.43 for 5.5, 6.0 and 6.5 bag plain concrete. For sandstone, the ratios were 0.56, 0.50, 0.49 for 5.5, 6.0 and 6.0 bag concrete; and for limestone, they were 0.53, 0.49, and 0.49 for the same cement contents. This was done to obtain a slump range of 2" to 4". The amount of necessary water was reduced by 5%, 10%, and 20% when air entraining, water reducers and super water reducers were used, respectively.

Compressive Strength

Within the same coarse aggregate group, the addition of water reducers (WR) and super water reducers (SWR) generally increased the overall strength of the concrete. The additional strength gained (over the reference) due to these admixtures was more evident when SWRs were used. Also, at later ages the difference in strength between the admixture added concrete and reference concrete decreased.

a. Gravel:

In this group of coarse aggregate, after 28 days, with the use of water reducers, an increase of 21% in the compression strength over the reference was obtained on the average. When SWRs were used the average gain in strength was 58% over the reference at 28 days. Figures 1 and 2 in the Appendix show the effect of the water reducers and super water reducers on 6.5 bag air-entrained and non-air entrained concrete. Table 3, page 12, lists the average values for percent increase for all of the mixes run in this project. The addition of super water reducers to a 5.5 bag concrete produced higher strength than the plain 6.5 concrete; therefore, a savings in cement is anticipated when SWRs are used.

The increase in the cement content from 5.5 bags to 6.5 bags caused an average increase in strength of 13% in the non-air entrained concrete; for the air entrained concrete, it was about 5%. After 200 days, the strength for the non-air entrained reference mixes varied from 6926 psi (5.5 bag) to 7385 psi (6.5 bag). For the air entrained mixes after 200 days, the strength varied from 4814 psi (5.5 bags) to 5162 psi (6.5 bags). Figures 3 and 4, in the Appendix depict the plot of compressive strength vs age for the three cement contents used in this study for non-air entrained and air entrained concrete, respectively.

Actual break data for all the speciments tested are listed in Table 7 in the Appendix.

b. Sandstone:

The addition of water reducers and super water reducers in the sandstone concrete mixes caused an increase of 20% and

59% (over the reference mix) respectively, after 28 days of moist curing. Generally the increase over the reference concrete was more evident in the air-entraining mixes. The 5.5 bag mixes with super water reducers produced higher strength than a 6.5 bag concrete (reference mix). A savings in cement is anticipated when super water reducers are used. Figures 5 and 6 show the effect of the water reducers and super water reducers on the 6.5 bag non-air entrained and air-entrained concrete.

In this group of coarse aggregate the increase in the cement content from 5.5 bags to 6.5 bags caused an average increase of 28% in the compressive strength of the plain non-air entrained concrete. The air entrained reference mix did not show any significant rise in strength when the cement content was increased. Figures 7 and 8 in the Appendix shows the relationship between the increase in the cement content and the strength. For the non-air entrained, plain concrete the compressive strength varied from 5839 psi (6 bags) to 7632 (6.5 bags) psi. For the air entrained concrete the compressive strength varied from 5121 psi (5.5 bags) to 5424 psi (6.0 bags) after 200 days of curing.

c. Limestone:

In the limestone group, the addition of water reducers caused an average increase of 26%, and the super water reducers caused an average increase of 55% in the compressive strength of the 28-day old specimens. The effect of these admixtures did not decrease with age, and the same percent increase in compressive strength was achieved in 7 day, 28 day and 200 day breaks. Figures 9 and 10 in the Appendix show the relationship between strength and the addition of water reducers and super water reducers on 6.5 bag non-air entrained and air entrained concrete mixes. The increase in the cement content from 5.5 bags (per cubic yard) to 6.5 bags caused a 32% increase in compressive strength at 200 days. The increase in compressive strength at 7 and 28 days due to the increase in cement content was not significant. Figures 11 and 12 in the Appendix show the relationship between the increase in cement content and strength in the non-air entrained and the air entrained concrete. The range of strength after 200 days varied from 6210 psi to 8163 psi for non-air entrained concrete, and from 4317 psi to 5742 psi for air entrained mixes. In limestone, the addition of SWR caused the 5.5 bag non-air concrete to have higher strength than 6.5 bag plain (no admixture) concrete.

Figures 13 through 18 in the Appendix show the relationship between the age and the strength for gravel, limestone and sandstone, air and non-air concrete in each of the cement factors evaluated in this study. In those groups of mixes with no air-entraining agents, the limestone and sandstone showed comparable strength; gravel showed slightly less strength (about 5%). However, when air entraining agents were used, all of these aggregates showed comparable strength in 6 and 6.5 bag concrete; in the 5.5 bag concrete air entrained sandstone showed the highest strength.

TABLE 3

Percent increase over the reference* in compressive strength with the use of water reducers and super water reducers.

Type of Coarse Aggregate	Admixture	7-Day	28-Day	200-Day
GRAVEL	WR	33%	21%	9%
	SWR	76%	56%	34%
	WR+AIR	39%	23%	6%
	SWR+AIR	83%	60%	55%
SANDSTONE	WR	25%	21%	14%
	SWR	65%	37%	20%
	WR+AIR	30%	20%	13%
	SWR+AIR	70%	81%	54%
LIMESTONE	WR	17%	17%	12%
	SWR	46%	43%	29%
	WR+AIR	36%	35%	41%
	SWR+AIR	72%	67%	79%

*There are two groups of reference mixes, one for non-air entrained and one for the air entrained mixes. the percentages indicated for the WR + Air and SWR + Air mixes are based on the reference concrete which had air entraining agents.

Tensile Strength

a Gravel

The tensile strength was measured by the Splitting Tensile Test. In the gravel aggregate mixes, the tensile strength increased with age and also with the addition of water reducers and super water reducers. The gravel concrete specimens with no air entraining benefited the most by the addition of the water reducers and super water reducers in gaining tensile strength over the reference concrete. Table 4, page 15, lists the percent increase in tensile strength for non-air and air entrained concrete for 7-day, 28-day and 200-day concrete due to the use of water reducers (WR) and super water reducers (SWR) in gravel, sandstone and limestone concrete.

The water reducers and super water reducers seemed to have the most effect on early age concrete; and it was decreased with time. When air-entraining agents were used, the WRS and SWRs admixtures were less effective in increasing the strength. Table 7 in the Appendix lists all of the individual break results for all ages. For 200-day concrete, tensile values varied from 385 psi (5.5 bag) to 478 psi (6.5 bag) for plain air entrained concrete. For non-air concrete the strength was approximately 580 psi. The cement content increase did not change the tensile strength significantly in non-air gravel concrete.

b. Sandstone

The addition of water reducers and super water reducers caused the tensile strength of concrete to increase. Table 4, page 15 lists the percent increase gained due to these admixtures in air and non-air entrained concrete. As indicated in this table, the air entraining agents helped water reducers and super water reducers in achieving a higher percentage of increase in tensile strength over reference concrete. For sandstone concrete without the WR and SWR, the 6.5 bag no-air concrete produced a tensile strength of 549 psi and 411 psi when air entraining was used in the same mix. Table 7 in the Appendix lists the individual strength results for sandstone mixes.

c. Limestone

In the limestone concrete mixes as for the previous mixes, the addition of WR and SWR caused the tensile strength to increase as indicated on Table 4.

The range of tensile strength for non-air entrained reference concrete (no WR or SWR) varied from 533 (6 bags) to 596 psi (6.5 bags). For the air entrained limestone concrete, the increase in the cement content did not necessarily cause an increase in the tensile strength. The highest tensile strength in air entrained reference mixes was 500 psi achieved by a 6.0 - bag cement content.

From overall evaluation of the tensile strength data, it is concluded that the types of coarse aggregate evaluated in this study did not affect the tensile strength of concrete. The addition of SWR, however, increases the splitting tensile strength considerably.

TABLE 4

Percent increase over the reference* in splitting tensile strength with use of water reducers and super water reducers.

Type of Coarse Aggregate	Admixture	7-Day	28-Day	200-Day
	WR	37%	14%	8%
GRAVEL	SWR	59%	28%	29%
	WR+Air	19%	10%	11%
	SWR+Air	49%	20%	39%
	WR	22%	11%	7%
SANDSTONE	SWR	36%	18%	12%
	WR+Air	19%	26%	16%
	SWR+Air	45%	58%	40%
	WR	10%	15%	7%
LIMESTONE	SWR	41%	39%	18%
	WR+Air	28%	15%	18%
	SWR+Air	47%	41%	20%

*There are two groups of reference mixes, one for non-air entrained and one for the air entrained mixes. The percentages indicated for WR + Air and SWR + Air mixes are based on the reference concrete which had air-entraining agents.

Flexural Strength

a. Gravel:

In the concrete specimens made with gravel, the addition of WRs and SWRs increased the flexural strength of concrete. The percent increase over the reference concrete for gravel, sandstone and limestone is indicated in Table 5, page 18, for both air entrained and non-air entrained concrete. On the average, the water reducers increased the flexural strength about 10% and SWR increased the flexural strength by 20%. The actual flexural strength breaks are indicated in Table 7 in the Appendix. After 28 days of curing, none of the concrete specimens tested had flexural strength less than 500 psi even with the lowest cement content. After 28 days, a 6.0 bag concrete gravel mix produced a flexural strength of 616 psi for non-air entrained and 571 psi for air entrained concrete.

b. Sandstone:

Like all other mixes, increases in flexural strength were observed when WR and SWRs were used as indicated in Table 5. The percent increases over reference were comparable to those of gravel mixes when WR and SWR were used.

For 28 days (6.0 bag concrete), a flexural strength of 633 psi was obtained for non-air entrained, and 575 psi when air was used. Flexural strengths above 500 psi were obtained after 28 days in all of the mixes.

c. Limestone:

As indicated in the limestone strength data, this type of coarse aggregate produced higher flexural strength than comparable mixes of gravel and sandstone concrete. The addition of water reducers and super water reducers increased the flexural strength of concrete. Percent increase over reference concrete are indicated in Table 5, page 18. All of the concrete specimens (except 7-day 5.5 air entrained concrete) showed flexural strength in excess of 500 psi. All of the non-air entrained concrete mixes produced concrete with flexural strength above 600 psi after 28 days. A 6.0 bag no-air limestone concrete produced flexural strength of 747 psi, and 628 psi when air was used. From overall evaluation of the flexural strength data, it is concluded that the gravel and sandstone concrete are comparable and that limestone will produce higher flexural strength.

Table 7 in the Appendix lists all of the strength data for all mixes.

TABLE 5

Percent of reference in flexural strength of concrete due to the use of WR and SWRs

C. Aggregate	Admixture	7-Day	28-Day	200-Day
GRAVEL	WR	17%	1%	11%
	SWR	19%	17%	20%
	WR+Air	15%	9%	8%
	SWR+Air	38%	22%	28%
SANDSTONE	WR	11%	9%	13%
	SWR	27%	22%	19%
	WR+Air	17%	9%	5%
	SWR+Air	45%	34%	17%
LIMESTONE	WR	6%	9%	8%
	SWR	25%	19%	13%
	WR+Air	26%	18%	16%
	SWR+Air	38%	39%	34%

*There are two groups of reference mixes one for non-air entrained and one for the air entrained mixes. The percentage indicated for WR + Air and SWR + Air mixes are based on the reference concrete which had air-entraining agents.

Abrasion

The abrasion test in this project is defined as wear of surface or loss of mortar (gram/cm^2) of the concrete specimens subjected to the rotating cutter method as described in ASTM C-944. According to ASTM, this method gives an indication of the relative wear resistance of mortar and concrete based on testing of cored or fabricated specimens and has been successfully used in the quality control of highways and bridge concrete subject to traffic. The abrasion device consists of a drill press or similar device with a chuck capable of holding and rotating the abrading cutter at a speed of 200 rpm and exerting a constant force of 10.0 kgf on the test specimen surface. The rotating cutter consists of 24 No. 1 Desmond-Huntington grinding dressing wheels with the overall diameter of 3 1/4 inches. The desired load is directly placed on the spindle that turns the cutter to maintain a constant load.

The abrasion results listed in Table 8 was measured on concrete specimens containing gravel, sandstone and limestone. The gravel and sandstone concrete did not show any significant difference in abrasion loss. However 50% less abrasion loss was noticed in the limestone group. The super water reducers also helped reduce the abrasion loss. Although abrasion loss on limestone aggregate is generally higher than gravel, the lower abrasion loss noticed in limestone concrete could be attributed to the strength of the mortar and the source of limestone used in this study.

Freeze and Thaw:

The durability or the resistance of gravel concrete to rapid freezing and thawing was very poor when no air entraining agents were used. The addition of air entraining agents improved the durability resistance considerably. For example, a non-air entrained 5.5 bag concrete had a durability factor of 12 after 59 cycles; the same mix with air entraining had a durability factor of 53 after 261 cycles. When water reducing admixtures were introduced, an increase in the resistance of the mixes without air entraining agents was observed; however, when air entraining was introduced to the mixes which contained the water reducing or super water reducing admixture, the durability factor decreased. These admixtures when combined with air entraining agents seemed to have an adverse effect on the durability of gravel concrete. When subjected to freeze and thaw environment, the gravel must be air entrained.

Sandstone concrete showed excellent resistance to rapid freeze and thaw. Limestone concrete also showed good resistance to freeze and thaw tests. These aggregates are more suitable for a concrete which will be subjected to severe freezing and thawing than regular gravel. Table 8 in the Appendix shows all of the durability data. Due to the equipment problems, tests to measure scaling resistance to deicing chemicals were not performed on all the samples; therefore, it will not be discussed herein. From what is indicated in the rapid freezing and thawing test, the same results would have probably been obtained in the scaling tests.

Although there are no established criteria for acceptance or rejection of concrete in terms of durability factors, the number of cycles of freezing and thawing and durability factors are values which can be used for comparison purposes for different types of concretes, types of aggregates used in the mixes or other mix property comparisons. Some guidance in interpretation can be obtained from the following: a factor smaller than 40 means that the concrete is probably unsatisfactory with respect to frost resistance; 40-60 is the range for concrete with doubtful performance; and above 60 is probably satisfactory.

There is no doubt, however, that some accelerated freezing and thawing tests result in the destruction of concrete that in practice would be satisfactory and durable. While the number of cycles of freezing and thawing in a test and in actual concrete are not related, it may be interesting to note that in most of the United States there are more than 50 such cycles per year.

Shrinkage:

In the shrinkage tests, the 28-day old concrete specimens made with gravel showed the least amount of shrinkage. Addition of super water reducers decreased the amount of shrinkage in the gravel and limestone series. The shrinkage data listed in Table 9 in the Appendix shows the gravel group to have the least amount of shrinkage (0.017% on the average) and sandstone the most amount of shrinkage (.033%). The limestone group had an average shrinkage of 0.026%.

Time of Set:

The time of set by penetration was run on the cement paste in a one gallon jar after the coarse aggregate was removed by sifting. This test was not performed on the sandstone group due to the lack of aggregate. In both groups of aggregate tested (limestone and gravel), water reducer and super water reducer agents acted as set retarders. The delay setting time was more noticeable when water reducers were used. There is no effect on setting time of concrete by the type of coarse aggregate used. The time of set data are shown in Table 10 in the Appendix.

Absorption:

The gravel and sandstone group had about the same absorption rate with limestone being slightly higher. The addition of water reducers and super water reducers decrease the absorption rate by 0.8% to 1.45%. The air entrained mixes usually showed slightly higher absorption rate. Values of all the absorption tests are listed in Table 9 in the Appendix.

90 day Chloride Permeability Results:

This test was performed to provide data and information for the evaluation of the ingress of chloride ions into concrete made with different types of coarse aggregate under evaluation in this study. The gravel group showed the lowest accumulation of chloride ions at the depth of 1/2". he average 95% chloride* level for all of the plain (no air) reference mixes was 10.31 lbs/yd^3 and at the depth of 1" was 2.48 lbs/yd^3. The increase in the cement content did not make noticeable reduction in the ingress of chloride ions. The sandstone group showed an accumulation of 12.24 and 7.3 lbs/ft^3 at depths of 1/2" and 1", respectively. The limestone had 95% chloride values of 21.50 lbs/yd^3 at 1/2" depth, and 6.99 lbs/yd^3 at 1" depth.

The air entraining admixtures in the gravel and sandstone group caused an increase in the accumulation of chloride ions. This increase of up to 55% was more evident when no other admixture was used. In the limestone group, the addition of air entraining did not cause considerable increases in chloride accumulation.

The water reducing and super water reducing agents caused a reduction in the accumulation of chloride in most of the mixes. This reduction ranged from 7% to 16% for water reducer agents and 21% to 39% for super water reducers.

* The 95% chloride level given here is generally considered an appropriate measure of overall permeability since it is a single statistically obtained chloride level which indicates that 95% of the chloride content at a particular depth encountered in the sample will be less than or equal to that value. It is based on the sample mean, standard deviation and the assumption that the data is normally distributed.

COST AND AVAILABILITY:

The local cost* of the gravel was approximately $7.78 to $8.68 per ton, the sandstone $6.80 per ton and the limestone $12 to $14 per ton at the time of this study. There were no local agents available to supply the needed sandstone and all of the sandstone needed for mixing could not be obtained. Table 11 in the Appendix lists the sources for limestone and sandstone.

LIMESTONE CONCRETE EXPERIMENTAL PAVING CONSTRUCTION:

Although not a part of this study, it is worthwhile to indicate that two short sections of U.S. 90 Highway located between Garden City and Calumet, in St. Mary Parish (State Project 424-05-15) were paved with limestone aggregate in September 1978 and April 1979. Grade B Kentucky limestone was used to pave 1545 feet of the westbound lanes from station 260+20 to 244+75. Grade D limestone from the same source was used to pave 1690 feet of the eastbound lanes from station 243+70 to 260+60. Air entraining and water reducing agents were used in this operation. Both sections were opened to traffic in October 1979. The fourth year evaluation indicated that the limestone and gravel concrete both produced the similar skid numbers. The visual observation indicated that both sections (limestone and the gravel reference) are in good condition after approximately four years of service. The evaluation of this pavement could be used as a part of the implementation of this research project.

In April 1981 approximately one mile section of the southbound lanes of U.S. 61 north of Baton Rouge was overlaid with a 5.8 bag concrete containing limestone aggregate, air agent and a set retarder. This was the first concrete overlay construction in Louisiana. The performance of the pavement has been satisfactory so far and is being monitored under a separate study.

* Suppliers terminal, Baton Rouge, Louisiana.

CONCLUSIONS

The following conclusions have been reached after overall evaluation of the data obtained.

1. From overall comparisons of the strength and durability data, it is concluded that limestone and sandstone are good alternatives to the river gravel normally used in concrete if economic factors are favorable and these aggregates are available. General improvements were seen, especially in flexural strength and durability properties, when limestone aggregates were used.

2. The addition of water reducers and super water reducers definitely increases the strength of concrete In all of the mixes evaluated, SWR caused the mixes with low cement content to have equivalent or higher strength than concrete with higher cement content. The super water reducer admixture can be beneficial in increasing the strength of concrete without increasing the cement content. These admixtures also increased the abrasion resistance of concrete, caused less shrinkage in concrete and helped in reduction of accumulated chloride ions as determined in the 90 day chloride ponding tests.

3. Air entraining agents caused a substantial increase in the durability factor of gravel concrete. Sandstone and limestone concrete specimens showed excellent resistance to rapid freezing and thawing. When air entraining agents were used in mixes containing super water reducers and water reducers, the durability factors were reduced. Since non-air entrained limestone or sandstone concrete showed better freeze and thaw resistance than air entrained gravel concrete, the minimum amount, or no, air entraining agents could be used in concrete made with limestone or sandstone coarse

aggregates. Although air entraining agents provided a better durability factor against freezing and thawing, they also increased the amount of accumulated chloride ions as indicated by the 90 day permeability test.

4. The type of coarse aggregate did not affect the properties of the plastic concrete.

RECOMMENDATIONS

1. Use of sandstone or limestone should be continued as an alternative to silicious gravel in all types of concrete.

2. Because air entraining agents improve durability, they are highly recommended when river gravel must be used as the coarse aggregate in concrete. The strength of air entrained concrete may be also increased by use of WR or SWRs.

3. In areas of the country with severe freezing and thawing, use of sandstone and limestone will provide much better protection for concrete than silicious gravel.

4. Due to high flexural strength and durability, use of limestone is recommended in paving concrete.

5. Use of SWR should be allowed in concrete when high strength and good workability are required.

6. The effect of water reducers and super water reducers on durability properties of the air entrained concrete should be further studied.

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APPENDIX

TABLE 6

PLASTIC MIX DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Slump, in.	Air Content,%	Unit Wt., lbs./ft.^{3}	Conc. Temp.	Lab. Temp.
1	Gravel	5.5	Non-Air	None	4"	1.0	146.4	73°F	72°F
2	Gravel	5.5	Non-Air	WR	4"	1.5	147.2	70°F	69°F
3	Gravel	5.5	Non-Air	SWR	4"	2.5	147.2	70°F	68°F
4	Gravel	5.5	Air	None	3-3/4"	4.7	141.2	71°F	70°F
5	Gravel	5.5	Air	WR	3-3/4"	5.8	139.6	70°F	68°F
6	Gravel	5.5	Air	SWR	3-1/2"	4.7	143.2	71°F	68°F
7	Gravel	6.0	Non-Air	None	4-1/2"	1.4	145.2	72°F	69°F
8	Gravel	6.0	Non-Air	WR	4"	3.0	146.0	72°F	70°F
9	Gravel	6.0	Non-Air	SWR	3-1/2"	2.5	146.4	71°F	70°F
10	Gravel	6.0	Air	None	4"	5.9	140.0	71°F	71°F
11	Gravel	6.0	Air	WR	3-3/4"	5.3	142.0	74°F	73°F
12	Gravel	6.0	Air	SWR	4"	4.3	144.4	66°F	65°F
13	Gravel	6.5	Non-Air	None	3"	2.0	145.6	66°F	61°F
14	Gravel	6.5	Non-Air	WR	3-1/2"	2.9	145.6	65°F	64°F
15	Gravel	6.5	Non-Air	SWR	3"	2.0	148.4	72°F	71°F
16	Gravel	6.5	Air	None	4-1/2"	4.2	140.8	74°F	71°F
17	Gravel	6.5	Air	WR	3-1/4"	4.4	143.2	75°F	73°F
18	Gravel	6.5	Air	SWR	3-1/2"	4.2	145.6	72°F	70°F

Note: WR = Water Reducer
SWR = Super Water Reducer

TABLE 6 (CONTINUED)

PLASTIC MIX DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Slump, in.	Air Content,%	Unit Wt., lbs./ft.^{3}	Conc. Temp.	Lab. Temp.
19	Sandstone	5.5	Non-Air	None	3"	1.0	148.4	74°F	71°F
20	Sandstone	5.5	Non-Air	WR	3-1/4"	1.0	150.0	72°F	69°F
21	Sandstone	5.5	Non-Air	SWR	4"	1.3	150.8	67°F	69°F
22	Sandstone	5.5	Air	None	4"	5.8	142.4	75°F	73°F
23	Sandstone	5.5	Air	WR	4-1/2"	5.7	142.4	73°F	71°F
24	Sandstone	5.5	Air	SWR	3-1/2"	4.7	143.6	70°F	68°F
25	Sandstone	6.0	Non-Air	None	4-1/4"	0.7	150.4	70°F	69°F
26	Sandstone	6.0	Non-Air	WR	4-1/4"	0.6	149.6	72°F	69°F
27	Sandstone	6.0	Non-Air	SWR	4"	1.2	152.0	75°F	73°F
28	Sandstone	6.0	Air	None	3"	4.9	143.2	76°F	73°F
29	Sandstone	6.0	Air	WR	3-1/4"	5.8	142.8	73°F	72°F
30	Sandstone	6.0	Air	SWR	3-1/4"	4.3	146.8	74°F	71°F
31	Sandstone	6.5	Non-	None	3-1/2"	1.3	149.2	72°F	70°F
32	Sandstone	6.5	Non-Air	WR	3-1/4"	2.4	148.8	73°F	71°F
33	Sandstone	6.5	Non-Air	WR	3-1/2"	1.6	151.6	70°F	68°F
34	Sandstone	6.5	Air	None	3"	4.5	143.6	73°F	72°F
35	Sandstone	6.5	Air	WR	3-1/2"	5.1	144.0	71°F	68°F
36	Sandstone	6.5	Air	SWR	3-1/2"	4.0	147.2	73°F	70°F

Note: N.A. = Not Available (lack of aggregate material for compaction test)

TABLE 6 (CONTINUED)

PLASTIC MIX DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Slump, in.	Air Content,%	Unit Wt., lbs./ft.^{3}	Conc. Temp.	Lab. Temp.
37	Limestone	5.5	Non-Air	None	3-3/4"	0.7	150.4	74°F	70°F
38	Limestone	5.5	Non-Air	WR	3-1/2"	1.2	152.4	74°F	71°F
39	Limestone	5.5	Non-Air	SWR	4"	0.7	154.4	74°F	70°F
40	Limestone	5.5	Air	None	3"	5.1	146.0	77°F	75°F
41	Limestone	5.5	Air	WR	4-1/4"	4.9	145.6	67°F	64°F
42	Limestone	5.5	Air	SWR	3-1/2"	4.4	148.0	70°F	68°F
43	Limestone	6.0	Non-Air	None	3"	1.0	150.4	75°F	73°F
44	Limestone	6.0	Non-Air	WR	3-1/2"	2.0	150.0	74°F	72°F
45	Limestone	6.0	Non-Air	SWR	4"	1.2	153.6	75°F	74°F
46	Limestone	6.0	Air	None	3-3/4"	4.9	144.4	76°F	74°F
47	Limestone	6.0	Air	WR	3-1/2"	4.7	146.0	73°F	69°F
48	Limestone	6.0	Air	SWR	3-3/4"	4.5	148.0	72°F	68°F
49	Limestone	6.5	Non-Air	None	4"	1.1	149.6	73°F	73°F
50	Limestone	6.5	Non-Air	WR	4"	1.3	151.6	69°F	66°F
51	Limestone	6.5	Non-Air	SWR	3-3/4"	1.3	151.2	69°F	66°F
52	Limestone	6.5	Air	None	3-3/4"	4.9	144.8	70°F	66°F
53	Limestone	6.5	Air	WR	4-1/2"	4.4	146.0	72°F	70°F
54	Limestone	6.5	Air	SWR	3-1/2"	4.6	146.0	70°F	65°F

TABLE 7

STRENGTH DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Compressive Strength, psi 7 Day	Compressive Strength, psi 28 Day	Compressive Strength, psi 200 Day	Splt. Tensile, psi 7 Day	Splt. Tensile, psi 28 Day	Splt. Tensile, psi 200 Day	Flexural Strength, psi 7 Day	Flexural Strength, psi 28 Day	Flexural Strength, psi 200 Day
1	Gravel	5.5	Non-Air	None	3163	4761	6926	296	428	587	528	695	733
2	Gravel	5.5	Non-Air	WR	4494	6151	7132	416	511	562	642	637	862
3	Gravel	5.5	Non-Air	SWR	6060	7332	8645	418	525	739	633	742	883
4	Gravel	5.5	Air	None	2691	3831	4814	312	354	385	475	631	712
5	Gravel	5.5	Air	WR	3581	4480	5144	325	422	434	462	554	585
6	Gravel	5.5	Air	SWR	5227	6443	7709	508	495	616	633	708	785
7	Gravel	6.0	Non-Air	None	3148	4329	5645	285	429	436	517	616	721
8	Gravel	6.0	Non-Air	WR	4538	5621	7020	433	505	537	625	642	820
9	Gravel	6.0	Non-Air	SWR	5354	7061	8646	557	548	653	660	793	945
10	Gravel	6.0	Air	None	3174	4061	5115	305	403	453	517	571	612
11	Gravel	6.0	Air	WR	4120	5186	5913	379	452	531	608	629	768
12	Gravel	6.0	Air	SWR	4208	5530	7132	362	472	531	662	683	738
13	Gravel	6.5	Non-Air	None	3931	5159	7385	363	459	575	567	720	802
14	Gravel	6.5	Non-Air	WR	4464	5397	6590	424	484	562	625	687	788
15	Gravel	6.5	Non-Air	SWR	6599	7786	9252	521	605	643	795	824	974
16	Gravel	6.5	Air	None	2662	4070	5162	295	550	478	433	517	683
17	Gravel	6.5	Air	WR	4117	5118	5580	379	434	495	550	600	665
18	Gravel	6.5	Air	SWR	5942	7173	8640	486	567	672	658	800	1041

TABLE 7 (CONTINUED)

STRENGTH DATA

Mix No.	Aggregate	Cement Content, sacks/yd.	Type Mix	Admixture	Compressive Strength, psi 7 Day	28 Day	200 Day	Splt. Tensile, psi 7 Day	28 Day	200 Day	Flexural Strength, psi 7 Day	28 Day	200 Day
19	Sandstone	5.5	Non-Air	None	3010	4705	6328	304	403	551	471	579	717
20	Sandstone	5.5	Non-Air	WR	4105	6063	7244	406	464	574	566	675	820
21	Sandstone	5.5	Non-Air	SWR	5236	6540	7456	455	457	601	574	754	821
22	Sandstone	5.5	Air	None	3124	4052	5121	282	380	459	433	608	633
23	Sandstone	5.5	Air	WR	3899	5100	5621	383	434	545	583	629	700
24	Sandstone	5.5	Air	SWR	5168	7674	8539	470	606	704	667	746	729
25	Sandstone	6.0	Non-Air	None	3628	5006	5839	337	447	514	546	633	708
26	Sandstone	6.0	Non-Air	WR	4759	6284	7132	416	532	545	600	692	750
27	Sandstone	6.0	Non-Air	SWR	5839	6973	7208	424	491	545	687	708	767
28	Sandstone	6.0	Air	None	3159	4005	5424	334	347	404	479	575	633
29	Sandstone	6.0	Air	WR	4019	5127	6511	391	505	525	512	625	654
30	Sandstone	6.0	Air	SWR	5135	7014	7856	452	563	642	653	750	762
31	Sandstone	6.5	Non-Air	None	4087	6036	7632	389	469	549	554	687	658
32	Sandstone	6.5	Non-Air	WR	4379	6484	8042	424	469	615	571	692	775
33	Sandstone	6.5	Non-Air	SWR	6646	8065	9129	510	607	660	742	858	887
34	Sandstone	6.5	Air	None	3227	4022	5203	340	352	411	467	522	562
35	Sandstone	6.5	Air	WR	4467	4988	5610	361	415	398	512	604	575
36	Sandstone	6.5	Air	SWR	5933	7267	7974	456	536	596	683	775	755

TABLE 7 (CONTINUED)

STRENGTH DATA

Mix No.	Aggregate	Cement Content, sacks/yd.	Type Mix	Admixture	Compressive Strength, psi			Splt. Tensile, psi			Flexural Strength, psi		
					7 Day	28 Day	200 Day	7 Day	28 Day	200 Day	7 Day	28 Day	200 Day
37	Limestone	5.5	Non-Air	None	3816	4755	6210	396	408	560	586	600	738
38	Limestone	5.5	Non-Air	WR	4361	5565	6876	425	470	567	619	736	757
39	Limestone	5.5	Non-Air	SWR	5884	7522	8616	552	692	691	686	811	786
40	Limestone	5.5	Air	None	2815	3245	4317	347	374	454	472	522	586
41	Limestone	5.5	Air	WR	3716	4717	7061	389	471	546	569	633	708
42	Limestone	5.5	Air	SWR	4591	5542	7968	423	509	551	654	745	750
43	Limestone	6.0	Non-Air	None	4067	5312	6631	375	417	533	636	747	789
44	Limestone	6.0	Non-Air	WR	4426	5922	7320	373	512	636	700	727	866
45	Limestone	6.0	Non-Air	SWR	6255	7503	9134	574	528	698	866	861	958
46	Limestone	6.0	Air	None	3168	4040	4974	349	423	500	500	628	668
47	Limestone	6.0	Air	WR	4237	4841	7208	440	474	558	605	689	711
48	Limestone	6.0	Air	SWR	5545	6901	9652	513	610	609	703	864	840
49	Limestone	6.5	Non-Air	None	3746	4888	8163	380	478	596	572	694	755
50	Limestone	6.5	Non-Air	WR	5047	6051	9487	470	518	547	589	697	847
51	Limestone	6.5	Non-Air	SWR	4894	6337	9134	497	574	551	700	747	833
52	Limestone	6.5	Air	None	2915	3707	5742	296	378	438	472	547	584
53	Limestone	6.5	Air	WR	4178	5262	6675	434	414	534	639	703	700
54	Limestone	6.5	Air	SWR	5174	6016	9123	501	543	520	633	744	703

TABLE 8

DURABILITY DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Freeze and Thaw, No. Cycles	D.F.	Abrasion Resistance, Grams/cm^2
1	Gravel	5.5	Non-Air	None	59	12.0	0.0150
2	Gravel	5.5	Non-Air	WR	30	6.0	0.0130
3	Gravel	5.5	Non-Air	SWR	131	26.1	0.0085
4	Gravel	5.5	Air	None	261	53.0	0.0191
5	Gravel	5.5	Air	WR	105	21.0	0.0085
6	Gravel	5.5	Air	SWR	126	25.1	0.0085
7	Gravel	6.0	Non-Air	None	24	4.9	0.0319
8	Gravel	6.0	Non-Air	WR	202	40.0	0.0130
9	Gravel	6.0	Non-Air	SWR	93	18.6	0.0064
10	Gravel	6.0	Air	None	162	32.0	0.0170
11	Gravel	6.0	Air	WR	132	26.0	0.0130
12	Gravel	6.0	Air	SWR	147	29.0	0.0060
13	Gravel	6.5	Non-Air	None	59	12.0	0.0149
14	Gravel	6.5	Non-Air	WR	120	24.0	0.0148
15	Gravel	6.5	Non-Air	SWR	72	14.0	0.0107
16	Gravel	6.5	Air	None	170	34.0	0.0150
17	Gravel	6.5	Air	WR	64	13.0	0.0850
18	Gravel	6.5	Air	SWR	146	29.3	0.0110

TABLE 8 (CONTINUED)

DURABILITY DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Freeze and Thaw, No. Cycles	D.F.	Abrasion Resistance, Grams/ cm^2
19	Sandstone	5.5	Non-Air	None	300	100.0	0.0110
20	Sandstone	5.5	Non-Air	WR	283	80.0	0.0128
21	Sandstone	5.5	Non-Air	SWR	123	24.5	0.0064
22	Sandstone	5.5	Air	None	300	97.0	0.0255
23	Sandstone	5.5	Air	WR	300	99.0	0.0149
24	Sandstone	5.5	Air	SWR	298	94.0	0.0085
25	Sandstone	6.0	Non-Air	None	117	23.0	0.0240
26	Sandstone	6.0	Non-Air	WR	300	99.0	0.0150
27	Sandstone	6.0	Non-Air	SWR	174	35.0	0.0021
28	Sandstone	6.0	Air	None	300	95.0	0.0170
29	Sandstone	6.0	Air	WR	300	100.0	0.0210
30	Sandstone	6.0	Air	SWR	300	100.0	0.0298
31	Sandstone	6.5	Non-Air	None	300	100.0	0.0190
32	Sandstone	6.5	Non-Air	WR	300	100.0	0.0064
33	Sandstone	6.5	Non-Air	SWR	160	32.0	0.0085
34	Sandstone	6.5	Air	None	300	100.0	0.0190
35	Sandstone	6.5	Air	WR	300	100.0	0.0128
36	Sandstone	6.5	Air	SWR	300	100.0	0.0085

TABLE 8 (CONTINUED)

DURABILITY DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Freeze and Thaw, No. Cycles	D.F.	Abrasion Resistance, Grams / cm^2
37	Limestone	5.5	Non-Air	None	98	19.7	0.0084
38	Limestone	5.5	Non-Air	WR	141	28.3	0.0085
39	Limestone	5.5	Non-Air	SWR	107	21.3	0.0063
40	Limestone	5.5	Air	None	300	72.0	0.0083
41	Limestone	5.5	Air	WR	300	82.0	0.0128
42	Limestone	5.5	Air	SWR	300	90.0	0.0260
43	Limestone	6.0	Non-Air	None	181	36.2	0.0080
44	Limestone	6.0	Non-Air	WR	356	71.1	0.0110
45	Limestone	6.0	Non-Air	SWR	161	32.0	0.0060
46	Limestone	6.0	Air	None	300	73.0	0.0060
47	Limestone	6.0	Air	WR	300	86.0	0.0053
48	Limestone	6.0	Air	SWR	300	89.0	0.0060
49	Limestone	6.5	Non-Air	None	307	61.5	0.0060
50	Limestone	6.5	Non-Air	WR	203	41.0	0.0060
51	Limestone	6.5	Non-Air	SWR	127	25.4	0.0080
52	Limestone	6.5	Air	None	300	100.0	0.0130
53	Limestone	6.5	Air	WR	300	76.0	0.0110
54	Limestone	6.5	Air	SWR	300	85.0	0.0064

TABLE 9

OTHER TEST DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	28 Day Dry Shrinkage	Scaling Resistance Rating	Scaling Resistance No. Cycles	95 Percentile, 90 Day Permeability, lbs./yd.^{3} @1/2" Depth	95 Percentile, 90 Day Permeability, lbs./yd.^{3} @1" Depth	Absorption,
1	Gravel	5.5	Non-Air	None	-0.019%	N.A.		11.74	2.30	5.0
2	Gravel	5.5	Non-Air	WR	-0.022%	N.A.		6.97	None	4.1
3	Gravel	5.5	Non-Air	SWR	-0.015%	N.A.		4.44	1.39	2.7
4	Gravel	5.5	Air	None	-0.018%	N.A.		19.46	8.58	3.9
5	Gravel	5.5	Air	WR	-0.019%	N.A.		13.12	3.08	5.1
6	Gravel	5.5	Air	SWR	-0.019%	N.A.		9.42	None	2.4
7	Gravel	6.0	Non-Air	None	-0.022%	N.A.		7.34	3.59	4.7
8	Gravel	6.0	Non-Air	WR	-0.018%	N.A.		8.70	None	2.1
9	Gravel	6.0	Non-Air	SWR	-0.007%	N.A.		11.40	4.39	3.2
10	Gravel	6.0	Air	None	-0.020%	N.A.		14.75	7.24	3.8
11	Gravel	6.0	Air	WR	-0.019%	N.A.		12.98	5.71	3.2
12	Gravel	6.0	Air	SWR	-0.014%	N.A.		10.50	7.06	3.0
13	Gravel	6.5	N.A.	None	-0.016%	N.A.		11.85	1.54	3.2
14	Gravel	6.5	Non-Air	WR	-0.013%	N.A.		13.02	0.94	3.3
15	Gravel	6.5	Non-Air	SWR	-0.013%	N.A.		8.59	5.97	2.1
16	Gravel	6.5	Air	None	-0.018%	N.A.		13.73	2.35	5.5
17	Gravel	6.5	Air	WR	-0.025%	N.A.		15.98	7.09	2.1
18	Gravel	6.5	Air	SWR	-0.009%	N.A.		8.08	2.18	3.3

Note: N.A. = Not Available (Testing apparatus out of operation for scaling test)

TABLE 9 (CONTINUED)

OTHER TEST DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	28 Day Dry Shrinkage	Scaling Resistance Rating	Scaling Resistance No. Cycles	95 Percentile, 90 Day Permeability, lbs./yd.^{3} @1/2" Depth	95 Percentile, 90 Day Permeability, lbs./yd.^{3} @1" Depth	Absorption,%
19	Sandstone	5.5	Non-Air	None	-0.032%	N.A.		15.93	12.02	3.2
20	Sandstone	5.5	Non-Air	WR	-0.031%	N.A.		14.08	4.76	3.4
21	Sandstone	5.5	Non-Air	SWR	-0.025%	N.A.		6.43	0.62	2.2
22	Sandstone	5.5	Air	None	-0.033%	N.A.		30.10	10.70	5.9
23	Sandstone	5.5	Air	WR	-0.033%	N.A.		8.40	3.60	4.4
24	Sandstone	5.5	Air	SWR	-0.035%	N.A.		7.89	None	2.8
25	Sandstone	6.0	Non-Air	None	-0.026%	5	49	8.25	0.84	5.2
26	Sandstone	6.0	Non-Air	WR	-0.034%	2	50	10.80	0.47	3.4
27	Sandstone	6.0	Non-Air	SWR	-0.025%	1	50	7.90	None	2.1
28	Sandstone	6.0	Air	None	-0.036%	N.A.		11.77	6.57	4.3
29	Sandstone	6.0	Air	WR	-0.039%	N.A.		12.06	6.18	5.3
30	Sandstone	6.0	Air	SWR	-0.039%	N.A.		4.74	None	3.8
31	Sandstone	6.5	Non-Air	None	-0.033%	N.A.		12.56	8.82	1.6
32	Sandstone	6.5	Non-Air	WR	-0.030%	N.A.		13.45	3.72	4.5
33	Sandstone	6.5	Non-Air	SWR	-0.023%	N.A.		7.92	0.20	2.5
34	Sandstone	6.5	Air	None	-0.030%	N.A.		25.64	13.89	4.8
35	Sandstone	6.5	Air	WR	-0.047%	N.A.		20.20	3.38	5.4
36	Sandstone	6.5	Air	SWR	-0.043%	N.A.		25.93	4.065	2.7

Note: N.A. = Not Available (Testing apparatus out of operation for scaling test)

TABLE 9 (CONTINUED)

OTHER TEST DATA

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	28 Day Dry Shrinkage	Scaling Rating	Resistance No. Cycles	95 Percentile, 90 Day Permeability, lbs./yd.^{3} @1/2" Depth	@1" Depth	Absorption,%
37	Limestone	5.5	Non-Air	None	-0.028%	5	11	20.70	7.50	5.0
38	Limestone	5.5	Non-Air	WR	-0.028%	5	26	25.40	10.00	3.9
39	Limestone	5.5	Non-Air	SWR	-0.025%	4	50	3.47	3.45	3.2
40	Limestone	5.5	Air	None	-0.038%	1	54	22.63	7.47	4.8
41	Limestone	5.5	Air	WR	-0.024%	3	50	22.10	6.07	4.7
42	Limestone	5.5	Air	SWR	-0.021%		N.A.	20.10	None	3.4
43	Limestone	6.0	Non-Air	None	-0.025%		N.A.	24.24	7.27	2.3
44	Limestone	6.0	Non-Air	WR	-0.023%		N.A.	21.55	5.29	4.1
45	Limestone	6.0	Non-Air	SWR	-0.029%		N.A.	12.43	None	2.7
46	Limestone	6.0	Air	None	-0.023%		N.A.	16.47	4.89	4.9
47	Limestone	6.0	Air	WR	-0.025%		N.A.	11.20	2.83	4.4
48	Limestone	6.0	Air	SWR	-0.026%		N.A.	10.55	2.03	3.1
49	Limestone	6.5	Non-Air	None	-0.034%	5	14	19.58	6.20	5.9
50	Limestone	6.5	Non-Air	WR	-0.029%	5	19	6.87	None	4.7
51	Limestone	6.5	Non-Air	SWR	-0.020%	5	15	13.66	2.52	3.9
52	Limestone	6.5	Air	None	-0.022%	2	50	13.73	4.52	6.0
53	Limestone	6.5	Air	WR	-0.028%	5	21	18.62	4.30	1.2
54	Limestone	6.5	Air	SWR	-0.022%	3	50	17.5	4.88	4.5

Note: N.A. = Not Available (Testing apparatus out of operation for scaling test)

TABLE 10

SETTING TIME

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Time of Set Hr. - Min. Initial	Time of Set Hr. - Min. Final	Retardation Hr. - Min. Initial	Retardation Hr. - Min. Final
1	Gravel	5.5	Non-Air	None	4:48	6:20	----	----
2	Gravel	5.5	Non-Air	WR	5:51	8:18	1:03	1:58
3	Gravel	5.5	Non-Air	SWR	6:00	7:38	1:12	1:18
4	Gravel	5.5	Air	None	5:24	7:15	----	----
5	Gravel	5.5	Air	WR	8:21	10:30	2:57	3:15
6	Gravel	5.5	Air	SWR	6:23	7:54	0:59	0:39
7	Gravel	6.0	Non-Air	None	5:30	7:24	----	----
8	Gravel	6.0	Non-Air	WR	6:57	10:48	1:27	3:24
9	Gravel	6.0	Non-Air	SWR	6:57	10:48	1:27	3:24
10	Gravel	6.0	Air	None	4:57	6:57	----	----
11	Gravel	6.0	Air	WR	7:15	9:27	2:18	2:30
12	Gravel	6.0	Air	SWR	5:30	7:27	0:33	0:30
13	Gravel	6.5	Non-Air	None	5:48	7:51	----	----
14	Gravel	6.5	Non-Air	WR	8:33	11:18	2:45	3:27
15	Gravel	6.5	Non-Air	SWR	6:45	9:11	0:57	1:20
16	Gravel	6.5	Air	None	7:45	9:50	----	----
17	Gravel	6.5	Air	WR	10:39	12:36	2:54	2:46
18	Gravel	6.5	Air	SWR	5:45	7:15	(-)2:10	(-)2:35* low lab temp.

(-) accelerated set

TABLE 10 (CONTINUED)

SETTING TIME

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Time of Set Hr. - Min. Initial - Final	Retardation Hr. - Min. Initial - Final
19	Sandstone	5.5	Non-Air	None	N.A.	N.A.
20	Sandstone	5.5	Non-Air	WR	N.A.	N.A.
21	Sandstone	5.5	Non-Air	SWR	N.A.	N.A.
22	Sandstone	5.5	Air	None	N.A.	N.A.
23	Sandstone	5.5	Air	WR	N.A.	N.A.
24	Sandstone	5.5	Air	SWR	N.A.	N.A.
25	Sandstone	6.0	Non-Air	None	N.A.	N.A.
26	Sandstone	6.0	Non-Air	WR	N.A.	N.A.
27	Sandstone	6.0	Non-Air	SWR	N.A.	N.A.
28	Sandstone	6.0	Air	None	N.A.	N.A.
29	Sandstone	6.0	Air	WR	N.A.	N.A.
30	Sandstone	6.0	Air	SWR	N.A.	N.A.
31	Sandstone	6.5	Non-Air	None	N.A.	N.A.
32	Sandstone	6.5	Non-Air	WR	N.A.	N.A.
33	Sandstone	6.5	Non-Air	SWR	N.A.	N.A.
34	Sandstone	6.5	Air	None	N.A.	N.A.
35	Sandstone	6.5	Air	WR	N.A.	N.A.
36	Sandstone	6.5	Air	SWR	N.A.	N.A.

Note: N.A. = Not Available (lack of aggregate material for time of set test)
(-) accelerated set

TABLE 10 (CONTINUED)

SETTING TIME

Mix No.	Aggregate	Cement Content, sacks/yd.^{3}	Type Mix	Admixture	Time of Set Hr. - Min. Initial	Time of Set Hr. - Min. Final	Retardation Hr. - Min. Initial	Retardation Hr. - Min. Final
37	Limestone	5.5	Non-Air	None	6:30	8:09	-	-
38	Limestone	5.5	Non-Air	WR	7:00	8:54	0:30	0:45
39	Limestone	5.5	Non-Air	SWR	8:05	9:39	1:35	1:30
40	Limestone	5.5	Air	None	4:54	6:57	-	-
41	Limestone	5.5	Air	WR	7:04	8:56	2:10	1:59
42	Limestone	5.5	Air	SWR	4:47	6:18	0:07	(-)0:49
43	Limestone	6.0	Non-Air	None	5:42	7:28	-	-
44	Limestone	6.0	Non-Air	WR	7:30	10:24	1:48	2:56
45	Limestone	6.0	Non-Air	SWR	5:43	8:13	0:01	0:45
46	Limestone	6.0	Air	None	5:21	7:05	-	-
47	Limestone	6.0	Air	WR	6:03	7:30	0:42	0:25
48	Limestone	6.0	Air	SWR	5:44	6:58	0:23	0:07
49	Limestone	6.5	Non-Air	None	6:00	8:09	-	-
50	Limestone	6.5	Non-Air	WR	8:12	10:27	2:12	2:18
51	Limestone	6.5	Non-Air	SWR	6:51	9:00	0:51	0:51
52	Limestone	6.5	Air	None	5:30	6:57	-	-
53	Limestone	6.5	Air	WR	6:53	8:37	1:23	1:40
54	Limestone	6.5	Air	SWR	5:17	6:40	0:13	(-)0:17

(-) accelerated set

TABLE 11

APPROVED

COARSE AGGREGATE SOURCES

	Source No.	Location	Approved Type
SANDSTONE			
	A051	Duffield Quarry Russellville, Ark.	PCC
	A052	M & M Rock Co. P.O. Box 1190 Conway, Ark. 72032	PCC

(None of these available locally in B. R., must be from Quarry)

	Source No.	Location	Approved Type
LIMESTONE			
	A077	Gifford-Hill & Co. P.O. Box 6615 Shreveport, La. 71106	PCC (excluding bridge decks)
	A037	Reed Crushed Stone Co. P.O. Box 35 Gilbertsville, Ky. 42044	"
	A040	Three Rivers Rock Co. * P.O. Box 218 Smithland, Ky. 42081	"
		Westlake Quarry & Materials P.O. Box 358 Illmo, Missouri 63754	"
	A044	(Gray's Pt. Quarry)	"
	A043	Same as above (Neely's Landing Quarry)	"

* La. Limestone Aggregates, Inc.
P.O. Box 24326
Baton Rouge, La. 70808

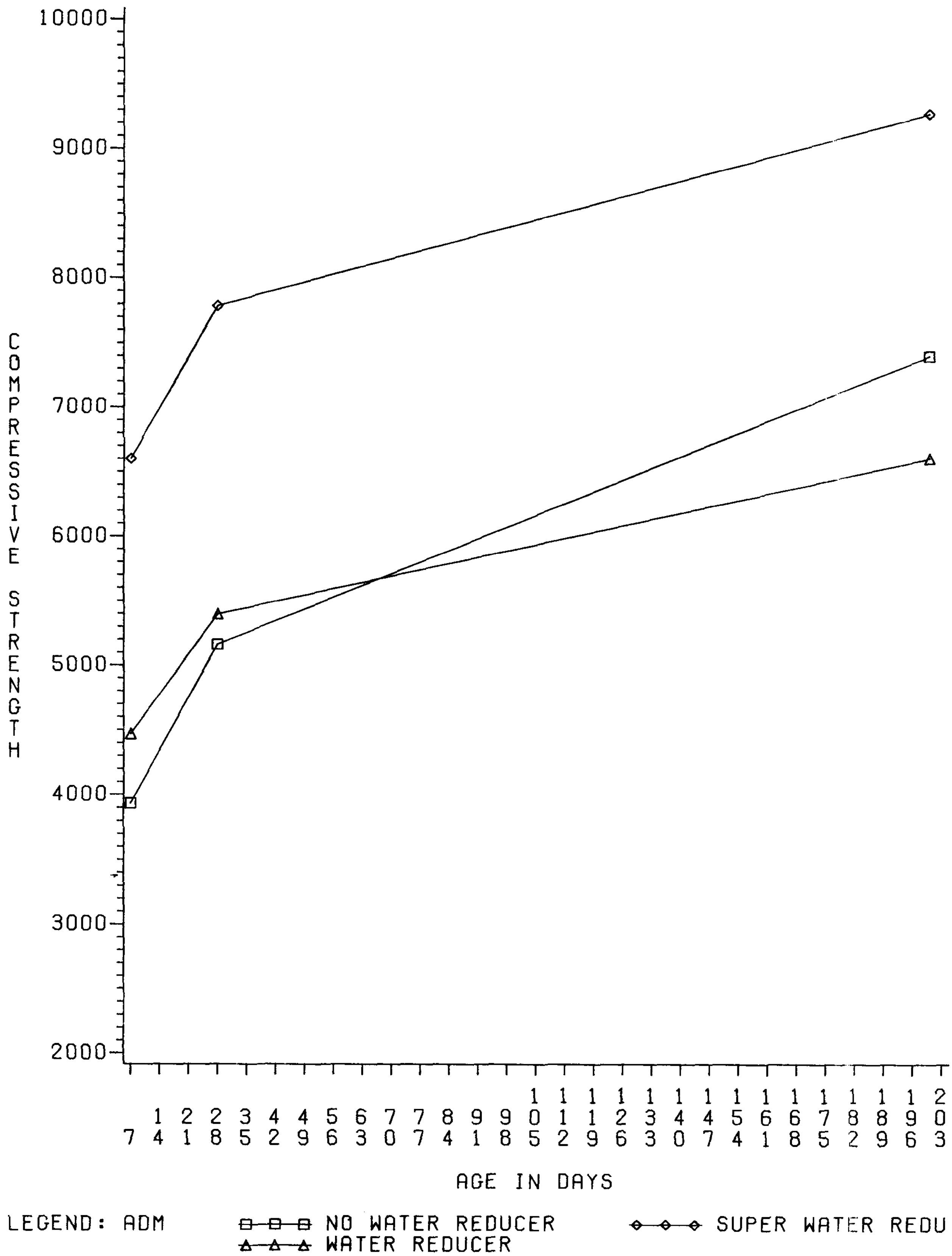

FIGURE 1

COMPRESSIVE STRENGTH VS. AGE, IN GRAVEL
6.5 BAG NO AIR CONCRETE WITH WR & SWR

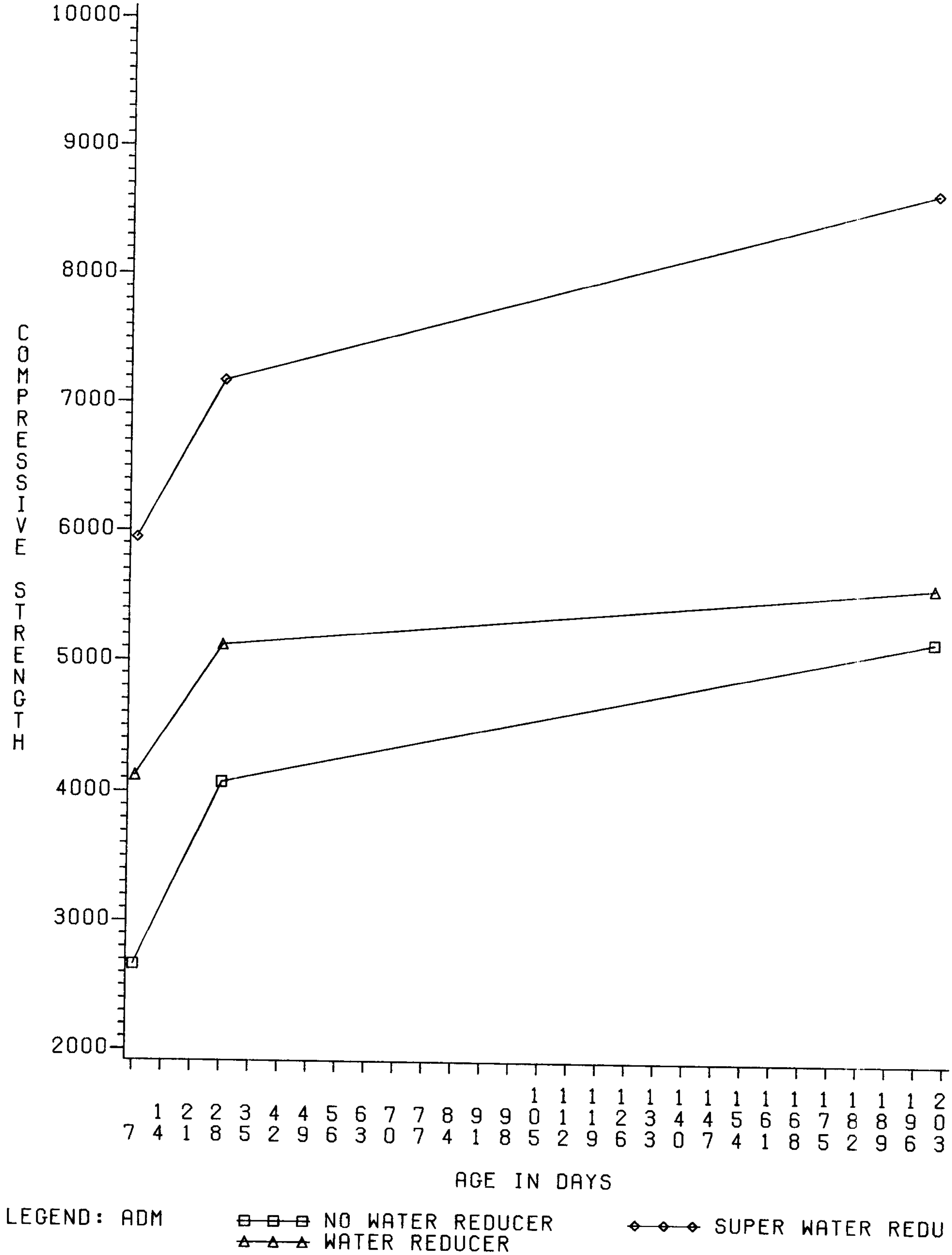

FIGURE 2

COMPRESSIVE STRENGTH VS. AGE IN GRAVEL
6.5 BAG WITH AIR, WR & SWR

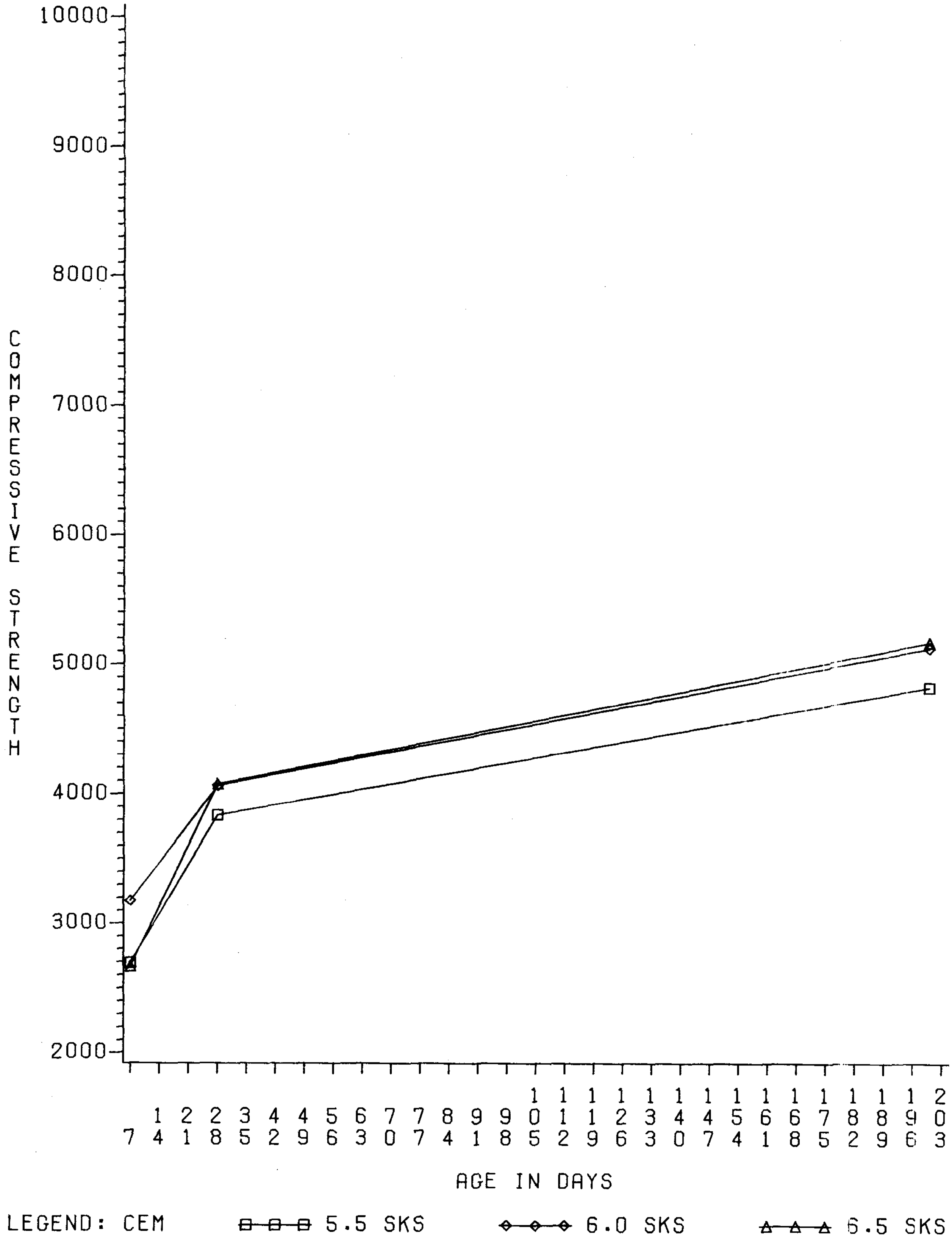

FIGURE 4

COMPRESSIVE STRENGTH VS. AGE IN GRAVEL AIR ENTRAINED CONCRETE WITH 5.5, 6.0 & 6.5 BAG CEMENT FACTOR

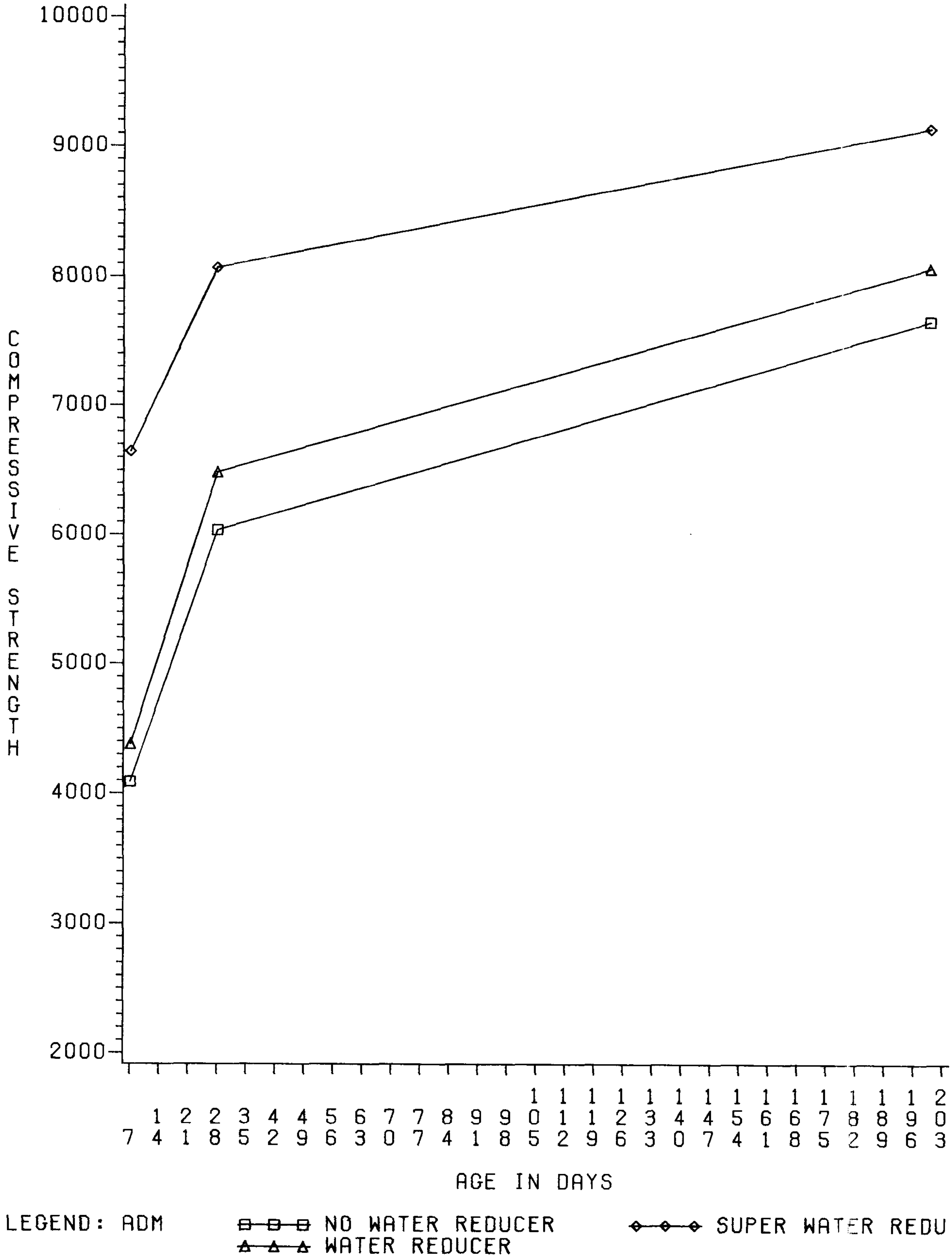

FIGURE 5

COMPRESSIVE STRENGTH VS. AGE IN 6.5 BAG
NO AIR SANDSTONE CONCRETE WITH WR & SWR

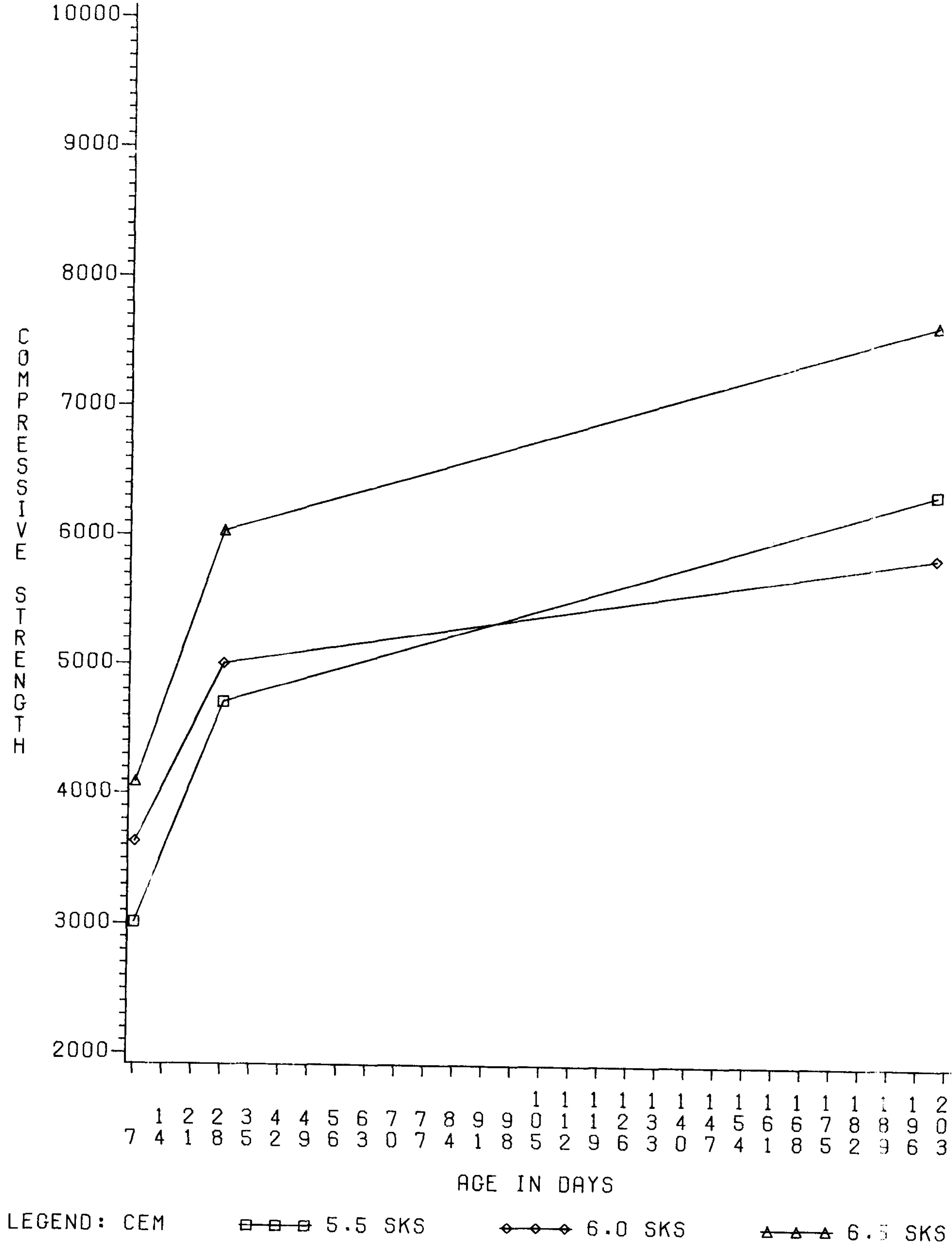

FIGURE 7

COMPRESSIVE STRENGTH VS. AGE IN SANDSTONE
NO AIR CONCRETE WITH 5.5, 6.0 & 6.5 BAG
CEMENT FACTOR

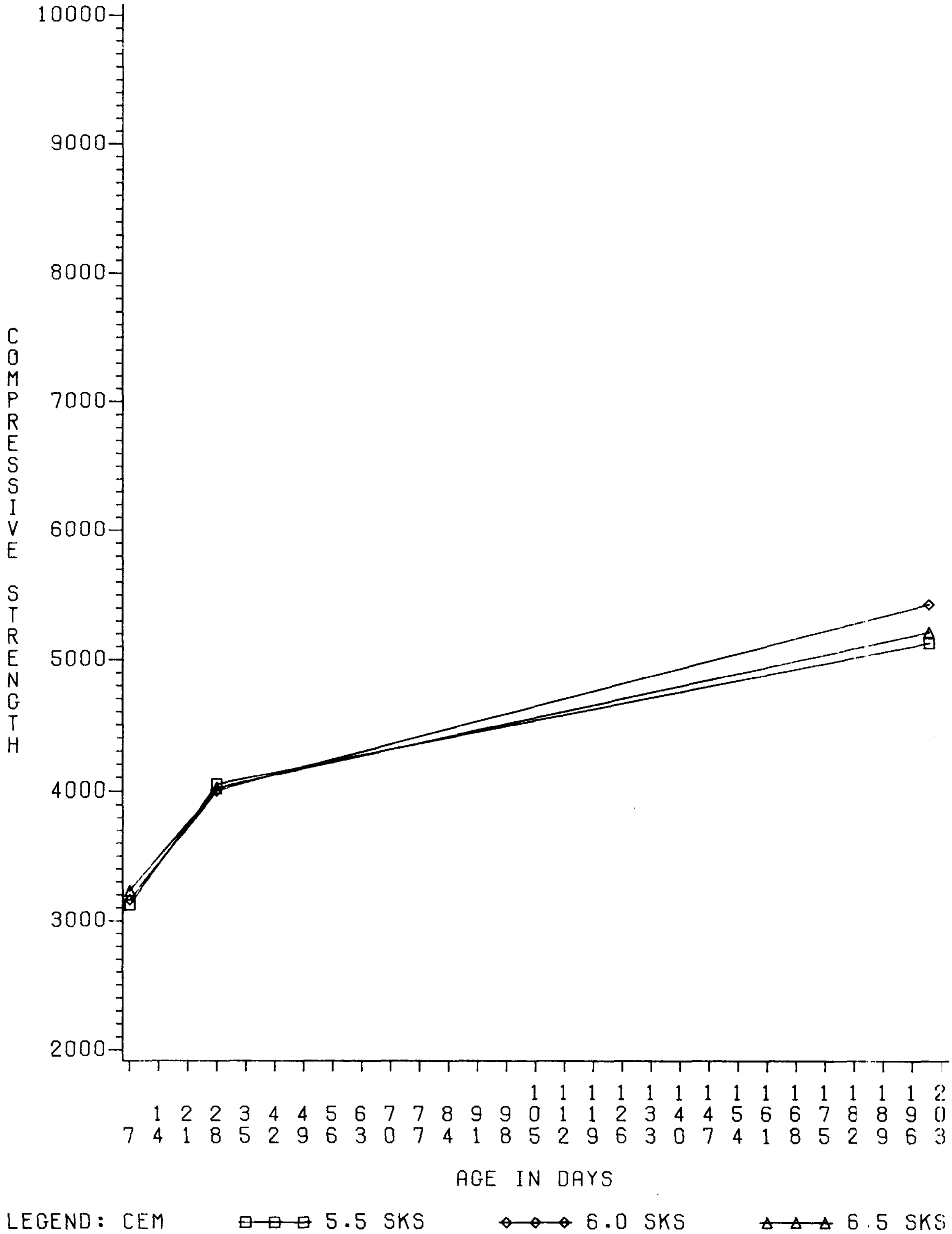

FIGURE 8

COMPRESSIVE STRENGTH VS. AGE IN SANDSTONE AIR ENTRAINED CONCRETE WITH 5.5, 6.0 & 6.5 BAG CEMENT FACTOR

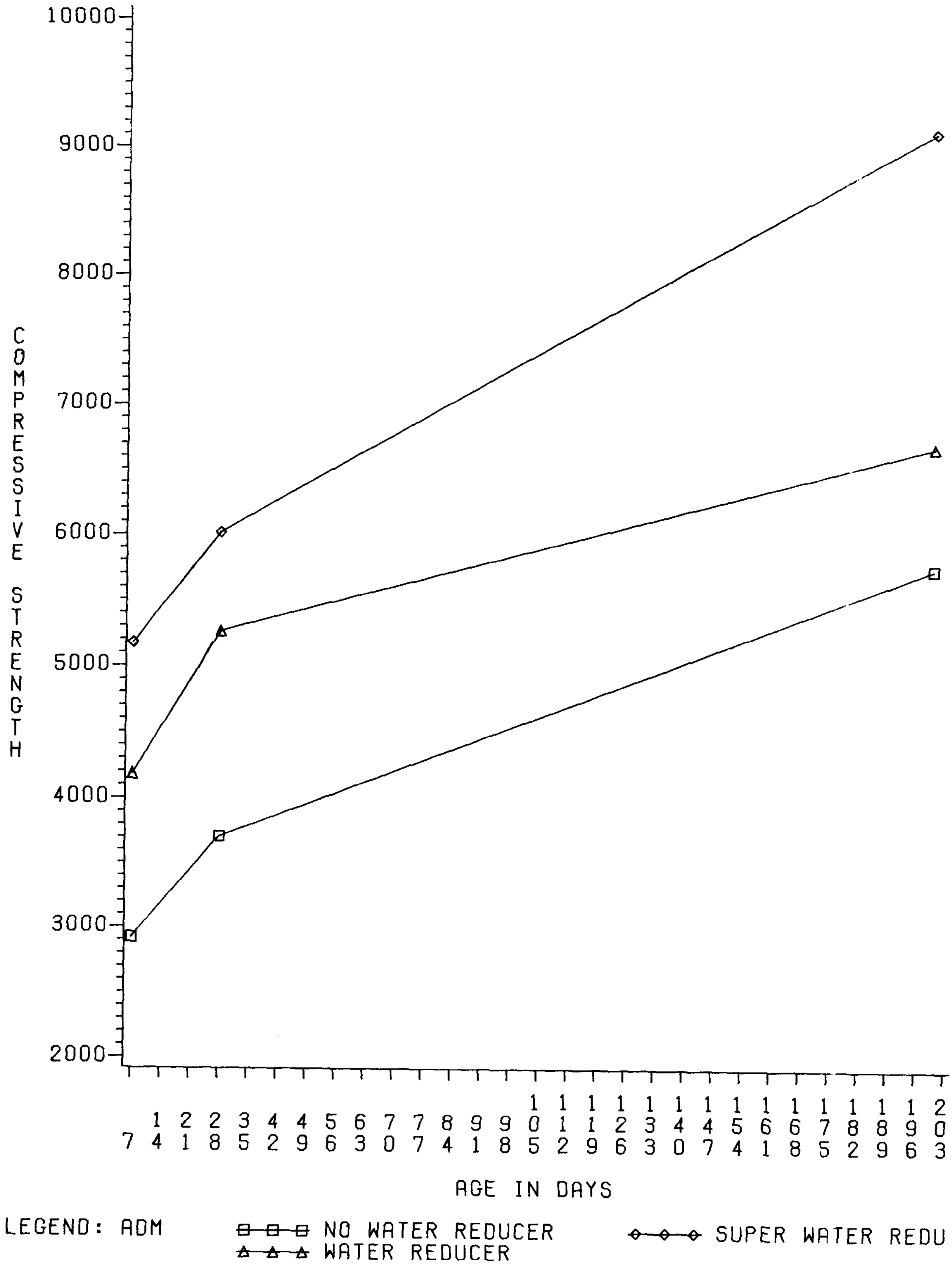

FIGURE 10

COMPRESSIVE STRENGTH VS. AGE IN 6.5 BAG AIR ENTRAINED LIMESTONE CONCRETE WITH WR & SWR

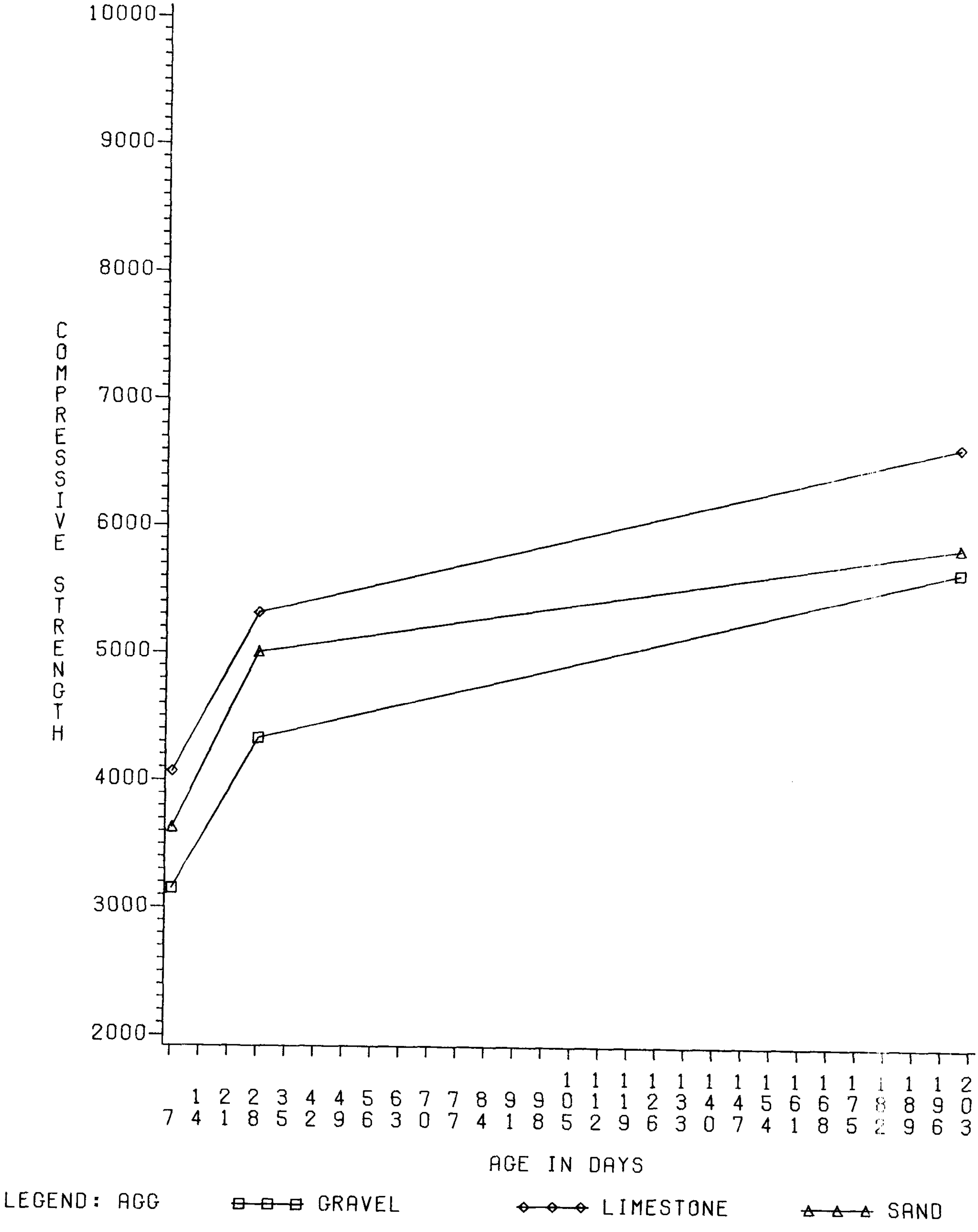

FIGURE 15

COMPRESSIVE STRENGTH VS. AGE IN 6.0 BAG NO AIR CONCRETE WITH GRAVEL, LIMESTONE & SANDSTONE

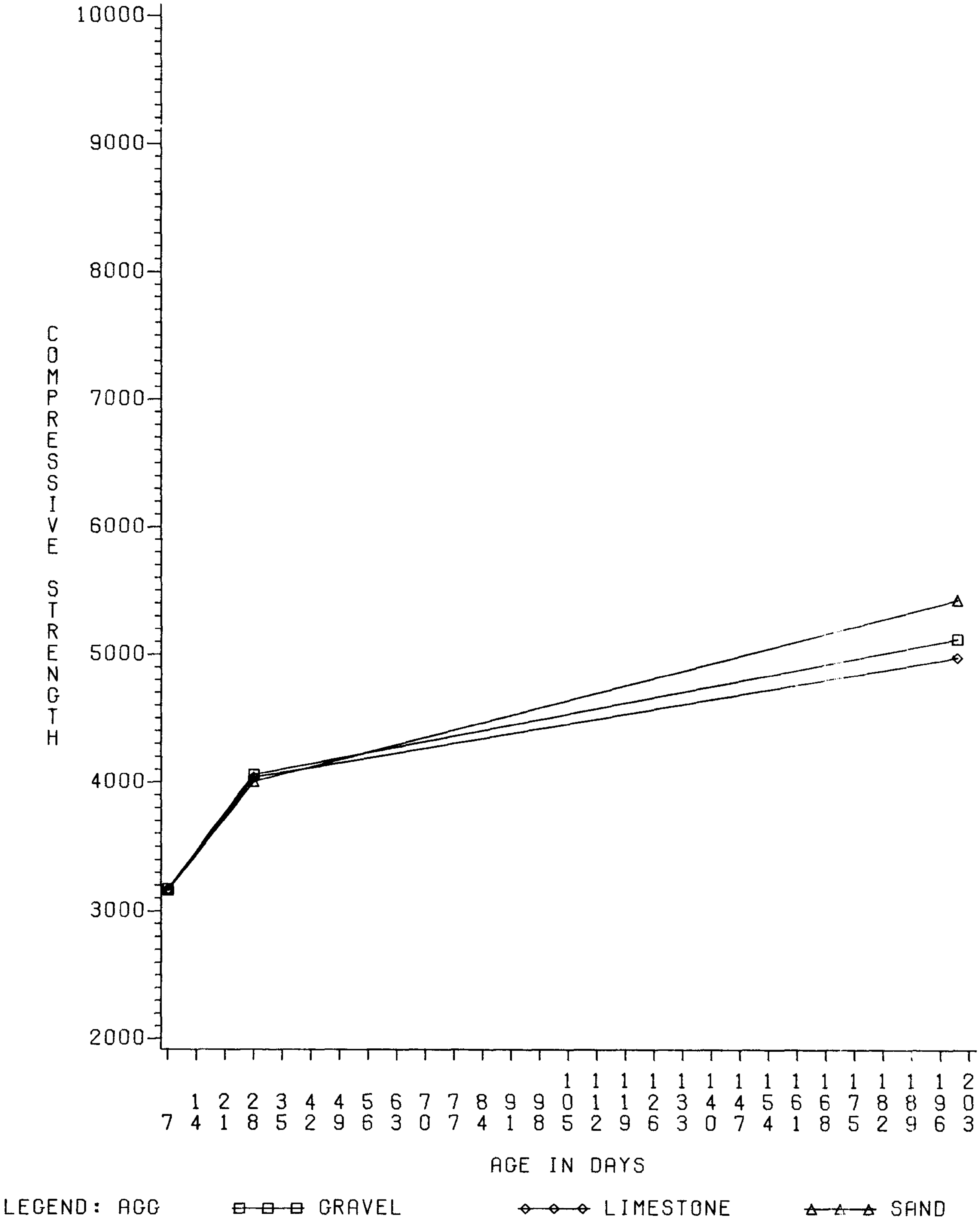

FIGURE 16

COMPRESSIVE STRENGTH VS. AGE IN 6.0 BAG AIR ENTRAINED CONCRETE WITH GRAVEL, LIMESTONE & SANDSTONE

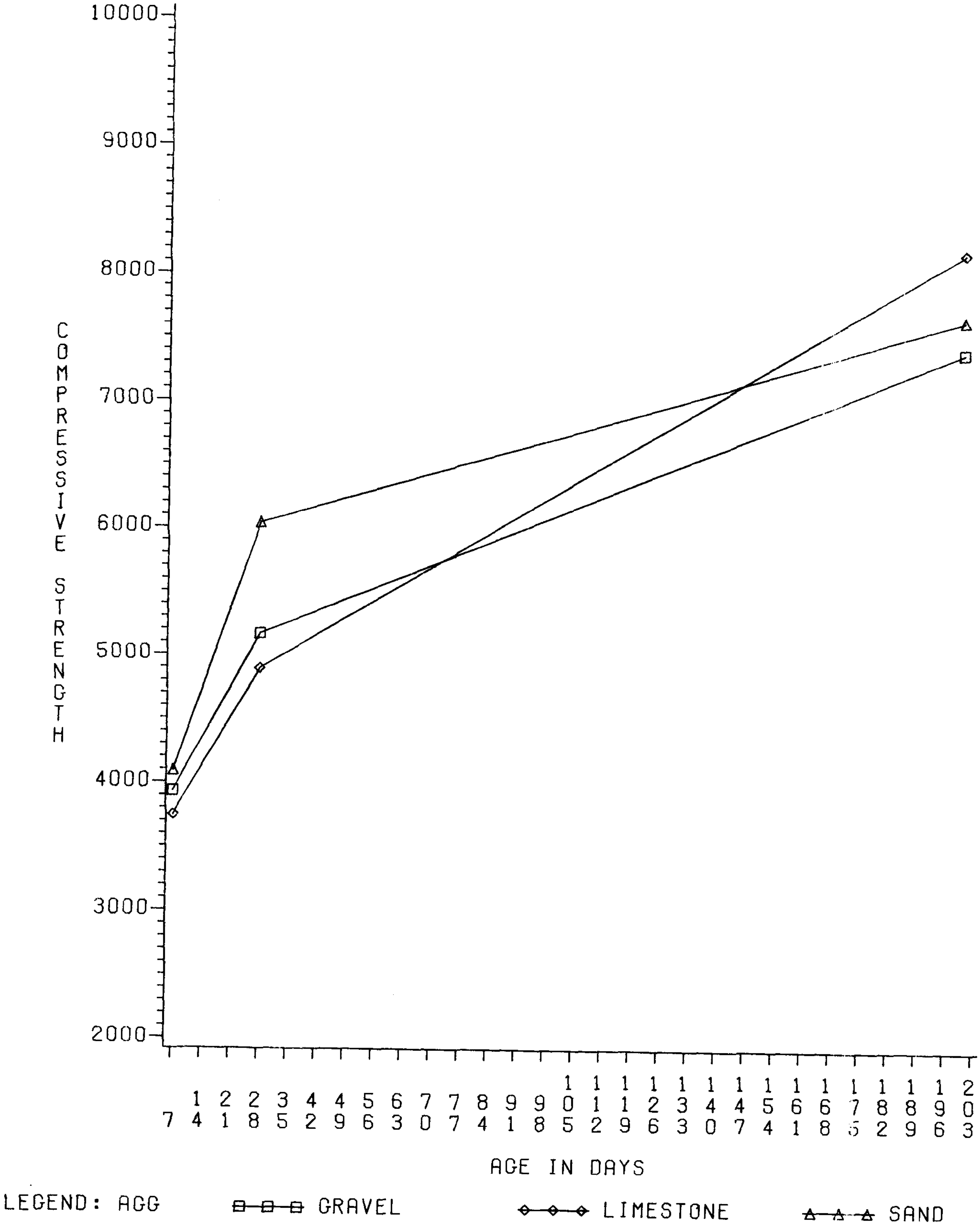

FIGURE 17

COMPRESSIVE STRENGTH VS. AGE IN 6.5 BAG NO AIR CONCRETE WITH GRAVEL, LIMESTONE & SANDSTONE

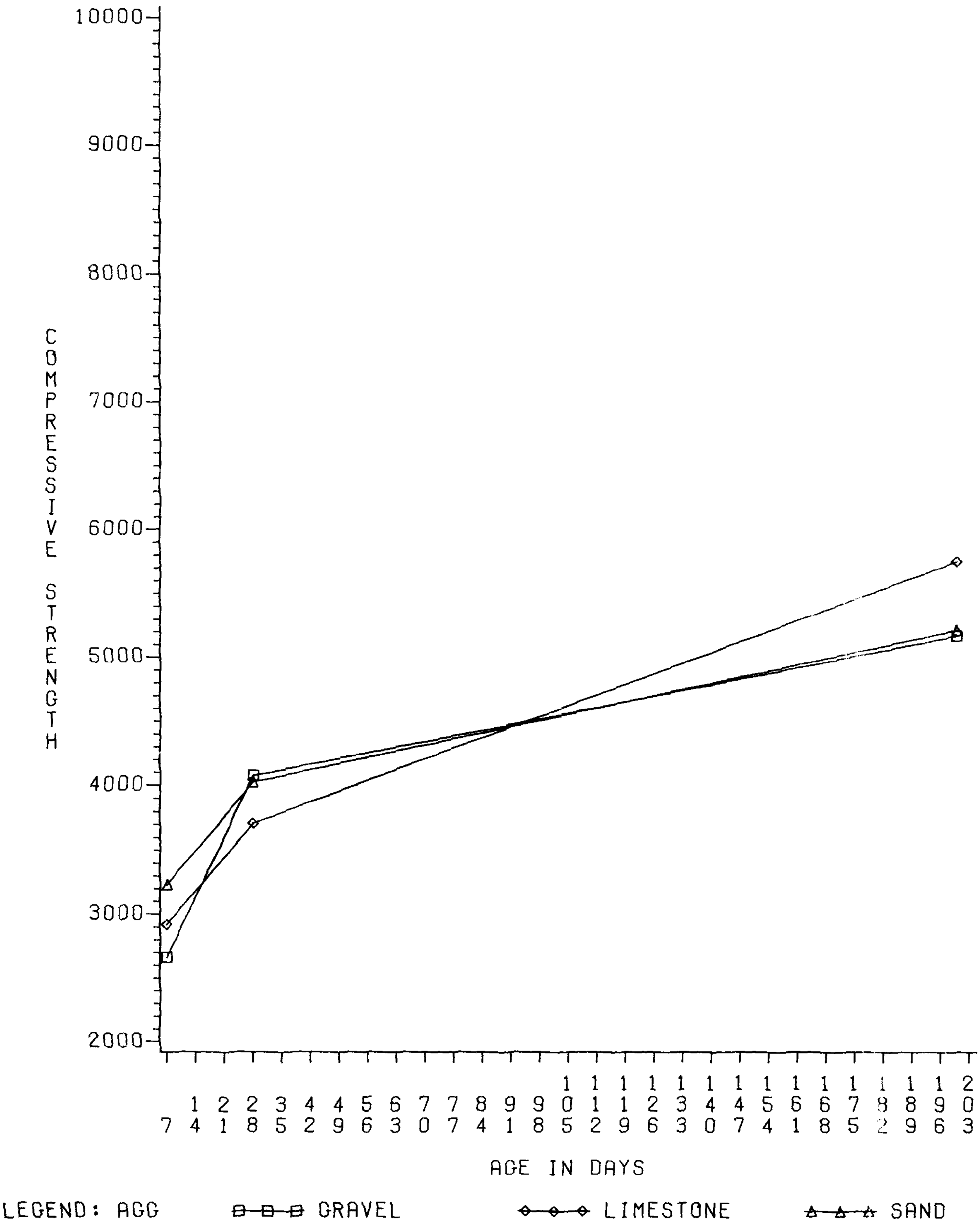

FIGURE 18

COMPRESSIVE STRENGTH VS. AGE IN 6.5 BAG AIR ENTRAINED CONCRETE WITH GRAVEL, LIMESTONE & SANDSTONE

STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
MATERIAL TESTING SYSTEM
EXCEPTION REPORT FOR THE TEST OF
GRADE A COARSE AGGREGATE (CRUSHED STONE) FOR CONC. (203)
DISTRICT 22

Sandstone

PROJECT NO....MATLAB LAB NO....22-353069
DATE SAMPLED..07-27-81 IDENT... QUANTITY..AMPLE
SUBMITTED BY..W. T. BURT, MATERIALS ENGINEER
SOURCE........M & M ROCK CO. CONWAY, ARK.
PURPOSE.......SOURCE APPROVAL SPEC CODE.3
REMARKS.......236 D
THIS SAMPLE MEETS THE REQUIREMENTS FOR SOURCE APPROVAL
ITEM NUMBER...

TEST	VALUE	RESULT
1/2 INCH	100	
3/8 INCH	97	
NO. 4	39	
NO. 8	15	
NO. 10	13	
NO. 16	10	
NO. 30	7	
NO. 40	7	
NO. 100	5	
NO. 200	4	
ABSORPTION, %	1.2	
SPECIFIC GRAVITY (SSD)	2.64	
WEIGHT/CU. FT., DRY LOOSE	92.3	
WEIGHT/CU. FT., DRY RODDED	99.0	
POLISH VALUE	45	
SPECIFIC GRAVITY (APP)	2.69	
ABRASION, % LOSS	19.1	
SOUNDNESS, % LOSS	1.6	
SOFT FRAGMENTS, %	2.7	

REMARKS..THIS SAMPLE MEETS THE REQUIREMENTS FOR SOURCE APPROVAL

COPIES TO:
DISTRICT LAB ENGINEER
PROJECT ENGINEER
DISTRICT ENGINEER

W. T. BURT BY s/J. T. Ashby, Jr.
MATERIALS ENGINEER

STATE OF LOUISIANA 04-30-82
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
MATERIAL TESTING SYSTEM
EXCEPTION REPORT FOR THE TEST OF
GRADE A COARSE AGGREGATE (GRAVEL) FOR CONCRETE(202)
DISTRICT 22

PROJECT NO....GENERAL LAB NO....22-368613
DATE SAMPLED..09-02-81 IDENT... QUANTITY..AMPLE
SUBMITTED BY..W. T. BURT, MATERIALS ENGINEER
SOURCE........MATERIAL PRODUCERS GRANGEVILLE
PURPOSE.......SOURCE APPROVAL SPEC CODE.3
REMARKS.......UNRES. IN PCC DUE TO MORTAR BAR RESULTS REF. 22-356588
THIS SAMPLE MEETS THE REQUIREMENTS FOR SOURCE APPROVAL
ITEM NUMBER...

TEST	VALUE	RESULT
1 1/2 INCH	100	
1 1/4 INCH	99	
1 INCH	93	
3/4 INCH	78	
5/8 INCH	58	
1/2 INCH	38	
3/8 INCH	20	
NO. 4	2	
NO. 8	1	
ABSORPTION, %	1.7	
SPECIFIC GRAVITY (SSD)	2.54	
ALKALINITY		FAIL
SPECIFIC GRAVITY (APP)	2.60	
ABRASION, % LOSS	18.3	
SOUNDNESS, % LOSS	4.6	

REMARKS..THIS SAMPLE MEETS THE REQUIREMENTS FOR SOURCE APPROVAL

OPIES TO:
DISTRICT LAB ENGINEER
PROJECT ENGINEER
DISTRICT ADMINISTRATOR

W. T. BURT BY J. T. Ashley Jr.
MATERIALS ENGINEER