CEMENT STUDY
PHASES I, II, and III

by

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RESEARCH REPORT NO. 39

Research Project No. 63-2Ch-C
Louisiana HPR 1(7)

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

June, 1970

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SYNOPSIS

This report is the result of a three phase research program in which cements and aggregates from various suppliers were studied in an effort to evaluate and improve various constitutents in concrete mixes. The major emphasis of this study has been on the classification of cements based on tricalcium silicate values, the behavior of these cements when used in concrete mixes, and finally, the potential reactivity of aggregates used in concrete supplied to the Louisiana Department of Highways.

The experience gained from this study indicated the following:

(1) The method of classifying cements according to tricalcium silicate is inadequate since the tricalcium silicate values showed poor correlation with compressive strength of concrete.

(2) There was no relationship between compressive strength and modulus of elasticity for the cement mixes studied.

(3) There is a poor relationship between the Chemical Method (ASTM C-289) and the Mortar Bar Expansion Method (ASTM C-227) for determining the potential reactivity of aggregates; and, the Chemical Method is incomplete without the supplemental data of the Mortar Bar Expansion Method.

(4) All deleterious aggregate specimens, except one, molded and tested according to ASTM C-227, "Alkali Reactivity of Cement Aggregate Combination," showed less than a .05% increase in overall expansion at the end of a 3 month test period and all aggregate specimens showed less than 0.1% at the end of the 6 month test.

(5) There was no significant difference chemically in the cements studied that affected the physical properties of the concrete mixes.

INTRODUCTION

During the summer of 1963, Louisiana was faced with a problem concerning premature initial setting of concrete. The concrete mix, although designed for a 3 inch slump, became very stiff during the manipulating procedure in the truck. This problem initiated a research project to evaluate the constituents in concrete. By sampling and testing all the cement plants within a 500 mile radius of Louisiana and all aggregate suppliers within the State, a thorough knowledge should be obtained and possibly better concrete could be produced.

The cements were analyzed chemically and physically according to ASTM procedures and classified according to their C_3S values (tricalcium silicate). A random selection of various cements whose C_3S values were grouped accordingly were selected for further study with a common source of aggregate for Compressive Strength, Freeze Thaw Cycling and subsequent modulus of elasticity degradation readings. The final phase of this project was to conduct the "Potential Reactivity of Aggregate (Chemical Method) ASTM C-289 and determine if any of the state suppliers have deleterious aggregates. The deleterious aggregates found were subjected to the "Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar Bar Method) ASTM C-227.

SCOPE

This research project is divided into three phases:

Phase I - The objective of this phase was to study physical and chemical properties of cements from sources within a 500 mile radius of Louisiana. A system of classifying these samples was undertaken as a prerequisite step for Phases II and III.

Phase II - The objective of this phase consisted of evaluating the groups of cements selected from Phase I when used in concrete mixes. The cements were grouped according to their C_3S values which resulted in five groups. From each of these five groups, two or three mills were selected for testing as follows. Group I had two cement mills, Group II had three cement mills, Group III had three cement mills, Group IV had two cement mills and Group V had two cement mills.

Phase III - The objective of this phase consisted in performing the Test for Potential Reactivity of aggregate (Chemical Method) on all aggregates used by the Louisiana Department of Highways and determining from this test if the aggregates are innocuous or deleterious. The deleterious aggregate was subjected to the "Potential Alkali Reactivity of Cement Aggregate Combination" (Mortar Bar Method) ASTM C-227.

METHOD OF PROCEDURE

Approximately 132 samples of cement representing 66 mills from 17 states were tested. These are identified in Table I. Samples from these wide areas were studied to determine any variables that may exist. A system of classifying these samples was developed. It involved grouping the cements according to their respective tricalcium silicate values. Random samples within these groups were selected for Phase II. The following list represents the classification and the samples within each grouping:

Group I - C_3S Values less than 40

<u>Identification</u>

A-1
B-2
B-4
D-2
G-2
K-1
M-4
P-2

Group II - C_3S Values between 40-45

<u>Identification</u>

B-1
D-3
D-4
D-5
D-6
E-1
G-3
A-8
A-15
H-2
G-6
E-3
M-2

Group III - C_3S Values between 45-50

Identification

B-3
C-3
D-1
F-1
F-2
F-3
G-1
G-4
A-2
A-3
A-9
A-12
A-13
H-1
I-1
J-1
L-1
O-1
E-4
E-6
M-3

Group IV - C_3S Values between 50-55

Identification

B-5
A-5
A-6
A-11
G-5
M-1
N-2
O-2
E-5
E-7
E-8
P-1
P-3

Group V - C_3S Values above 55

Identification

C-1
C-2
A-4
A-7
A-10
A-14
L-2
N-1
E-2

Concrete mixes were made from the following samples selected from the above mentioned grouping: A-1, M-4, D-3, G-3, E-3, B-3, A-3, E-4, B-5, M-1, C-2 and E-2.

From these mixes data was obtained as to the amount of water required, air content and the setting time. In addition, specimens were made to test compressive strength at 7 and 28 days, 3, 6 and 12 months, freeze and thaw tests were performed for durability comparison, and shrinkage characteristics were determined.

Samples from approximately seven locations of local aggregate were obtained from sources that supply the Louisiana Department of Highways. The Potential Reactivity of Aggregates (Chemical Method) tests were performed in accordance with ASTM C-289-64. The data obtained was analyzed and the aggregates were classified according to the division between innocuous and deleterious aggregates. The deleterious aggregates were combined with cement and Potential Alkali Reactivity of Cement - Aggregate Combinations (Mortar Bar Method) was conducted.

TEST PROCEDURES

The methods of tests used were as follows:

	ASTM METHOD
Standard Method of Chemical Analysis of Portland Cement	C 114-58
Method of Test for Air Content of Hydraulic Cement Mortar	C 185-59
Method of Test for Autoclave Expansion of Portland Cement	C 151-60
Method of Test for Compressive Strength of Hydraulic Cement Mortar (2 inch-cube)	C 109-58
Method of Test for Fineness of Portland Cement by Air Permeability Apparatus	C 204-55
Method of Test for Normal Consistency of Hydraulic Cement	C 187-58
Method of Test for Tensile Strength of Hydraulic Cement Mortar	C 190-59
Method of Test for Time of Setting of Hydraulic Cement by Gilmore Needle	C 266-58T
Method of Test for Specific Gravity of Hydraulic Cement	C 188-44
Method of Test for Time of Setting of Hydraulic Cement by Vicat Needle	C 191-58
Method of Test for Fineness of Portland Cement by the Turbidimeter	C 115-58
Method of Test for Fineness of Hydraulic Cement by the No. 325 Sieve	C 430-69T

	ASTM Method
Potential Reactivity of Aggregates (Chemical Method)	ASTM C 289-64
Potential Alkali Reactivity of Cement - Aggregate Combination (Mortar Bar Method)	ASTM C 227-64
Method of Test for Compressive Strength	AASHO T 126-60 and AASHO T 22-60
Method of Test for Freeze and Thaw Resistance	ASTM C 291-61 and ASTM C 215-60
Method of Test for Setting Time	ASTM C 403-63
Method of Test for Air Content	AASHO T 152
Method of Test for Slump of Concrete	ASTM C 143-58
Method of Test for Shrinkage	AASHO T 160-60
Method of Test on Cement	ASTM C 150-64

DISCUSSION OF RESULTS

In the first Interim Report the value for tricalcium silicate varied from a low of 26.17 to a high of 62.18. There were eight cement samples whose C_3S values were below forty. For each of these respective samples, the C_2S, C_3A, C_4AF, Tensile Strength, Compressive Strength, Blaine Fineness and Normal consistency values were accumulated and averaged. The tricalcium silicate average for these samples was 35.76. The remaining cements were classified as follows: for a C_3S value between forty and forty-five, there were thirteen cements; for a C_3S value between forty-five and fifty, there were twenty-two cements; for a C_3S value between fifty and fifty-five, there were thirteen cements and for a C_3S value greater than fifty-five, there were nine cements. The average C_3S values for these ranges versus, C_2S, C_3A, C_4AF, Tensile Strength, Compressive Strength, Blaine Fineness and Normal Consistency were analyzed to determine if any correlation was possible. The C_3S versus Compressive Strength indicated that a definite trend was established in which the C_3S values increased with an increase in Compressive Strength.

The same general type of curve was obtained by plotting C_3S versus the Tensile Strength. As the C_3S values increased, the Tensile Strength also increased. This was expected due to the former relationship established between compressive strength and tensile strength and compressive strength versus C_3S. It was also found that as the C_3S values increased, the C_2S values decreased and as the C_3S values decreased, the C_2S values increased. The curve produced when the C_3S values were plotted against the C_2S values showed a negative slope which is indicative of the mathematical formula for calculating C_2S values from C_3S values. According to the formula for calculating C_2S values, as the C_3S increase the C_2S values approach zero and as the C_3S values decrease and approach zero, the C_2S values increase to a value equal to 2.87 times the silicon dioxide.

A method of establishing a classification system was developed based on tricalcium silicate values. The second phase of this report was to evaluate these various classifications of elements in actual Class A concrete mixes; and determine first if tricalcium silicate values actually affect the properties of concrete mixes, and, secondly, if tricalcium silicate values should be specified.

Table 2 of the Appendix lists the tricalcium silicate values, the compressive strength and tensile strengths for cement, and the compressive strengths for concrete 7 days and 28 days. There was no correlation between the following values.

Tricalcium Silicate and Compressive Strength of Cement Briquette (7 days).

Tricalcium Silicate and Tensile Strength of Cement Briquette (7 days).

Tricalcium Silicate and Compressive Strength of Concrete (7 days).

Tricalcium Silicate and Compressive Strength of Concrete (28 days).

Compressive Strength (cubes) and Tensile Strength (briquette).

Compressive Strength cubes) and Compressive Strength of Concrete Cylinders (7 days).

Compressive Strength (cubes) and Compressive Strength of Concrete Cylinders (28 days).

The original concept as determined in Phase I, of the increase in compressive strength with increase in tricalcium silicate is not a true relationship according to the findings of this phase. There appears to be a trend but the values are inconsistent.

The correlation coefficient between tricalcium silicate and compressive strength of cement briquettes was calculated by using the method of least squares. The correlation coefficient was 0. 46. (This value was low and it indicated that the original relationship between tricalcium silicate and compressive strength was probably erroneous).

Freeze and thaw durability test were conducted on concrete specimens made with the classified cements and local suppliers of aggregate. The results of the tests are tabulated in Table 3. As can be seen from the results, there was no correlation between Durability Factor and cement classification according to C_3S values. In addition there was no correlation between Durability Factor and 7 day cured specimens and 28 day cured specimens. Although all mixes produced acceptable compression strength levels, the Durability Factor appeared to be quite low in most cases. However, no correlation between Durability and performance of concrete mixes has been made. Therefore for Louisiana, just because a mix has a low Durability Factor does not necessarily mean poor concrete.

The shrinkage of the concrete made from the classified cements using a local supplier for aggregate was determined using AASHO Designation T 160-60. These values are tabulated in Table 4 of the Appendix. An analysis of the data indicated that the standard deviation was 0. 0078 and 95% of the samples fall within the 0. 024 and 0. 047 range. Therefore, it can be said that no significant changes occur between the concrete made from the classified cements as far as the percent shrinkage is concerned.

The concrete cylinders were prepared in accordance with AASHO T 126-60 and AASHO T 22-60 for Class A concrete. The correlation coefficient for compressive strength of concrete cylinders (7 day) and cement cubes, prepared according to ASTM C 109-58 was 0. 20. This value was low and indicated that a low cement cube compressive strength does not necessarily mean that a low strength concrete will be obtained.

According to Tables 3 and 5 of the Appendix all types of Class A Concrete had a 7 day compressive strength in excess of 3, 800 psi, 28 days compressive strength in excess of 5, 600 and a modulus of elasticity in the range of 5. 7 to

6.5×10^6 for 7 days. The slump for all mixes remained fairly constant in the range of 3 inches and the water content varied from 5.16 to 5.58 gallons per sack of cement. The strength of all the mixes proved to be better than average with no apparent malfunctions of the cement or aggregates.

The correlation coefficient between compressive strength of concrete (7 day) and compressive strength of concrete (28 day) was 0.49. The relationship between 7 day concrete and 28 day concrete indicates that the slope for the rate of hydration for the concrete studied is not the same. Each concrete studied gave a different slope for 7 day cure to 28 day cure for compressive strength. In Table 5 the results of compressive strength are tabulated for 7 day, 28 day, 3 month, 6 month and 12 month period of curing. Examination of this data revealed that for each sample studied, the rate of hydration increased significantly for the first 28 days then began to level off and increase gradually upto 12 months.

Table 6 of the Appendix lists the distribution of aggregate samples obtained from suppliers of the Louisiana Department of Highways. Figure I is a graph obtained from the calibration curve correlating the transmittance of light (410 mu wavelength) with concentration of standard silica solutions measured in millimoles per liter. The transmittance of a sample solution was determined by measurements with the photometer. The concentration of an unknown solution, for a given transmittance was read from this curve. Dissolved silica from No. 50 to No. 100 aggregate material by a one-normal sodium hydroxide solutions. Data indicated that the range for Sc of sand aggregates were 6 to 252. The values of Sc for gravel aggregates were 16 to 332. Table 7 of the Appendix lists transmittances, concentrations, and Sc, dissolved silica, for coarse and fine aggregates.

The reduction of alkalinity involved the titration of 20-milliliter aliquot solutions with hydrochloric acid to the phenolphthalein endpoint. Data obtained for reduction in alkalinity for gravel aggregates indicated the range of alkalinity was from 25 to 632. The range in alkalinity for sand aggregates was from 5 to 625.

Table 8 of the Appendix lists the calculations of the quantity Rc, Reduction in Alkalinity, for the aggregate solutions. Results of these tests were not correct for some aggregates primarily because of extraneous reduction of alkalinity produced by the reaction of sodium hydroxide with carbonates of magnesium or ferrous iron or certain silicates of magnesium. In the presence of soluble silica, calcium carbonate can also cause increase in Rc.

Points obtained from Table 9, listing silica concentration and alkalinity, were superimposed over the chart of Figure II.[1] The result was a graph of the

1 Figure II, Illustration of Division between Innocuous and Deleterious Aggregates on Basis of Reduction in Alkalinity Test. ASTM C 289-64, pages 198-199.

chart with the co-ordinates Sc and Rc of the aggregate solutions studied. For most aggregates, a potentially deleterious degree of alkali reactivity was indicated if the data point, obtained by plotting Sc and Rc, falls to the right of the boundary line shown in Figures 2, 3 and 4. A potentially deleterious aggregate was one that contained any materials that were potentially reactive with alkalies in cement in a sufficient amount to cause excessive expansion of mortar or concrete.

A potentially innocuous aggregate was indicated if the data point obtained by plotting Sc and Rc, falls to the left of the boundary line shown in Figures 2, 3 and 4. A potentially innocuous aggregate was one that contained materials that were potentially unreactive with alkalies in cement.

Figure 3 is a graph of sand aggregates with co-ordinates Rc and Sc superimposed on the chart. Figure 4 is a graph of the gravel aggregate with co-ordinates Rc and Sc superimposed on Chart 2. Results of tests are not correct for some aggregates, primarily because of extraneous reduction of alkalinity or decrease in dissolved silica concentration as produced by a series of reactions of sodium hydroxide.

For most aggregates, a relationship between dissolved silica and reduction in alkalinity was observed. For instance, most sand aggregates had both low amounts of dissolved silica and low values for reduction in alkalinity. For sand aggregates with relatively high soluble silica content, a high reduction in alkalinity was observed. The same relationship applied for gravel aggregate samples.

A total of 91 different aggregate samples were tested according to ASTM C 289. Forty-nine of the aggregates were coarse, while 42 were categorized as fine aggregates. Data indicated that 33 sands were innocuous (78.6%), five sands were deleterious (11.9%), and four sands could not be determined because of extraneous reduction in alkalinity (9.5%). Fifteen gravels were deleterious (30.6%), 33 were innocuous (67.3%), and one gravel could not be determined because of extraneous reduction (2.1%).

Unknown	% Sand	% Gravel
Innocuous	78.6	67.3
Deleterious	11.9	30.6
Undetermined	9.5	2.1

Tests on the determination of crystalloidal silica and reduction in alkalinity from the chemical method of determining the potential reactivity of aggregates prompted this second part of Phase III. There were twenty samples that were prepared according to ASTM C 227-64, "Potential Alkali Reactivity of Cement - Aggregate Combinations" (Mortar Bar Method). Listed in Table 10 of the

Appendix are the percentiles from the average value of expansion of all test specimens molded from the same cementitious mixture. The three month Mortar Bar expansion readings, according to Table 10, indicated that only one sample failed to meet the requirements of ASTM C-33 "Specifications for Concrete Aggregates" at the end of three months. This sample however, was lower than the 0.1% expansion requirements of the same specification at the end of six months. According to ASTM C-33, the three month expansion limit of 0.05% is not valid whenever the six month expansion results are available.

According to the Chemical Test Method for determining the potential reactivity of aggregates, all twenty samples were considered deleterious. However, the Mortar Bar Expansion Test indicated that although the aggregates were considered deleterious, and some expansion did occur, no evidence of cracking or spalling was visible in the specimens. Thus a true relationship between the Chemical Test Method and the Mortar Bar Expansion Test Method was not found in this study. The degree of aggregate reactivity cannot be predicted from the Chemical Method without the Mortar Bar Test as a supplement.

CONCLUSION

The following conclusions regarding the evaluation of various types of cements, cement-aggregate mixtures, and mortar bar expansion results are as follows:

(1) There was no significant difference chemically in the cements studied that affected the physical properties of the concrete mixes.

(2) The method of classifying cements according to tricalcium silicate is inadequate since the tricalcium silicate values showed poor correlation with compressive strength of concrete.

(3) There was no relationship between compressive strength and modulus of elasticity for the cement mixes studied.

(4) There is a poor relationship between the Chemical Method (ASTM C-289) and the Mortar Bar Expansion Method (ASTM C-227) for determining the potential reactivity of aggregates; and the Chemical Method is incomplete without the supplemental data of the Mortar Bar Expansion Method.

(5) All deleterious aggregate specimens, except one, molded and tested according to ASTM C-227, "Alkali Reactivity of Cement Aggregate Combination," showed less than a .05% increase in overall expansion at the end of a 3 month test period and all aggregate specimens, showed less than 0.1% at the end of the 6 month test.

APPENDIX

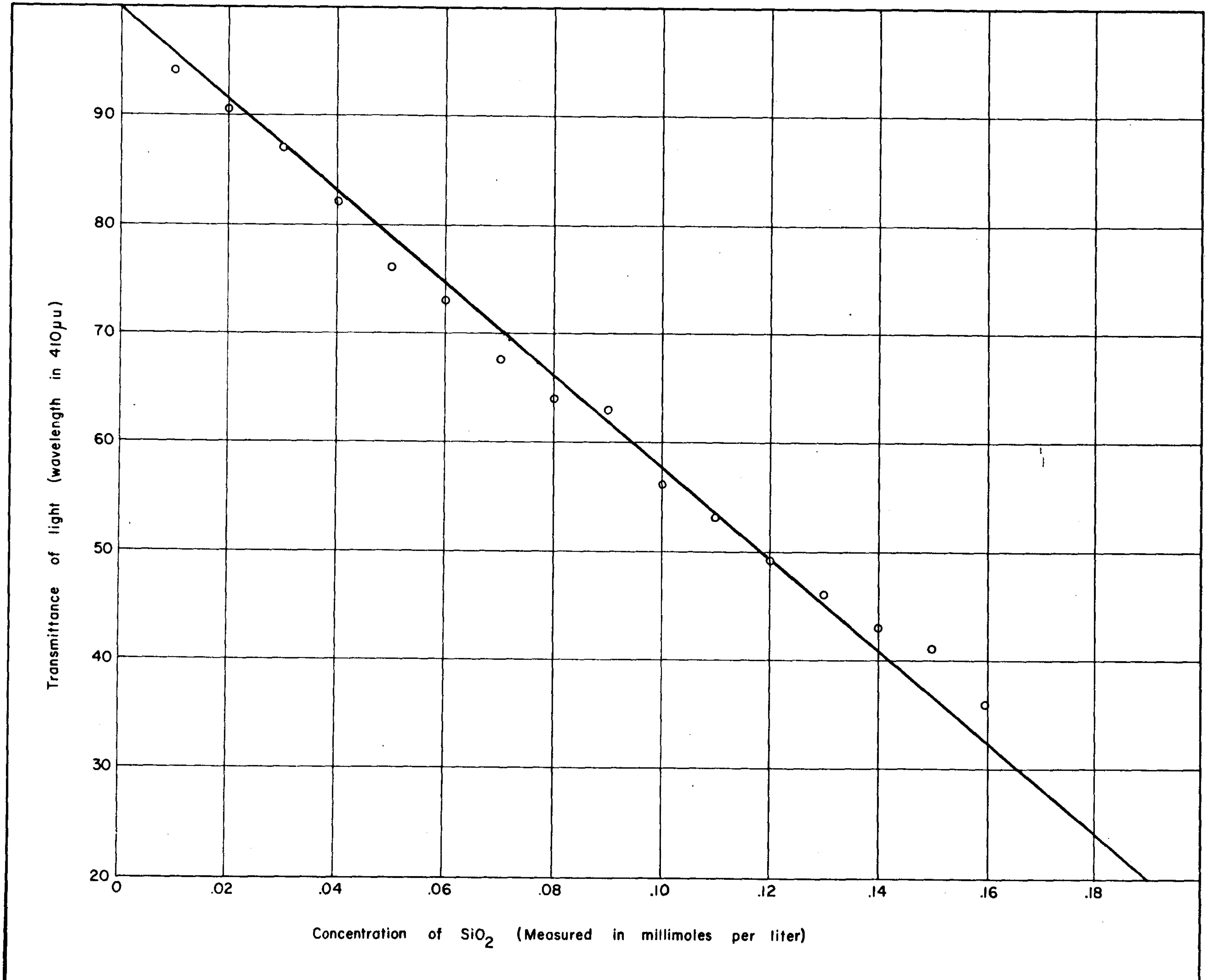

Figure 1 - This graph illustrates the relationship between Transmittance of Light Concentration of SiO_2

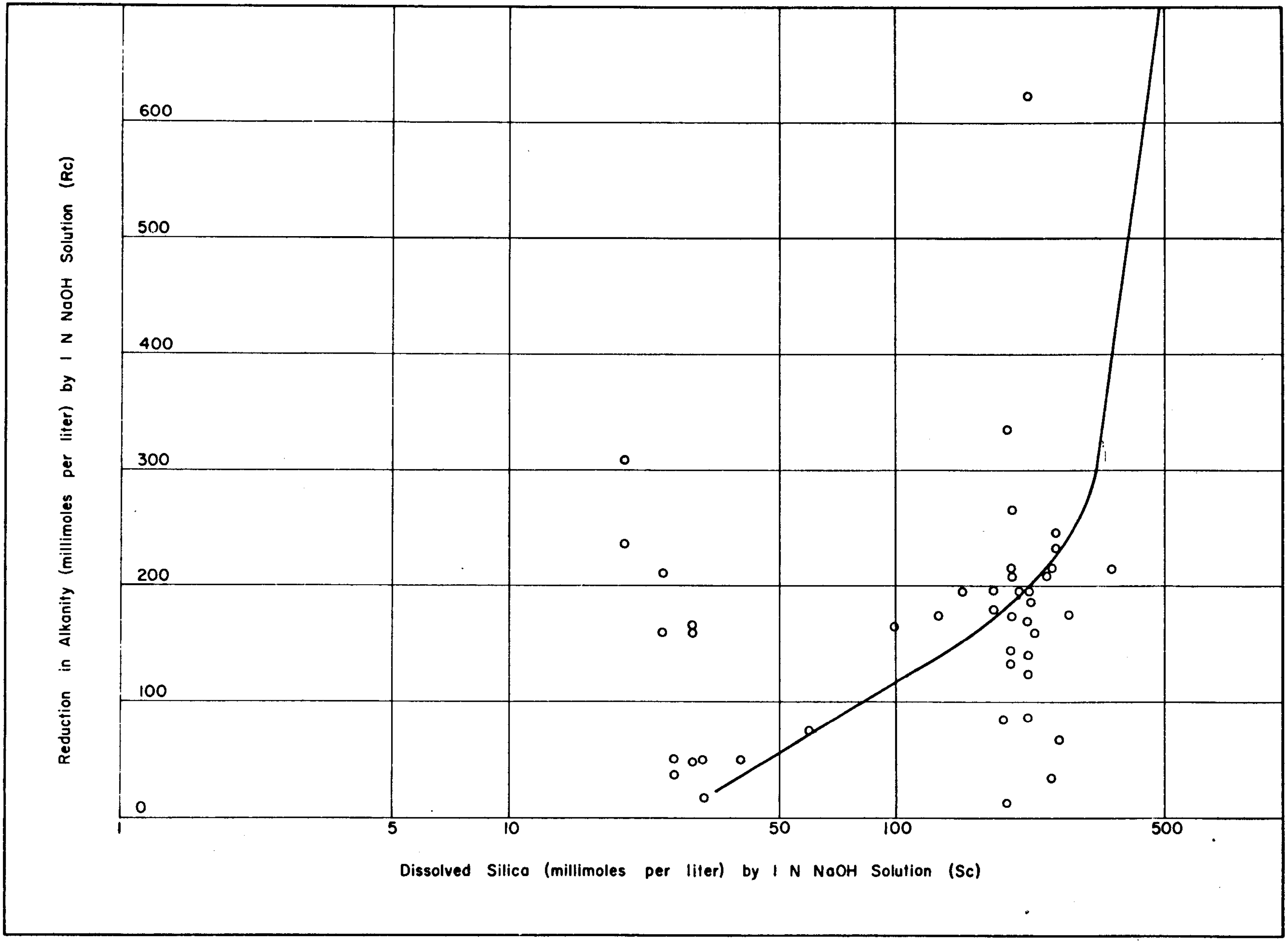

Figure 2 - This graph illustrates the relationship between Reduction in Alkanity and Dissolved Silica for Gravel Aggregate Samples only.

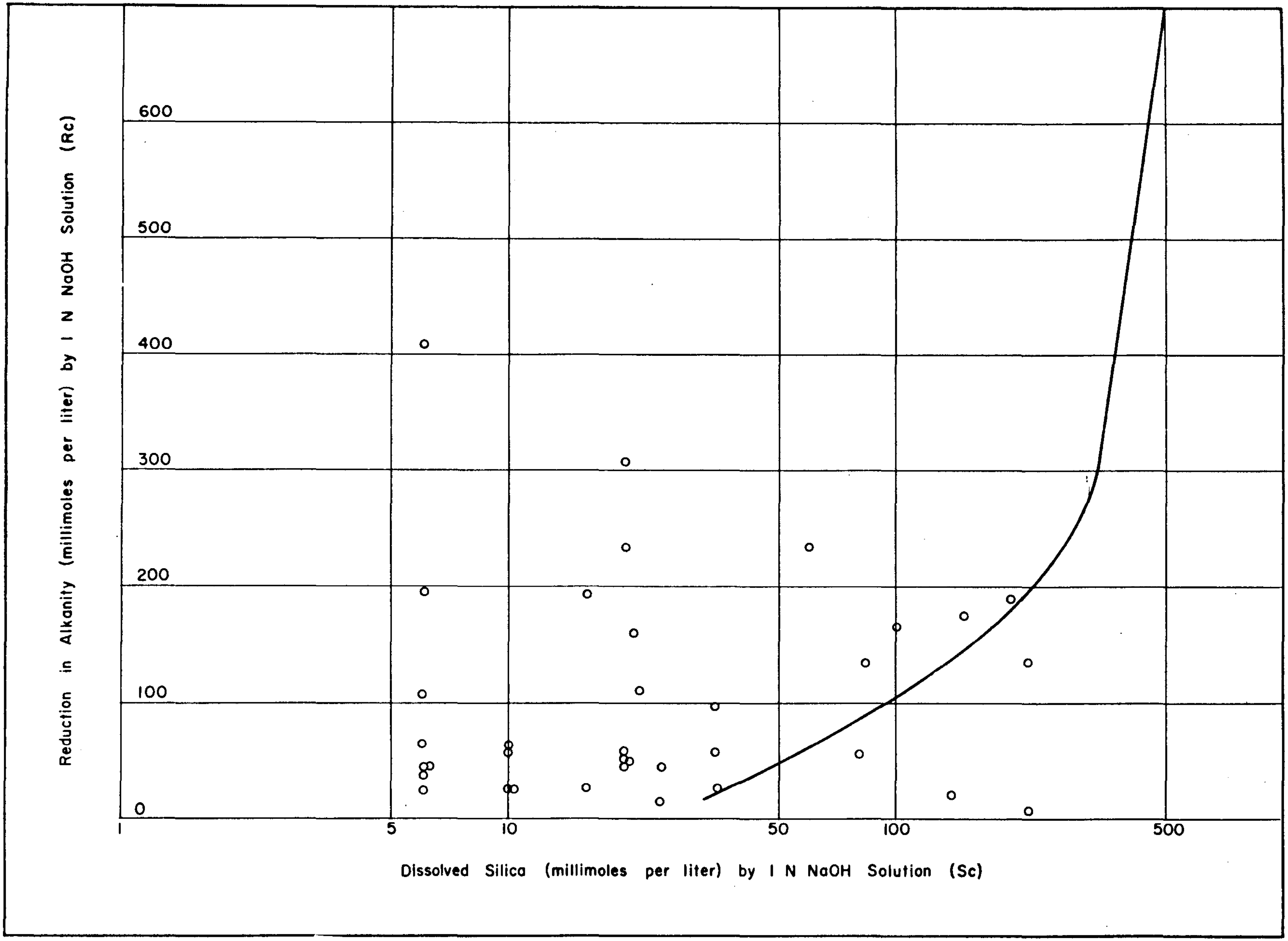

Figure 3 - This graph illustrates the relationship between Reduction in Alkanity and Dissolved Silica for Sand Aggregate Samples only.

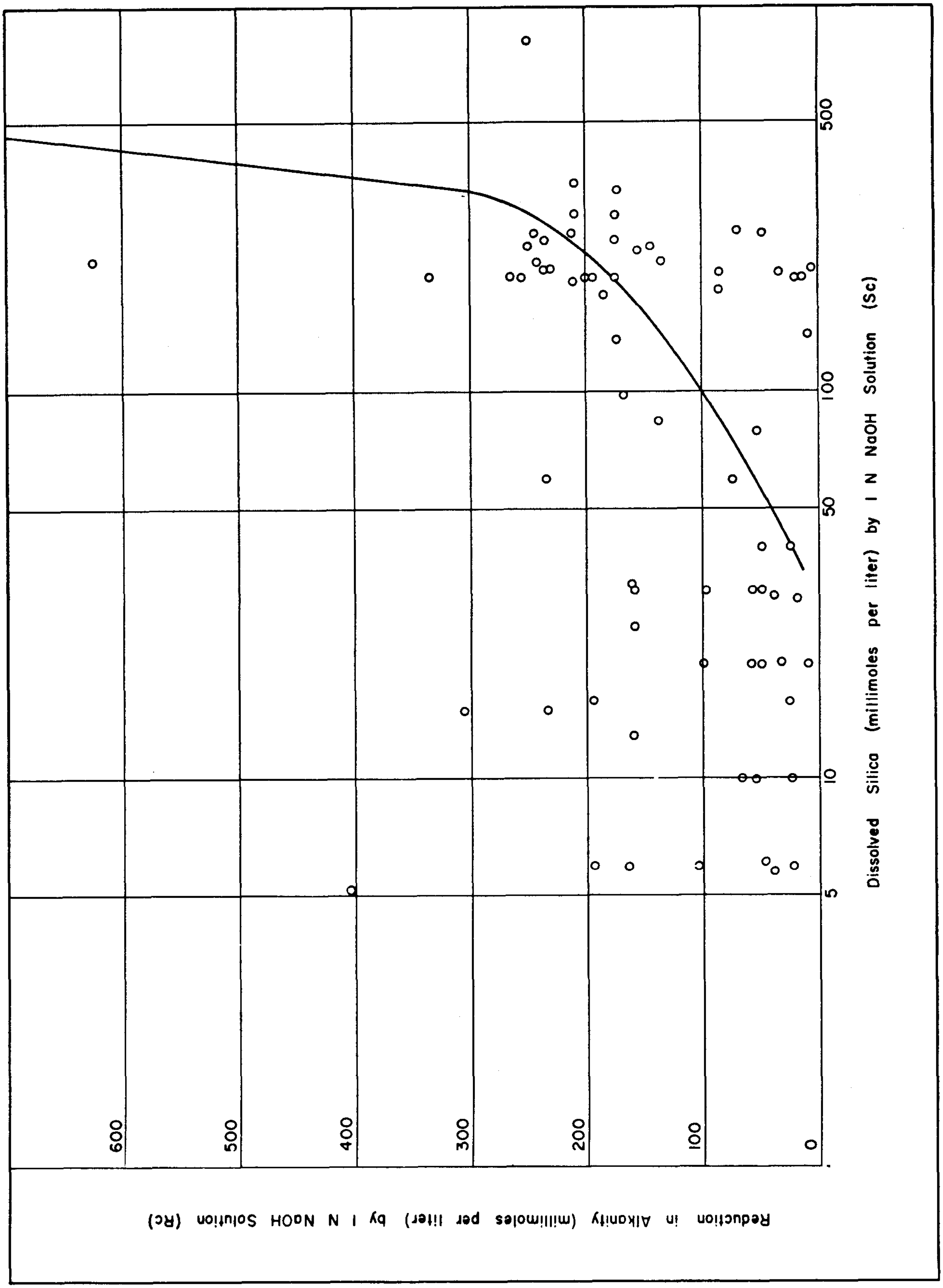

Figure 4 - This graph illustrates the relationship between Reduction in Alkanity, and Dissolved Silica for all Aggregate Samples Tested.

TABLE 1

IDENTIFICATION OF SAMPLES

Identification	Source
A-1	Texas Portland Cement Company Echo, Texas
A-2	Trinity Cement Company Houston, Texas
A-3	Ideal Cement Company Houston, Texas
A-4	Gulf Coast Cement Company Houston, Texas
A-5	Lone Star Cement Company Houston, Texas
A-6	Long Horn Cement Company San Antonio, Texas
A-7	Halliburtion Cement Company Corpus Christi, Texas
A-8	Trinity Cement Company Fort Worth, Texas
A-9	Universal Cement Company Waco, Texas
A-10	San Antonio Cement Company San Antonio, Texas
A-11	Lone Star Cement Company Dallas, Texas
A-12	South West Cement Company Odessa, Texas
A-13	Trinity Cement Company Dallas, Texas
A-14	Lone Star Cement Company Abilene, Texas
A-15	Texas Industries Cement Company Midlothian, Texas
A-16	South Western Cement Company El Paso, Texas
B-1	Missouri Portland Cement Company Sugar Creek, Missouri
B-2	Marquette Cement Company Cape Girdeau, Missouri

Identification	Source
B-3	Alpha Cement Company Alpha, Missouri
B-4	Atlas Cement Company Hannibal, Missouri
B-5	Missouri Portland Cement Company Missouri
C-1	Lehigh Cement Company Miami, Florida
C-2	Florida Portland Cement Company Miami, Florida
C-3	Florida Portland Cement Company Tampa, Florida
C-4	Lehigh Cement Company Bunnell, Florida
D-1	General Portland Cement Company Chattanooga, Tennessee
D-2	Penn. Dixie Cement Company Kingsport, Tennessee
D-3	Ideal Cement Company Knoxville, Tennessee
D-4	Penn. Dixie Royal Cement Company Richard, Tennessee
D-5	Marquette Cement Company Nashville, Tennessee
D-6	Marquette Cement Company Carvan, Tennessee
E-1	Lone Star Cement Company Demopolis, Alabama
E-2	Lone Star Cement Company Birmingham, Alabama
E-3	Universal Atlas Cement Company Leads, Alabama
E-4	Southern Cement Company Roberta, Alabama
E-5	Lehi Cement Company Birmingham, Alabama
E-6	Alpha Cement Company Birmingham, Alabama
E-7	National Cement Company Ragland, Alabama
E-8	Ideal Cement Company Mobile, Alabama

Identification	Source
F-1	Ideal Cement Company Ada, Oklahoma
F-2	Oklahoma Cement Company Pryor, Oklahoma
F-3	Dewey Cement Company Tulsa, Oklahoma
G-1	Lehigh Cement Company Iola, Kansas
G-2	General Cement Company Fredonia, Kansas
G-3	Monarch Cement Company Humbalt, Kansas
G-4	Universal - Atlas Cement Company Independence, Kansas
G-5	Ashgrove Cement Company Chanute, Kansas
G-6	Lone Star Shanee Cement Company Mission, Kansas
H-1	Ideal Cement Company Okay, Arkansas
H-2	Arkansas Cement Company Foreman, Arkansas
I-1	Portland Cement Company Kosmosbal, Kentucky
J-1	Castle - Haynes Cement Company Castle Haynes, North Carolina
K-1	Gaint Cement Company Harleyville, South Carolina
L-1	Mississippi Valley Cement Company Redwood, Mississippi
L-2	Marquette Cement Company Brandon, Mississippi

Identification	Source
M-1	Marquette Cement Company Ogelesby, Illinois
M-2	Alpha Cement Company La Salle, Illinois
M-3	Medusa - Dixon Cement Company Illinois
M-4	Missouri Portland Cement Company Illinois
N-1	Penn. - Dixie Cement Company Clinchville, Georgia
N-2	Marquette Cement Company Rockmoor, Georgia
O-1	Ideal Cement Company Superior, Nebraska
O-2	Ashgrove Cement Company Louisville, Nebraska
P-1	Ideal Cement Company Lake Charles, Louisiana
P-2	Ideal Cement Company Baton Rouge, Louisiana
P-3	Portland Cement Company New Orleans, Louisiana

TABLE 2

STRENGTH VERSUS TRICALCIUM SILICATE VALUES

Sample No.	C_3S	Compressive Strength (Cement 7-day)	Tensile Strength (Cement 7-day)	Compressive Strength (Concrete 7-day)	Compressive Strength (Concrete 28-day)
A-3	47.23	4375	407	3816	5606
E-2	58.49	5700	403	4358	5783
D-3	44.81	5333	385	4034	6037
C-2	57.19	5850	373	4558	6130
B-5	52.29	4366	365	4157	6301
M-1	34.40	3482	388	4323	5684
M-4	40.80	4433	363	4511	6919
E-3	53.32	4250	418	4788	6290
G-3	41.86	5133	412	3981	6094
E-4	44.21	5783	417	5053	5707
B-3	48.43	4666	405	3827	5613
A-1	40.93	5083	415	3775	

TABLE 3

RESULTS OF FREEZE AND THAW DURABILITY

	7 Day Cure			28 Day Cure		
Sample No.	F&T Cycles	Relative Dynamic Mod.	Durability Factor	F&T Cycles	Relative Dynamic Mod.	Durability Factor
A-3	8	39.0	1.04	71	55.2	13.06
E-2	8	35.3	.94	30	36.9	3.69
D-3	18	58.2	3.49	98	59.5	19.44
C-2	10	50.0	1.67	60	59.7	11.94
B-5	47	56.0	8.77	133	60.5	26.82
M-1	8	57.7	1.54	37	55.2	6.81
M-4	8	15.5	0.41	33	49.2	5.41
E-3	9	35.4	1.62	36	53.8	6.46
G-3	8	46.7	1.25	31	55.1	5.69
E-4	10	54.9	1.83	39	49.0	6.37
B-3	7	65.9	1.54	58	56.7	10.96
A-1	7	28.3	0.66	25	54.8	4.57

TABLE 4

SKRINKAGE

Sample No.	% Shrinkage
A-3	0.035
E-2	0.024
D-3	0.033
C-2	0.042
B-5	0.034
M-1	0.033
M-4	0.037
E-3	0.047
G-3	0.035
E-4	0.034
B-3	0.035
A-1	0.016

TABLE 5

COMPRESSIVE STRENGTH (PSI)
OF CONCRETE MIXTURES

Sample No.	7 day	28 day	3 month	6 month	12 month
A-3	3816	5606	7179	7032	6936
E-2	4358	5783	6589	7190	7170
D-3	4034	6037	7253	7367	7809
C-2	4558	6130	7538	7534	8169
B-5	4511	5684	7462	7508	8110
M-1	4323	6301	7425	7444	8080
M-4	4157	6400	7202	7368	8145
E-3	4788	6919	7674	7691	7898
G-3	3981	6290	7185	7609	7596
E-4	5053	6094	7025	7197	7393
B-3	3827	5707	6437	6820	6769
A-1	3775	5613	6684	6684	7497

TABLE 6

DISTRIBUTION OF AGGREGATES

District	Type	Unknown	Distributor
03	g	1	Morrowville
03	g	2	Morrowville
08	g	3	Lutesville
02	g	4	Jahncke (New Orleans)
02	g	5	Jahncke
08	g	6	Lutesville
02	g	7	Jahncke
02	g	8	Jahncke
03	s	9	Morrowville
03	s	10	Morrowville
08	s	11	Lutesville
08	s	12	Lutesville
02	s	13	Jahncke
02	s	14	Jahncke
61	s	15	Holloway (Cole, La.)
61	s	16	Holloway
61	s	17	Red Stick (Baywood, La.)
61	s	18	Red Stick
04	s	19	Braswell (Minden, La.)
04	s	20	Braswell
04	g	21	Ouchita (Monroe, La.)
61	g	22	Baton Rouge
61	g	23	Red Stick
62	g	24	W. R. Core (Covington, La.)
04	g	25	Braswell
61	g	26	Acme Gravel (Baton Rouge)
62	g	27	Tangipahoa (Amite, La.)
08	g	28	Gifford Hill (Turkey Creek)
--	--	29	--
58	g	30	Mack & Anders (Faraday)
Natchez	s	31	St. Catherine
58	s	32	Chisum (Sicily Island)
Natchez	g	33	St. Catherine
04	g	34	Monroe
04	s	35	Ouchita
58	s	36	Mack & Anders
58	g	37	Chisum
58	s	38	Monroe
61	s	39	Lambert (St. Francisville)

TABLE 6 (cont'd.)

District	Type	Unknown	Distributor
61	g	40	Lambert
62	g	41	Howard
61	g	42	Feliciana (Jackson)
61	g	43	Holloway
58	s	44	Amyx (Jena)
61	s	45	Baton Rouge
61	g	46	La. Sand & Gravel (B. R.)
58	g	47	Amyx
61	s	48	La. Sand & Gravel
07	g	49	Gifford Hill (Indian Village)
07	s	50	Gifford Hill (Indian Village)
08	g	51	Gifford Hill (Turkey Creek)
08	s	52	Gifford Hill (Turkey Creek)
07	g	53	Trinity (Longville)
07	s	54	Trinity
62	g	55	La. Industries (Tangipahoa)
62	g	56	Standard Materials (Slidell)
62	g	57	W. R. Core
--	--	58	--
--	--	59	--
--	--	60	--
08	g	61	Mid-State Materials
08	g	62	Lutesville
08	s	63	Mid-State (Woodworth)
--	--	64	--
08	g	65	Mid-State
08	s	66	Mid-State Materials
62	s	67	La. Industries
62	g	68	La. Industries
08	s	69	Lutesville
03	s	70	Grimmet, Jones & Taylor
03	g	71	Grimmet, Jones & Taylor
62	s	72	W. R. Core
62	s	73	Standard Materials
62	g	74	La. Industries
62	s	75	Jahncke Service (Sun, La.)
62	s	76	Core (Amite)
62	g	77	Core
62	s	78	Core Pit (Sun, La.)

TABLE 6 (cont'd)

District	Type	Unknown	Distributor
62	s	79	La. Industries
62	g	80	Jahncke Service
62	s	81	Lakeview (Bogalusa)
62	g	82	Core Pit (Sun, La.)
62	g	83	Lakeview
62	g	84	Big Rock Sand & Gravel
62	s	85	Standard S. & G.
62	g	86	Anderson (Amite)
62	s	87	Anderson
62	g	88	Howard
62	s	89	Kinchen (Hammond)
62	s	90	Jahncke Service (Tangipahoa)
62	s	91	Howard
62	g	92	Jahncke Service
62	g	93	Joe Bendin (Hmito, La.)
62	g	94	Standard Sand & Gravel
62	s	95	Big Rock Sand & Gravel

TABLE 7 CALCULATION OF Sc

(Silica dissolved from No. 50- No. 100 Aggregate Material (millimoles per liter) by 1-Normal Sodium Hydroxide Solution.)

Unknown	Type	Transmittance	Concentration	Sc
1	g	56	.097	194
2	g	47	.119	238
3	g	48	.116	232
4	g	91	.015	30
5	g	90	.017	34
6	g	87	.020	40
7	g	90	.017	34
8	g	42	.130	260
9	g	47	.119	238
10	s	96	.003	6
11	s	94	.008	16
12	s	95	.005	10
13	s	96	.003	6
14	s	95	.005	10
15	s	96	.003	6
16	s	95	.005	10
17	s	96	.003	6
18	s	96	.003	6
19	s	95	.005	10
20	s	94	.008	16
21	g	76	.050	100
22	g	53	.100	200
23	g	42	.130	260
24	g	50	.112	224
25	g	83	.030	60
26	g	51	.109	218
27	g	42	.130	260
28	g	38	.141	282
29	--	--	----	----
30	g	50	.112	224
31	s	85	.029	58
32	s	95	.005	10
33	g	44	.0126	25.2
34	g	57	.095	190
35	s	91	.015	30
36	s	90	.017	34
37	g	53	.100	200
38	s	92	.010	20
39	s	80	.041	82
40	g	43	.129	258
41	g	70	.064	128

TABLE 7 (cont'd.)

Unknown	Type	Transmittance	Concentration	Sc
42	g	49	.110	220
43	g	47	.119	238
44	s	90	.017	34
45	s	90	.017	34
46	g	52	.100	200
47	g	58	.092	184
48	s	89	.020	40
49	g	41	.133	266
50	s	84	.029	58
51	g	44	.126	252
52	s	87	.020	40
53	g	41	.133	266
54	s	87	.024	40
55	g	46	.121	242
56	g	52	.100	200
57	g	45	.120	240
58	--	--	----	---
59	--	--	----	---
60	--	--	----	---
61	g	51	.109	218
62	g	89	.020	40
63	s	54	.100	200
64	--	--	----	---
65	g	57	.095	190
66	s	90	.017	34
67	s	92	.010	20
68	g	51	.109	218
69	s	92	.010	20
70	s	90	.017	34
71	g	94	.008	16
72	s	90	.017	34
73	s	44	.126	252
74	g	50	.112	224
75	s	72	.050	100
76	s	55	.100	200
77	g	49	.110	220
78	s	49	.110	220
79	s	68	.070	140
80	g	46	.120	240
81	s	49	.110	220
82	g	21	.180	360

TABLE 7 (cont'd.)

Unknown	Type	Transmittance	Concentration	Sc
83	g	26	.116	332
84	g	55	.098	196
85	s	96	.003	6
86	g	50	.112	224
87	s	93	.010	20
88	g	52	.100	200
89	s	93	.010	20
90	s	96	.003	6
91	s	96	.003	6
92	g	52	.100	200
93	g	50	.112	224
94	g	56	.097	194
95	s	94	.008	16

Type of Aggregate is designated as either sand (s) or gravel (g).
Transmittance is the transmittance of aliquots of aggregate samples measured by a photoelectric photometer at wavelength 410 mu.
Concentration is the concentration of silica in the aggregate solution measured in the photometer, millimoles per liter. This is read directly from Figure 1.
Sc is the concentration of dissolved silica from aggregate material (millimoles per liter) by a one-normal sodium hydroxide solution.

TABLE 8 CALCULATION OF Rc

Reduction In Alkalinity (millimoles per liter)

Unknown	Type	Ml. of HCl Used	Ml. of Blank	Rc
1	g	16.45	19.5	210
2	g	16.45	19.5	210
3	g	15.6	19.5	195
4	g	15.2	19.5	215
5	g	18.6		215
6	g	16.5		150
7	g	19.4		50
8	g	14.8	19.1	215
9	s	16.4	19.1	135
10	s	5.24		193
11	s	5.24		193
12	s	23.4	19.1	?
13	s	17.8		65
14	s	18.0	19.1	55
15	s	18.6	19.1	25
16	s	18.6	19.1	25
17	s	18.2	19.1	45
18	s	18.2	19.1	45
19	s	18.6	19.1	25
20	s	18.6	19.1	25
21	g	15.8	19.1	165
22	g	13.8		265
23	g	14.2	19.1	245
24	g	14.2	19.1	245
25	g	17.6	19.1	75
26	g	16.2	19.1	145
27	g	18.4	19.1	35
28	g	19.6	19.1	?
29	--	--	---	----
30	g	17.8	19.1	65
31	s	14.4	19.1	235
32	s	17.8	19.1	65
33	g	18.4	19.1	160
34	g	19.0	19.1	35
35	s	9.8	19.1	625
36	s	16.1	19.3	175
37	g	16.2	19.3	115
38	s	19.2	19.3	50
39	s	17.3	20.0	135

TABLE 8 (cont'd.)

Unknown	Type	Ml. of HCl Used	Ml. of Blank	Rc
40	g	15.35	20.0	233
41	g	16.5	20.0	175
42	g	7.55	20.0	622.5
43	g	16.6	20.0	170
44	s	18.1	20.0	95
45	s	18.9	20.0	55
46	g	15.2	19.8	232.5
47	g	15.4	19.8	220
48	s	19.4	19.8	20
49	g	17.4	19.8	70
50	s	22.6	----	?
51	g	18.4	19.1	25
52	s	21.2		?
53	g	19.6	20.0	45
54	s	21.4	20.0	?
55	g	16.3	20.0	185
56	g	15.6	20.0	220
57	g	15.9	20.0	210
58	--	---	----	-----
59	--	---	----	-----
60	--	---	----	-----
61	g	17.25	20.0	132.5
62	g	19.0	20.0	50
63	s	16.6	20.0	172
64	--	21.6	20.0	---
65	g	16.1	20.0	195
66	s	19.5	20.0	25
67	s	18.0	20.0	130
68	g	16.8	20.0	175
69	s	19.0	20.0	50
70	s	18.5	18.8	15
71	g	15.2	18.8	180
72	s	12.5	18.8	315
73	s	14.2	18.8	130
74	g	10.2	17.2	350
75	s	13.9	17.2	165
76	s	9.8		100
77	g	15.3	17.2	36.6
78	s	12.1	17.2	110

TABLE 8 (cont'd.)

Unknown	Type	Ml of HCl Used	Ml. of Blank	Rc
79	s	15.7		10
80	g	11.7	17.2	245
81	s	14.3		5
82	g	12.9	17.2	215
83	g	17.1	17.2	175
84	g	16.4	17.	5.5
85	s	13.0		38.5
86	g	13.0		231
87	s	12.5	17.2	231
88	g	11.6	17.2	258.5
89	s	17.1	17.2	5
90	s	16.4	17.2	40
91	s	13.0	17.2	210
92	g	13.0	17.2	210
93	g	12.5	17.2	235
94	g	11.6	17.2	275
95	s	17.0	17.2	10

Type of Aggregate is designated as either sand (s) or gravel (g).
Milliliters of hydrochloric acid used to titrate an unknown to the phenolphthalein endpoint is designated as Ml. of HCl Used.
Milliliters of hydrochloric acid used to titrate the blank to the phenolphthalein endpoint is designated as Ml. of Blank
Rc is the quantity measured as reduction in alkalinity (millimoles per liter)

TABLE 9 CALCULATION OF POTENTIAL REACTIVITY OF AGGREGATES

Unknown	Type	Sc	Rc	Category
1	g	194	210	I
2	g	238	210	I
3	g	232	195	I
4	g	30	215	I
5	g	34	215	I
6	g	40	150	I
7	g	34	50	I
8	g	260	215	I
9	s	238	135	I
10	s	6	193	I
11	s	16	193	I
12	s	10	?	?
13	s	6	65	I
14	s	10	55	I
15	s	6	25	I
16	s	10	25	I
17	s	6	45	I
18	s	6	45	I
19	s	10	25	I
20	s	16	25	I
21	g	100	165	I
22	g	200	265	I
23	g	260	245	I
24	g	224	245	I
25	g	60	75	I
26	g	218	145	Del.
27	g	260	35	Del.
28	g	282	?	?
29	--	---	--	---
30	g	224	195	I
31	s	58	235	I
32	s	10	65	I
33	g	25. 2	160	I
34	g	190	35	Del.
35	s	30	625	I
36	s	34	175	I
37	g	200	115	Del.
38	s	20	50	I
39	s	82	135	I
40	g	258	233	I

TABLE 9 (cont'd.)

Unknown	Type	Sc	Rc	Category
41	g	128	175	I
42	g	220	662.5	I
43	g	238	170	Del.
44	s	34	95	I
45	s	34	55	I
46	g	200	232.5	I
47	g	184	220	I
48	s	40	20	I
49	g	266	70	Del.
50	s	58	?	?
51	g	252	25	Del.
52	s	40	?	?
53	g	266	45	I
54	s	40	?	?
55	g	242	185	Del.
56	g	200	220	I
57	g	240	210	Del.
58	--	---	---	----
59	--	---	---	----
60	--	---	----	----
61	g	218	132.5	Del.
62	g	40	50	I
63	s	200	172	Del.
64	--	---	---	----
65	g	190	195	I
66	s	34	25	I
67	s	20	130	I
68	g	218	175	Del.
69	s	20	50	I
70	s	35	15	I
71	g	242	315	I
72	s	34	180	I
73	s	252	130	Del.
74	g	224	350	I
75	s	100	165	I
76	s	200	100	Del.
77	g	22	36.6	I
78	s	22	110	I
79	s	140	10	Del.
80	g	240	245	I

TABLE 9 (cont'd.)

Unknown	Type	Sc	Rc	Category
81	s	220	5	Del.
82	g	360	215	Del.
83	g	332	175	Del.
84	g	196	5. 5	Del.
85	s	6	38. 5	I
86	g	224	231	I
87	s	20	231	I
88	g	200	258. 5	I
89	s	20	5	I
90	s	6	40	I
91	s	6	210	I
92	g	200	210	I
93	g	224	235	I
94	g	194	275	Del.
95	s	16	10	I

Type of Aggregate is designated as either sand (s) or gravel (g).
Sc is the quantity of silica dissolved from aggregate material (millimoles per liter) by a one-normal sodium hydroxide solution as measured by photoelectric photometer.
Rc is the quantity measured as reduction in alkalinity (millimoles per liter)
Category is the division of aggregates according to innocuous (I) and deleterious (Del.).

	Deleterious Samples
Sands	5
Gravels	15

	Innocuous Samples
Sands	33
Gravels	33

	Undetermined Samples
Sands	4
Gravels	1

TABLE 10

MORTAR BAR EXPANSION PERCENTAGES

Bar No.	3 Months	6 Months	12 Months
1	.0330	.0160	.0365
2	.0430	.0310	.0560
3	.0360	.0270	.0390
4	.0520	.0300	.0560
5	.0290	.0120	.0270
6	.0400	.0170	.0300
7	.0360	.0160	.0300
8	.0400	.0200	.0440
9	.0020	.0140	.0030
10	.0070	.0060	.0050
11	.0090	.0170	.0150
12	.0050	.0160	.0090
13	.0030	.0050	.0140
14	.0080	.0130	.0440
15	.0230	.0280	.0630
16	.0240	.0340	.0520
17	.0060	.0140	.0340
18	.0130	.0320	.0440
19	.0300	.0520	.0730
20	.0410	.0700	.0890

LOUISIANA HIGHWAY RESEARCH

CEMENT STUDY

Research Project No. 63-2Ch-C
Louisiana HPR 1(3)

Interim Progress Report No. 1

August, 1965

HIGHWAY RESEARCH REPORT

CEMENT STUDY
LOUISIANA HPR 1(3)
RESEARCH PROJECT NO. 63-2Ch-C
INTERIM REPORT NO. 1

August 1965

SCOPE

The scope of this project was to study various chemical and physical properties of cements from sources within a 500 mile radius of Louisiana. A system of classifying these samples was undertaken as a prerequisite step for Phases II and III.

PRESENT STATUS OF PROJECT

Approximately 132 samples representing 66 mills and 17 states were tested. These are identified in Table VI. Samples from these wide areas were studied to determine any variable that may exist. A system of classifying these samples was developed. It involved grouping the cements according to their respective tricalcium silicate values. Random samples within these groups were selected for Phase II. The following list represents the classification and the samples within each grouping:

C_3S Values less than 40

Identification

A-1
B-2
B-4
D-2
G-2
K-1
M-4
P-2

C_3S Values between 40-45

Identification
B-1
D-3
D-4
D-5
D-6
E-1
G-3
A-8
A-15
H-2
G-6
E-3
M-2

C_3S Values between 45-50

Identification
B-3
C-3
C-4
D-1
F-1
F-2
F-3
G-1
G-4
A-2
A-3
A-9
A-12
A-13
H-1
I-1
J-1
L-1
O-1
E-4
E-6
M-3

C_3S Values between 50-55

Identification
B-5
A-5
A-6
A-11
G-5
M-1
N-2
O-2
E-5
E-7
E-8
P-1
P-3

C_3S Values above 55

Identification
C-1
C-2
A-4
A-7
A-10
A-14
L-2
N-1
E-2

The random samples selected from the above mentioned grouping for further study in Phase II were: A-1, M-4, D-3, G-3, E-3, B-3, A-3, E-4, B-5, M-1, C-2, E-2.

TEST PROCEDURES

The Chemical and Physical testing of cements is completed. The results are given in the Appendix under Tables I and II. The test procedures used are given in the following paragraphs.

	ASTM Method
Standard Method of Chemical Analysis of Portland Cement	C 114-58
Method of Test for Air Content of Hydraulic Cement Mortar	C 185-59
Method of Test for Autoclave Expansion of Portland Cement	C 151-60
Method of Test for Compressive Strength of Hydraulic Cement Mortar (2 inch-cube)	C 109-58
Method of Test for Fineness of Portland Cement by Air Permeability Apparatus	C 204-55
Method of Test for Normal Consistency of Hydraulic Cement	C 187-58
Method of Test for Tensile Strength of Hydraulic Cement Mortar	C 190-59
Method of Test for Time of Seting of Hydraulic Cement by Gilmore Needle	C 266-58T
Method of Test for Specific Gravity of Hydraulic Cement	C 188-44
Method of Test for Time of Setting of Hydraulic Cement by Vicat Needle	C 191-58
Method of Test for Fineness of Portland Cement by the Turbidimeter	C 115-58
Method of Test for Fineness of Hydraulic Cement by the No. 325 Sieve	C 430-60T

DISCUSSION OF RESULTS

Physical Tests

The physical results are tabulated in Table I of the Appendix. A correlation was evident between the tensile strength (ASTM C 190-59, and the compressive strength (ASTM C 109-58) for 3 and 7 day age. These relationships are illustrated in Figures 1 and 2. The slope of the line for both Figures is the same indicating that the rate of hardening affected the tensile and compressive strength similarly.

Three methods were used to determine the fineness of cements. There was an expected relationship between these results, and it was obtained. Figure 3 shows the relationship between the Turbidimeter sq. cm/gm (ASTM C 115-58) and the Blaine Fineness apparatus sq. cm/gm (ASTM C 204-55). As the values of the Turbidimeter increased the value of the Blaine Fineness apparatus also increased correspondingly. Figure 4 shows the relationship between the Turbidimeter and the Per Cent Passing No. 325 Mesh Sieve (ASTM C 430-60T). As the percentage increased, the Turbidimeter showed an increase in the square centimeters of cement in a gram of sample. Figure 5 shows the relationship between the Blaine Fineness Apparatus sq. cm/gm and the Per Cent Passing No. 325 Mesh Screen. As the amount of cement passing the 325 screen increased, the square centimeters of cement per gram of sample increased. These three figures all indicated the same phenomina, namely, that the finer the cement, the higher the surface area per gram of cement.

A correlation was attempted between the Normal Consistency (ASTM C 187-58) and the Blaine Fineness Apparatus. It seems evident, that the finer the cement, the more the surface area, then consequently more water should be required. However, according to the results tabulated in Table I, these two variables showed no trend whatsoever. In addition, relationships between the normal consistency versus the Vicat Time of Set (ASTM C 191-58) and the normal consistency versus the Gillmore Time of Set (ASTM C 266-58T) were attempted. According to tabulated results there was no trend between these variables. In summary it may be noted that possibly the lack of relationship between these variables could be attributed to the close similarities between physical properties for Type I Portland Cement.

Chemical Results

The chemical results are tabulated in Table II of the Appendix. From the determination of silicon dioxide, iron oxide, aluminum oxide, calcium oxide, and sulfur trioxide, it was possible to calculate the tricalcium silicate (C_3S), the dicalcium silicate (C_2S), the tricalcium aluminate (C_3A), and the tetracalcium aluminoferrite (C_4AF). In addition, the magnesium oxide, loss on ignition, and insoluble residue were determined to qualify the cement samples for Type I according to "Table I - Chemical Requirements" Specifications for Portland Cement (ASTM C 150-60). Sodium and Potassium oxides were analyzed to determine any deviation which may prove to be of some value.

An attempt was made to plot each result of Chemical Analyses versus each result of Physical Analyses. There was no relationship between any of these variables. It was then decided to attempt a general classification of cements which would possible yield some correlation between variables.

The value for tricalcium silicate varied from a low of 26.17 to a high of 62.18. In Table III, cements were classified according to their tricalcium silicate values. There were eight cement samples whose C_3S values were below forty. For each of these respective samples, the C_2S, C_3A, C_4AF, Tensile Strength, Compressive Strength, Blaine Fineness and Normal Consistency values were accumulated and averaged. The tricalcium silicate average for these samples was 35.76. The remaining cements were classified as follows: for a C_3S value between forty and forty-five, there were thirteen cements; for a C_3S value between forty-five, and fifty, there were twenty-two cements; for a C_3S value between fifty and fifty-five, there were thirteen cements, and for a C_3S value greater than fifty-five, there were nine cements. The average C_3S values for these ranges versus, C_2S, C_3A, C_4AF, Tensile Strength, Compressive Strength, Blaine Fineness, and Normal Consistency were analyzed to determine if any correlation was possible. By plotting C_3S versus Compressive Strength (Figure 6), a definite trend was established in which the C_3S values increased with an increase in Compressive Strength. This relationship was expected, because it is believed that C_3S is related to strength.

Figure 7 shows the same general type of curve which was obtained by plotting C_3S versus the Tensile Strength. As the C_3S values increased, the Tensile Strength also increase. This was expected due to the former relationship established between compressive strength and tensile strength (Figure 1) and compressive strength versus C_3S (Figure 6). It was also found that as the C_3S values increased, the C_2S values decreased, and as the C_3S values decreased, the C_2S values increased. The curve produced when the C_3S values were plotted against the C_2S values (Figure 8) showed a negative slope which is indicative of the mathematical formula for calculating C_2S values from C_3S values. According to the formula for calculating C_2S values, as the C_3S increase the C_2S values approach zero and as the C_3S values decrease and approach zero, the C_2S values increase to a value equal to 2.87 times the silicon dioxide.

The C_3A average values were analyzed for possible relationships with

Compressive Strength, Tensile Strength, and per cent water. There was no relationship between these values. This may be due to the fact that all these cements are too closely related for any deviation. The C_3A values ranged from a low of 4.83 to a high of 16.46. The average values for the aforementioned classification, as based on C_3S values, showed the low C_3A was 11.26 and the high was 13.39. An attempt was made to correlate the average C_3A values and the % SO_3, but there was no relationship. There was also no relationship between C_3A, % SO_3 and Gillmore Final Setting Time (ASTM C-266-58T). The sulfur trioxide is admitted to cement in the form of gypsum, and its function is to control the setting time of cement providing the C_3A values are controlled. The optimum amount of gypsum in cement still remains unanswered. The % SO_3 in these samples ranges from 1.78 minimum to 2.86 maximum, and the C_3A values ranged from 7.21 (except sample B - 2 which was 4.83) to 16.46. Therefore, it is evident that both the % SO_3 and C_3A values are well controlled. According to L. A. Gudovich,[1] "The amount of gypsum to be added to Portland Cement depends principally on the amount of C_3A present and on the velocity with which it combines with gypsum." Thus, there should be a relationship between the % SO_3 and the C_3A.

According to Table III all % SO_3 values ranged between 2.22 and 2.49, and all Gillmore Final Setting Times ranged between three hours and fifty-six minutes to four hours and twenty-five minutes. Thus, any significant findings would be impossible unless some cement samples showed more erratic properties.

If a cement sample showed a high C_3A content and a low SO_3 content, then this would be fast setting cement. Whereas, a relatively low C_3A content and a relatively high SO_3 content (above 3.0), would be a slow setting cement. The larger the SO_3 content for a given C_3A content, the longer the setting time. If a high sulfate resistant cement is desired, the C_3A should be kept at a low value and SO_3 should be kept at a high value. This would hinder the reaction of the C_3A with the SO_3 and thus would allow the SO_3 other combinations.

Table IV shows the cements classified according to Compressive Strength. There were five classifications; namely, below 4000 psi, between 4000 and 4500 psi, between 4500 and 5000 psi, between 5000 and 5500 psi, and compressive strength values greater than 5500 psi. Average values of C_3S, C_3A, C_4AF, % SO_3, Blaine Finess Apparatus and Gillmore Final Time of Setting were computed. There was no relationship between any of these variables. Therefore, a decision was made not to consider this table for classification.

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[1]Gudovich, L. A., Tsement, 1950, No. 2.

Table V, which classifies cements according to their normal consistencies (ASTM C-187), was considered for classification. Different ranges of per cent water were initiated, and accumulation of other variables such as, Tensile Strength, Compressive, Blaine Fineness, C_3A, C_4AF, and C_3S were averaged and analyzed to no avail. The original trend of increasing Tensile Strength being accompanied by increasing Compressive Strength, increasing C_3S, decreasing C_2S values was not true. Thus this classification system was also abandoned.

Table VI is a master list of all cement samples received. It includes the source, city and state of each respective sample.

The conclusion which follows takes the analysis of Table III and sets up expectations for cements which will undergo Phase II of this study.

CONCLUSION

There were 132 samples, representing 66 mills, included in this study. Approximately twelve samples will be used for Phase II of this study which involves actual concrete mix designs. The following samples will be selected from the classification of Table III: A-1, M-4, from C_3S values below forty; samples D-3, G-3, E-3 from C_3S values between 40-45; samples B-3, A-3, E-4 from C_3S values between 45-50; samples B-5, M-1 from C_3S values between 50-55; samples C-2, E-2 from C_3S values greater than 55. These samples will be analyzed again, and more exhaustive tests involving concrete mix design will be conducted in order to better establish a better understanding of the effect these particular cement samples will have on concrete properties.

FUTURE STATUS OF PROJECT

Chemical and physical analysis according to ASTM specifications will be conducted on each sample submitted for Phase II. Phases II and III of this study will commence as soon as both work plans enclosed herein are approved.

WORK PLAN

CEMENT STUDY
State Project No. 63-2Ch-C
Louisiana HPR 1(3)
Phase II

SCOPE

Phase II of this study will consist of evaluating the groups of cements selected from Phase I. The cements were grouped according to their C_3S values which resulted in five groups. From each of these five groups, two or three mills were selected for testing as follows. Group 1 has two cement mills, Group II has three cement mills, Group III has three cement mills, Group IV has two cement mills and Group V has two cement mills.

A sufficient amount of cement will be obtained from each mill for the necessary tests.

METHODOLOGY

Concrete mixes will be made with each source of cement to be tested. From these mixes data will be obtained as to the amount of water required, air content and the setting time. In addition specimen will be made to test compressive strength at 7 and 28 days, 3, 6, and 12 months, freeze and thaw tests will be preformed for durability comparison, and shrinkage characteristics will be determined.

The cements will be retested in the same manner as described in Phase I, to determine if the same characteristics are present as was found initially. The chemical analysis will be performed prior to making concrete to insure that the cements are still in the same group as the original samples.

The test procedure to be followed in this study will be as follows:

Compressive Strength - AASHO T 126-60 and AASHO T 22-60
Freeze and Thaw Resistance - ASTM C 291-61 and ASTM C 215-60
Setting Time - ASTM C 403-63
Air Content - LDH TR 203-62
Slump of Concrete - LDH TR 207-64
Shrinkage - AASHO T 160-60
Test on Cement - ASTM C 150-64

The work on this phase of the project will commence as soon as the cement samples are received. This should be in late September or October, 1965.

ESTIMATED COST

Labor	$5,000.00
Materials	$ 200.00
Equipment Rental	1,000.00
Report	500.00
Total	$6,700.00

WORK PLAN

CEMENT STUDY
State Project No. 63-2Ch-C
Louisiana HPR 1(3)
Phase III

SCOPE

Phase III of this study will consist in performing the Test for Potential Reactivity of aggregate (Chemical Method) on all aggregates used by the Louisiana Department of Highways and determining from this test if the aggregates are innocuous or deleterious.

METHODOLOGY

Samples of approximately 7 types of hardrock aggregate will be obtained from sources that supply the Louisiana Department of Highways. The tests will be performed in accordance with ASTM C 289-64 - Potential Reactivity of Aggregates (Chemical Method). The data obtained will be analyzed and the aggregates will be classified according to the division between innocuous and deleterious aggregates on the basis of reduction in alkalinity test. The deleterious aggregate will be combined with each cement received in Phase II of this study and Potential Alkali Reactivity of Cement - Aggregate Combinations (Mortar Bar Method) will be conducted.

The test procedures to be followed in this study will be as follows:

Test Method	ASTM Designation
Potential Reactivity of Aggregates (Chemical Method)	ASTM C 289-64
Potential Alkali Reactivity of Cement - Aggregate Combination (Mortar Bar Method)	ASTM C 227-64

The work on this phase does not depend upon completion of Phase II. Phase III will commence immediately, and once the aggregates are classified, then the deleterious aggregates will be combined with each cement from Phase II and the Potential Alkali Reactivity of Cement - Aggregate Combinations (Mortar Bar Method) will be conducted.

Estimated Cost

Labor		$7,500.00
Materials		$1,000.00
Report		$ 500.00
	Total	$9,000.00

Duration of Project 24 months

APPENDIX

SAMPLE CALCULATIONS

1. Tricalcium Silicate (C_3S) = 4.07(% CaO) - 7.60(% SiO_2) - 6.72(% Al_2O_3) - 1.43(% Fe_2O_3) - 2.85(% SO_3)

2. Di Calcium Silicate (C_2S) = 2.87(% SiO_2) - .754(% 3CaO . SiO_2)

3. Tricalcium Aluminate (C_3A) = 2.65(% Al_2O_3) - 1.69(% Fe_2O_3)

4. Tetracalcium Aluminoferrite (C_4AF) = 3.04(% Fe_2O_3)

TABLE I

PHYSICAL RESULTS

Sample No.	C-187 Normal Consistency in %	C-151 Auto-clave in %	C-191 Time of Set Vicat Hrs	C-191 Time of Set Vicat Min	C-266 Time of Set Gilmore (Initial) Hrs	C-266 Time of Set Gilmore (Initial) Min	C-266 Time of Set Gilmore (Final) Hrs	C-266 Time of Set Gilmore (Final) Min	C-204 Fineness Blaine sq. cm./gr.	C-430 Fineness Passing 325 Mesh in %	C-115 Fineness Turbidimeter sq. cm/gr.	C-190 Tensile Strength 3 days PSI	C-190 Tensile Strength 7 days PSI	C-109 Compressive Strength 3 days PSI	C-109 Compressive Strength 7 days PSI	C-185 Air Contents %	C-188 Specific Gravity
A-1	25.6	-.03	3	15	2	45	4	50	3345	93.3	1940	283	367	2,483	4,167	8.2	3.21
A-2	25.4	-.02	2	30	2	30	4	30	3130	92.0	1783	303	398	2,983	4,950	9.0	3.20
A-3	26.8	+.04	2	30	2	20	4	40	3203	92.0	1823	280	373	2,500	4,283	9.4	3.18
A-4	24.0	-.11	2	30	2	15	3	30	3325	92.7	1977	323	401	3,400	4,582	9.1	3.18
A-5	25.4	-.08	2	35	2	30	3	40	3250	92.8	1929	347	407	3,550	5,050	8.7	3.21
A-6	26.2	+.03	2	25	3	15	5	00	3198	92.5	1831	367	403	3,783	5,152	9.9	3.18
A-7	25.4	-.10	2	40	2	35	4	45	3284	93.0	1899	354	403	3,766	5,232	10.9	3.17
A-8	25.6	-.02	2	10	2	15	3	10	3396	91.3	1930	330	413	3,583	5,250	8.2	3.17
A-9	25.6	-.12	2	35	2	35	3	55	3407	93.8	1979	340	410	3,316	5,000	8.6	3.20
A-10	25.6	+.19	2	30	2	35	4	15	3142	90.4	1869	353	413	3,583	5,166	8.6	3.17
A-11	24.8	+.12	2	00	2	10	3	35	3400	93.8	1951	340	420	3,500	5,503	8.4	3.23
A-12	25.8	+.07	2	30	2	25	3	35	3497	94.5	1878	323	400	2,853	4,666	8.0	3.18
A-13	24.8	+.06	1	40	1	45	3	00	3321	93.4	2106	290	403	2,717	4,533	10.6	3.23
A-14	25.4	+.02	2	20	2	24	4	25	3398	94.3	1984	328	400	3,100	4,750	10.9	3.17
A-15	24.4	+.07	2	15	2	10	4	15	3176	92.1	1840	323	413	3,600	5,016	9.7	3.17
A-16	25.8	+.02	2	35	2	30	5	05	3235	92.5	1793	306	392	2,825	4,283	8.6	3.13
B-1	23.6	+.03	2	50	2	25	4	30	3230	92.8	1908	298	363	2,900	4,333	8.8	3.18
B-2	24.6	+.05	2	20	2	10	2	20	3380	93.8	1968	324	373	2,933	4,400	8.4	3.21
B-3	24.0	+.16	2	10	1	55	3	20	3564	94.5	1980	300	385	2,700	4,200	9.1	3.22
B-4	23.6	+.07	2	00	1	50	3	05	3432	93.5	1894	310	370	2,891	4,283	8.1	3.20
B-5	23.2	+.05	1	55	2	10	4	10	3338	92.7	1856	288	361	2,817	4,217	9.8	3.15
C-1	26.0	+.04	1	50	1	45	3	15	3293	91.7	1895	356	443	4,386	6,100	8.4	3.22
C-2	24.2	+.10	1	40	1	35	3	10	3718	95.2	2072	340	440	4,200	6,075	9.3	3.17
C-3	26.0	+.02	2	25	2	30	3	45	3755	96.5	1994	357	438	3,816	5,250	6.9	3.19
C-4	26.6	+.06	2	05	1	50	3	10	3510	95.2	2021	360	428	4,350	6,100	7.0	3.18
D-1	25.6	+.09	2	55	3	05	4	55	3639	96.5	1959	350	420	3,800	5,100	7.5	3.14
D-2	24.8	+.08	2	05	2	20	4	05	3444	93.1	1848	350	397	3,666	4,655	9.1	3.14
D-3	24.4	+.01	3	05	3	00	4	45	3460	93.2	1918	320	360	3,133	4,180	10.2	3.23
D-4	24.0	+.25	1	50	2	10	3	25	3550	92.7	1913	310	378	3,416	4,650	8.2	3.23
D-5	25.0	+.14	3	20	3	15	5	15	3585	95.1	1950	301	383	3,483	4,850	9.9	3.18
D-6	25.2	+.29	3	10	2	55	4	55	3360	91.7	1848	328	390	3,500	5,016	9.8	3.18
E-1	25.4	+.17	2	20	2	05	4	10	3481	93.5	1869	323	425	3,683	5,100	10.7	3.22
E-2	27.2	+.23	3	00	3	05	5	00	3495	95.0	1992	340	430	3,916	5,800	9.9	3.14
E-3	25.2	+.12	1	50	2	15	4	25	3720	95.5	2014	310	387	3,250	4,800	9.8	3.11
E-4	26.0	+.09	3	15	3	10	4	55	3254	92.0	1805	318	370	3,330	4,600	6.4	3.12
E-5	25.6	+.29	2	35	2	40	4	05	3702	96.3	1975	360	420	4,000	5,900	7.3	3.17
E-6	25.6	+.21	2	00	2	15	4	10	3760	96.1	2014	340	393	3,583	4,966	8.4	3.18
E-7	25.2	+.16	2	50	2	50	4	15	3300	92.5	1843	342	428	3,583	5,233	7.4	3.15
E-8	26.0	-.01	2	30	2	25	4	05	3115	91.6	1820	305	372	3,150	3,916	8.2	3.16
F-1	25.2	+.02	2	45	2	35	4	05	3186	91.7	1811	340	380	3,400	4,533	9.9	3.20
F-2	25.4	+.06	2	15	2	25	4	10	3137	91.1	1739	325	410	3,833	5,200	9.8	3.18
F-3	24.6	+.02	2	30	2	25	4	25	3421	93.6	1921	315	420	3,616	5,050	9.8	3.23
G-1	25.4	+.20	2	25	2	10	4	25	3205	92.7	1812	330	390	3,250	4,900	7.7	3.22
G-2	24.4	+.25	2	30	2	25	4	40	3187	92.2	1801	315	387	3,266	4,833	8.7	3.18
G-3	24.4	+.01	2	20	2	25	4	20	3350	91.4	1836	303	361	2,550	3,866	9.8	3.20

TABLE I (Continued)

PHYSICAL RESULTS

Sample No.	C-187 Normal Consistency in %	C-151 Auto-clave in %	C-191 Time of Set Vicat Hrs	- Min	C-266 Time of Set Gilmore (Initial) Hrs	- Min	(Final) Hrs	- Min	C-204 Fineness Blaine sq. cm./gr.	C-430 Fineness Passing 325 Mesh in %	C-115 Fineness Turbidimeter sq. cm/gr.	C-190 Tensile Strength 3 days PSI	7 days PSI	C-109 Compressive Strength 3 days PSI	7 days PSI	C-185 Air Contents %	C-188 Specific Gravity
G-4	24.6	+.05	2	00	2	20	4	35	3164	90.3	1729	297	410	2,383	4,800	10.9	3.17
G-5	24.6	+.10	2	15	2	00	4	00	3286	90.0	1878	296	360	2,466	3,666	9.1	3.18
G-6	23.2	+.06	2	55	2	35	4	00	3224	91.8	1773	290	370	2,817	3,733	7.6	3.23
H-1	26.6	+.11	2	30	2	15	4	35	3481	91.9	1955	293	315	2,950	3,766	9.3	3.14
H-2	25.0	+.12	1	42	1	50	3	00	3662	95.0	1986	290	375	3,050	3,933	7.1	3.15
I-1	25.4	+.07	2	25	2	20	3	20	3390	93.0	1820	280	360	2,467	3,650	7.2	3.20
J-1	25.2	-.01	3	20	3	05	4	40	3620	96.0	2099	326	411	3,375	4.750	8.2	3.19
K-1	24.4	+.02	2	20	2	09	3	25	3631	96.1	2110	290	375	3,050	4,283	6.7	3.15
L-1	25.6	-.02	2	24	2	38	3	55	3504	95.2	2050	323	398	3,500	4,783	7.4	3.19
L-2	24.4	+.01	2	05	2	22	3	45	3350	92.8	1819	328	398	3,025	4,400	7.4	3.16
M-1	24.8	+.10	2	05	2	25	4	05	3292	92.5	1798	321	393	3,275	4,733	7.1	3.18
M-2	25.6	+.17	2	15	2	20	4	05	3416	93.5	1938	310	370	2,950	3,916	10.1	3.15
M-3	25.8	+.09	3	40	3	25	5	00	3360	93.0	1847	308	380	2,883	4,000	9.7	3.15
M-4	23.4	+.18	3	35	3	20	6	20	3446	93.3	1927	290	380	3,000	4,266	10.4	3.16
N-1	23.8	+.04	1	50	1	55	3	20	3450	91.9	1908	290	363	2,900	4,380	7.5	3.18
N-2	25.0	+.14	2	05	2	00	4	00	3565	95.6	2099	322	395	3,550	5,033	8.3	3.16
O-1	25.2	+.12	2	10	2	15	4	40	3420	93.7	1869	303	380	2,775	4,100	7.9	3.12
O-2	23.6	+.13	2	25	2	20	4	05	3224	91.1	1747	333	392	3,233	4,450	7.9	3.17
P-1	25.2	-.02	2	55	3	00	5	15	3260	95.3	1860	330	412	2,733	4,416	8.0	3.12
P-2	25.2	+.11	2	00	2	15	4	00	3225	92.7	1805	305	352	2,833	4,666	9.2	3.12
P-3	24.6	-.11	2	15	2	20	4	35	3398	94.9	1820	340	403	3,050	4,550	8.8	3.13

TABLE II - CHEMICAL RESULTS

Identification	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Ign.	Insol.
A-1	25.25	1.96	5.45	65.06	1.20	2.56	.97	.47
B-1	23.30	1.98	4.96	64.30	2.72	2.25	1.05	.25
B-2	24.19	3.54	4.08	62.53	3.56	2.64	1.71	.34
B-3	21.48	2.51	5.71	63.71	3.36	2.08	1.12	.28
B-4	21.18	2.71	6.62	63.08	2.19	2.61	1.38	.15
B-5	22.26	2.28	4.95	64.62	3.00	2.21	1.55	.17
C-1	19.32	2.85	7.57	66.55	.94	2.42	.98	.43
C-2	20.98	2.29	6.31	66.67	.77	2.42	1.27	.27
C-3	22.00	2.03	5.75	64.82	2.60	2.25	1.24	.30
C-4	20.88	3.02	7.12	65.24	.30	2.61	1.20	.68
D-1	21.60	2.56	5.50	64.33	3.25	2.60	1.21	.42
D-2	22.83	2.02	5.96	64.53	1.71	2.71	.78	.54
D-3	21.96	2.78	6.21	64.06	1.64	2.26	1.63	.39
D-4	20.85	2.22	6.32	62.87	4.34	2.69	1.54	.31
D-5	20.98	3.36	7.00	63.59	3.88	2.02	1.46	.45
D-6	20.94	2.58	7.12	64.19	2.94	2.22	1.51	.51
E-1	19.76	3.82	8.08	64.39	1.04	2.54	1.13	.51
F-1	21.38	2.61	6.32	64.92	2.26	2.12	.97	.24
F-2	21.80	2.48	6.40	65.07	1.81	2.45	2.45	.29
F-3	21.50	2.24	6.50	64.62	2.48	2.38	.65	.18
G-1	20.68	3.00	6.70	63.62	3.54	2.29	.62	.16
G-2	21.56	2.40	7.00	63.82	2.62	2.39	.96	.16
G-3	22.28	3.01	5.94	64.59	1.65	1.81	1.02	.17
G-4	20.80	2.53	6.71	64.37	1.52	2.26	1.95	.18
A-2	22.32	2.48	5.66	65.69	1.10	2.41	.62	.17
A-3	22.00	2.78	6.16	64.90	1.36	1.99	.71	.18
A-4	21.44	3.35	5.23	65.57	1.20	2.34	1.18	.20
A-5	21.66	3.38	5.67	65.32	1.09	2.47	.68	.24
A-6	20.56	2.13	7.57	65.97	.96	2.12	1.28	.17
A-7	21.58	2.20	5.83	66.40	1.17	2.27	.96	.16
A-8	20.33	2.81	7.97	64.52	1.34	2.32	1.29	.14
A-9	20.52	2.34	7.40	65.17	.99	2.64	1.32	.19
A-10	20.24	2.20	7.20	67.02	.81	1.99	1.07	.17
A-11	20.64	3.16	6.70	65.75	.76	2.54	1.43	.23
A-12	21.54	2.39	6.67	65.55	.98	2.07	2.00	.42
A-13	21.22	2.76	6.66	65.50	.85	2.53	1.05	.21
A-14	22.04	2.97	5.11	66.21	1.08	1.78	1.05	.23
A-15	20.84	2.93	7.73	65.27	.88	2.61	.76	.14
G-5	21.10	2.77	6.83	65.48	2.20	2.06	1.25	.19
H-1	21.06	1.86	7.38	66.14	.99	2.42	.96	.33
H-2	21.52	1.70	6.92	64.07	.83	2.10	.93	.32
I-1	21.62	2.88	6.94	65.78	2.32	2.03	1.25	.16
G-6	21.82	3.03	5.91	63.50	3.86	1.93	1.09	.15
J-1	22.00	3.20	5.76	65.13	1.40	2.12	1.23	.24

TABLE II - CHEMICAL RESULTS (Cont.)

Identification	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Ign.	Insol.
K-1	22.68	2.41	6.89	65.76	.96	2.12	1.50	.29
L-1	21.82	3.95	5.33	64.59	1.68	2.28	1.20	.19
L-2	20.76	3.98	5.26	65.36	1.59	2.42	1.35	.23
M-1	20.38	2.92	6.44	63.97	2.71	2.74	1.36	.26
N-1	21.84	2.42	5.48	66.61	.96	2.24	1.09	.21
N-2	19.84	3.33	6.37	63.45	3.99	2.32	1.09	.24
A-16	21.72	2.47	6.43	63.68	1.84	2.26	1.38	.42
O-1	21.62	2.45	6.35	65.18	.96	2.51	1.78	.47
O-2	21.54	2.42	5.38	64.00	4.17	2.34	.91	.28
E-2	21.46	1.71	5.57	65.65	2.89	2.13	1.19	.32
E-3	21.04	1.97	6.77	63.78	2.92	2.63	1.14	.24
E-4	22.64	2.08	4.98	64.30	2.70	2.14	1.20	.27
E-5	21.06	2.04	5.92	64.30	3.84	2.70	1.[illegible]6	.41
E-6	21.86	2.25	5.31	64.03	3.67	2.22	1.32	.38
E-7	21.56	2.22	5.94	64.58	3.19	2.06	1.44	.32
E-8	22.24	2.86	5.52	65.55	.71	2.01	1.46	.31
M-2	20.34	3.10	7.34	63.20	2.39	2.18	1.66	.37
M-3	22.14	2.78	5.80	63.63	2.44	2.10	1.18	.23
M-4	22.10	2.86	6.10	63.28	2.86	2.39	.63	.29
P-1	22.42	2.85	4.91	65.68	1.10	2.26	1.19	.25
P-2	23.82	2.24	6.10	65.20	1.11	2.51	.73	.24
P-3	21.08	2.59	6.65	64.55	1.04	2.43	2.38	.26

TABLE II - CHEMICAL RESULTS (Cont.)

Identification	% Na_2O	% K_2O	Identification	% Na_2O	% K_2O
A-1	0.37	0.06	G-5	0.25	0.31
B-1	0.13	0.32	H-1	0.00	0.14
B-2	0.18	0.385	H-2	0.00	0.215
B-3	0.005	0.41	I-1	0.032	0.52
B-4	0.00	0.745	G-6	0.11	0.39
B-5	0.31	0.275	J-1	0.093	0.22
C-1	0.00	0.06	K-1	0.00	0.15
C-2	0.00	0.10	L-1	0.52	0.16
C-3	0.00	0.18	L-2	0.008	0.17
C-4	0.38	0.02	M-1	0.162	0.44
D-1	0.00	0.245	N-1	0.00	0.14
D-2	0.02	0.50	N-2	0.00	0.435
D-3	0.00	0.41	A-16	0.014	0.45
D-4	0.00	0.425	O-1	0.083	0.29
D-5	0.00	0.29	O-2	0.06	0.35
D-6	0.00	0.22	E-2	0.067	0.24
E-1	0.015	0.285	E-3	0.00	0.33
F-1	0.00	0.36	E-4	0.00	0.35
F-2	0.00	0.46	E-5	0.00	0.26
F-3	0.135	0.29	E-6	0.00	0.475
G-1	0.126	0.235	E-7	0.00	0.18
G-2	0.105	0.305	E-8	0.33	0.03
G-3	0.103	0.33	M-2	0.195	0.62
G-4	0.07	0.32	M-3	0.03	1.04
A-2	0.35	0.07	M-4	0.046	0.54
A-3	0.493	0.13	P-1	0.404	0.15
A-4	0.395	0.08	P-2	0.319	0.18
A-5	0.345	0.06	P-3	0.448	0.155
A-6	0.00	0.23			
A-7	0.485	0.03			
A-8	0.00	0.42			
A-9	0.02	0.575			
A-10	0.00	0.425			
A-11	0.035	0.185			
A-12	0.00	0.155			
A-13	0.007	0.25			
A-14	0.185	0.365			
A-15	0.03	0.275			

TABLE II - CHEMICAL RESULTS (Cont.)

Identification	C_3S	C_2S	C_3A	C_4AF
A-1	26.17	52.74	11.13	5.96
B-1	42.04	35.17	9.80	6.02
B-2	30.65	46.31	4.83	10.76
B-3	48.16	25.33	10.89	7.63
B-4	39.97	30.65	12.96	8.24
B-5	51.00	25.43	9.26	9.64
C-1	62.18	8.56	15.24	8.66
C-2	59.32	15.49	12.85	6.96
C-3	48.80	26.32	11.77	6.17
C-4	47.24	24.31	13.76	9.14
D-1	49.63	24.57	10.25	7.78
D-2	38.47	36.52	12.38	6.14
D-3	42.28	31.15	11.52	8.45
D-4	44.11	26.58	13.00	6.75
D-5	41.76	28.72	12.87	10.21
D-6	44.25	26.73	14.51	7.84
E-1	44.89	22.86	14.96	11.61
F-1	49.49	24.04	12.34	7.93
F-2	45.62	28.17	12.77	7.54
F-3	45.94	27.07	13.44	6.81
G-1	45.92	24.73	12.69	9.12
G-2	38.61	32.76	14.49	10.30
G-3	44.17	30.64	10.65	9.15
G-4	48.76	22.93	13.50	7.69
A-2	49.28	26.90	10.81	7.54
A-3	45.90	28.53	11.63	8.45
A-4	57.32	18.31	8.20	10.18
A-5	51.26	23.51	9.31	10.28
A-6	52.28	19.59	16.46	9.86
A-7	57.44	18.62	11.73	6.69
A-8	43.90	25.24	16.37	8.54
A-9	48.69	22.18	15.66	9.92
A-10	61.74	11.54	15.36	6.69
A-11	53.96	18.55	12.41	9.61
A-12	48.94	24.92	13.64	7.26
A-13	49.60	23.50	12.98	8.39
A-14	58.31	19.29	8.52	9.03
A-15	43.69	26.87	15.53	8.91
G-5	50.41	22.55	13.42	8.42
H-1	49.98	22.76	12.69	5.65
H-2	42.29	29.88	15.47	5.17
I-1	46.87	26.72	13.52	8.76

TABLE II - CHEMICAL RESULTS (Cont.)

Identification	C_3S	C_2S	C_3A	C_4AF
G-6	43.06	30.16	10.54	9.21
J-1	48.55	26.53	9.86	9.73
K-1	39.49	35.32	14.19	7.33
L-1	49.09	25.61	7.45	12.01
L-2	60.30	14.12	7.21	12.09
M-1	50.21	20.63	12.13	8.88
N-1	58.45	18.61	10.43	7.36
N-2	53.28	16.77	11.25	10.12
A-16	40.92	31.48	7.93	7.51
O-1	47.64	26.13	12.69	7.45
O-2	50.49	23.75	10.70	7.36
E-2	58.15	17.75	11.87	5.20
E-3	43.87	27.31	14.61	5.99
E-4	47.10	29.46	9.68	6.32
E-5	51.25	21.80	12.24	6.20
E-6	49.24	25.61	10.27	6.84
E-7	50.02	24.16	11.99	6.75
E-8	50.85	25.49	9.79	8.69
M-2	42.67	26.20	14.21	9.42
M-3	47.76	27.53	10.67	8.45
M-4	37.70	35.00	11.33	8.69
P-1	53.41	24.07	8.20	8.66
P-2	35.02	41.96	12.38	6.81
P-3	51.23	21.87	11.66	7.87

TABLE III

Classification According to Tricalcium Silicate (C_3S) Values

Ident.	C_2S	C_3A	C_4AF	Ten Str.	% SO_3	Comp. Str.	Bl. Fine	Final Time Set	% H_2O
For C3S less than 40 (35.76)									
A-1	52.74	11.13	5.96	367	2.56	4167	3345	4:50	25.6
B-2	46.31	4.83	10.76	373	2.64	4400	3380	4:30	24.6
B-4	30.65	12.96	8.24	370	2.61	4283	3432	3:05	23.6
D-2	36.52	12.38	6.14	397	2.71	4655	3444	4:05	24.8
G-2	32.76	14.49	10.30	387	2.39	4833	3187	4:40	24.4
K-1	35.32	14.19	7.33	375	2.12	4283	3631	3:25	24.4
M-4	35.00	11.33	8.69	380	2.39	4266	3446	6:20	23.4
P-2	41.96	12.38	6.81	352	2.51	4666	3225	4:00	25.2
Average	38.47	11.62	8.20	378	2.49	4400	3409	4:25	24.4
For C3S 40-45 (43.31)									
B-1	35.17	9.80	6.02	363	2.25	4333	3230	4:30	23.6
D-3	31.15	11.52	8.45	360	2.26	4180	3460	4:45	24.4
D-4	26.58	13.00	6.75	378	2.69	4650	3550	3:25	24.0
D-5	28.72	12.87	10.21	383	2.02	4850	3585	5:15	25.0
D-6	26.73	14.51	7.84	390	2.22	5016	3360	4:55	25.2
E-1	22.86	14.96	11.61	425	2.54	5100	3481	4:10	25.4
G-3	30.64	10.65	9.15	361	1.81	3866	3350	4:20	24.4
A-8	25.24	16.37	8.54	413	2.32	5250	3396	3:10	25.6
A-15	26.87	15.53	8.91	413	2.61	5016	3176	4:15	24.4
H-2	29.88	15.47	5.17	375	2.10	3933	3662	3:00	25.0
G-6	30.16	10.54	9.21	370	1.93	3733	3224	4:00	23.2
E-3	27.31	14.61	5.99	387	2.63	4800	3720	4:25	25.2
M-2	26.20	14.21	9.42	370	2.18	3916	3416	4:05	25.6
Average	28.27	13.39	8.25	384	2.27	4511	3432	4:10	24.7
For C3S 45-50 (48.10)									
B-3	25.33	10.89	7.63	385	2.08	4200	3564	3:20	24.0
C-3	26.44	12.00	6.18	438	2.27	5250	3755	3:45	26.0
C-4	24.31	13.76	9.14	428	2.61	6100	3510	3:10	26.6
D-1	24.57	10.25	7.78	420	2.60	5100	3639	4:55	25.6
F-1	24.04	12.34	7.93	380	2.12	4533	3186	4:05	25.2
F-2	28.17	12.77	7.54	410	2.45	5200	3137	4:10	25.4
F-3	27.07	13.44	6.81	420	2.38	5050	3421	4:25	24.6

TABLE III (Cont.)

Classification According to Tricalcium Silicate (C_3S) Values

Ident.	C_2S	C_3A	C_4AF	Ten Str.	% SO_3	Comp. Str.	Bl. Fine	Final Time Set	% H_2O
For C_3S 45-50 (48.10) (Cont.)									
G-1	24.73	12.69	9.12	390	2.29	4900	3205	4:25	25.4
G-4	22.93	13.50	7.69	410	2.26	4800	3164	4:35	24.6
A-2	26.90	10.81	7.54	398	2.41	4950	3130	4:30	25.4
A-3	28.53	11.63	8.45	373	1.99	4283	3203	4:40	26.8
A-9	22.18	15.66	9.92	410	2.64	5000	3407	3:55	25.6
A-12	24.92	13.64	7.26	400	2.07	4666	3497	3:35	25.8
A-13	23.50	12.98	8.39	403	2.53	4533	3321	3:00	24.8
H-1	22.76	12.69	5.65	315	2.42	3766	3481	4:35	26.6
I-1	26.72	13.52	8.76	360	2.03	3650	3390	3:20	25.4
J-1	26.53	9.86	9.73	411	2.12	4750	3620	4:40	25.2
L-1	25.61	7.45	12.01	398	2.28	4783	3504	3:55	25.6
O-1	26.13	12.69	7.45	380	2.51	4100	3420	4:40	25.2
E-4	29.46	9.68	6.32	370	2.14	4600	3254	4:55	26.0
E-6	25.61	10.27	6.84	393	2.22	4966	3760	4:10	25.6
M-3	27.53	10.67	8.45	380	2.10	4000	3360	5:00	25.8
Average	25.63	11.96	7.41	394	2.29	4700	3406	4:09	25.5
For C_3S 50-55 (51.51)									
B-5	25.43	9.26	9.64	361	2.21	4217	3338	4:10	23.2
A-5	23.51	9.31	10.28	407	2.47	5050	3250	3:40	25.4
A-6	19.59	16.46	9.86	403	2.12	5152	3198	5:00	26.2
A-11	18.55	12.41	9.61	420	2.54	5503	3400	3:35	24.8
G-5	22.55	13.42	8.42	360	2.06	3666	3286	4:00	24.6
M-1	20.63	12.13	8.88	393	2.74	4733	3292	4:05	24.8
N-2	16.77	11.25	10.12	395	2.32	5033	3565	4:00	25.0
O-2	23.75	10.70	7.36	392	2.34	4450	3224	4:05	23.6
E-5	21.80	12.24	6.20	420	2.70	5900	3702	4:05	25.6
E-7	24.16	11.99	6.75	428	2.06	5233	3300	4:15	25.2
E-8	25.49	9.79	8.69	372	2.01	3916	3115	4:05	26.0
P-1	24.07	8.20	8.66	412	2.26	4416	3260	5:15	25.2
P-3	21.87	11.66	7.87	403	2.43	4550	3398	4:35	24.6
Average	22.19	11.43	8.71	396	2.41	4804	3334	4:06	24.9

TABLE III (Cont.)

Classification According to Tricalcium Silicate (C3S) Values

Ident.	C2S	C3A	C4AF	Ten Str.	% SO3	Comp. Str.	Bl. Fine	Final Time Set	% H2O
For C3S larger than 55 (59.25)									
C-1	8.56	15.64	8.66	443	2.42	6100	3293	3:15	26.0
C-2	15.49	12.85	6.96	440	2.42	6075	3718	3:10	24.2
A-4	18.31	8.20	10.18	401	2.34	4582	3325	3:30	24.0
A-7	18.62	11.73	6.69	403	2.27	5232	3284	4:45	25.4
A-10	11.54	15.36	6.69	413	1.99	5166	3142	4:15	25.6
A-14	19.29	8.52	9.03	400	1.78	4750	3398	4:25	25.4
L-2	14.12	7.21	12.09	398	2.42	4400	3350	3:45	24.4
N-1	18.61	10.43	7.36	363	2.24	4380	3450	3:20	23.8
E-2	17.75	11.87	5.20	430	2.13	5800	3495	5:00	27.2
Average	15.81	11.26	8.10	410	2.22	5170	3384	3:56	25.1

TABLE IV

Classification According to Compressive Strength Values

Ident.	C_2S	C_3A	C_4AF	% SO_3	Bl. Fine	Gilmore Final Set
Compressive Strength (7 days) less than 4000						
G-3	44.17	10.65	9.15	1.81	3350	4:20
G-5	50.41	13.42	8.42	2.06	3286	4:00
H-1	49.98	12.69	5.65	2.42	3481	4:35
H-2	42.29	15.47	5.17	2.10	3662	3:00
I-1	46.87	13.52	8.76	2.03	3390	3:20
G-6	43.06	10.54	9.21	1.93	3224	4:00
E-8	50.85	7.97	8.69	2.01	3115	4:05
M-2	42.67	14.21	9.42	2.18	3416	4:05
Average	46.29	12.31	8.06	2.07	3365	3:56
Compressive Strength (7 days) 4000-4500 psi						
A-1	26.17	11.13	5.96	2.56	3345	4:50
B-1	42.04	9.80	6.02	2.25	3230	4:30
B-2	30.65	4.83	10.76	2.64	3380	2:20
B-3	48.16	10.89	7.63	2.08	3564	3:20
B-4	39.97	12.96	8.24	2.61	3432	3:05
B-5	51.00	9.26	9.64	2.21	3338	4:10
D-3	42.28	11.52	8.45	2.26	3460	4:45
A-3	45.90	11.63	8.45	1.99	3203	4:40
K-1	39.49	14.19	7.33	2.12	3631	3:25
L-2	60.30	7.21	12.09	2.42	3350	3:45
N-1	58.45	10.43	7.36	2.24	3450	3:20
A-16	40.92	7.93	7.51	2.26	3235	5:05
O-1	47.64	12.69	7.45	2.51	3420	4:40
O-2	50.49	10.70	7.36	2.34	3224	4:05
M-3	47.76	10.67	8.45	2.10	3360	5:00
M-4	37.70	11.33	8.69	2.39	3446	6:20
Average	44.31	10.45	8.25	2.31	3380	4:11
Compressive Strength (7 days) 4500-5000 psi						
D-2	38.47	12.38	6.14	2.71	3444	4:05
D-4	44.11	13.00	6.75	2.69	3550	3:25
D-5	41.76	12.87	10.21	2.02	3585	5:15
F-1	49.49	12.34	7.93	2.12	3186	4:05
G-1	45.92	12.69	9.12	2.29	3205	4:25

TABLE IV (Cont.)

Classification According to Compressive Strength Values

Ident.	C_2S	C_3A	C_4AF	% SO_3	Bl. Fine	Gilmore Final Set
Compressive Strength (7 days) 4500-5000 psi (Cont.)						
G-2	38.61	14.49	10.30	2.39	3187	4:40
G-4	48.76	13.50	7.69	2.26	3164	4:35
A-2	49.52	10.81	7.54	2.41	3130	4:30
A-4	57.32	8.20	10.18	2.34	3325	3:30
A-9	48.69	15.66	9.92	2.64	3407	3:55
A-12	48.94	13.64	7.26	2.07	3497	3:35
A-13	49.60	12.98	8.39	2.53	3321	3:00
A-14	58.31	8.52	9.03	1.78	3398	4:25
J-1	48.55	9.86	9.73	2.12	3620	4:40
L-1	49.09	7.45	12.01	2.28	3504	3:55
M-1	50.21	12.13	8.88	2.74	3292	4:05
E-3	43.87	14.61	5.99	2.63	3720	4:25
E-4	47.10	9.68	6.32	2.14	3254	4:55
E-6	49.24	10.27	6.84	2.22	3702	4:10
Average	47.77	11.85	8.43	2.34	3394	4.11
Compressive Strength (7 days) 5000-5500 psi						
C-3	48.80	11.75	6.17	2.26	3755	3:45
D-1	49.63	10.25	7.78	2.60	3639	4:55
D-6	44.25	14.51	7.84	2.22	3360	4:55
E-1	44.89	14.96	11.61	2.54	3481	4:10
F-2	45.62	12.77	7.54	2.45	3137	4:10
F-3	45.94	13.44	6.81	2.38	3421	4:25
A-5	51.26	9.31	10.28	2.47	3250	3:40
A-6	52.28	16.46	9.86	2.12	3198	5:00
A-7	57.44	11.73	6.69	2.27	3284	4:45
A-8	43.90	16.37	8.54	2.32	3396	3:10
A-10	61.74	15.36	6.69	1.99	3142	4:15
A-15	43.69	15.53	8.91	2.61	3176	4:15
N-2	53.28	11.25	10.12	2.32	3565	4:00
E-7	50.02	11.99	6.75	2.06	3300	4:15
Average	49.48	13.26	8.26	2.32	3365	4.16

TABLE IV (Cont.)

Classification According to Compressive Strength Values

Ident.	C_2S	C_3A	C_4AF	% SO_3	Bl. Fine	Gilmore Final Set
Compressive Strength (7 days) greater than 5500 psi						
C-1	62.18	15.24	8.66	2.42	3293	3:15
C-2	59.32	12.85	6.96	2.42	3718	3:10
C-4	47.24	13.76	9.14	2.61	3510	3:10
E-2	58.15	11.87	5.20	2.13	3495	5:00
E-5	51.25	12.24	6.20	2.70	3702	4:05
Average	55.63	13.19	7.23	2.45	3544	3:44

TABLE V

Classification According to Normal Consistency Values

Ident.	Ten Str.	Comp. Str.	Bl. Fine	C_3A	C_4AF	C_3S
Normal Consistency less than 24%						
B-1	363	4333	3230	9.80	6.02	42.04
B-3	385	4200	3564	10.89	7.63	48.16
B-4	370	4283	3432	12.96	8.24	39.97
B-5	361	4217	3338	9.26	9.64	51.00
N-1	363	4380	3450	10.43	7.36	58.45
M-4	380	4266	3446	11.33	8.69	37.70
Average	370	4280	3410	10.78	7.93	46.22
Normal Consistency 24-24.5%						
C-2	440	6075	3718	12.85	6.96	59.32
D-3	360	4180	3460	11.52	8.45	42.28
D-4	378	4650	3550	13.00	6.75	44.11
G-2	387	4833	3187	14.49	10.30	38.61
G-3	361	3866	3350	10.65	9.15	44.17
A-4	401	4582	3325	8.20	10.18	57.32
A-15	413	5016	3176	15.53	8.91	43.69
K-1	375	4283	3631	14.19	7.33	39.49
L-2	398	4400	3350	7.21	12.09	60.30
Average	390	4654	3416	11.96	8.90	47.70
Normal Consistency 24.5-25.0%						
B-2	373	4406	3380	4.83	10.76	30.65
D-2	397	4655	3444	12.38	6.14	38.47
D-5	383	4850	3585	12.87	10.21	41.76
F-3	420	5050	3421	13.44	6.81	45.94
G-4	410	4800	3164	13.50	7.69	48.76
A-11	420	5503	3400	12.41	9.61	53.96
A-13	403	4533	3321	12.98	8.39	49.60
G-5	360	3666	3286	13.42	8.42	50.41
M-1	393	4733	3292	12.13	8.88	50.21
Average	395	4690	3366	12.00	8.55	45.53
Normal Consistency 25.0-25.5%						
D-5	383	4850	3585	12.87	10.21	41.76
D-6	390	5016	3360	14.51	7.84	44.25
E-1	425	5100	3481	14.96	11.61	44.89

TABLE V (Cont.)

Classification According to Normal Consistency Values

Ident.	Ten Str.	Comp. Str.	Bl. Fine	C_3A	C_4AF	C_3S
Normal Consistency 25.0-25.5% (Cont.)						
F-1	380	4533	3186	12.34	7.93	49.49
F-2	410	5200	3137	12.77	7.54	45.62
G-1	390	4900	3205	12.69	9.12	45.92
A-2	398	4950	3120	10.81	7.54	49.28
A-5	407	5050	3250	9.31	10.28	51.26
A-7	403	5232	3284	11.73	6.69	57.44
A-14	400	4750	3398	8.52	9.03	58.31
H-2	375	3933	3662	15.57	5.17	42.29
I-1	360	3650	3390	13.52	8.76	48.85
J-1	411	4750	3620	9.86	9.73	48.55
N-2	395	5033	3565	11.25	10.12	53.28
O-1	380	4100	3420	12.69	7.45	47.64
E-3	387	4800	3720	14.61	5.99	43.87
E-7	428	5233	3300	11.99	6.75	50.02
Average	395	4769	3394	12.35	8.34	48.28
Normal Consistency 25.5-26.0%						
A-1	367	4167	3345	11.13	5.96	26.17
C-1	443	6100	3293	15.24	8.66	62.18
C-3	438	5250	3755	11.75	6.17	48.80
D-1	420	5100	3639	10.25	7.78	49.63
A-8	413	5250	3396	16.37	8.54	43.90
A-9	410	5000	3407	15.66	9.92	48.69
A-10	413	5166	3142	15.36	6.69	61.74
A-12	400	4666	3497	13.64	7.26	48.94
L-1	398	4783	3504	7.45	12.01	49.09
A-16	392	4283	3235	7.93	7.51	40.92
E-4	370	4600	3254	9.68	6.32	47.10
E-5	393	5900	3702	12.24	6.20	51.25
E-6	393	4966	3760	10.27	6.84	49.24
E-8	372	3916	3115	9.79	8.69	50.85
M-2	370	3916	3416	14.21	9.42	42.67
M-3	380	4000	3360	10.67	8.45	47.76
Average	398	4816	3426	11.98	7.90	44.98

TABLE V (Cont.)

Classification According to Normal Consistency Values

Ident.	Ten Str.	Comp. Str.	Bl. Fine	C_3A	C_4AF	C_3S
Normal Consistency greater than 26.0%						
C-4	428	6100	3510	9.14	13.76	47.24
A-3	373	4283	3203	8.45	11.53	45.90
A-6	403	5152	3198	9.86	16.46	52.28
H-1	315	3766	3481	5.65	12.69	49.98
E-2	430	5800	3495	5.20	11.87	58.15
Average	389	5020	3377	7.66	13.29	50.71

TABLE VI

IDENTIFICATION OF SAMPLES

Identification	Source
A-1	Texas Portland Cement Company Echo, Texas
A-2	Trinity Cement Company Houston, Texas
A-3	Ideal Cement Company Houston, Texas
A-4	Gulf Coast Cement Company Houston, Texas
A-5	Lone Star Cement Company Houston, Texas
A-6	Long Horn Cement Company San Antonio, Texas
A-7	Halliburtion Cement Company Corpus Christi, Texas
A-8	Trinity Cement Company Fort Worth, Texas
A-9	Universal Cement Company Waco, Texas
A-10	San Antonio Cement Company San Antonio, Texas
A-11	Lone Star Cement Company Dalla, Texas
A-12	South West Cement Company Odessa, Texas
A-13	Trinity Cement Company Dallas, Texas
A-14	Lone Star Cement Company Abilene, Texas
A-15	Texas Industries Cement Company Midlothian, Texas
A-16	South Western Cement Company El Paso, Texas
B-1	Missouri Portland Cement Company Sugar Creek, Missouri
B-2	Marquette Cement Company Cape Girdeau, Missouri
B-3	Alpha Cement Company Alpha, Missouri

Identification	Source
B-4	Atlas Cement Company Hannibal, Missouri
B-5	Missouri Portland Cement Company Missouri
C-1	Lehigh Cement Company Miami, Florida
C-2	Florida Portland Cement Company Miami, Florida
C-3	Florida Portland Cement Company Tampa, Florida
C-4	Lehigh Cement Company Bunnell, Florida
D-1	General Portland Cement Company Chattanooga, Tennessee
D-2	Penn. Dixie Cement Company Kingsport, Tennessee
D-3	Ideal Cement Company Knoxville, Tennessee
D-4	Penn. Dixie Royal Cement Company Richard, Tennessee
D-5	Marquette Cement Company Nashville, Tennessee
D-6	Marquette Cement Company Carvan, Tennessee
E-1	Lone Star Cement Company Demopolis, Alabama
E-2	Lone Star Cement Company Birmingham, Alabama
E-3	Universal Atlas Cement Company Leads, Alabama
E-4	Southern Cement Company Roberta, Alabama
E-5	Lehi Cement Company Birmingham, Alabama
E-6	Alpha Cement Company Birmingham, Alabama
E-7	National Cement Company Ragland, Alabama
E-8	Ideal Cement Company Mobile, Alabama
F-1	Ideal Cement Company Ada, Oklahoma

Identification	Source
F-2	Oklahoma Cement Company Pryor, Oklahoma
F-3	Dewey Cement Company Tulsa, Oklahoma
G-1	Lehigh Cement Company Iola, Kansas
G-2	General Cement Company Fredonia, Kansas
G-3	Monarch Cement Company Humbalt, Kansas
G-4	Universal - Atlas Cement Company Independence, Kansas
G-5	Ashgrove Cement Company Chanute, Kansas
G-6	Lone Star Shanee Cement Company Mission, Kansas
H-1	Ideal Cement Company Okay, Arkansas
H-2	Arkansas Cement Company Foreman, Arkansas
I-1	Portland Cement Company Kosmosbal, Kentucky
J-1	Castle - Haynes Cement Company Castle Haynes, North Carolina
K-1	Giant Cement Company Harleyville, South Carolina
L-1	Mississippi Valley Cement Company Redwood, Mississippi
L-2	Marquette Cement Company Brandon, Mississippi
M-1	Marquette Cement Company Ogelesby, Illinois
M-2	Alpha Cement Company La Salle, Illinois
M-3	Medusa - Dixon Cement Company Illinois

Identification	Source
M-4	Missouri Portland Cement Company Illinois
N-1	Penn. - Dixie Cement Company Clinchville, Georgia
N-2	Marquette Cement Company Rockmoor, Georgia
O-1	Ideal Cement Company Superior, Nebraska
O-2	Ashgrove Cement Company Louisville, Nebraska
P-1	Ideal Cement Company Lake Charles, Louisiana
P-2	Ideal Cement Company Baton Rouge, Louisiana
P-3	Portland Cement Company New Orleans, Louisiana

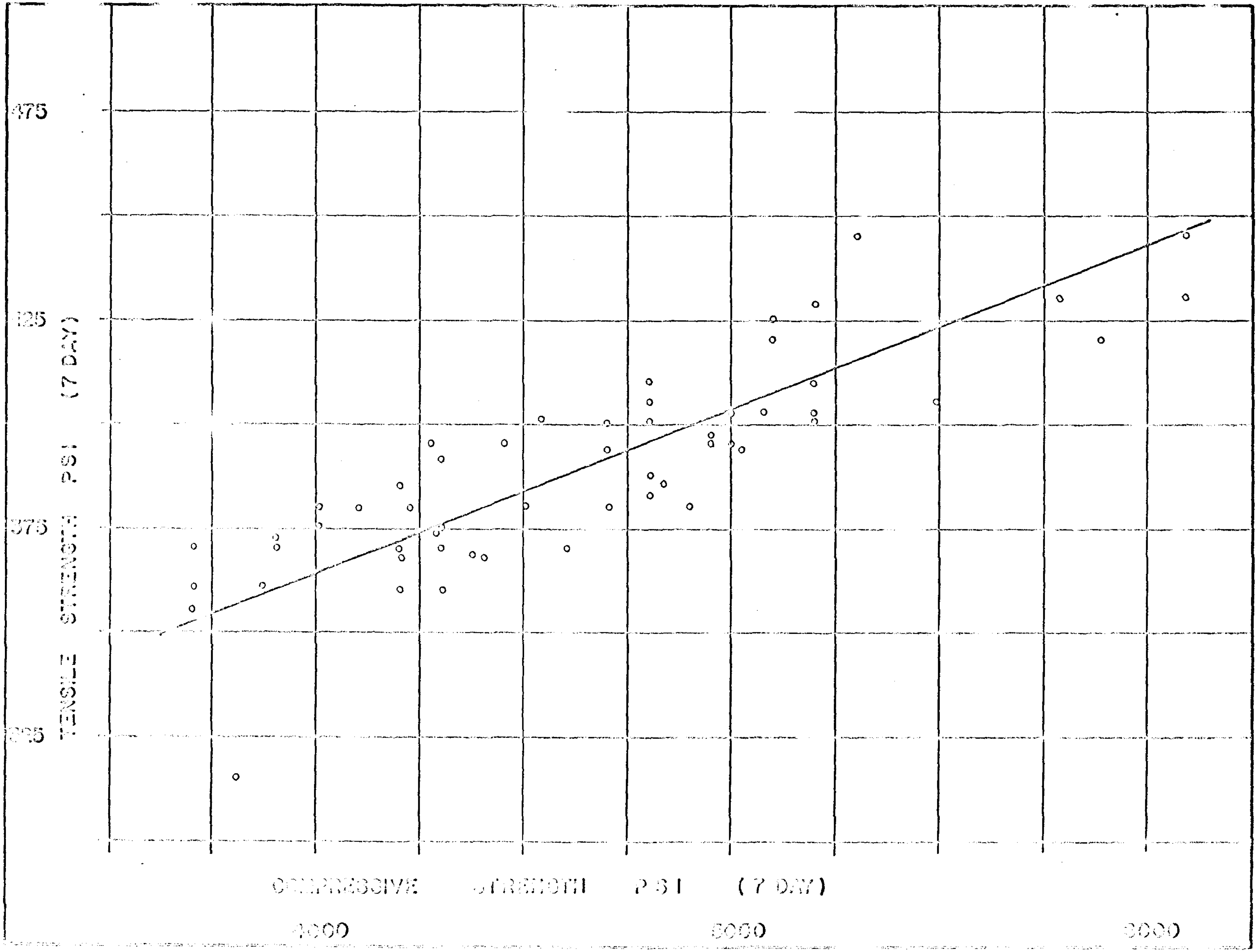

Figure 1 - Illustrates the relationship between Tensile Strength & Compressive Strength (7 day break)

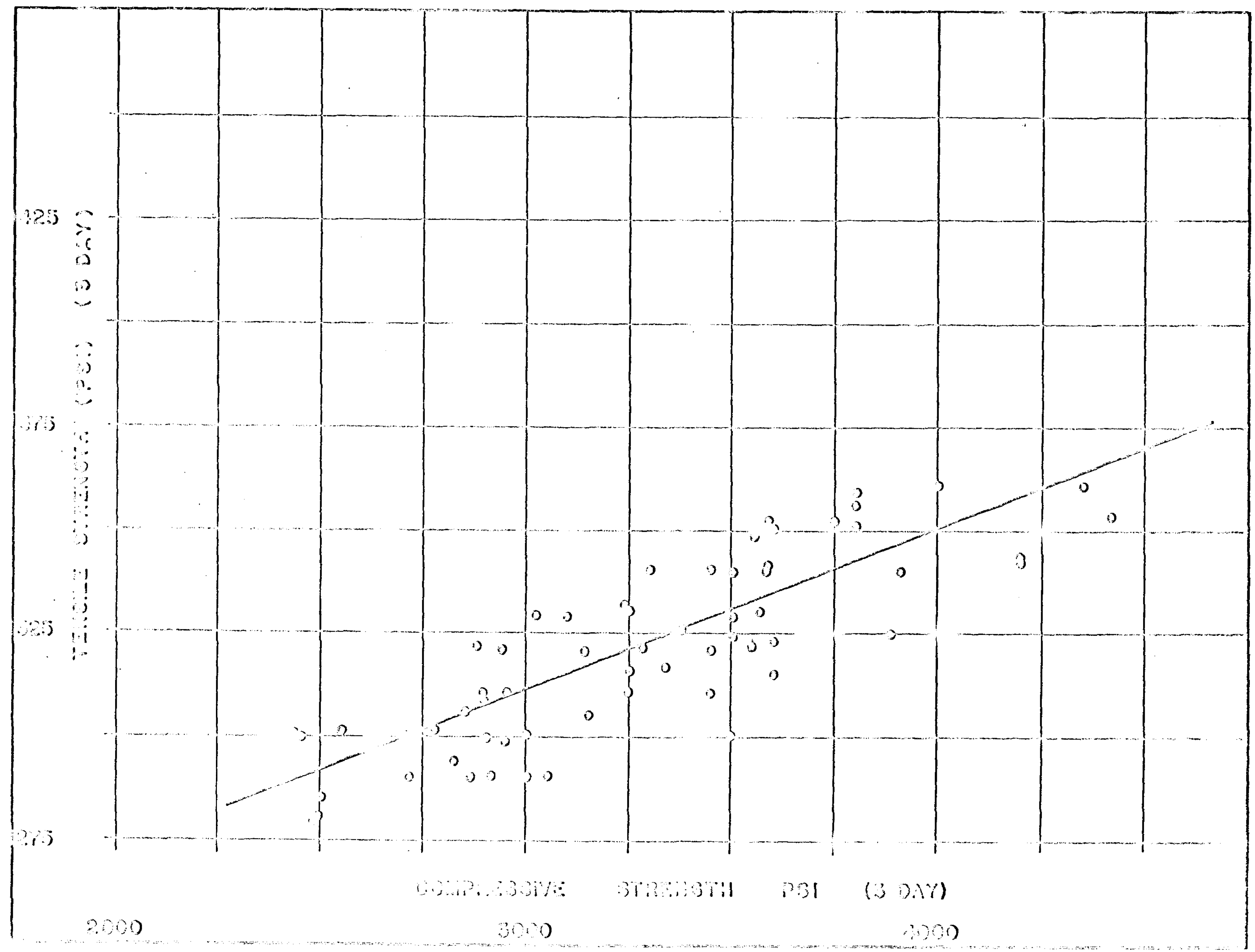

Figure 2 - Illustrates the relationship between Tensile Strength & Compressive Strength (3 day break)

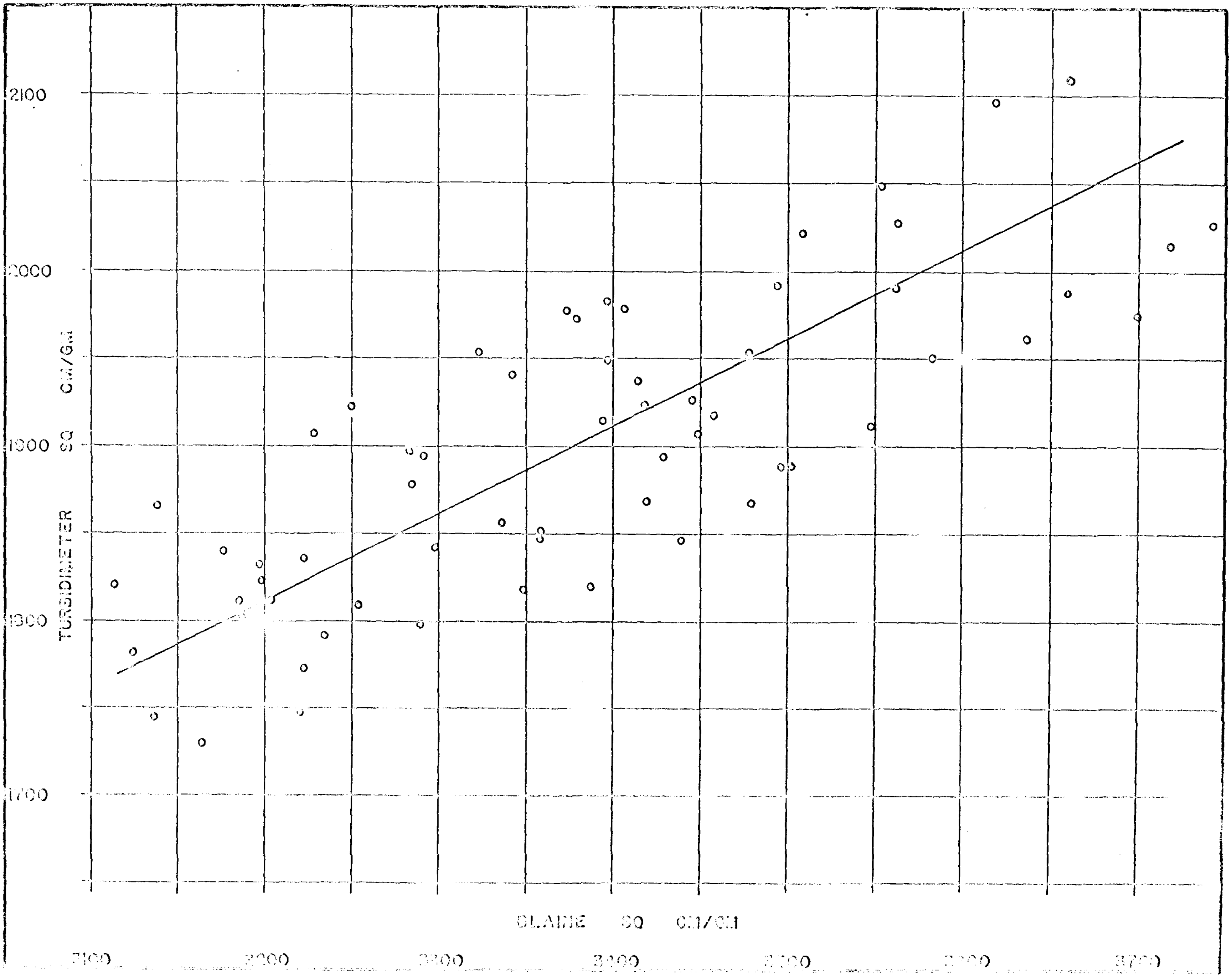

Figure 3 - Illustrates the relationship between the Turbidimeter and Blaine Fineness Apparatus (Sq cm/gm)

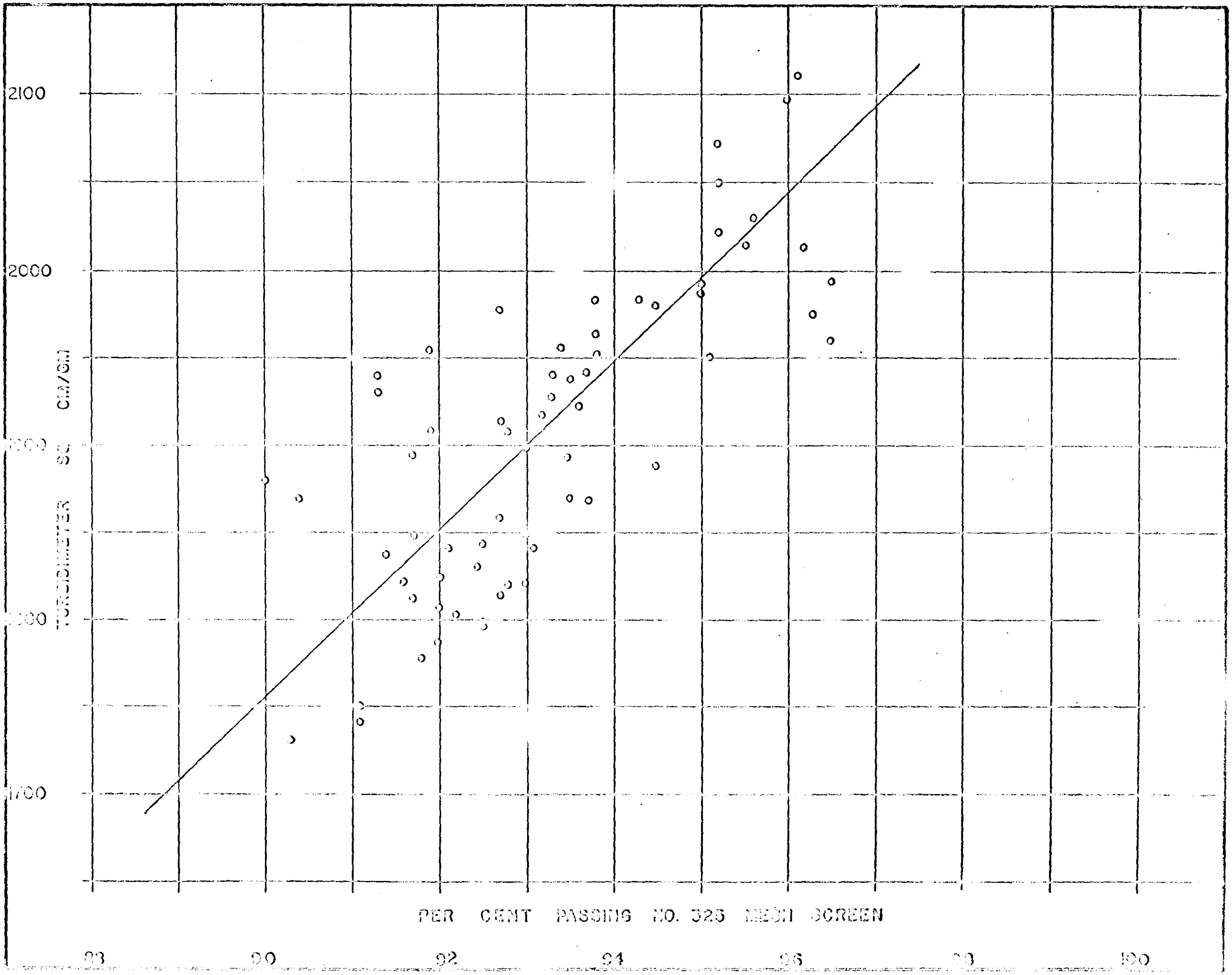

Figure 4 - Illustrates the relationship between the Turbidimeter Fineness apparatus & per cent passing No. 325 Mesh Screen.

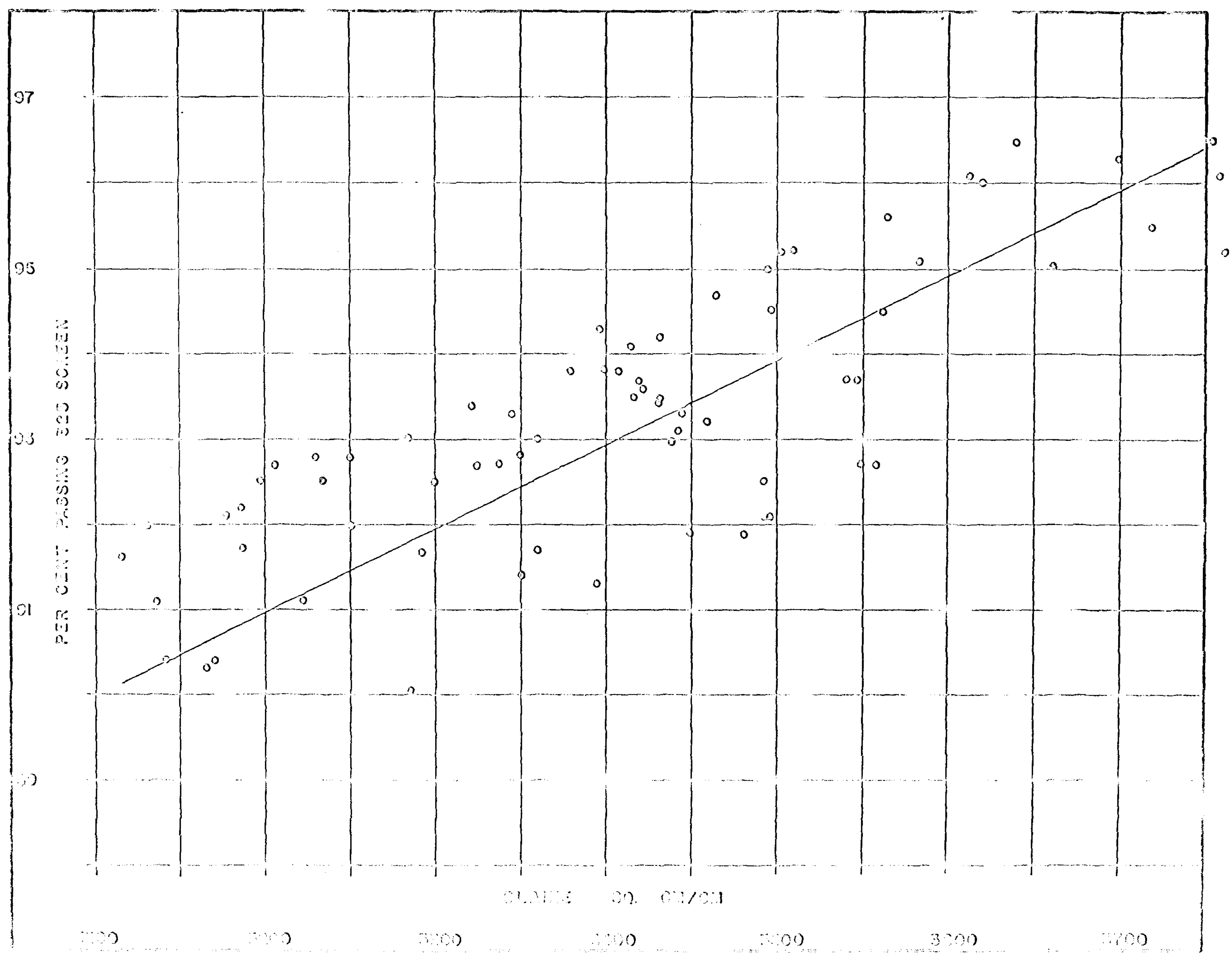

Figure 5 - Illustrates the relationship between the Per cent Passing No. 315 Mesh Screen & Blaine Fineness Apparatus

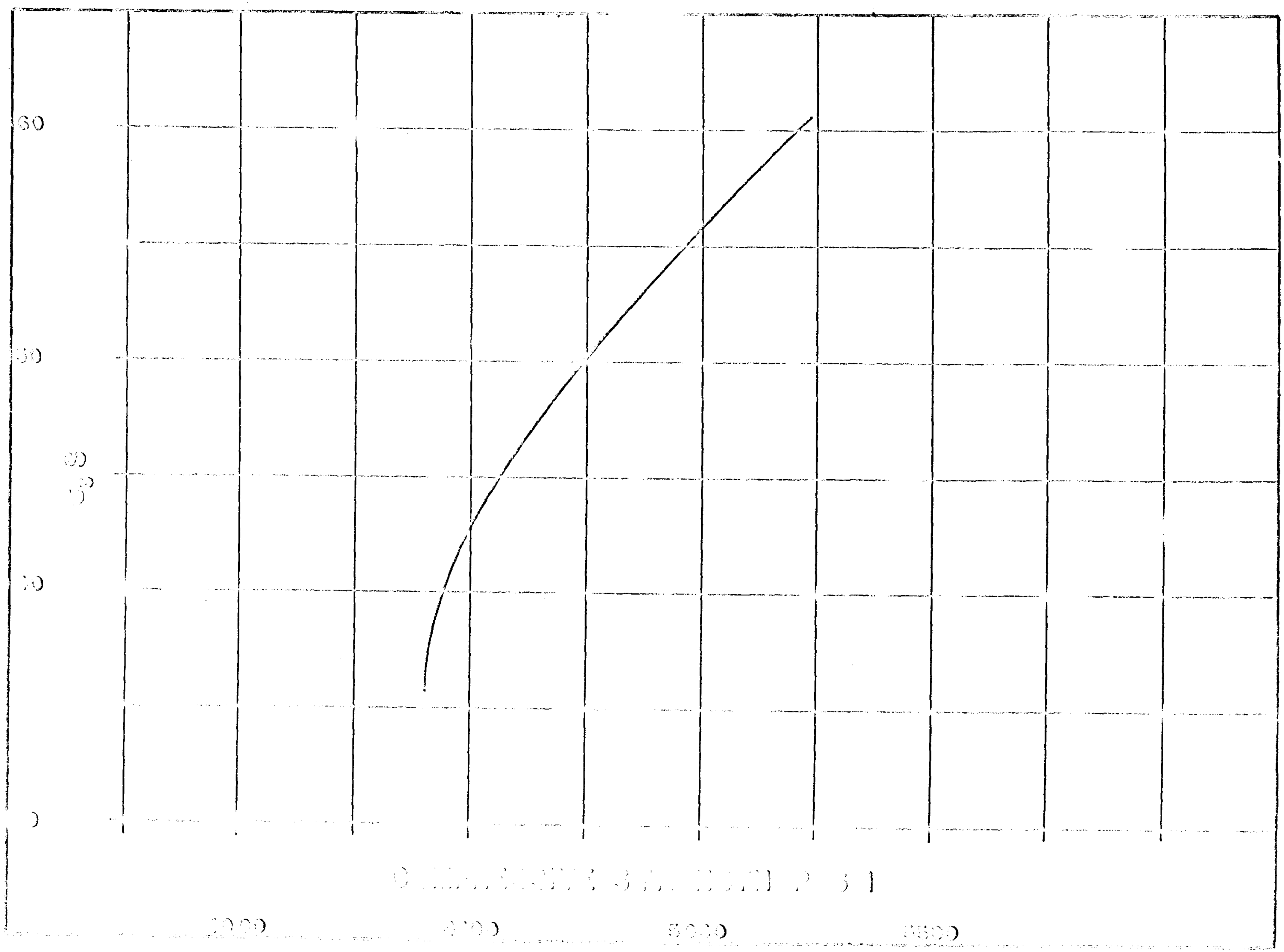

Figure 6 - Compares C_3S values versus compressive strength values.

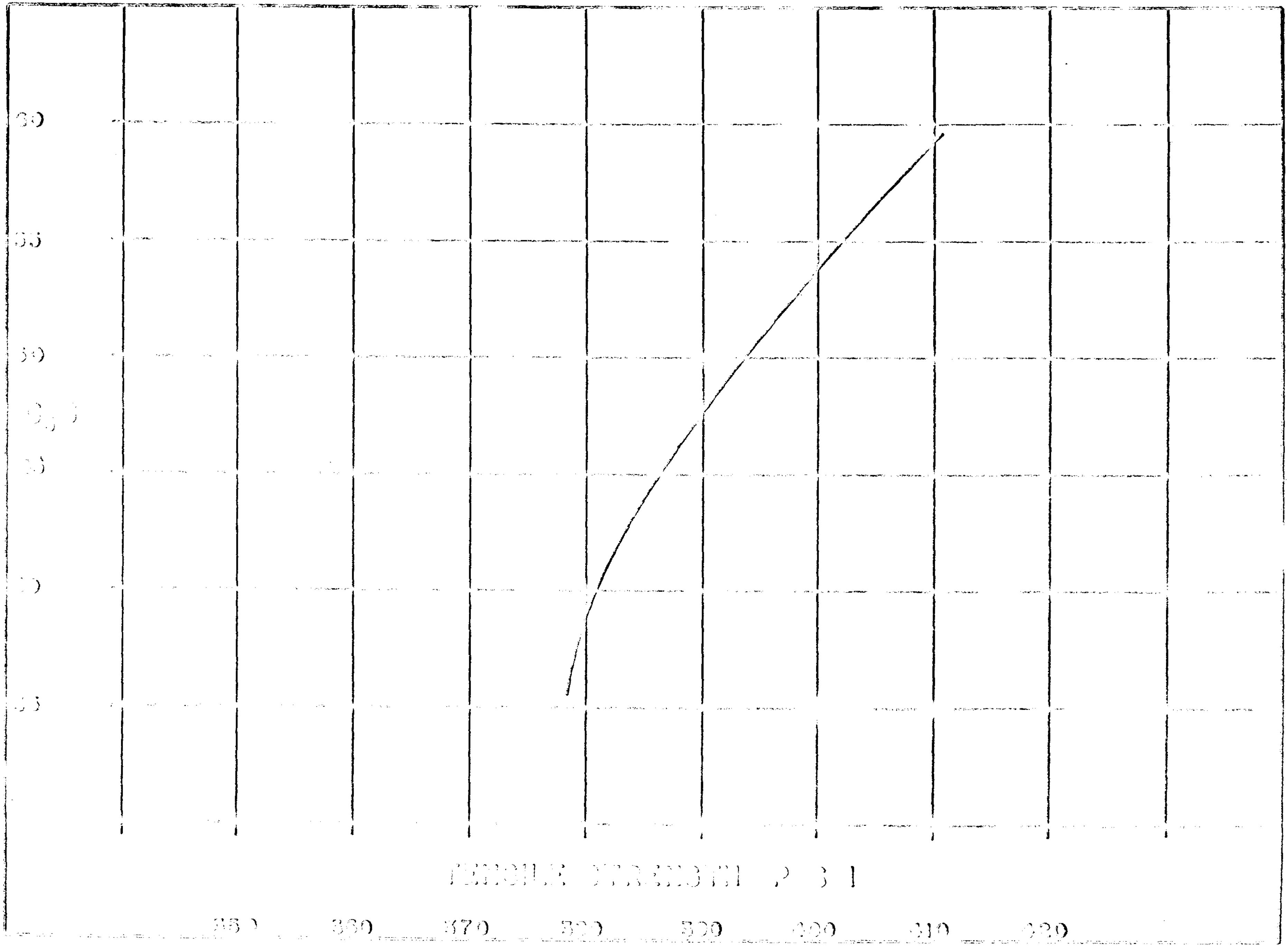

Figure 7 - Compares C_3S values versus Tensile strength values.

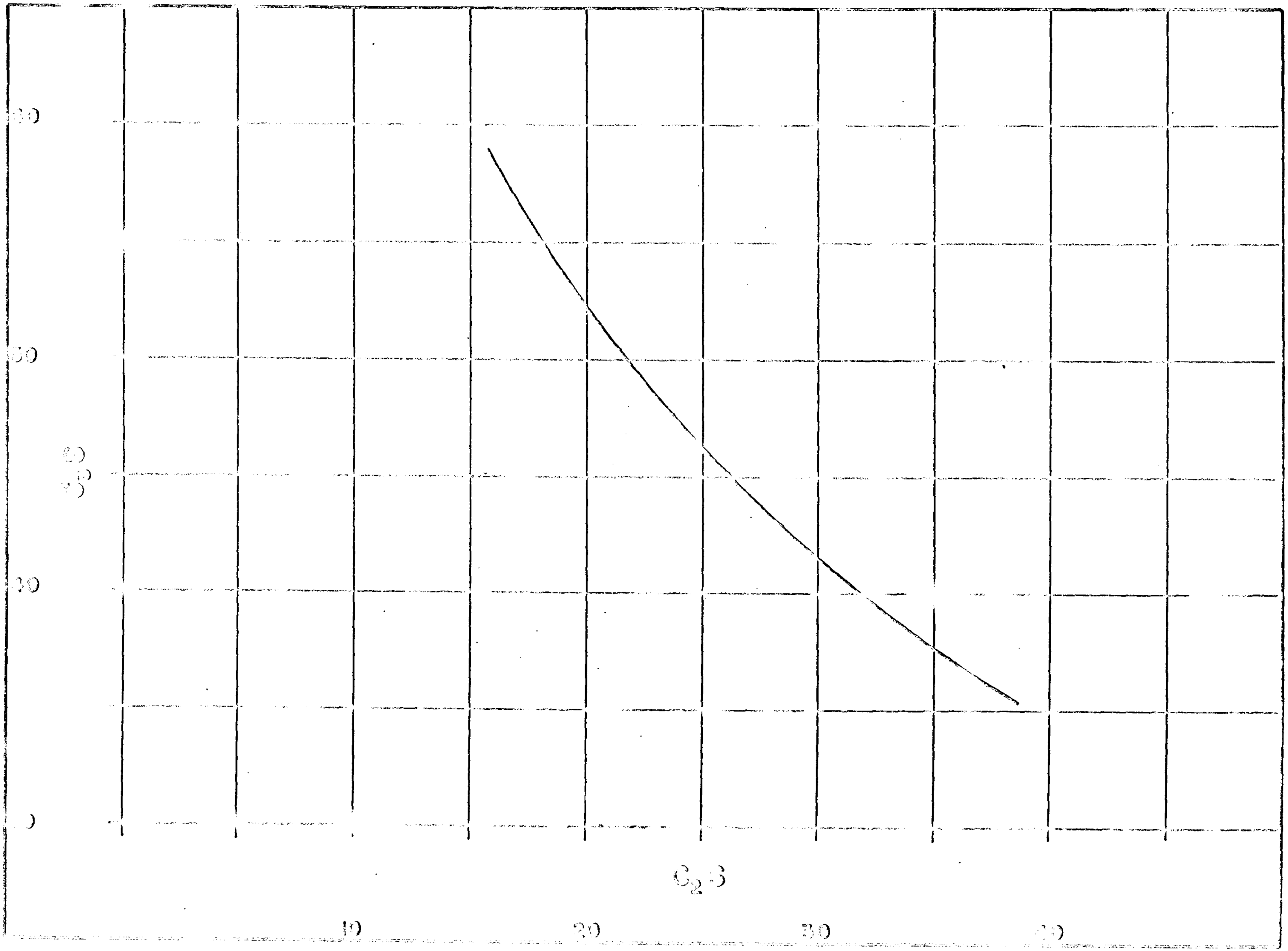

Figure 3 - Compares the C_3S values versus the C_2S values.

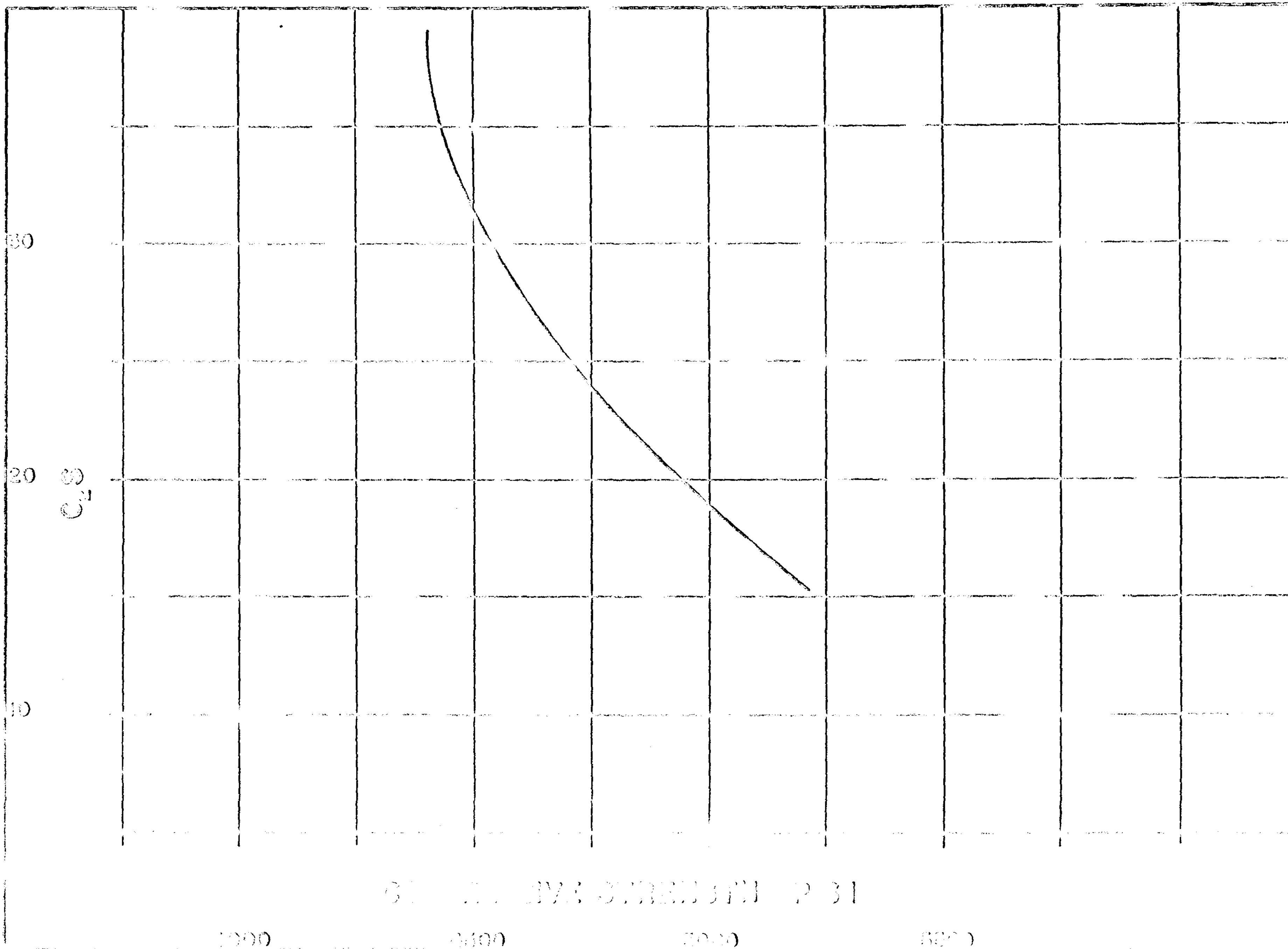

Figure 9 - Compares the C_2S values versus the compressive strength values.

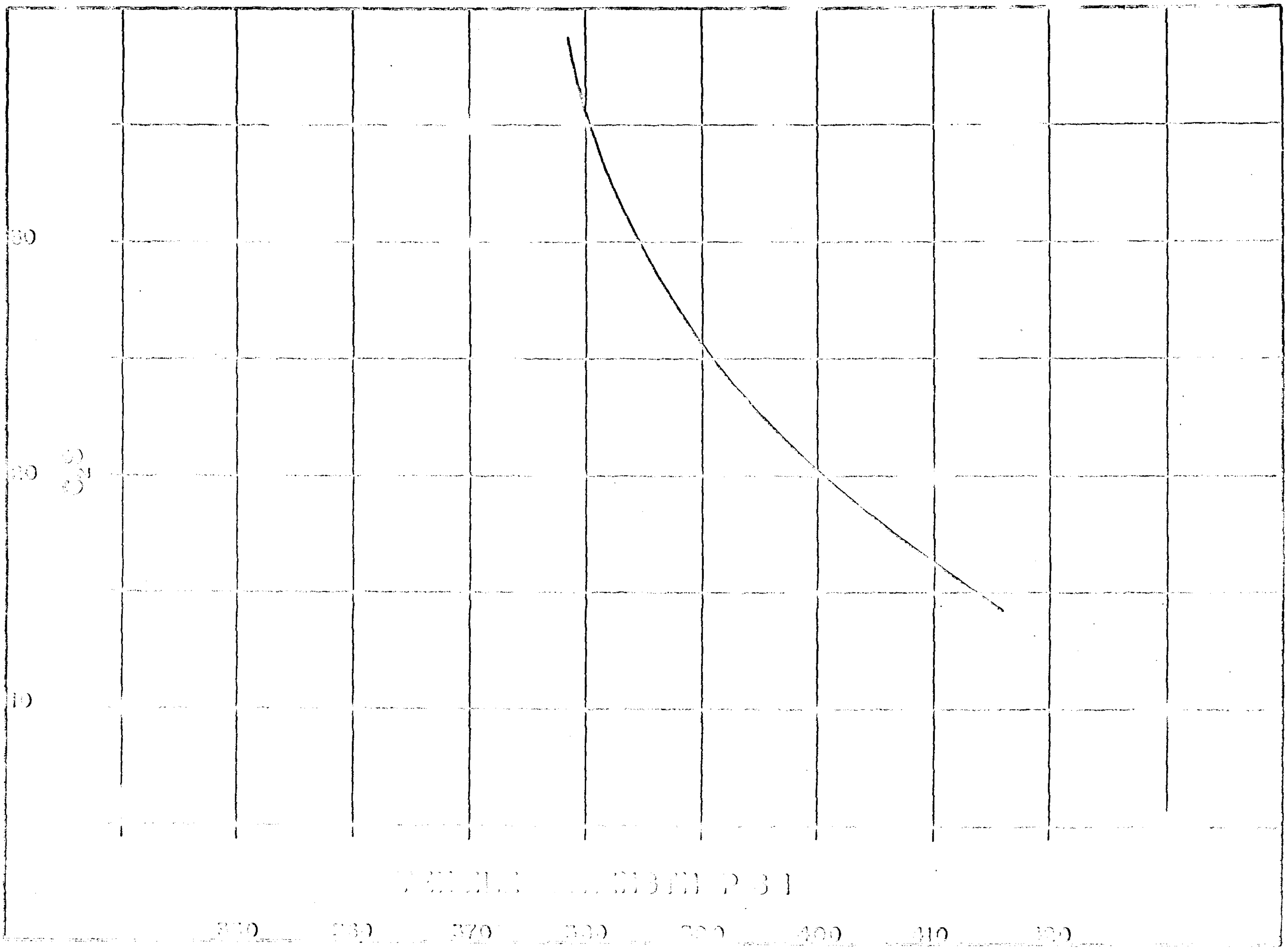

Figure 10 - Compares the C_2S values with the Tensile Strength values.