1899

Cement testing

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THESIS

FOR THE

Degree of Bachelor of Science

IN

Mining Engineering.

SUBJECT:

Cement Testing.

A. D. TERRELL, 1899.

CEMENT TESTING.

Derivation of Some Empirical Formulae, Showing Relation Between Breaking Strength and Various Functions Which Enter Into Cement Testing.

For a Thesis in 1898 I did some work on cement testing with very satisfactory results, but I did but little more than get a few ideas as to how to conduct the experiments to best advantage.

For the present year I have taken up the work for further investigation.

Some of the parts done last year are being varified by Mr. Tayman and myself.

Investigations along the line of cement testing are shown by current literature on the subject to be very varied in methods, and methods of proceedure.

Some are based on chemical analyses and some on physical tests.

Physical tests seem to be the most favored tests and are the ones taken up in my investigations.

Chemical Compounds in Cement.

Lime, Silicates of Calcium and Aluminum, Calcium Aluminates, Ferrites of Calcium and Silico-Alumino Ferrites of Calcium.

Cement from a general point of view may be classes as natural and artificial cements.

The deteriating agents of cements are internal and external.

Internal agencies are deficiency of active hydraulic constituents and presence of free lime or magnesia, the slacking of which after setting has begun, leads to cracking of the mortar.

External agencies will vary according to the surrounding medium into which the cement is placed, This may be fresh water, damp earth, or sea-water. Temperature apparently plays a great part in external agencies.

The subsequent results are obtained from the tensile strength per square inch and various other functions.

Apparatus.

The apparatus is practically the same as used in my work of 1898. The most important being:

1 Moulds,

2 Testing machine,

3 Sieves,

4 Others of minor importance, such as Thermometers, scales, trowels, etc.

The moulds are brass. They are made by Tinius Olsen & CO. and are of "Standard Type".

The testing machine was one of Rheile's make. The following being a rough diagram of parts:

The sieves used were made of brass wire cloth and of "standard mesh."

The cement was a good Portland cement. It was taken from the barrel in quantities sufficient for a given experiment, and well mixed. The mixing was to insure, as nearly as possible, an average composition for each briquette.

The cement was all sieved through a No. 20 mesh sieve, in order to get out large lumps and any foreign material that might be in it, such as chips, etc.

Sulphides.

I have made up some tests with sluphide of iron added to the cement both in raw and roasted condition, to ascertain the effect on the cement, if any.

The sulphide used was ground to pass through an eighty mesh sieve.

Water.

The water used was sometimes cistern and sometimes well water.

Preliminary Tests.

Fineness:- The tensile strength depends greatly upon the fineness of grinding, therefore this test should always be made. If time permitted, it would have made a very interesting experiment to find a curve showing the relation between tensile strength and varying fineness of the cement.

Sieves.

Sieves used for test of fineness were: viz.

No. 50 (2500 meshes to the square inch).

No. 100 (10000 meshes to the square inch).

No. 80 (6400 meshes to the square inch).

By taking average of several results I obtained the following percent rejected by a No. 50 sieve. 9percent., Percentage that passed through No. 50 and was rejected by No. 80 4.1 percent. Percentage that passed through No. 80 and was rejected by No. 100, 15.1 percent.

Soundness.

The test for soundness was made by mixing up some cement and shaping it into little pats. There was no sign of cracking or bulging.

Mixtures.

The experiments with varying quantity of water and sulphides were made by mixing the constituents by weight.

The sulphides and cement were thoroughly mixed before being made into briquettes.

Experiments.

Experiments for this thesis were carried on similar to those of last year, the object of each being to show graphically, and if possible an analytical relation, between varying functions.

It is hard to keep the different things constant, such as temperature, etc.

The temperature of the room and water was recorded for each batch of briquettes.

Experiment No. I.

The object of Experiment No. I was to find the relation between tensile strength per square inch and the time after mixing, everything else remaining constant.

The briquettes remained out of water after being made up.

The amount of water used was 375 grams. to 1500 grams of cement, or one-fourth as much water as cement.

These were made up in batches of eleven each. In breaking, one was taken from each batch at stated intervals of time and an average of strength at these equal intervals was calculated.

There were ten batches, so there would be an average breaking strength of ten briquettes for each point on curve.

Experiment No. II

Among the experiments of last year this is one I have attempted to varify. It is to find relation between tensile strength per square inch and time after mixing, all other conditions remaining as nearly constant as could be kept with facilities at hand.

The equation used for the discussion of curve last year apparently satisfies that of this year. The discussion of the curve will be given later.

Experiment No. III

One of the experiments carried out in my work is that of trying what effect the amount of water in which briquettes are placed will have on the tensile strength. The amount of water varied from that in air to several thousand c.c. The briquettes were made up with 375 grams of water per 1500 grams of cement.

Experiment No. IV.

In mixing cement and cement mortars the amount of water used seems to change the character of the resulting mixture . For this fourth experiment I have tried to see what this effect of change of quantity of water is.

The briquettes were made up in batches of ten,and each batch of briquettes broken at a given interval of time after mixing. As the amount of water increases,the cross-section decreases.

The cross sections in plotting were all reduced to the bases of one square inch.

The above briquettes after being made are left in air. The setting takes place from outside toward the center,as the medium in which cement sets would have to penetrate to the center by passing through the outer surface first.

Experiment V and VI.

In reading up some references I have found a few results on the effect of impurities in cement. Some of the data were collected from tests made by varying quantity of gypsum etc.

I have tried two experiments with iron sulphide. In No. 5 the sulphide was ground to pass through an 80 mesh sieve and then added to the cement in different percentages. For No. VI the sulphide was roasted after being ground to a 20 mesh.

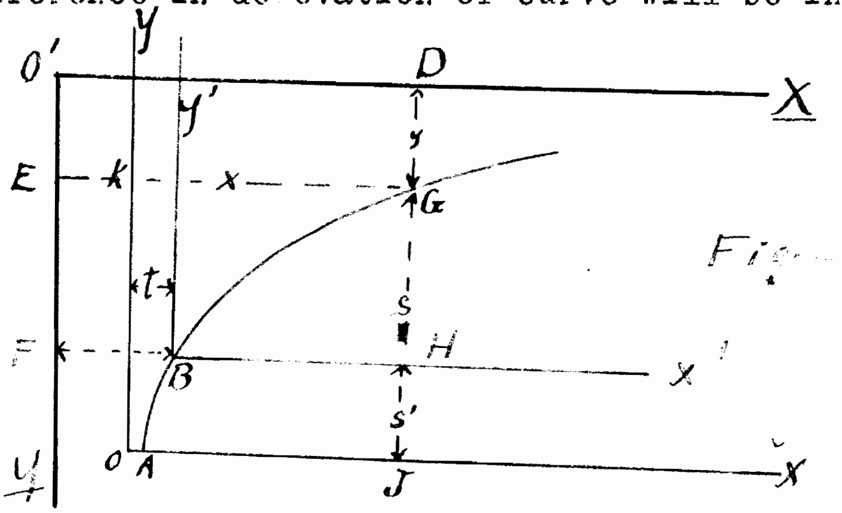
After the roasting it was ground to pass through an 80 mesh.

Discussion of Curve No.1.

The curve on Plate 1 was plotted from data on page .Strength per square inch being plotted as ordinates and time as abscissae.

The curve is shown in black ink. The curve drawn through the points plotted resembles that of an equilateral hyperbole referred to X Y as axes.

All reference in derevation of curve will be in Figure 1.



Let us assume that the equation referred to X Y axis is;

$$X\ Y = C \text{ - (1)}$$

C being a constant.

Let $S = G\ J$ = the average strength in pounds per square inch after mixing.

$t = G\ k$ = time in days after mixing before the briquettes were broken.

$a = O\ H$ = distance of x' axis from X axis.

$b = F\ B$ = " of y' axis from Y axis.

S' = average strength of ten briquettes for one day after mixing.

t' = time of breaking of first batch after mixing.

As the curve does not pass through the origin O. we can not deal with it readily unless we take some known point, such as B for reference. The coordinates of this point being s' and t' referred to the X'Y' axes.

Let us pass x' y' axes through B and use it as an origin, and transferring the equation to these new axes.

The values of x and y for any variable point on the curve such as G are:

$$X = (b+t-t')$$

$$Y = (a-s+s')$$

Substituting the values of x and y in equation (1) we have:-

$$(b+t-t')\ (a-s+s') = c \text{ - - - - - - - - - - - - - - - - } (2)$$

The value of x y = c is (ab) for the point B. Therefore for c we can substitute the value (a b). Equation(2) then becomes.

$$[b+(t-t')]\ [a-(s-s')] = ab \text{ - - - - - - - - - - - - } (3)$$

Multiplying out

$$ab - b\ (s-s') + a(t-t') - (t-t')\ (s-s') = ab$$

Calcelling the ab's and collecting

$$(t-t')\ [a-(s-s')] = b(s-s')$$

Dividing through by (t-t')

$$a - (s-s') = \frac{b(s-s')}{a\ (t-t')}$$

Dividing next by (s-s')

$$\frac{a}{b.(s-s')} - \frac{s-s'}{b\ (s-s')} = \frac{1}{t-t'}$$

or

$$\frac{a}{b}\left(\frac{1}{s-s'}\right) - \frac{1}{b} = \frac{1}{t-t'} \text{ - - - - - - - - - - - - - - } (4)$$

Dividing (4) by $\frac{a}{b}$ we have

$$\frac{1}{s - s'} - \frac{1}{a} = \frac{b}{a}\,\frac{1}{t - t'}$$

or

$$= \frac{1}{s - s'} = \frac{b}{a}\,\frac{1}{t - t'} + \frac{1}{a} \text{ - - - - - - - - - - - - - - (5)}$$

By inspection we see that (5) is in the general form of an equation to a straight line $\frac{b}{a}$ being the slope and $\frac{1}{a}$ the intercept on $\frac{1}{s - s'}$ axes.

If we then plot $\frac{1}{s - s'}$ as ordinates and $\frac{1}{t - t'}$ as abscissae, we will get a straight line if our assumption is true.

The points plotted from value of $\frac{1}{S - s'}$ and $\frac{1}{t - t'}$ (gives in Table of data for this curve) are shown on Plate I.

We see from this plot that a straight line will apparently satisfy the points.

Let us next investigate the meaning of the constant involved in this equation.

From the intercept on the $\frac{1}{S - S'}$ axis the value of $\frac{1}{a}$ taken from the plot is = .0023

$$\text{From which } a = \frac{1}{.0023} = 434.5$$

Likewise

$\frac{b}{a} = \tan\beta$ taken from the plot is = .0035

For the value of a = 434.5, and $\frac{b}{a}$ = tan = .0035 we find $b = a \tan\alpha = 1.52$.

S' and t' are the other constants that enter but whose value are given in the Table.

Having obtained the value of these constants, we may simplify equation (5) by putting in their values.

$$S' = 24.7$$

$$t' = 1$$

$$a = 434.5$$

$$b = 1.52$$

(5) then becomes $\frac{1}{s - 24.7} = .0035 \left(\frac{1}{t - 1}\right) + .0023$

or $$s = \frac{1.05681t - .97216}{.0012 + .00236t} \qquad \text{- - - - - - - - - - - - (6)}$$

By making $S = o$ we get $t = 22$ hours 19.2 minutes which shows from calculations and also from the plot of the curve that there is a certain length of time after mixing before the cement acquired any strength. This being the case it seems rational to call this (t) at which cement begins to show strength, the time of setting.

The equation (5) is a general one used in experiment No.(1) and probably can be applied to any neat cement. The constants varying however for each case in hand.

One of the most favoring features of equation (6) is that the strength approaches a finite limit at an infinite time. In the present discussion this finite value is $= a + s' = 434.5 + 24.7 = 459.2$ lbs. per square inch. This result is a very rational one for the curve approaches very nearly a horizontal line after comparatively short time.

With this curve the strength reaches a large percent of its maximum in a very short period.

Plate I

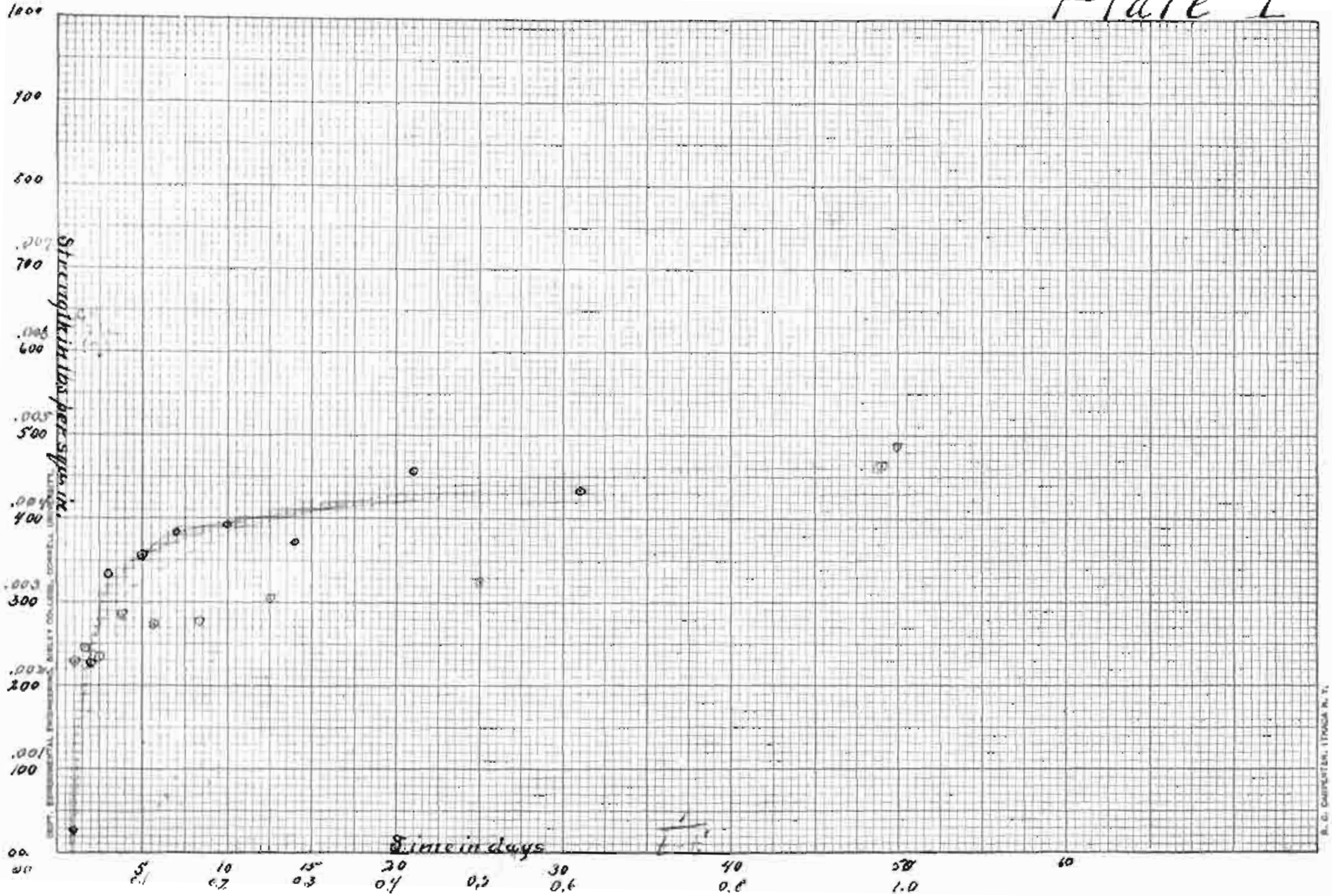

Strength in lbs per sq. in.
Time in days
1000
900
800
700
600
500
400
300
200
100
00
.007
.006
.005
.004
.003
.002
.001
5
10
15
20
30
40
50
60
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1.0

Table.

For Curve No. 1.

1	2	3	4	5	6
S Average Strength of ten Briquettes	t Time in days after mixing	$S-S'$ S minus Strength at one day	$t-t'$ t minus one day	$\frac{1}{S-S'}$	$\frac{1}{t-t'}$
24.7	1	0.0	0.0	∞	∞
228.5	2	203.8	1	.00489	1.
331.7	3	307.0	2	.00326	.5
354.8	5	330.1	4	.00303	.25
384.3	7	359.6	6	.00277	.166
392.9	10	368.2	9	.00272	.111
371.2	14	346.5	13	.00288	.077
457.1	21	432.4	20	.00231	.050
433.3	31	408.6	30	.00245	.033
465.8	49	441.1	48	.00227	.0208

Discussion of Curve No.II.

To verify the work done on this experiment last year, the data on page [illegible] were obtained.

The points on the curve were plotted from Table II.

It had the same general form of the curve gotten in 1898 and on applying the equation derived, it was found that it satisfied all the conditions.

The derivation of the equation will be found in the discussion of curve No.I.

The general form being:-

$$\frac{1}{s - s'} = \frac{b}{a}\left(\frac{1}{t - t'}\right) + \frac{1}{a}$$

The values of $\frac{1}{S - s'}$ and $\frac{1}{t - t'}$ were plotted giving practically a straight line.

The constants were investigated and their values obtained as before

$\frac{1}{a}$ = the intercept on $\frac{1}{s - s'}$ axis = .0015 from which a = 666.6

$\frac{b}{a}$ = tan = to the slope of the line = .0065.

By combining the values of a and $\frac{b}{a}$ we find b = 4.32

A + s' gives the strength that briquettes would reach at an infinite time, being the distance from x to <u>X</u> axis. As the asymptote meets a curve at infinity, by making $t = \infty$ we get value of $s = a + s'$ thus:-

$$\frac{1}{S - s'} = \frac{b}{a}\left(\frac{1}{t - t'}\right) + \frac{1}{a}$$

$$\frac{1}{S - s'} = \frac{1}{a} \text{ from which}$$

$$a = s - s'$$

or $s = a + s' = 666.6 + 31.1 = 697.7$ pounds per square inch.

You may obtain the distance of the $\frac{1}{s - s'}$ asymptote from y axis by taking values of b and t' direct from above calculations, or by making $s = \infty$

When $s = \infty$ equation (6) in previous discussion becomes:-

$$\frac{1}{\infty - s'} = \frac{b}{a} \quad \frac{1}{t - t'} + \frac{1}{a}$$

Dividing through by $\frac{1}{a}$ multiplying out and transforming we get

$$t = t' - b$$
$$t = 1 - 4.32 = -3.32$$

This value t has no physical meaning.

By substituting all the constants obtained, equation

$$\frac{1}{s - s'} = \frac{b}{a} \quad \frac{1}{t - t'} + \frac{1}{a}$$ becomes equal to

$$s = \frac{1.04665t - 84425}{.004 + .0015t}$$

By making s = 0

t = 19 hours. 14.4 minutes.

This value of t gives the time at which the cement sets.

For the cement used this year it took a longer time for it to set than that used last year.

It seems rational to draw the conclusion that this is the equation which fits the relation between breaking strength and time for cement in general.

The experiment for this particular case was carried on similar to experiment No.I of last year.

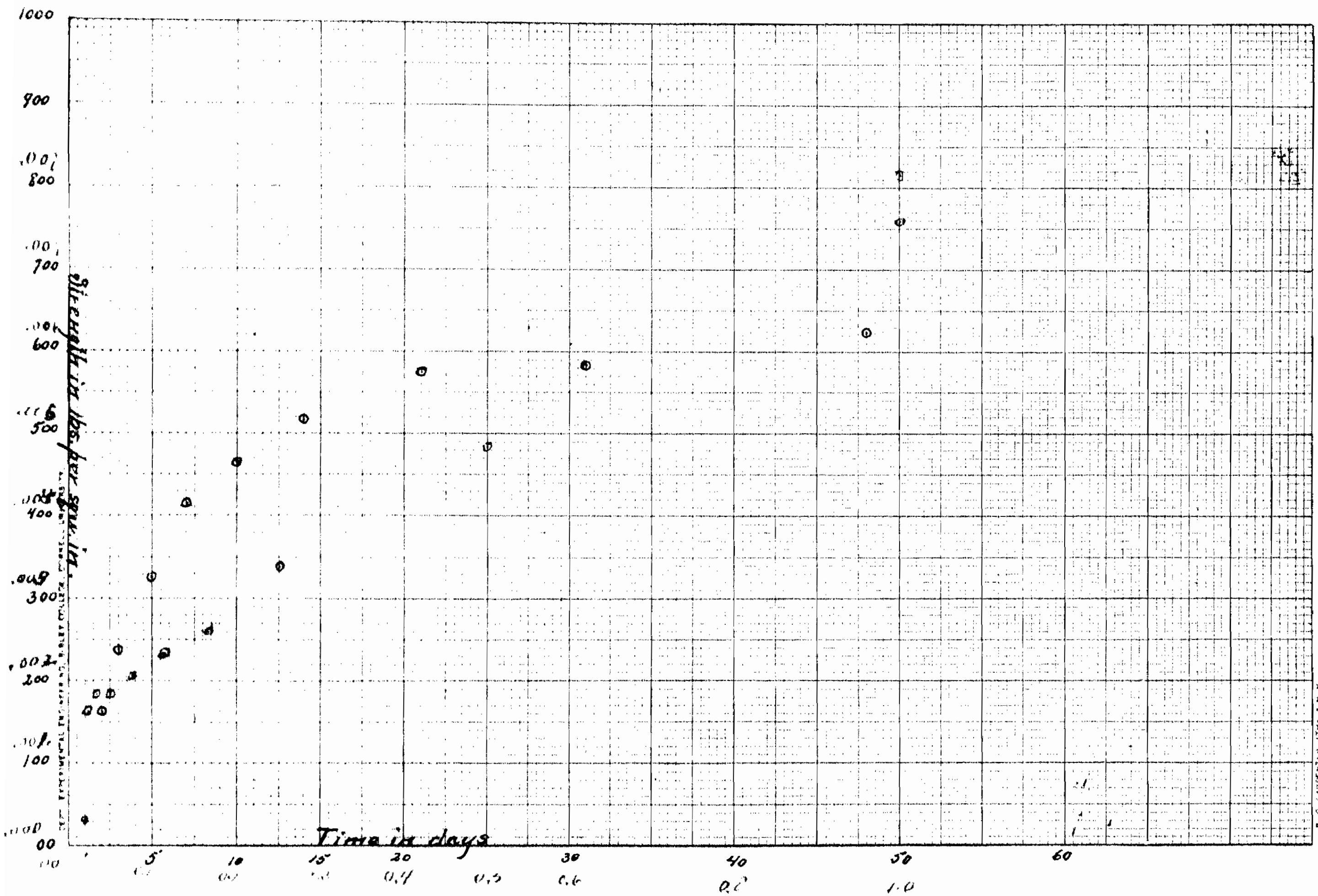

Strength in lbs. per sq. in.
Time in days
1000
900
800
700
600
500
400
300
200
100
00
5
10
15
20
25
30
40
50
60
R. C. CARPENTER, ITHACA N. Y.

Table For Curve No. II.

1	2	3	4	5	6
S Average Strength of ten briquettes	t Time in days after mixing	$S-S'$ S minus strength at one day	$t-t'$ t minus one day	$\frac{1}{S-S'}$	$\frac{1}{t-t'}$
31.1	1	0	0	∞	∞
163.1	2	132.0	1	.00757	1.000
238.1	3	207.0	2	.00483	0.500
326.4	5	295.3	4	.00339	0.250
414.2	7	383.1	6	.00259	0.166
464.2	10	433.1	9	.00231	0.111
517.6	14	486.5	13	.00205	0.077
575.2	21	544.1	20	.00184	0.050
582.3	31	551.2	30	.00182	0.033
622.4	47	591.3	46	.0161	.0217

Discussion of Curve No. III.

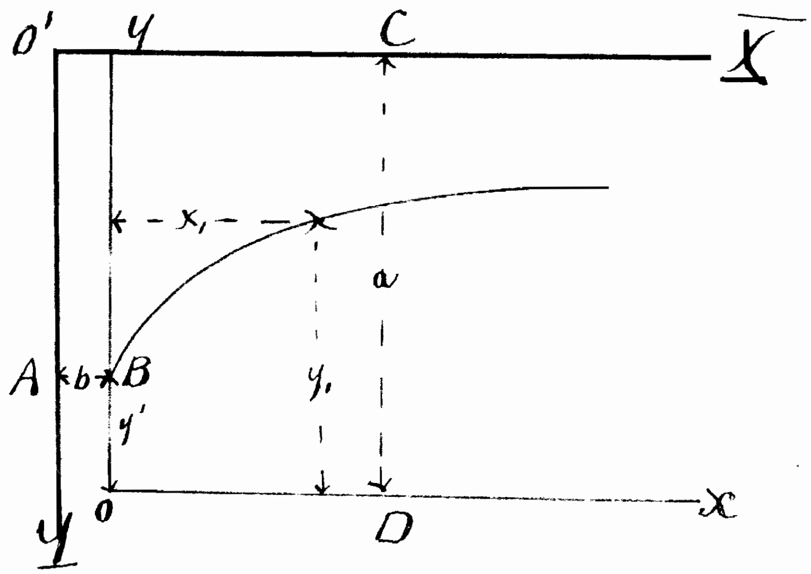
To obtain data for this curve the average of eleven briquettes was taken at end of forty days. The briquettes were placed eleven in a batch, in water. This quantity of water was varied from zero to practically an infinite amount.

The averages obtained were plotted on (Plate III). The data will be found at end of discussion.

The breaking strength was plotted as ordinates and the quantity of water as abscissae.

On plotting it was found that a fairly smooth curve could be drawn through the points. A deficiency of points made it hard to tell what sort of an equation would come near fitting the curve.

$xy^n = c$ referred to X Y axis might fit. For the following discussion I will use equation $xy = c$ - - - - - - - - - - - - - - - - (1)



Let A B = b = distance of Y axis from y and C D = a = distance of X axis from x.

Y' is the breaking strength with a zero quantity of water and has a known value.

From equation (1) we may substitute for x and y their values in terms of x_1 and y_1.

Take any point E on the curve, the

$$x = x_1 + b$$

and $$y = a - y_1$$

$$xy = (x_1 + b)\ (a - y_1) = c \text{ ---- ----------- } (2)$$

From the point B on the curve, we see that the value of c may be given partially in known quantities.

$$c = b(a - y')$$

By substituting this value of c in equation (2) we get

$$(x_1 + b)\ (a - y_1) = b(a - Y')$$

Multiplying out we get

$$x_1\ a - x_1\ y_1 + ab - by = ab - by'$$

collecting terms.

$$ax_1 - xy_1 = b\ (y_1 - y')$$

or $x_1\ (a - y_1) = b(y_1 - y')$

dividing by $(y_1 - y')$

$$\frac{a - y'}{y_1 - y'} = \frac{b}{x_1}$$

or $$\frac{a}{y_1 - y'} \quad \frac{-Y'}{y_1 - y'} = \frac{b}{x_1}$$

or $$\frac{x_1}{y_1 - y'} = ab - b\ (y_1) \text{ ----------------- } (3)$$

By inspection we see that equation (3) is in general form for an equation to a straight line, which being the case we ought to obtain a straight line on plotting $\frac{x_1}{y_1 - y'}$ and y_1 if our assumption is true.

$\frac{x_1}{y_1 - y'}$ was plotted as ordinates and y_1 as abscissae. A straight line apparently satisfies the points thus plotted.

Let us next investigate the constants which enter this equation.

Y' is known as it is the first point on the curve and lies on the y axis.

ab is the intercept on the $\frac{x_1}{y - y'}$ axis and b is the slope of the line, or the tangent of the angle the line makes with y axis.

The value of b is negative as we can readily see it should be from the curve.

$b = 9.6$

$ab = 610$

from which $a = 90$

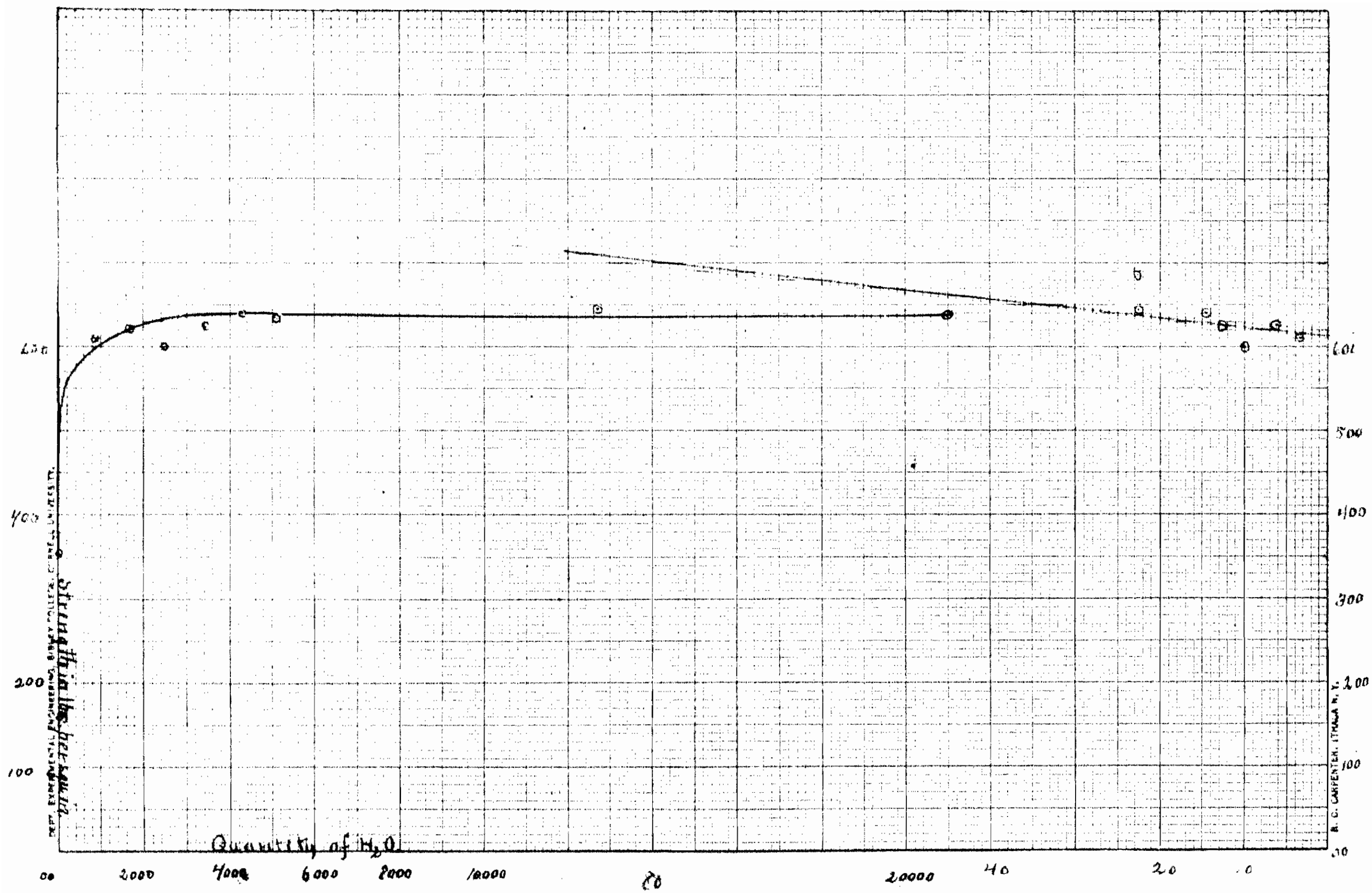
By substituting these values in equation (3) we can transform our equation into the following.

$$\frac{x_1}{y_1 - 301} = 610 - 9.6(y_1)$$

The value (a) is the strength that a briquette would reach with an infinite amount of H_2O (water) present and (b) being negative would have no physical meaning.

As this was an entirely new experiment it was difficult to tell which points would be the most valuable on the curve. Since the curve was plotted it shows very plainly that we should have several points between the value 850 c.c. and 0 c. c. To get these it would be necessary to construct some kind of special apparatus so that you could cover your briquettes with a mere film of water.

The conclusions to be drawn from this experiment as seen now is that the quantity of water in which the cement sets has very little to do with the strength after a very small quantity of water is used.


Strength in lbs per sq in
Quantity of H_2O
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY
R. C. CARPENTER, ITHACA N. Y.
100
200
400
500
00
2000
4000
6000
8000
10000
20000
40
20
500
400
300
200
100
10

1	2	3
y_1 Strength in lbs. per squ. in Ave.	Varying quant. of water containing the briquettes.	$\frac{x_1}{y_1 - y'}$
351.0	000 cc.	—
610.2	850 "	3.28
622.3	1700 "	6.27
600.1	2550 "	10.24
622.4	3400 "	12.53
640.5	4250 "	14.69
631.5	5100 "	
643.4	25500 "	86.53

Discussion of Curve No.IV.

This curve is one obtained by plotting the data on page 20 These data were gotten as described in experiment IV.

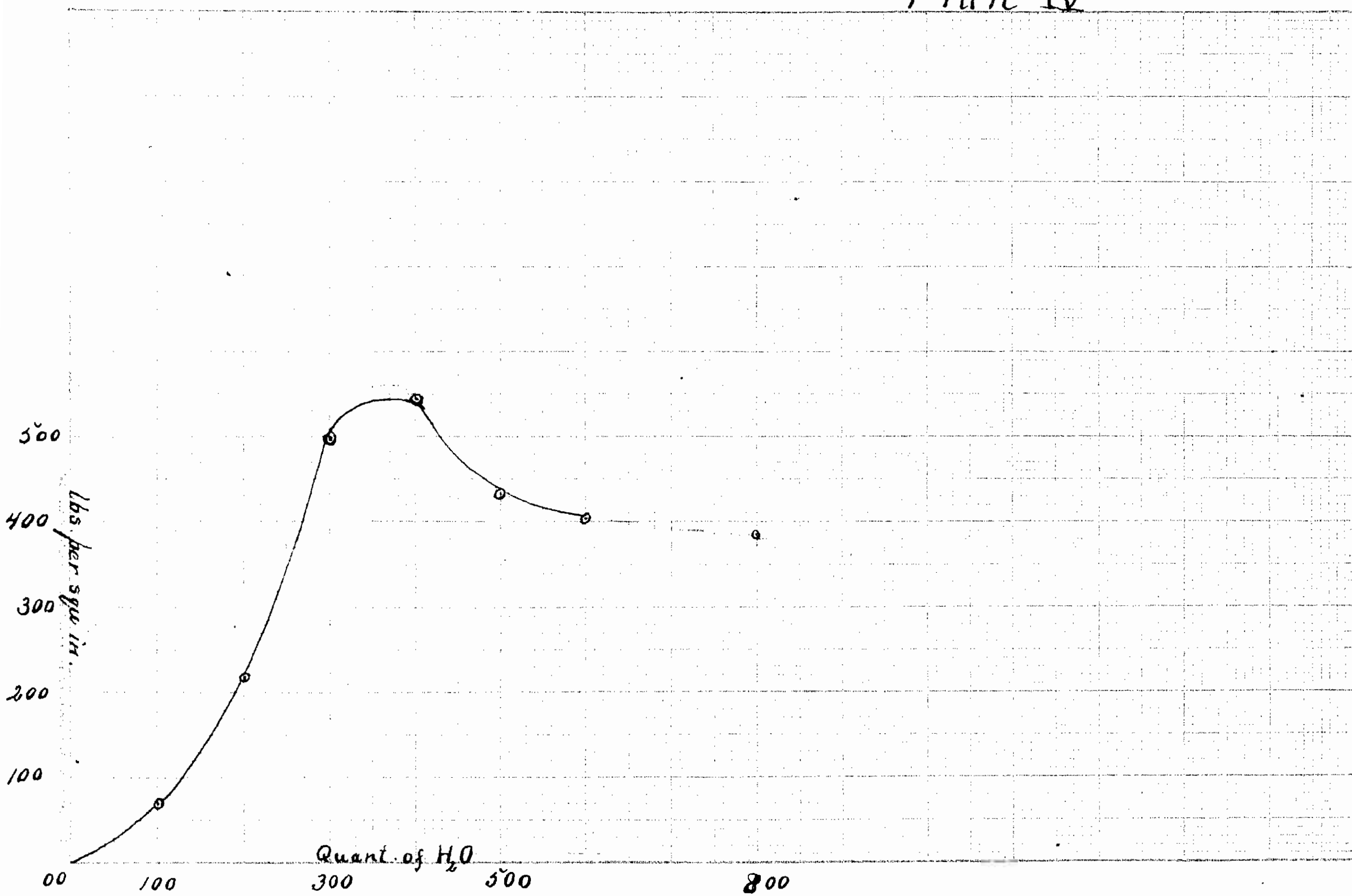
The amount of water as plotted is that used per batch and not for a single briquette. The resulting curves however would be similar as the amount of water per briquette is directly proportional to the amount per batch.

By examining the plot it is plain to see that the curve reaches a maximum verticle ordinate. This maximum value apparently occurs about the value of 375 pounds per square inch.

It can also be seen that the curve would pass through the origin. We however naturally come to this conclusion from the fact that with no water present there would be no opportunity for the cement to set.

If instead of the moulds in the last few points on the curve being partly filled with cement and partly with water until the cement held all the water it could hold in its interstices, the strength would in all probability, reach a maximum and remain at a constant strength throughout.

Plate IV



500
400
300
200
100
lbs per squ in.
00
100
300
500
800
Quant of H_2O

Table IV

Varying Quant. of H_2O	
Quant. H_2O in c.c.	Average strength of ten briquettes.
100	70.5
200	218.9
300	500.0
400	544.2
500	431.4
600	378.8
800	346.6

Discussion of Curve No. V.

This curve can be found on plate V. The data used in plotting will be found on page.

The strength per square inch was plotted along the verticle and the percentage of sulphide along the horizontal.

A very smooth curve satisfies most of the points. For investigation I have tried to fit an hyperbolic equation to the curve. As this was an entirely new experiment I did not get the points situated in the best position to be of most value in working up the curve.

For an equation let us assume.

$XY = K$ referred to X Y as axes - - - - - - - -(1)

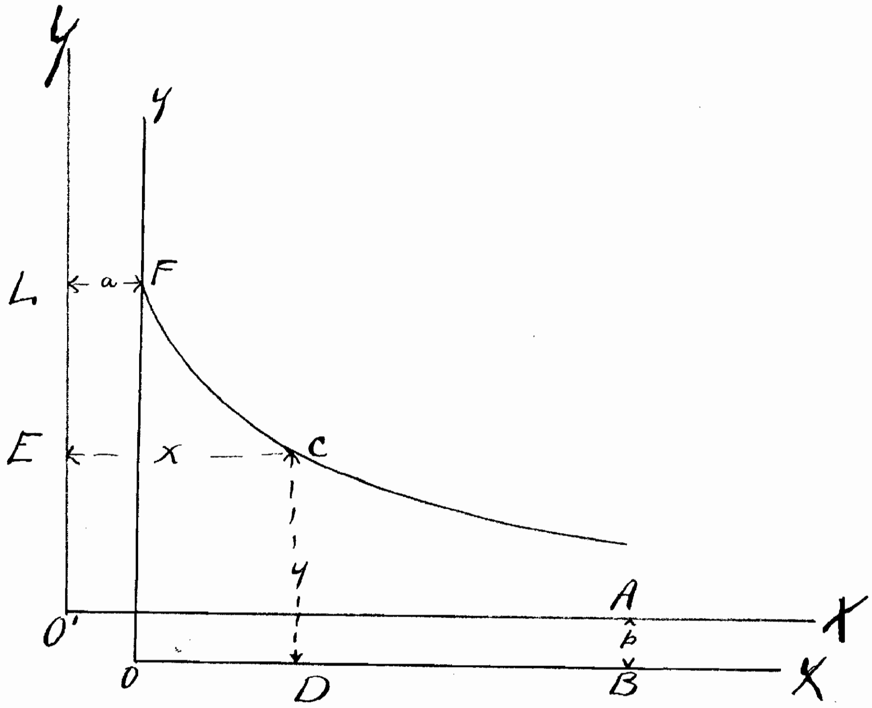
K represents a constant

s = average strength of five briquettes in pounds per square inch.

p = percentage of the sulphide in the cement.

(a and b) = the distance between xX axis and yY axis respectively.

S'= OF



For reference we will take known point F.

Let C be any point on the curve whose co-ordinates are x and y.

AB = b

LF = a

EC = $x = p + a$

CD = $y = s - b$

Substituting these values in equation (1) we get.

$(p+a)\ (y - b) = K$ - - - - - - - - - - - - - - - - - - - (2)

The value K is equal to a $(S' - b)$

Putting this value of K in equation (2) we have

$(p+a(\ (S - b) = K = a(s' - b)$

Multiplying out and reducing to simple form we get.

$$s = \frac{a(s' - s)}{p} + b \qquad (3)$$

This equation is the general form for a straight line and if our assumption is correct we should get a straight line on plotting s and $\frac{S' - s}{p}$.

Not having a satisfactory value for s' I assumed the value 490. By plotting s along the vertical and $\frac{S' - s}{p}$ along the horizontal an approximately straight line was obtained. This line is shown on plate (1).

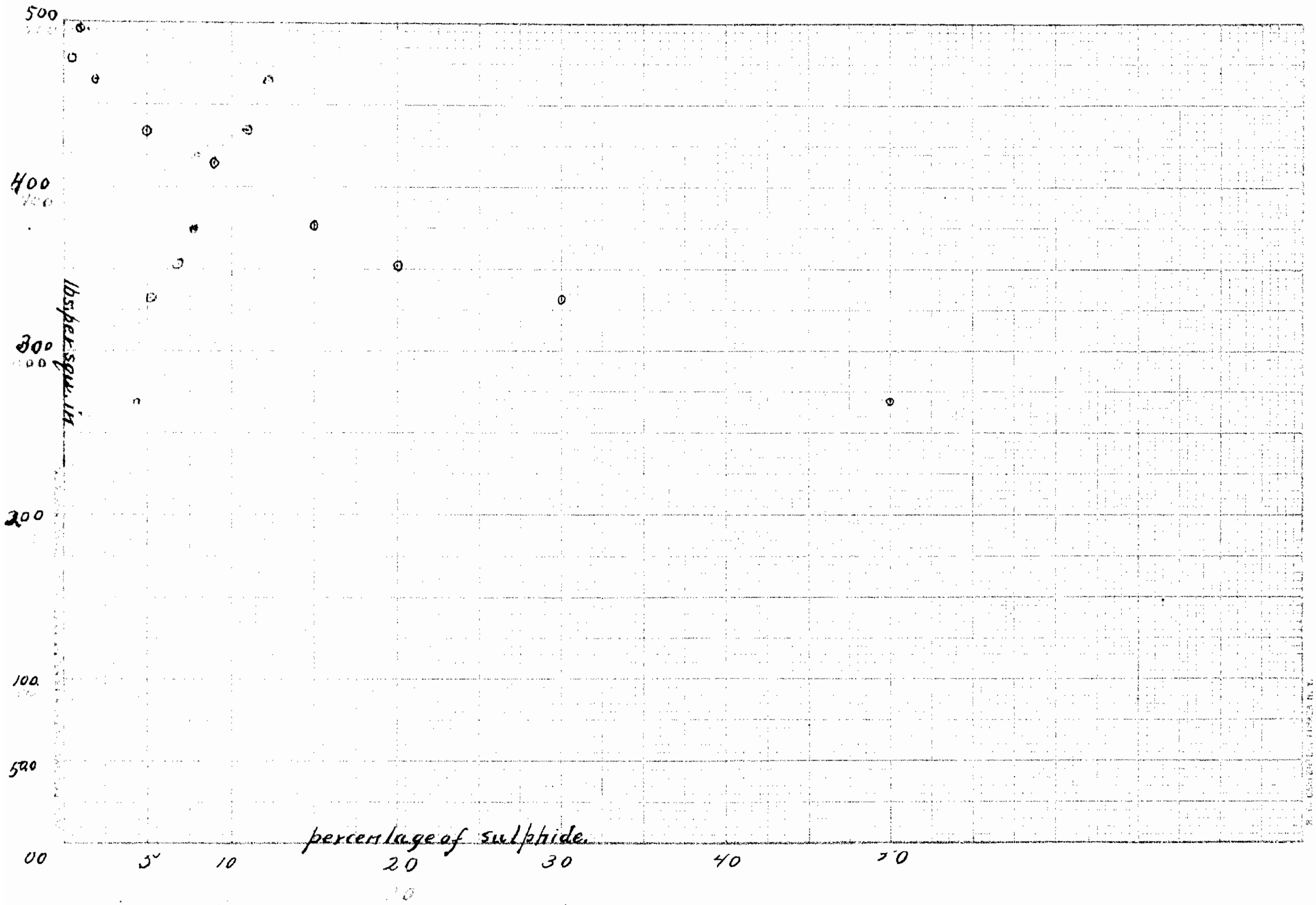
a = tan = 18.72 =

$s = \frac{18.72(490 - s)}{p} + \ldots$

b = 232 = intercept on the s axis

The curve seems satisfactory but there may be other things which would enter ~~and~~ if I used a longer proportion of sulphide.

From the curve as it is now we would draw the conclusion that the sulphide has some strength when no cement is present at all.



500
400
300
200
100
lbs per squ. in
00
10
20
30
40
percentage of sulphide.

1	2	3	4
S	p		s' – s
average Strength of ten briquettes	Percentage of Sulphide	$\frac{s'-s}{p}$	Strength of neat briquettes minus s
	0.0	0	0
479	.5	22	11
496.4	1.0	6.4	6.4
465.6	2.0	12.2	24.4
435.2	5.0	10.9	54.8
419.4	9.0	7.8	70.6
375.6	15.0	7.6	124.4
353.2	20.0	6.9	136.8
332.4	30.0	5.2	157.6
269.4	50.0	4.4	203.6

Discussion of Curve Number VI.

The data forthis curve were obtained similar to the one in No. V. The plot will be found on Plate (VI) and the data on page

The strength per square inch was plotted as ordinates and per-cent of roasted sulphide as abscissae. It can readily be seen that the strength decreases pretty rapidly with addition of roasted suplhide.

The points are somewhat scattered in order to be able to tell a great deal in regard to the curve.

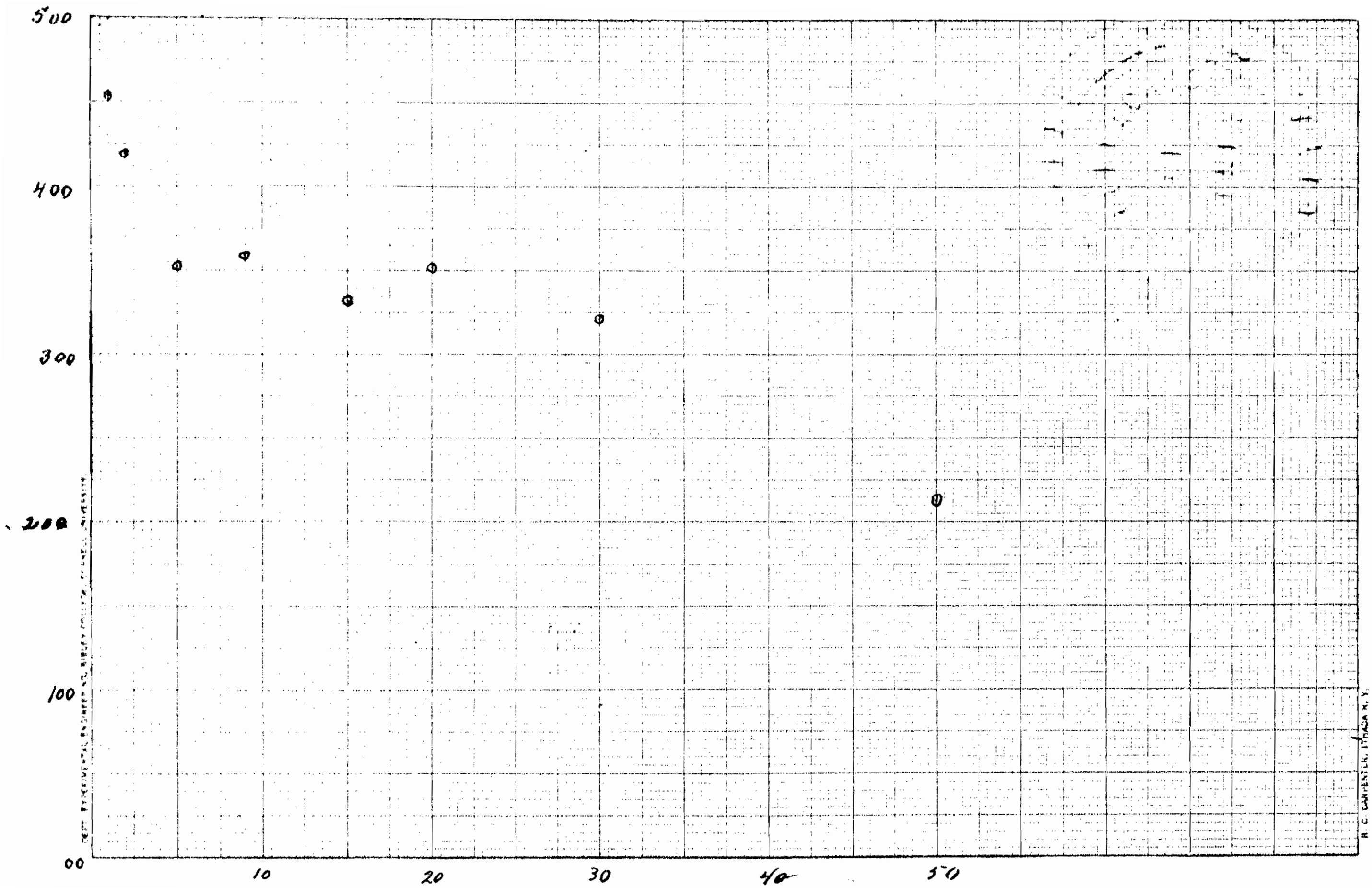
The data I have obtained can only give some general idea as to the results to which we looked forward in the beginning of the experiment.

From these data some one may be able to perform the experiment and draw more concise conclusions than can be done at present.

From a little test briquette that was made it seems doubtful if the raw (roasted sulphide) would have much if any strength.

Besides what has been done this year on the cement testing there is a number yet to be investigated.

The question of temperature is among the most important.


500
400
300
200
100
00
10
20
30
40
50

Data

Neat Cement Out of Water.

Batch α	Tempt. of Room = 18.° " " H_2O = 16.5°	
No.	Time in Days.	Strength in lbs. per squ. in.
1	1	26
2	2	239
3	3	352
4	5	452
5	7	535
6	10	484
7	14	380
8	21	436
9	31	483
10	49	465
11		

Batch β	Tempt. of Room = 15.° " " H_2O = 15.°	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	22
2	2	186
3	3	386
4	5	434
5	7	312
6	10	478
7	14	332
8	21	530
9	31	468
10	49	410
11		

Batch γ	Tempt. of Room = 15° " " H_2O = 15°	
No.	Time in Days	Strength in lbs per squ. in.
1	1	18
2	2	189
3	3	282
4	5	330
5	7	332
6	10	320
7	14	362
8	21	400
9	31	512
10	49	462
11		

Batch Δ	Tempt. of Room = 10° " " H_2O = 10°	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	18
2	2	274
3	3	366
4	5	362 ?
5	7	414
6	10	456
7	14	398
8	21	477
9	31	396
10	49	444
11		

Batch E	Tempt. of Room = 12°	
	" " H_2O = 15°.25	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	24
2	2	245
3	3	330
4	5	254?
5	7	434
6	10	386
7	14	264?
8	21	426
9	31	450
10	49	508
11		

Batch G	Tempt. of Room = 17°.5	
	" " H_2O = 18°.5	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	31
2	2	260
3	3	356
4	5	400
5	7	332
6	10	420
7	14	414
8	21	432
9	31	420
10	49	500
11		

Batch N	Tempt of Room = 19.5°	
	" " H_2O = 14.75°	
No.	Time in Days	Strength in lbs per squ. in.
1	1	22
2	2	236
3	3	307
4	5	347
5	7	386
6	10	385
7	14	406
8	21	500
9	31	370?
10	49	533
11		

Batch O	Tempt. of Room	
	" " H_2O =	
No.	Time in Days	Strength in lbs per squ. in.
1	1	25
2	2	258
3	3	340
4	5	327
5	7	398
6	10	390
7	14	378
8	21	432
9	31	426
10	49	487
11		

Batch U	Tempt. of Room = 16°.5 " " H_2O = 20°.5	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	31
2	2	214
3	3	342
4	5	307
5	7	368.
6	10	290?
7	14	396
8	21	504
9	31	400
10	49	433
11		

Batch K	Tempt. of Room = 16°.5 " " H_2O = 17°.5	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	30
2	2	180
3	3	274
4	5	335
5	7	332
6	10	320
7	14	382
8	21	434
9	31	403
10	49	416
11.		

Batch O	Tempt. of Room = 17.5°	
	" " H_2O = 19.5°	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	38
2	2	182
3	3	251
4	5	344
5	7	432
6	10	558
7	14	512
8	21	564
9	31	666
10	47	656
11		

Batch II	Tempt. of Room =	
	" " H_2O =	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	30
2	2	130
3	3	230
4	5	296
5	7	406
6	10	398
7	14	462
8	21	544
9	31	410 ?
10	47	505
11		

Batch ρ — Tempr. of Room = 17.5°; " " H_2O = 17.0°

No.	Time in Days	Strength in lbs. per squ. in.
1	1	27
2	2	148
3	3	206
4	5	318
5	7	394
6	10	471
7	14	490
8	21	544
9	31	605
10	47	650
11		

Batch Σ — Tempr. of Room = 12.0°; " " H_2O = 13.5°

No.	Time in Days	Strength in lbs. per squ. in.
1	1	23
2	2	184
3	3	236
4	5	298
5	7	500
6	10	407
7	14	494
8	21	608
9	31	603
10	47	556.
11		

Batch T	Tempt. of Room = 15.5° " " H_2O = 13.0°	
No.	Time in Days	Strength in lbs. per squ. in.
1	1	22
2	2	156
3	3	237
4	5	332
5	7	358
6	10	472
7	14	518
8	21	552
9	31	579
10	47	692
11		

Batch Ø	Tempt. of Room = 18.5° " " H_2O = 18.5°	
No	Time in Days	Strength in lbs. per squ. in.
1	1	36
2	2	188
3	3	238
4	5	352
5	7	390
6	10	453
7	14	522
8	21	520
9	31	586
10	47	678
11		

Batch ψ — Tempt. of Room = 13°C; " " H_2O = 16°C

No.	Time in Days	Strength in lbs. per squ. in.
1	1	34
2	2	164
3	3	226
4	5	308
5	7	394
6	10	440
7	14	540
8	21	634
9	31	546
10	47	588
11		

Batch ω — Tempt. of Room 15.5°; " " H_2O - 17°

No	Time in Days	Strength in lbs. per squ. in.
1	1	38
2	2	142
3	3	233
4	5	272
5	7	394
6	10	418
7	14	490
8	21	578
9	31	606
10	47	595
11		

Data

Cement in Varying Qant. of H_2O.

Set A'	Tempt. of Room = 12.0° " " H_2O = 11.5°	
No.	Time in Days	Strength in lbs. per squ. in.
1	40	318
2	"	332
3	"	383
4	"	272
5	"	358
6	"	373
7	"	356
8	"	382
9	"	374
10	"	374
11	"	338

Set B'	Tempt. of Room 19.5° " " H_2O = 17.5°	
No.	Time in Days	Strength in lbs. per squ. in.
1	40	626
2	"	654
3	"	608
4	"	618
5	"	538
6	"	574
7	"	652
8	"	638
9	"	580
10	"	610
11	"	604

Set C'	Tempt. of Room = 19.5°	
	" " H_2O = 19.5	
No.	Time in Days	Strength in lbs. per sq. in.
1	40	611
2	"	612
3	"	634
4	"	580
5	"	616
6	"	704
7	"	652
8	"	614
9	"	604
10	"	634
11	"	584

Set D'	Tempt of Room = 21.5°	
	" " H_2O = 18.0°	
No	Time in Days	Strength in lbs. per sq. in.
1	40	622
2	"	590
3	"	590
4	"	590
5	"	572
6	"	590
7	"	628
8	"	604
9	"	620
10	"	656
11	"	554

Set, E'	Temp. of Room = 17.0	
	" " H_2O = 17.5	
No.	Time in Days	Strength in lbs. per squ. in.
1.	40	613
2	"	620
3	"	602
4	"	662
5	"	629
6	"	688
7	"	618
8	"	675
9	"	608
10	"	558
11	"	573

Set, F'	Temp. of Room = 12.0	
	" " H_2O = 12.0	
No.	Time in Days	Strength in lbs. per squ. in.
1	40	647
2	"	560
3	"	664
4	"	705
5	"	624
6	"	670
7	"	650
8	"	646
9	"	604
10	"	648
11	"	627

Set G'	Tempt. of Room =	
	" " H_2O =	
No.	Time in Days	Strength in lbs. per squ. in.
1	40	646
2	"	600
3	"	656
4	"	623
5	"	626
6	"	634
7	"	641
8	"	601
9	"	654
10	"	634
11	"	

Set H'	Tempt. of Room = 17.0	
	" " H_2O 18.5	
No.	Time in Days	Strength in lbs. per squ. in.
1	40	679
2	"	698
3	"	666
4	"	608
5	"	680
6	"	588
7	"	616
8	"	644
9	"	691
10	"	595
11	"	612

Data

Cement + Varying % of H_2O.

Set I	Tempt. of Room = " " H_2O =	
No.	Time in Days	Strength in lbs. per squ. in.
1	28	520
2	"	518
3	"	489
4	"	582
5	"	418
6	"	528
7	"	485
8	"	460
9	"	504
10	"	496

Set II	Tempt. of Room = 19.25° " " H_2O = 20.5°	
No.	Time in Days	Strength in lbs. per squ. in.
1.	28	504
2.	"	530
3	"	573
4	"	554
5	"	538
6	"	622
7	"	516
8	"	534
9	"	505
10	"	566

Set III	Tempt. of Room = 16.6	
	" " H_2O = 17.0	
No.	Time in Days	Strength in lbs. per squ. in.
1	28	450
2	"	434
3	"	388
4	"	496
5	"	372
6	"	397
7	"	423
8	"	520
9	"	470
10	"	364

Set IV	Tempt. of Room 16.	
	" " H_2O = 16.	
No.	Time in Days	Strength in lbs. per squ. in.
1	28	256
2	"	254
3	"	245
4	"	242
5	"	186
6	"	194
7	"	240
8	"	150
9	"	232
10	"	190

Data.

Neat Cement

Set V	Tempt. of Room = 16.5°	
	" " H_2O = 16.0°	
No.	Time in Days	Strength in lbs. per squ. in.
1	28	50
2	"	75
3	"	87
4	"	95
5	"	60
6	"	60
7	"	76
8	"	9·4
9	"	46
10	"	62

Set VI	Tempt. of Room = 17	
	" " H_2O = 17	
No.	Time in Days	Strength in lbs per squ. in.
1	28	426
2	"	434
3	"	376
4	"	248
5	"	280
6	"	436
7	"	448
8	"	368
9	"	388
10	"	382

Data.

Cement + Iron Sulphide (Raw)

Set a	Tempt. of Room = 15°5 " " H_2O = 15°0	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	
2	"	
3	"	
4	"	
5	"	

Set b	Tempt. of Room = 19°0 " " H_2O = 18°5	
No	Time in Days	Strength in lbs. per squ. in.
1	12	507
2	"	474
3	"	462
4	"	474
5	"	478

Set c	Tempt. of Room = 19°0 " " H_2O = 18°5	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	478
2	"	520
3	"	480
4	"	476
5	"	528

Set d	Tempt. of Room = 19°0 " " H_2O = 18°5	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	480
2	"	455
3	"	450
4	"	482
5	"	461

Set e	Tempt. of Room = 18°.0 " " H_2O = 18°.0	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	404
2	"	418
3	"	458
4	"	432
5	"	464

Set f	Tempt. of Room = 18°.0 " " H_2O = 18°.0	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	380
2	"	394
3	"	458
4	"	434
5	"	431

Set g	Tempt. of Room = 18°.0 " " H_2O = 18°.0	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	364
2	"	404
3	"	326
4	"	366
5	"	418

Set h	Tempt. of Room = 19°.0 " " H_2O = 18°.0	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	324
2	"	336
3	"	392
4	"	360
5	"	354

Set i	Tempt. of Room = 19.0° " " H_2O = 18.5°	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	356
2	"	296
3	"	317
4	"	333
5	"	360

Set j	Tempt. of Room = 19.0° " " H_2O = 18.5°	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	242
2	"	272
3	"	270
4	"	281
5	"	282

Data.

Cement + Iron Sulpide (Roasted)

Set	Tempt of Room =	
	" " H_2O =	
K	Time in Days	Strength in lbs. per squ. in.

Set	Tempt. of Room =	
	" " H_2O =	
l	Time in Days	Strength in lbs. per squ. in.
1	12	424
2	"	362
3	"	492
4	"	434
5	"	340

Set	Tempt. of Room =	
m	" " H_2O =	
No	Time in Days	Strength in lbs. per squ. in.
1	12	362
2	"	438
3	"	493
4	"	520
5	"	448

Set	Tempt. of Room =	
n	" " H_2O =	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	475
2	"	376
3	"	452
4	"	342
5	"	451

Set o	Tempt. of Room = " " H_2O

No.	Time in Days	Strength in lbs. per squ. in.
1	12	308
2	"	362
3	"	344
4	"	375
5	"	379

Set q	Tempt. of Room = " " H_2O =

No.	Time in Days	Strength in lbs. per squ. in.
1	12	316
2	"	372
3	"	346
4	"	369
5	"	360

Set p	Tempt. of Room = " " H_2O =

No.	Time in Days	Strength in lbs. per squ. in.
1	12	352
2	"	329
3	"	382
4	"	366
5	"	358

Set r	Tempt. of Room = " " H_2O =

No.	Time in Days	Strength in lbs. per squ. in.
1	12	480
2	"	362
3	"	383
4	"	288
5	"	346

Set 5	Tempt. of Room =	
	" " H_2O =	
No.	Time in Days	Strength in lbs per squ. in.
1	12	360
2	"	324
3	"	300
4	"	316
5	"	312

Set t	Tempt. of Room =	
	" " H_2O =	
No.	Time in Days	Strength in lbs. per squ. in.
1	12	241
2	"	256
3	"	266
4	"	263
5	"	240