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Pressure transmission and green strength of clays as affected by time of ageing

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PRESSURE TRANSMISSION AND GREEN STRENGTH OF CLAYS AS AFFECTED BY TIME OF AGEING

BY

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THESIS

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PRESSURE TRANSMISSION AND GREEN STRENGTH OF CLAYS AS AFFECTED BY TIME OF AGEING

Introduction

Perfect dry pressing could only be attained if the mix possessed the properties of water in so far as pressure transmission is concerned. There are many factors, however, which tend to interfere with the transmixxion of pressure in the clay block, such as,- Differences in grain size, friction between the grains, entrapped air, dragging of the clay on the sides of the mould box and many other minor causes.

In an effort to solve some of the problems that are of vital interest to the Dry Press industry, the Committee on Dry Press Process of the National Brick Manufacturers Association has carried on extensive research at the Missouri School of Mines and Metallurgy, Rolla, Mo.

It was found[1] that better pressure transmission could be obtained if the clay grains were comparatively large, and that any great amount of fines tends to restrict the natural flow of the grains under pressure.

1. The Effect of Various Factors on Pressure Transmission in Dry Pressing. C. M. Dodd.

Anything that can be done to more thoroughly lubricate the grains and cut down friction on the sides of the mould box is a material aid in dry pressing.

From a consideration of the foregoing work, it was thought that perhaps ageing the tempered dry press mix would aid pressure transmission. The effect of ageing on clay is to allow the tempering water to slake the grains somewhat and to give time for the adsorbed water to be absorbed and soften the grains. Furthermore, it was thought that the more thorough distribution of water would beneficially affect the lubrication of the clay grains.

By the same line of reasoning, it was thought that ageing would have a beneficial effect on the green strength of the brick. The water would have time to be evenly distributed through out the mass and the plasticity would be fully developed.

It was the purpose, therefore, to determine the effect of ageing on dry pressed ware, by forming blocks, and brick after varying periods of ageing and testing them for uniformity of pressure transmission and green strength.

Materials Used.

It would hardly be within the scope of this work to determine the effect of ageing on every commercial dry press mix. Therefore, two clays were selected which would probably show the effects in an exaggerated manner. First, Ozark, a Missouri plastic fire clay was used to illustrate the properties of a plastic clay mix and second, Empire, a Missouri semi-flint clay, was used to illustrate the effect of ageing on semi-flint and flint clay mixes.

Grinding and Screening.

Both clays were plant ground, in a dry pan, through an 8 mesh screen and shipped to Rolla in sacks where they were used without any other treatment other than tempering.

Screen Analyses.

A representative sample from each clay was obtained by quartering 200 grams from 200 pounds of the clay. The quartered samples were placed in a Tyler Rotap Machine for twenty minutes, and the amounts retained on the various screens weighed to the nearest one hundredth of a gram. The results of the Screen Analyses are given in Table No. I.

Tempering.

It has been found in previous investigations[2] that the limits of percent water of plasticity are very narrow for good pressure transmission. The optimum moisture content for fire clay is between seven and nine percent. However, it was thought that a higher percentage of moisture would make the effect of ageing more pronounced. Therefore, the moisture content of the clay mix was adjusted to ten percent.

The tempering was done in 25 pound batches in a small kneading machine. The dry clay was poured into the machine and with the machine running, enough water was added to bring the total moisture content up to ten percent. The tempered clay was mixed for five minutes to insure thorough moisture distribution.

2. Transmission of Pressure as Affected by Moisture Content of Clay Mix. G. A. Page and F. F. Netzeband.

Schedule of Forming.

Since it was probable that the most important effects of ageing would become apparent within a few days, the schedule of forming was so arranged as to completely cover any tendency or trend during the first week. The schedule for forming was as follows:

Not aged.

After 1 day.

After 2 days.

After 4 days.

After 8 days.

After 14 days.

And from then on, at two week intervals until twelve blocks had been formed.

Forming.

The forming was done on a hydraulic dry press made by the Hydraulic Press Manufacturing Co. of Mt. Gilead, Ohio. The specifications of the press are as follows:

Maximum total pressure-- 135 tons, 6000 lbs.per square inch.

Mould box-- 20" x $9\frac{3}{4}$" x $4\frac{3}{4}$".

Lower ram travel-- 22 inches.

Mold box travel-- $1\frac{1}{4}$".

The pressure exerted on the column of clay at all times during the compression is indicated by a gage in the line between the electric plunger pump and the compression cylinder of the dry press. It has been found that the most advantageous pressure to apply in dry pressing is from 2000 to 3000 lbs. per sq. in.[3]

However, in order to exaggerate the effect of ageing, a pressure of 500 lbs. per sq. in. was used.

The time of application of pressure has been shown to be of little importance.[4] However, for the sake of uniformity, two seconds application was used in all cases.

As to the actual forming of the blocks, the lower ram was depressed two inches and the mould filled with clay. After making sure that the clay was evenly distributed in the mould, it was removed and weighed. This weight was three and one-half pounds, and this amount of clay was used in each layer of all subsequent blocks.

After each layer was put in the mould, a sheet of paper towel dusted with potters flint was laid on top to separate it from the next layer.

3. Pressure Transmission in Dry Pressing as affected by the Degree of Pressure. G. A. Page and F. F. Netzeband.

4. Pressure Transmission in Clays as Affected by time of Pressure Application. R. E. Lee.

The lower ram was then depressed two more inches and the same procedure repeated until eight layers were made.

Method of Determining Pressure Transmission.

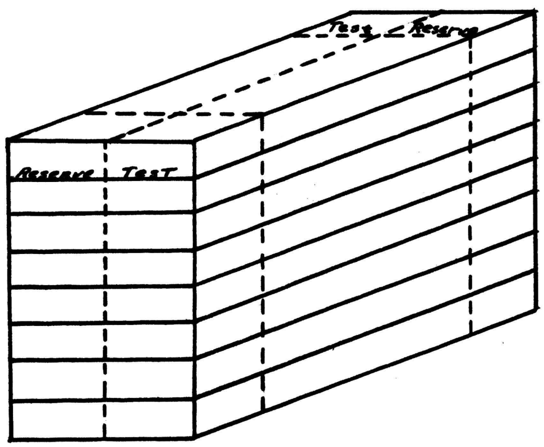
Several methods of ascertaining the transmission of pressure to the various parts of the block have been proposed, but most are unsatisfactory because of mechanical difficulties. The Method adopted by the Committee on Dry Press Process is based on the contention that the bulk density of a clay body is indicative of the pressure to which it has been submitted. In other words, if a certain layer is very dense it has been compressed more than a layer of low density. Since the apparent porosity is inversly proportional to the bulk density, and since apparent porosity is comparatively easy to determine , this property has been chosen to indicate the degree of pressure transmission through out the block.

The following formula was used:

$$\text{Apparent Porosity} = \frac{\text{Wt. Saturated} - \text{Wt. Dry.}}{\text{Wt. Saturated} - \text{Wt. Suspended}}$$

Marking and Breaking.

Immediately after forming, the blocks were marked so each layer could be **divided** into test pieces as shown in the following diagram.



These test pieces were two and one quarter inches square, and were each given a distinguishing mark with cobalt ink. Two pieces from opposite corners of each layer were tested and the other two pieces saved for a check if this were necessary.

The layers of the block could be easily separated because of the low bonding power of the flint dusted paper towels. The test pieces were broken off by marking with a knife along the line to be broken and striking the layer over a knife edge.

Drying.

The test pieces were air dried for at least two days, then they were dried thoroughly at 230°F.

Drying. Con't.

Upon removal from the drier they were placed in a dessicator to cool, then weighed dry. After the dry weight was obtained, they were placed in a bucket containing kerosene which was in turn lowered into an autoclave. They were soaked in the kerosene under a vacuum of 26" of mercury for two hours, then removed and kept submerged in the kerosene until the soaked and suspended weights could be obtained.

Test Procedure for Green Strength.

At the same time that each block was made, three standard sized brick were made. These brick were $9\frac{3}{4}$" x $4\frac{3}{4}$" x approximately $2\frac{1}{2}$", and were dried the same as the pressure transmission test pieces. On being removed from the drier, the test brick were broken on a Rheile Cross Breaking machine, and the Modulus of Rupture calculated, from the following formula.

$$M. R. = \frac{3PL}{2bd^2}$$

where, P -- Total breaking force in pounds.

L -- Distance between supports.

b -- Breadth.

d -- Depth.

The results of this test are given in Table No. 5.

Table No. 1

SCREEN ANALYSES OF THE DRY PANNED CLAYS.

Tyler Standard Sieve	Ozark.	Empire.
On 8	1.01	1.01
Thru 8 on 10	9.62	11.32
Thru 10 on 14	11.39	12.67
Thru 14 on 20	9.88	10.32
Thru 20 on 28	12.16	12.84
Thru 28 on 35	9.62	9.82
Thru 35 on 48	9.62	9.07
Thru 48 on 65	7.09	6.55
Thru 65 on 100	8.61	7.56
Thru 100 on 150	6.84	5.79
Thru 150 on 200	2.28	2.01
Thru 200	11.90	11.15
TOTAL	100.02	100.11

Table No. 2.

OZARK CLAY

VERTICAL VARIATION IN APPARENT POROSITY FOR

VARIATION IN TIME OF AGEING

Time of Ageing	LAYER							
	1	2	3	4	5	6	7	8
0	22.30	22.28	22.29	22.00	21.90	21.69	21.56	21.49
1	21.48	21.41	21.22	21.76	21.81	20.77	21.20	21.32
2	22.04	21.42	22.05	21.31	21.34	21.59	21.33	21.83
4	22.70	22.76	22.87	22.35	22.95	23.00	23.74	23.25
8	23.13	23.03	22.86	22.82	22.55	22.57	22.71	23.04
17	22.88	23.65	24.08	24.63	24.60	24.08	23.04	22.83
33	23.07	23.17	23.17	22.61	22.23	22.87		
48	23.52	23.39	23.27	23.08	23.75	23.57	22.63	23.02
63	23.73	24.08	24.07	23.21	22.97	23.40	24.31	23.79
77	25.00	24.58	25.74	24.14	23.40	23.68	23.77	23.54
91	22.92	23.30	22.68	22.80	23.16	22.70	22.77	22.00
105	22.88	22.85	23.32	22.28	23.01	23.45	23.06	23.29

Table No. 3

EMPIRE CLAY

VERTICAL VARIATION IN APPARENT POROSITY FOR

VARIATION IN TIME OF AGEING.

Time of Ageing	LAYER							
	1	2	3	4	5	6	7	8
0	21.23	21.97	21.48	21.45	22.08	21.39	21.29	21.59
1	21.51	22.46	21.78	21.50	21.53	21.44	21.61	21.58
2	21.78	21.40	21.95	21.31	21.31	21.26	21.50	21.25
4	22.08	22.27	22.25	21.88	21.97	22.31	22.12	21.85
8	20.88	21.65	21.65	21.81	21.55	21.34	20.94	20.51
13	20.48	21.37	20.27	21.37	20.76	20.90	20.37	20.70
29	21.36	21.77	21.44	21.30	20.95	20.64	20.88	20.82
44	21.39	21.35	20.79	21.15	20.85	21.09	21.15	21.06
59	22.20	22.87	21.93	21.37	22.32	22.12	21.99	21.21
73	21.93	21.54	22.30	22.03	21.91	22.50	21.38	20.98
87	21.63	21.59	21.19	22.11	21.54	21.06	21.63	22.41
101	21.40	21.75	21.25	21.23	21.96	22.04	21.55	21.80

Table No. 4

VARIATION IN PERCENT APPARENT POROSITY

WITHIN THE BLOCK

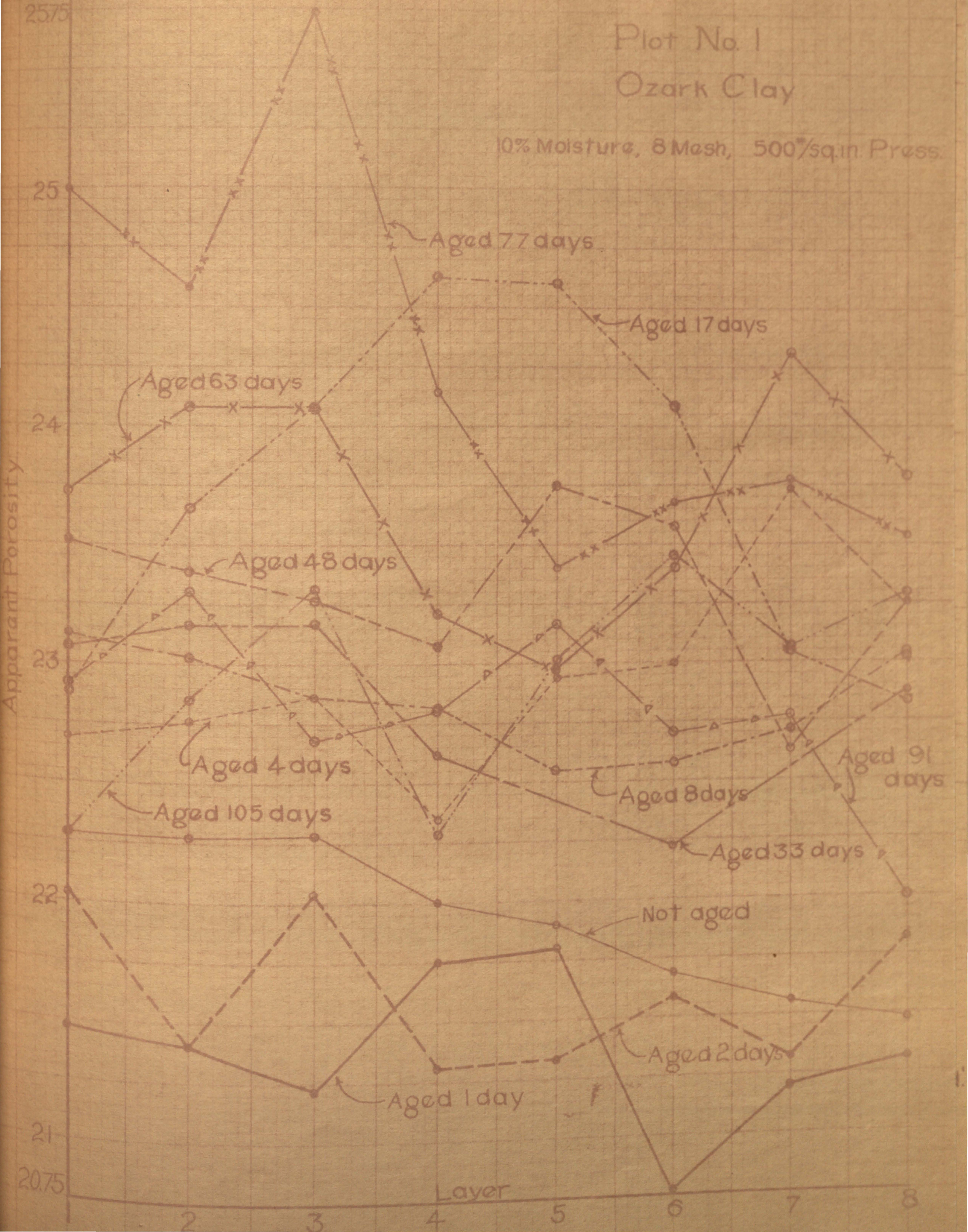
OZARK		EMPIRE	
Time of Ageing	Percent of Porosity	Time of Ageing	Percent of Porosity
0	.81	0	.85
1	1.04	1	1.02
2	.74	2	1.17
4	1.39	4	.46
8	.58	8	1.30
17	1.80	13	1.30
33	.94	29	1.13
48	1.12	44	.60
63	1.34	59	1.66
77	2.34	73	1.52
91	1.30	87	1.35
105	1.17	101	.81

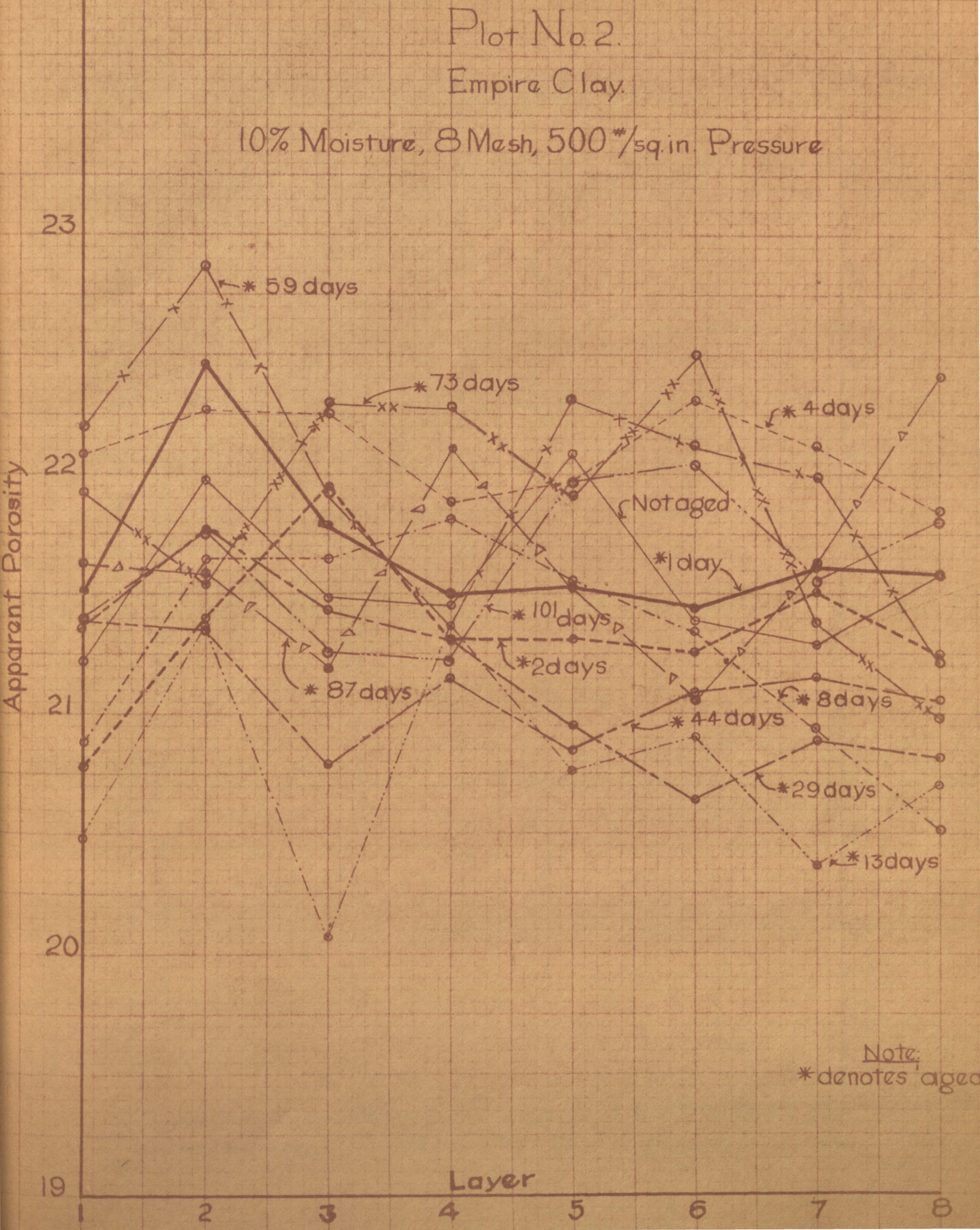
Table No. 5.

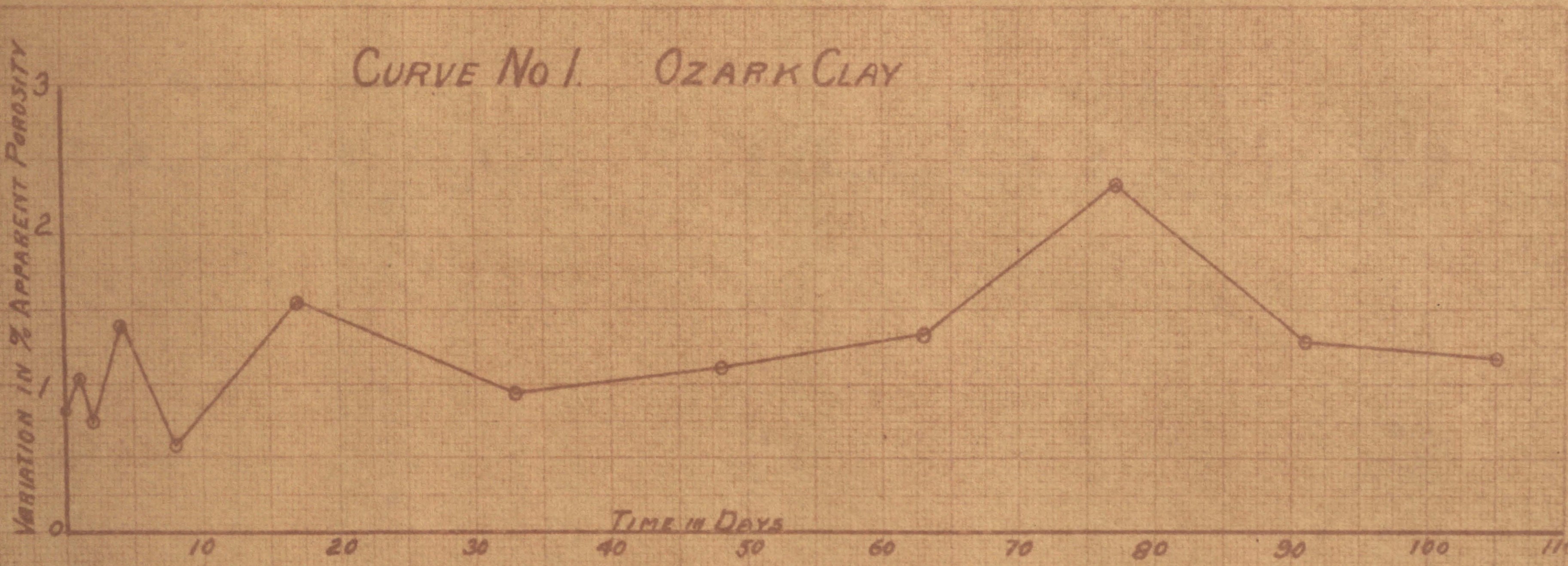
GREEN STRENGTH OF CLAYS AS AFFECTED

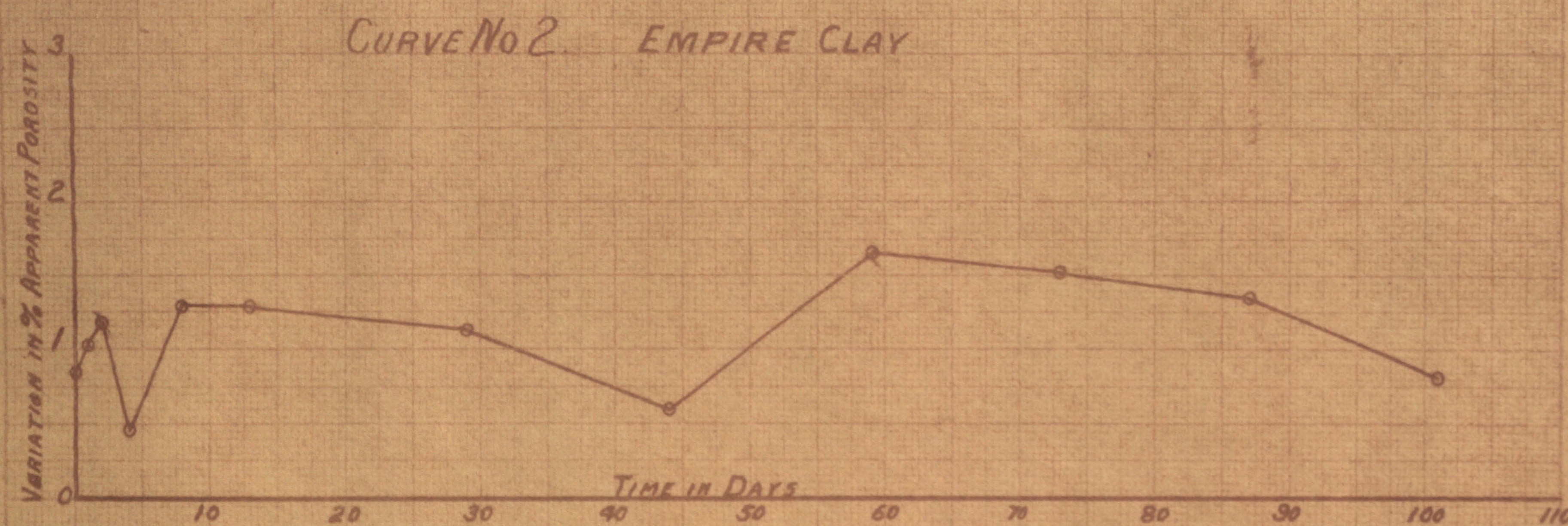
BY AGEING

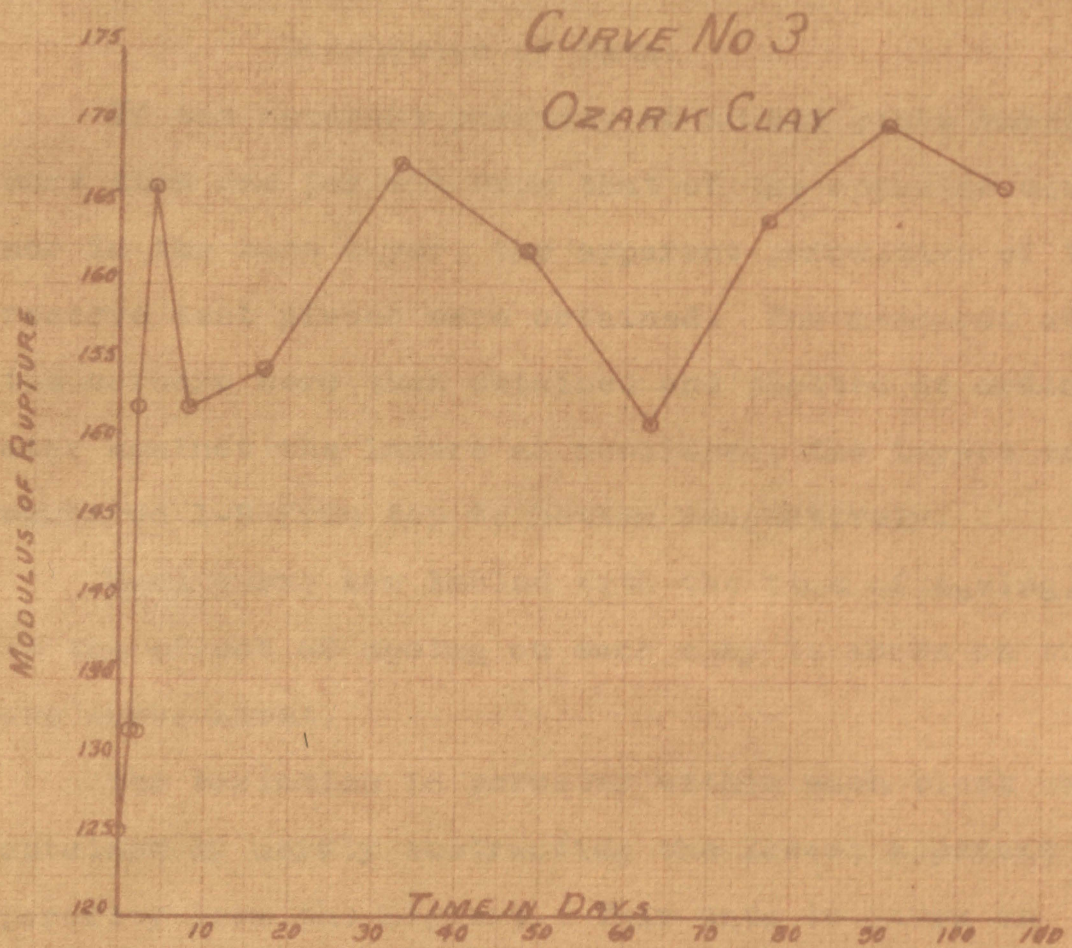
OZARK		EMPIRE	
Time of Ageing	Modulus of Rupture	Time of Ageing	Modulus of Rupture
0	125.3	0	89.3
1	131.6	1	97.3
2	152.4	2	114.6
4	166.2	4	108.4
8	152.3	8	109.4
17	154.7	13	111.6
33	167.8	29	108.2
48	162.3	44	108.9
63	151.3	59	105.6
77	164.3	73	99.7
91	170.3	87	112.2
105	166.5	101	105.5

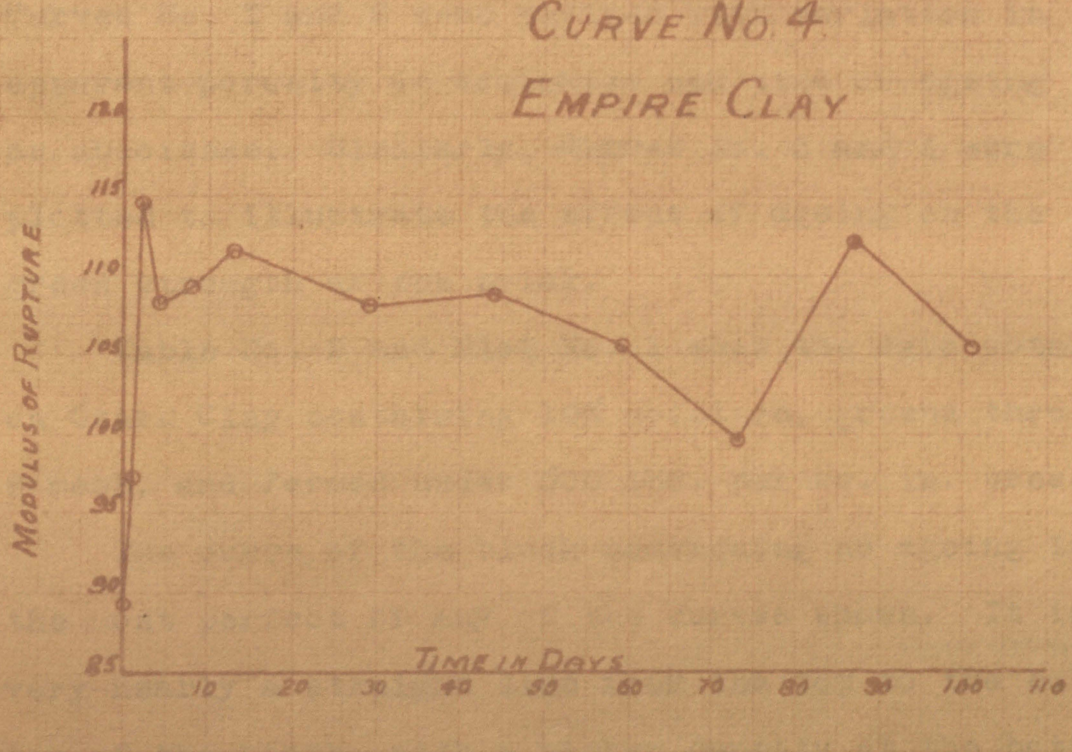

Plot No. 1
Ozark Clay
10% Moisture, 8 Mesh, 500#/sq.in. Press.
Apparent Porosity
25.75
25
24
23
22
21
20.75
Aged 77 days
Aged 17 days
Aged 63 days
Aged 48 days
Aged 4 days
Aged 105 days
Aged 8 days
Aged 91 days
Aged 33 days
Not aged
Aged 2 days
Aged 1 day
Layer
2
3
4
5
6
7
8


Plot No. 2.
Empire Clay.
10% Moisture, 8 Mesh, 500 #/sq. in. Pressure
Apparent Porosity
23
22
21
20
19
Layer
1
2
3
4
5
6
7
8
* 59 days
* 73 days
* 4 days
Not aged
* 1 day
* 101 days
* 2 days
* 87 days
* 8 days
* 44 days
* 29 days
* 13 days
Note:
* denotes 'aged


CURVE No 1. OZARK CLAY
VARIATION IN % APPARENT POROSITY
0
1
2
3
TIME IN DAYS
10
20
30
40
50
60
70
80
90
100
110


CURVE No 2. EMPIRE CLAY
VARIATION IN % APPARENT POROSITY
0
1
2
3
TIME IN DAYS
10
20
30
40
50
60
70
80
90
100
110


CURVE No 3
OZARK CLAY
MODULUS OF RUPTURE
TIME IN DAYS
175
170
165
160
155
150
145
140
135
130
125
120
10
20
30
40
50
60
70
80
90
100
110


CURVE No. 4
EMPIRE CLAY
MODULUS OF RUPTURE
TIME IN DAYS
120
115
110
105
100
95
90
85
10
20
30
40
50
60
70
80
90
100
110

Discussion of Data.

If the apparent porosity of a test piece varied more than one percent from that of the opposite corner in the same layer, the apparent porosities of the reserve test pieces were obtained. The averages of the corners were then obtained and plotted as ordinates against the layers as abscissae, the layers being numbered 1-8 from top to bottom respectively.

Each curve was labled with the time of ageing, so the effect of ageing on each clay is shown on the one curve sheet.

The variation in porosity within each block was obtained by merely subtracting the lowest apparent porosity from the highest. This data is given in Table No. 4. To represent this data graphically, Curves No. 1 and 2 were plotted with variation in apparent porosity as ordinates and time of ageing as abscissae. Similarly, Curves No. 3 and 4 were plotted to illustrate the effect of ageing on the green strength of the brick.

Table No. 2 and Plot No. 1 show the data obtained on Ozark Clay containing 10% moisture, ground thru 8 mesh, and formed under 500 lbs. per sq. in. pressure.

The curve of the block undergoing no ageing is the most perfect of any of the curves shown. It is very nearly a straight line from the top to the bottom of the block, with a higher density at the bottom.

Because of an inherent feature of the hydraulic press used, that of the lower ram moving with the top stationary, it is natural for the bottom of the block to be compressed more than the top. However, the variation should be uniform from top to bottom of the block.

The curve for the next block, that of clay aged one day, was a little more erratic. The porosity was very nearly the same at the top and the bottom, but there was a difference of about one percent between the fifth and sixth layers. The curves for two, four, and eight days ageing were all rather erratic, but there seems to be no relation between them. It may be observed that the average apparent porosity is lower for both the second and third blocks than it was at the start of the test. After ageing four days the average apparent porosity became greater than at the start and at no time during the run did it fall back to the original average.

This observation is of no value in itself except that the increase in porosity might be of some help in explaining the extreme variation in pressure transmission in some of the remaining blocks.

Block No. 6, 17 days ageing, was the first to show extreme variation in pressure transmission. The shape of the curve indicates that the block was dense at both top and bottom but soft in the middle. Blocks No. 9 and 10 were also poor examples of pressure transmission. No. 9, 63 days ageing, was dense at the top and bottom with soft layers next to the ends and a dense center. No. 10, 77 days, ageing was very soft in the second layer from the top.

Strangely enough, Brick No. 11, 91 days ageing, exhibited good pressure transmission, but the next No. 12, 105 days ageing was erratic and inexplicably more dense at the top than at the bottom.

Curve No. 1. illustrates the relation between the variation in percent apparent porosity and time of ageing. This curve shows that in general, the variation increases with ageing. The lowest variation occurred after eight days and the greatest variation was after seventy seven days ageing.

It might be said that although ageing does not beneficially affect pressure transmission, eight to ten days ageing does not materially harm the Ozark clay mix.

Table No. 3 and Plot No. 2 show the results obtained on Empire clay containing 10% moisture, screened through 8 mesh, and formed under a pressure of 500 lbs. per sq. in. At first glance, it can be seen that there is less variation in pressure transmission in the Empire clay than in the Ozark Clay.

Unlike Ozark clay, the Empire mix evidenced improvement in pressure transmission after four days ageing. With no ageing, it was found that the block tended to be soft in the center and this condition continued during the first two days ageing. The block for four days ageing was good but after eight days, the variation was comparatively high. This block apparently had a soft center but was dense at both top and bottom. After thirteen days ageing, the total variation was the same as for eight days, but the curve was much more erratic. Twenty nine days ageing produced a fairly smooth curve from top to bottom of the block. Forty four days ageing produced a block with very little variation in porosity, However, since it was both preceded and followed by blocks exhibiting fairly poor pressure transmission, it should not be concluded that clay should be aged for this period. The last three blocks were all rather erratic.

Curve No. 2 shows that four days ageing produces the least variation in apparent porosity. From a study of this curve, it might be said that ageing for more than 4 - 5 days is detrimental to pressure transmission.

Curve No. 3 illustrates the effect of ageing on the green strength of Ozark clay brick. The rise in strength during the first four days is very marked, and from then on, the strength fluctuates through a range of twenty pounds per square inch, modulus of rupture.

Curve No. 4 shows the effect of ageing on Empire clay as regards green strength. Again, the green strength showed decided improvement after ageing only three days. Ozark Block No. 9 and Empire Block No. 10 were both comparatively weak. This discrepancy may be attributed to the fact that these test brick were allowed to absorb moisture from the air after drying. The rest of the brick were broken immediately after they cooled enough to be handled.

The results of the Modulus of Rupture tests would have been more reliable if more test specimens could have been used. However, lack of facilities for storing the aged clay prevented the making of more than three brick at each period.

Conclusions.

The Ozark clay appeared to be better suited to pressure transmission before ageing than afterwards. This may be attributed to several causes.

First, -- Good pressure transmission depends on the unrestriced flow of grains through out the mass. Before ageing, the clay grains were fairly hard and the recent addition of tempering water had not had an opportunity to soak into the grains. The moisture was merely adsorbed on the surfaces of the grains. This adsorbed moisture acted as a lubricant, which lowered the resistance to flow of the grains. As the moisture soaked into the grains, the whole mass became more soft and instead of tending to transmit the pressure through out the mass, the grains seemed to absorb the energy in becoming deformed.

Second, -- Another factor that perhaps had something to do with the prevention of pressure transmission is the fact that the clays swelled and became more open textured after ageing. This increased pore space apparently tended to oppose the transmission of pressure. When pressure was applied, the tendency seemed to be for the grains to move together and close the pores instead of transmitting the pressure to the other grains.

Third, -- The last item is the fact that the addition of water causes the clay to slake down into finer grains. That fine grains are objectionable has been shown by previous work, so this is probably one reason why the pressure transmission was unfavorably affected by ageing.

The apparent porosity of the Empire blocks was not affected as much by ageing as the Ozark. This was to be expected because the semp-flint clay is not as easily slaked and softened as the more plastic Ozark clay.

The plastic Ozark clay appeared better without ageing, while 3-4 days ageing seemed to help the semi-flint Empire clay. This fact lends strength to the theory that the only benefit pressure transmission derives from ageing is the softening of the surface of the grains by the tempering water. The plastic Ozark clay grains immediately absorbed enough water to make their surfaces slick, while the Empire clay being less plastic required several days to become as completely lubricated. In both clays, when the water soaked through the grains, they became soft, and good pressure transmission was hindered.

Keeping in mind the various peculiarities of the clays as shown by this research work, ageing for from 2-4 days for Ozark and 3-5 days for Empire clay might be recommended. This takes into consideration the advantage gained from the increased strength due to ageing. A high green strength is a most desirable feature in the dry press process.

Summary

The findings of this research work may be briefly summarized as follows:

1. Ozark clay requires no ageing but ageing Empire clay for 3-5 days is beneficial.
2. The green strength of both Ozark and Empire clay is increased by 3-4 days ageing.
3. Therefore, 2-4 days ageing for Ozark and 3-5 days ageing for Empire is recommended.

Recommendations for Further Research.

More conclusive results could in all probability be obtained if the procedure used in this research work were varied in several instances, viz-

1. The moisture content should be adjusted to 8% instead of 10%. Ten percent moisture made the clay too wet. It was difficult to insure uniform distribution of clay grains in the mould box of the dry press.

2. The number of test brick for the green strength determination should be increased to at least six.

3. In preparing the clays for storage, the entire amount of clay used should be tempered and mixed thoroughly in a mixing box. Then it should be divided into twelve equal parts and placed in separate, sealed containers and not disturbed until used. This would insure uniformity of test conditions.

Acknowledgement.

The writer wishes to express his appreciation to Prof. C. M. Dodd for his kind assistance and advice in performing this work.

Bibliography.

1. Bulletin No. 109. National Brick Manufacturers Association. "Investigations of the Dry Press Process". C. M. Dodd, G. A. Page, and F. F. Netzeband.

2. "The Effect of Various Factors on Pressure Transmission". C. M. Dodd.