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The Properties of refractories in zinc metallurgy. Part III. Comparison of various clays

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THE PROPERTIES OF REFRACTORIES IN ZINC METALLURGY.

PART III. COMPARISON OF VARIOUS CLAYS.

-By-

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A

THESIS

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in partial fulfillment of the work required for the

DEGREE OF

MASTER OF SCIENCE IN METALLURGY.

Rolla, Missouri,

1 9 2 6.

Approved: H. W. Lawrence

Acting Superintendent of the Mississippi Valley Experiment Station of the U. S. Bureau of Mines.

C O N T E N T S.

I L L U S T R A T I O N S.

T A B L E S.

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INTRODUCTION .

This thesis, presented to the Faculty of the School of Mines and Metallurgy of the University of Missouri in partial fulfillment of the work required for the Degree of Master of Science in Metallurgy, contains a description of a part of a general investigation on the subject of the refractories used in the distillation of zinc. This investigation has been in progress for the past eighteen months at the Mississippi Valley Experiment Station of the United States Bureau of Mines, Department of Commerce, in cooperation with the School of Mines and Metallurgy of the University of Missouri.

The first phase of this investigation had for its theme the determination of the properties of the fire clays and body mixtures now used in the manufacture of zinc retorts.

The second phase deals with the comparative value of various grog materials presenting possibilities of use in the manufacture of zinc retorts.

The purpose of the third phase of the investigation is the comparison of the properties of bodies made from various clays which present possibilities of utilization for the manufacture of retorts for the distillation of zinc.

This thesis covers that part of the experimental work which has been completed on the third phase of the investigation.

REASONS FOR THE INVESTIGATION.

The cost of retorts is a very important item in the distillation of zinc. The life of these retorts is very short in comparison to the life of refractories used in other branches of metallurgy; it varies from thirty to seventy-five days, and depends upon many factors, among which are the quality of retorts used, the properties of the ore smelted, the kind of fuel used, and the type of retort furnace.

A retort is about eight inches in internal diameter, has walls about one inch in thickness and is from fifty to sixty inches in length; it is supported from the two ends only. It carries, besides its own weight, a charge of a hundred pounds of reduction fuel and zinc ore, distributed uniformly throughout its length. It is heated to a maximum temperature of about 1400° C. on the outside (corresponding to a temperature of 1250° to 1300° C. on the inside). During charging and discharging the retort is subjected to mechanical shocks and strains of no small magnitude and to thermal changes due to the fact that a stream of water is used for cleaning, and a cold, damp charge is introduced into the retort when it is still at a yellow heat. In the distillation process more or less corrosive slags are produced and the retort must be able to resist their action at high temperatures. The refractories used must produce a non-porous wall at elevated temperatures to prevent as far as possible the escape of zinc vapors and the entrance of furnace gases. Since it is

not likely that the absorption of zinc can be prevented, the retort should be of such quality that this inevitable absorption will be a minimum. The average zinc smelter contains from four thousand to five thousand retorts, which are in continuous use when the smelter is operating to full capacity.

The life of the retort has additional importance aside from its initial cost, due to the fact that the absorption of zinc in new retorts occasions an important loss, and because of the loss in capacity that results during the first twenty-four hours after a new retort is in the furnace (in some plants) before it is charged.

Because of the rigorous conditions that zinc retorts must meet and because of the large consumption in all zinc smelters, the importance of high quality retorts at minimum cost is apparent.

MATERIALS USED.

The bond clays used in this investigation were collected at the advice of Mr. G. A. Bole, Superindentent of the Ceramic Experiment Station of the United States Bureau of Mines. In a general way they are representative types of bond clays from clay producing districts, located near the zinc smelting centers. However, no attempt was made to secure every possible gradation among the various types of clays because of the experimental difficulties that would be entailed. A description of the clays used together with the standard grog which was used throughout this phase of the investigation is given in tabulated form below.

C l a y s.

Laboratory Number	Description
1	"A" Grade sagger clay from Hickory, Ky.
2	Fire clay from Salina, Pa.
3	Milled Cheltenham fire clay; used as a standard of comparison.
4	Plastic fire clay from Mayfield, Ky.
5	St. Louis fire clay
7	Black gumbo China clay, Poplar Bluff, Mo.
8	Fire clay from Wellsville, Mo.
9	Middle Vein fire clay from Joliet, Ill.
10	Grade 3 fire clay from Gordon, Ga.
11	Fire clay from Trenton, N. J.
12	Fine blue clay from Metuchen, N. J.

G r o g.

1	Broken saggers.

Body Mixtures.

All body mixtures are based on percentage by weight of the clays and grog used. Three body mixtures were made from each clay with an increase of ten per cent in clay content in each mixture over the lowest multiple of ten per cent that would mold successfully. Two exceptions are to be noted, namely, with Clay No. 2 whose plasticity was so low that the mixture of highest clay content would have contained seventy per cent clay, which was considered impractical, and with Clay No. 7 whose plasticity was so great that a twenty per cent mixture could be molded, but was also considered impractical. A description of these is given below in tabulated form.

Laboratory Number of Body Mixture	Laboratory Number of Clay used	Percentage of Clay used (Difference is per cent grog)
1 - 3	1	30
1 - 4	1	40
1 - 5	1	50
2 - 5	2	50
2 - 6	2	60
3 - 3	3	30
3 - 4	3	40
3 - 5	3	50
4 - 3	4	30
4 - 4	4	40
4 - 5	4	50
5 - 3	5	30

5 - 4	5	40
5 - 5	5	50
6 - 3	6	30
6 - 4	6	40
6 - 5	6	50
7 - 3	7	30
7 - 4	7	40
8 - 4	8	40
8 - 5	8	50
8 - 6	8	60
9 - 4	9	40
9 - 5	9	50
9 - 6	9	60
10 - 3	10	30
10 - 4	10	40
10 - 5	10	50
11 - 3	11	30
11 - 4	11	40
11 - 5-	11	50
12 - 3	12	30
12 - 4	12	40
12 - 5	12	50

It will be noted that in the laboratory numbers of the body mixtures the number preceding the dash denotes the laboratory number of the clay used and the number following denotes the per cent of clay in the mix, the final zero being omitted.

TESTS MADE.

Unless otherwise noted all tests were made in accordance with the standard methods outlined in the test codes of the American Society for Testing Materials and the American Ceramic Society.

Chemical Analyses.

The material from which the sample was taken was crushed in a jaw crusher to pass a 6 mesh sieve. The sample was coned and quartered to the amount desired and ground in an agate mortar to pass a 65 mesh sieve. It was then coned and quartered again; one-half was reserved as a sample for the determination of the cone deformation value and the other half was ground in an agate mortar to pass a 100 mesh sieve and used for chemical analysis. On all the clays and the grog the following was determined: Ignition loss, silica, alumina, iron oxide, titania, lime, magnesia, Na_2O, and K_2O, as shown under experimental results.

Cone Deformation Value.

The sample, prepared as above noted, was molded into test cones in steel molds to the size and shape of the pyrometric cones as manufactured by Edward Orton, Junior. The test cones and pyrometric cones were mounted on a circular plaque of convenient size to insert in the furnace used. This mounting was such that the troweled face of both the test and pyrometric cones made an angle of seventy-five degrees with the horizontal. The cone plaque composition was as follows:

50 per cent - Number 2 St. Louis plastic fire clay

25 per cent - Calcined flint clay

25 per cent - Alundum cement.

In the deformation value determinations, Fulton's grananular resistance furnace was used, a drawing of which appears as Figure 1. This furnace was operated by a motor generator set, which permitted very accurate voltage control up to 125 volts. A hole drilled in the bottom of the furnace permitted, by means of natural draft, a circulation of air, which was sufficient to maintain an oxidizing atmosphere without appreciably cooling the furnace. The cones were set on a cylindrical support, which held them approximately in the middle of the tube, and which served to preheat the air before it came in contact with the cones. This air at the temperature of the furnace passed around the periphery of the plaque. The rate of heating was approximately ten degrees per minute after 800° C. was passed. The deformation value of a cone is indicated when the tip bends over and touches the plaque and is reported as the serial number of the standard pyrometric cone which concurrently deforms.

Drying Shrinkage.

All body mixtures were pugged to a soft, plastic consistency in a laboratory pug mill. The pugged mixtures were allowed to rot for about two weeks to increase their workability. They were then allowed to dry until in a condition to be properly molded. The firing behavior, transverse strength, sag, and spall tests were molded at the same time. The test pieces for drying shrinkage were formed in a

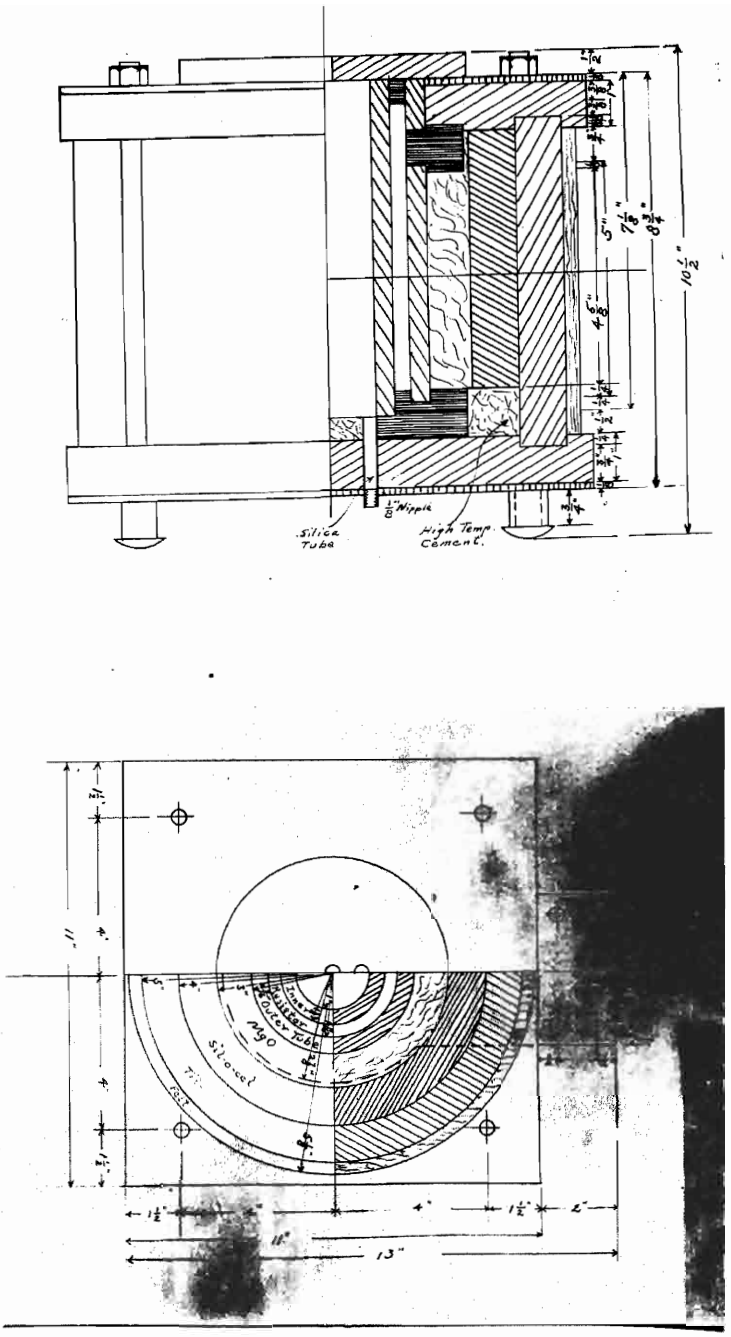


Figure 1.

Fulton's Grananular Resistance Furnace.

steel mold; the size was one and one eighth inches by one and one-eighth inches by one and seven-eighths inches. The plastic volume was determined in a Schurecht overflow volumeter to the nearest 0.1 cubic centimeter; kerosene was used as the immersion fluid. After determining the plastic volume the pieces were dried with a cloth to remove the film of kerosene and allowed to stand at room temperature until air dry, twenty-four to thirty-six hours. They were further dried at a temperature of 110° C. until constant weight was attained. Cooling was done in a desiccator. The dry pieces were then soaked in kerosene for twelve hours and the dry volume obtained in a mercury volumeter, designed by Prof. R. O. Jackson. This volumeter is shown in Figure 2.

In this volumeter a steel piston, carrying a rubber ring, makes a mercury tight fit in a steel cylinder. Lugs fitting into slots provide for locking the piston always in the same position. The displaced mercury is forced up into a burette, which is fitted in a hole in the piston. This burette is partially surrounded by a protective brass cage. The bottom of the piston is cone-shaped to prevent the trapping of air bubbles. The burette of sufficient height to contain all the mercury displaced by the test pieces. Zero readings were taken after each test piece was removed, rather than before its insertion, so that any error due to mercury entering the pores would be eliminated. This apparatus is sufficiently accurate, and the manipulation is simple and rapid.

The per cent volume shrinkage was calculated as follows:

$$\text{Per cent volume shrinkage} = \frac{\text{Plastic Volume} - \text{Dry Volume}}{\text{Dry Volume}} \times 100$$

Figure 2.

Mercury Volumeter.

Water of Plasticity.

The test pieces were identical in size and made in the same manner as those for the drying shrinkage tests. The plastic test piece was weighed on a balance to an accuracy of 0.01 gram, dried according to the method outlined for the drying shrinkage tests and re-weighed with the same accuracy as before. The water of plasticity was calculated as follows:

$$\text{Per cent Water of Plasticity} = \frac{\text{Plastic weight - Dry weight}}{\text{Dry weight}} \times 100$$

Firing Behavior.

The test pieces were formed and the dry volume was determined as described under drying shrinkage. The test pieces were then placed in a kiln, a view of which is shown in Figure 3. This kiln has provisions for both oil and gas firing; gas was used for temperatures below 1000° C. The temperature distribution was sufficiently uniform throughout the kiln. The temperature was controlled by both Orton cones and by noble metal thermocouples, but reported in degrees Centigrade. The heating rate was 50° C. per hour. Test pieces were burned at 800° C., 1000° C., 1100° C., 1200° C., 1300° C., and 1400° C. After burning they remained in the furnace until cool enough to handle; they were then placed in a desiccator. After cooling to room temperature the fired weight was determined to an accuracy of 0.01 gram on a balance. The weighed test pieces were then boiled for two hours in distilled water and, after cooling to room temperature in the water, the saturated weight was determined on a balance to the same accuracy as before.

Figure 5.

Test Kiln.

The fired volume of the same test pieces was then determined on the mercury volumeter as described under drying shrinkage. The following data were then calculated as indicated:

$$\text{Per cent Porosity} = \frac{\text{Saturated fired weight} - \text{Fired weight}}{\text{Fired volume}} \times 100$$

$$\text{Per cent Volume Change} = \frac{\text{Dry volume} - \text{Fired volume}}{\text{Dry volume}} \times 100$$

$$\text{Per cent Absorption} = \frac{\text{Saturated fired weight} - \text{Fired weight}}{\text{Fired weight}} \times 100$$

Transverse Strength.

The samples used to determine transverse strength were formed in a steel mold and measured one inch by one inch by seven inches. These test pieces were dried by the standard method described before; care was taken during the air drying period to turn the test pieces every twelve hours to prevent warping. The test pieces were broken on a machine as shown in Figure 4. For this test the pieces were supported on knife edges of one-fourth inch radius and measuring five inches from center to center. The beam, on which the load was applied, carried a third knife edge, also of one-fourth inch radius, which rested on the test piece midway between the other two knife edges. Shot was used to supply the weight for breaking and was slowly fed into the container carried on the end of the beam. The depth and width of the piece at the break were measured, together with the breaking load in pounds. The modulus of rupture was calculated as follows:

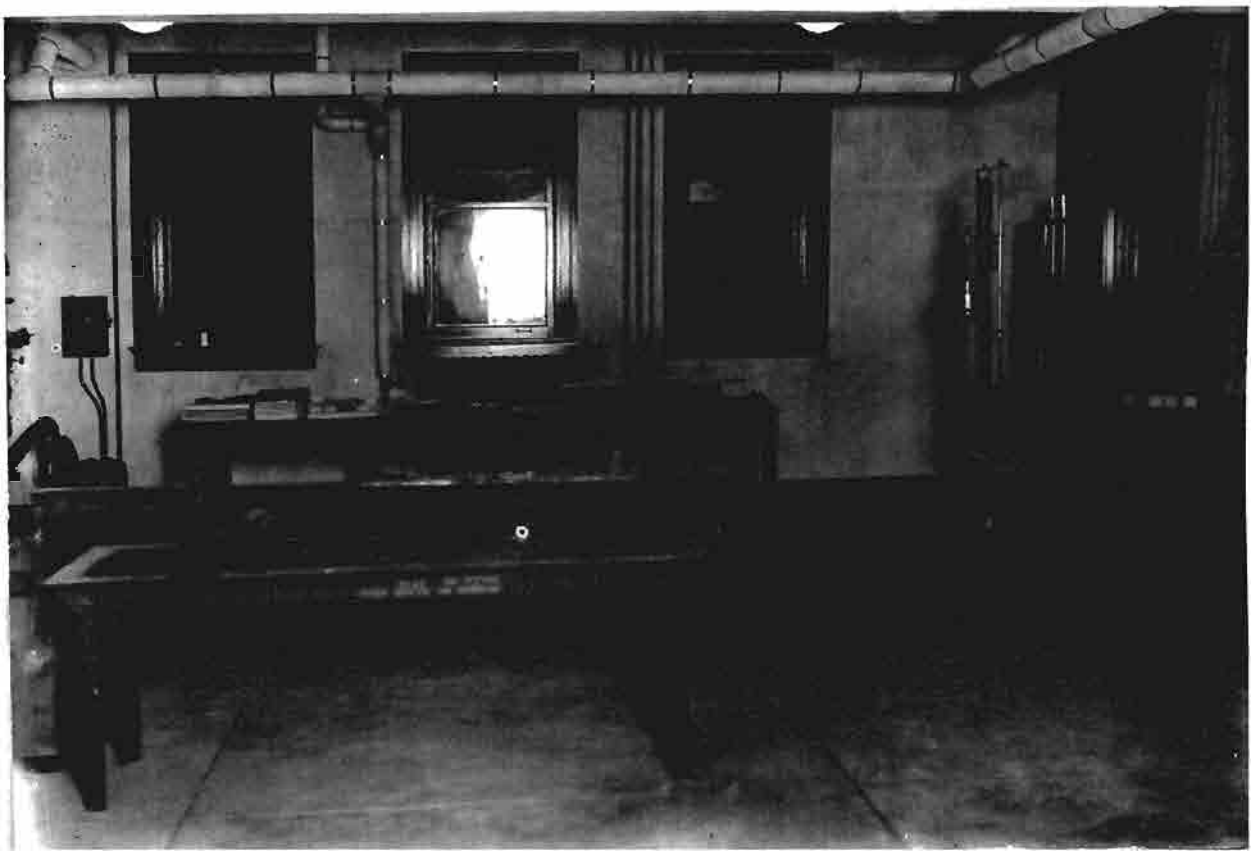


Figure 4.

Transverse Strength Testing Machine.

$$\text{Modulus of Rupture} = \frac{\text{Breaking load x Span of knife edges x 3}}{\text{Breadth of bar x Depth of bar x 2}}$$

Screen Analysis.

The screen analysis of the standard grog used was determined as part of another investigation and is given under experimental results. No screen analysis was run on the clays which were all crushed to pass a six mesh screen.

EXPERIMENTAL RESULTS.

On the following pages will be found the tabulated results of the tests made on the various clays and body mixtures, together with curves, which were plotted from these results.

Table I.

Analyses And Deformation Points of Clays and Grog.

Clay Number	Ignition loss	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	Deformation Point (Orton cone)
1	11.18	53.14	31.32	0.76	2.31	Trace	Trace	0.0	0.25	32 - 33
2	10.66	48.81	33.03	1.70	2.57	Trace	0.75	0.22	1.70	30
3	11.18	53.07	29.56	1.96	1.42	0.79	.63	.16	.25	28 - 29
4	7.81	66.02	21.84	.76	1.86	Trace	.15	0.0	.47	29
5	9.09	62.92	23.45	1.87	1.31	Trace	.33	0.0	.25	28
7	17.07	60.29	19.37	.94	.92	Trace	Trace	0.0	.32	29 - 30
8	10.63	55.18	27.89	2.87	1.41	Trace	.30	.16	.95	30 - 31
9	9.36	59.16	25.10	2.08	1.36	Trace	.61	.13	1.43	27- 28
10	14.07	45.97	36.79	1.24	1.22	Trace	.34	0.0	Trace	33 - 34
11	9.30	62.18	24.13	1.44	1.21	Trace	.36	0.0	1.24	30
12	12.79	49.91	32.68	2.30	1.62	Trace	Trace	0.0	.10	32
Grog No. 1	.21	62.66	32.34	1.35	1.87	.56	.23	0.0	.55	30 - 31

Table II.

Chemical Analyses of Body Mixtures.

Laboratory Number of Body Mixture	Percentage of Grog content, Balance clay	Chemical Analyses								
		Ignition loss	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O
1 - 3	30	3.71	59.80	32.03	1.17	2.00	0.39	0.16	0.00	0.46
1 - 4	40	4.88	58.85	31.93	1.11	2.05	.34	.14	0.00	.43
1 - 5	50	6.45	57.90	31.83	1.06	2.09	.28	.12	0.00	.40
2 - 5	50	5.44	55.74	32.69	1.53	2.22	.28	.49	.11	1.13
2 - 6	60	6.48	54.35	32.75	1.56	2.29	.22	.54	.13	1.24
3 - 3	30	3.50	59.78	31.51	1.53	1.74	.72	.35	.05	.46
3 - 4	40	4.60	58.82	31.23	1.59	1.69	.74	.39	.06	.43
3 - 5	50	5.70	57.87	30.95	1.66	1.65	.77	.43	.08	.40
4 - 3	30	2.49	63.67	29.19	1.17	1.86	.39	.21	0.00	.53
4 - 4	40	3.25	64.00	28.14	1.11	1.86	.34	.20	0.00	.52
4 - 5	50	4.01	64.34	27.09	1.06	1.87	.28	.19	0.00	.51
5 - 3	30	2.87	62.74	29.67	1.51	1.70	.39	.26	0.00	.46
5 - 4	40	3.76	62.76	28.78	1.56	1.65	.34	.27	0.00	.43
5 - 5	50	4.65	62.79	27.89	1.61	1.59	.28	.28	0.00	.40
7 - 3	30	5.27	61.95	28.45	1.29	1.59	.39	.16	0.00	.48
7 - 4	40	6.96	61.71	27.15	1.19	1.49	.34	.14	0.00	.46
8 - 4	40	4.38	59.67	30.56	1.96	1.69	.22	.26	.06	.71
8 - 5	50	5.42	58.92	30.12	2.11	1.64	.28	.27	.08	.75
8 - 6	60	6.46	58.17	29.67	2.26	1.59	.22	.27	.10	.79
9 - 4	40	3.87	61.26	29.44	1.64	1.67	.34	.38	.05	.90
9 - 5	50	4.79	60.91	28.72	1.72	1.62	.28	.42	.07	.99
9 - 6	60	5.70	60.56	28.00	1.79	1.56	.22	.46	.08	1.08
10 - 3	30	4.37	57.65	33.68	1.32	1.68	.39	.26	0.00	.39
10 - 4	40	5.75	55.98	34.12	1.31	1.61	.34	.27	0.00	.33
10 - 5	50	7.14	54.32	34.57	1.30	1.55	.28	.28	0.00	.28
11 - 3	30	2.94	62.52	29.88	1.38	1.67	.39	.27	0.00	.76
11 - 4	40	3.85	62.47	29.06	1.39	1.61	.34	.28	0.00	.83
11 - 5	50	4.76	62.42	28.24	1.40	1.55	.28	.29	0.00	.90
12 - 3	30	3.98	58.85	32.44	1.64	1.80	.39	.16	0.00	.42
12 - 4	40	5.24	57.56	32.48	1.73	1.77	.34	.14	0.00	.37
12 - 5	50	6.50	56.28	32.51	1.83	1.75	.28	.12	0.00	.33


24
22
20
18
16
14
12
10
8
6
4
2
Drying Shrinkage
—Legend—
low clay
medium clay
high clay
5 7 3 4 12 10 11 2 1 9 3
Test Numbers of Bodies

Table III.

Water of Plasticity and Drying Shrinkage of Body Mixtures.

Body Mixture	Drying Shrinkage (Per cent)	Water of Plasticity (Per cent)
1 - 3	6.96	17.06
1 - 4	7.97	19.50
1 - 5	10.97	20.24
2 - 5	6.81	16.16
2 - 6	9.28	16.83
3 - 3	3.40	14.69
3 - 4	8.50	15.77
3 - 5	8.86	16.28
4 - 3	5.47	14.68
4 - 4	8.25	14.30
4 - 5	8.51	16.82
5 - 3	2.37	12.78
5 - 4	6.68	13.50
7 - 3	7.19	14.57
7 - 4	7.17	19.56
8 - 4	7.73	14.18
8 - 5	9.65	15.78
8 - 6	9.04	16.01
9 - 4	7.55	15.55
9 - 5	10.24	17.38
9 - 6	9.22	17.92
10 - 3	5.58	19.74
10 - 4	9.57	20.65
10 - 5	10.64	22.55
11 - 3	6.43	18.19
11 - 4	9.35	18.10
11 - 5	10.71	20.74
12 - 3	5.56	18.76
12 - 4	11.07	22.30
12 - 5	11.84	24.02

Figure 5.

Water of Plasticity and Drying Shrinkage of Body Mixtures.

Table IV.

Firing Behavior of Body Mixtures.

Laboratory Number of Body Mixture	Temperature of firing, Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Percent)	Absorption (Per cent)
1 - 3	800	0.00	30.00	16.39
	1000	1.30	30.31	16.47
	1100	1.20	29.37	15.90
	1200	2.00	28.84	15.50
	1300	2.94	27.70	14.82
	1400	5.78	24.11	12.49
1 - 4	800	0.15	31.15	17.34
	1000	0.72	31.40	17.77
	1100	1.51	31.45	17.67
	1200	3.76	29.08	15.78
	1300	5.22	27.83	14.81
	1400	8.71	22.97	11.76
1 - 5	800	0.00	33.11	18.63
	1000	1.58	32.67	18.29
	1100	4.45	30.89	16.85
	1200	6.69	29.04	15.54
	1300	8.10	27.98	14.15
	1400	14.93	20.81	10.10
2 - 5	800	0.00	29.14	15.84
	1000	1.14	29.36	15.81
	1100	2.71	27.98	14.74
	1200	4.08	25.17	13.00
	1300	4.95	20.87	10.70
	1400	5.60	16.91	8.62
2 - 6	800	0.00	29.24	15.86
	1000	2.06	29.13	15.68
	1100	3.83	27.90	14.60
	1200	6.37	23.29	11.78
	1300	6.67	18.78	9.49
	1400	6.12	14.91	7.57
3 - 3	800	0.00	27.10	14.41
	1000	.67	27.27	14.31
	1100	.27	27.02	14.18
	1200	.83	26.16	13.65
	1300	1.03	26.09	13.61
	1400	4.12	22.06	11.42

(Continued on next page).

Table IV (Continued).

Laboratory Number of Body Mixture	Temperature of firing Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Percent)	Absorption (Per cent)
3 - 4	800	0.00	28.15	15.00
	1000	1.06	28.46	15.07
	1100	1.00	27.97	14.81
	1200	1.52	27.04	14.23
	1300	2.09	25.47	13.18
	1400	4.24	21.86	11.16
3 - 5	800	0.00	28.53	15.27
	1000	1.02	29.44	15.75
	1100	2.35	28.28	14.88
	1200	3.30	26.98	13.99
	1300	4.78	24.49	12.56
	1400	7.04	21.22	10.64
4 - 3	800	0.00	25.30	13.28
	1000	.40	24.40	13.27
	1100	.07	27.20	14.02
	1200	.68	25.41	13.26
	1300	1.48	25.09	12.92
	1400	4.03	22.04	11.01
4 - 4	800	0.00	27.00	14.22
	1000	0.00	27.85	14.58
	1100	.47	27.36	14.26
	1200	1.73	25.42	13.10
	1300	2.41	24.41	12.48
	1400	4.81	20.63	10.23
4 - 5	800	0.00	28.56	15.32
	1000	0.00	29.37	15.63
	1100	1.17	28.51	15.08
	1200	2.91	26.72	13.87
	1300	3.24	25.95	13.44
	1400	7.37	19.65	9.66
5 - 3	800	0.13	24.84	12.76
	1000	.47	25.99	13.45
	1100	.07	24.82	13.03
	1200	.41	25.16	12.87
	1300	1.33	23.28	11.78
	1400	3.82	19.93	9.85

(Continued on next page).

Table IV (Continued).

Laboratory Number of Body Mixture	Temperature of firing Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Percent)	Absorption (Per cent)
5 - 4	800	0.00	25.39	13.07
	1000	.33	25.34	12.94
	1100	.39	24.70	12.52
	1200	.93	24.87	12.63
	1300	1.93	22.65	11.37
	1400	3.69	20.09	9.93
5 - 5	800	0.00	26.44	13.75
	1000	.60	26.66	13.76
	1100	1.55	26.16	13.46
	1200	1.89	25.31	12.93
	1300	3.30	23.02	11.55
	1400	5.28	20.44	10.06
7 - 3	800	0.00	32.66	18.60
	1000	.33	32.49	18.33
	1100	.67	32.20	18.14
	1200	1.00	31.00	17.40
	1300	2.19	30.12	16.68
	1400	4.56	26.44	14.33
7 - 4	800	0.00	35.60	21.15
	1000	.88	35.80	21.18
	1100	1.08	34.86	20.42
	1200	2.19	32.65	18.97
	1300	3.61	32.14	18.27
	1400	6.09	29.77	16.63
8 - 4	800	0.00	26.28	13.69
	1000	1.00	26.63	13.79
	1100	1.44	26.08	13.40
	1200	2.57	24.17	12.28
	1300	3.23	23.40	11.81
	1400	6.06	18.78	9.18
8 - 5	800	0.00	27.09	14.19
	1000	1.15	28.51	14.99
	1100	2.69	27.18	14.17
	1200	4.36	24.68	12.51
	1300	5.56	23.22	11.60
	1400	8.46	17.41	8.46

(Continued on next page).

Table IV (Continued).

Laboratory Number of Body Mixture	Temperature of firing, Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Per cent)	Absorption (Per cent)
8 - 6	800	0.00	27.98	14.84
	1000	1.80	25.58	15.00
	1100	3.09	27.12	14.07
	1200	5.19	24.39	12.29
	1300	8.08	20.07	9.83
	1400	9.36	15.69	7.54
9 - 4	800	0.00	28.66	15.46
	1000	.94	28.82	15.37
	1100	1.20	27.78	14.69
	1200	3.43	24.94	12.83
	1300	4.46	22.08	11.23
	1400	7.38	18.10	8.98
9 - 5	800	0.00	29.75	16.20
	1000	.93	29.80	16.05
	1100	2.56	28.40	15.06
	1200	6.16	23.99	12.22
	1300	6.46	22.09	11.19
	1400	9.39	16.78	8.26
9 - 6	800	0.00	29.36	15.90
	1000	1.65	29.33	15.61
	1100	3.45	27.68	14.48
	1200	7.28	22.72	11.44
	1300	9.45	18.05	8.87
	1400	11.23	14.60	7.05
10 - 3	800	0.00	33.65	19.47
	1000	1.03	34.22	19.64
	1100	1.51	32.60	18.45
	1200	2.64	31.14	17.36
	1300	4.64	29.98	15.75
	1400	6.08	25.18	13.46
10 - 4	800	0.00	33.87	19.69
	1000	1.31	34.44	19.84
	1100	3.31	31.59	18.01
	1200	5.00	30.49	16.81
	1300	6.51	29.73	16.20
	1400	8.02	27.55	14.75

(Continued on next page).

Table IV (Continued).

Laboratory Number of Body Mixture	Temperature of firing, Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Per cent)	Absorption (Per cent)
10 - 5	800	0.14	35.75	21.38
	1000	1.78	36.34	21.52
	1100	4.72	34.04	19.58
	1200	6.11	31.21	17.44
	1300	9.38	29.75	16.25
	1400	10.92	27.26	14.68
11 - 3	800	0.00	30.29	16.69
	1000	.40	30.98	17.03
	1100	.67	30.43	16.69
	1200	1.65	28.08	15.16
	1300	2.78	27.25	14.62
	1400	7.04	21.36	10.88
11 - 4	800	0.00	31.48	17.69
	1000	.51	32.37	18.08
	1100	1.55	30.80	16.00
	1200	3.05	29.06	15.71
	1300	4.99	25.91	13.65
	1400	7.82	21.74	11.14
11 - 5	800	0.00	32.84	18.71
	1000	1.37	33.58	19.06
	1100	2.78	31.42	17.36
	1200	5.40	28.07	15.12
	1300	8.25	25.67	13.60
	1400	9.81	23.54	12.14
12 - 3	800	0.00	32.60	18.48
	1000	.44	32.72	18.47
	1100	1.37	31.68	17.67
	1200	1.66	31.32	17.34
	1300	2.41	30.37	16.78
	1400	5.10	25.84	13.80

(Continued on next page).

Table IV (Continued).

Laboratory Number of Body Mixture	Temperature of firing, Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Per cent)	Absorption (Per cent)
12 - 4	800	0.00	34.84	20.50
	1000	1.08	35.49	20.81
	1100	1.51	34.28	19.87
	1200	3.45	33.49	19.17
	1300	4.50	31.60	15.77
	1400	8.32	26.96	14.59
12 - 5	800	0.00	36.15	21.55
	1000	1.65	36.04	21.24
	1100	3.03	34.95	20.32
	1200	6.16	32.70	18.35
	1300	6.62	31.85	17.83
	1400	10.45	28.43	15.26

Table IV (Continued).

Laboratory Number of Body Mixture	Temperature of firing, Degrees Centigrade	Volume Shrinkage (Per cent)	Porosity (Per cent)	Absorption (Per cent)
12 - 4	800	0.00	34.84	20.50
	1000	1.08	35.49	20.81
	1100	1.51	34.28	19.87
	1200	3.45	33.49	19.17
	1300	4.50	31.60	15.77
	1400	8.32	26.96	14.59
12 - 5	800	0.00	36.15	21.55
	1000	1.65	36.04	21.24
	1100	3.03	34.95	20.32
	1200	6.16	32.70	18.35
	1300	6.62	31.85	17.83
	1400	10.45	28.43	15.26

Volume Shrinkage of Body Mixtures

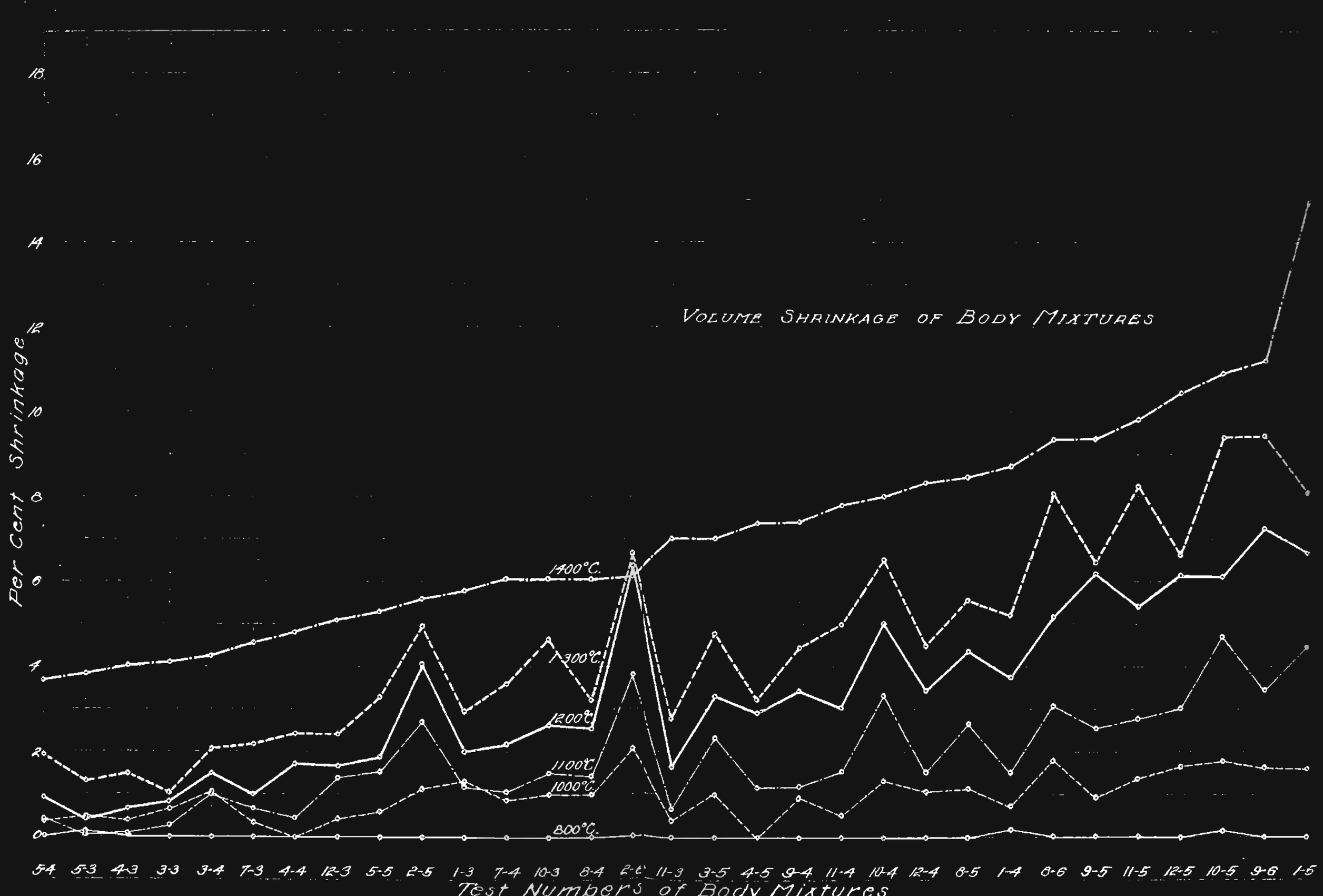
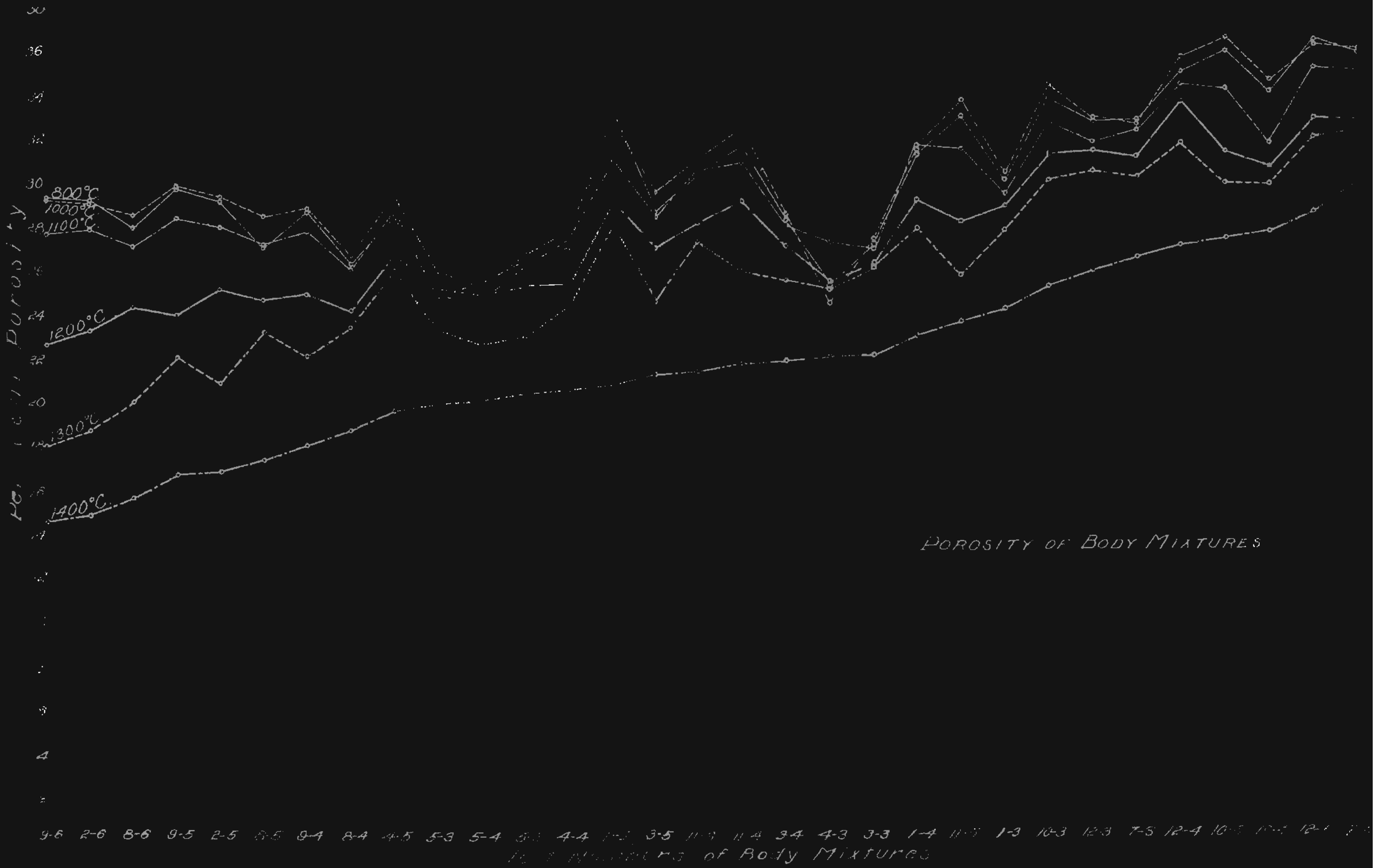


Figure 6.

Volume Shrinkage of Body Mixtures.


800°C
1000°C
1100°C
1200°C
1300°C
1400°C
Porosity
Porosity of Body Miatures
9-6 2-6 8-6 9-5 2-5 8-5 9-4 8-4 4-5 5-3 5-4 4-4 3-5 3-4 4-3 3-3 1-4 1-3 10-3 12-3 7-5 12-4
of Body Mixtures

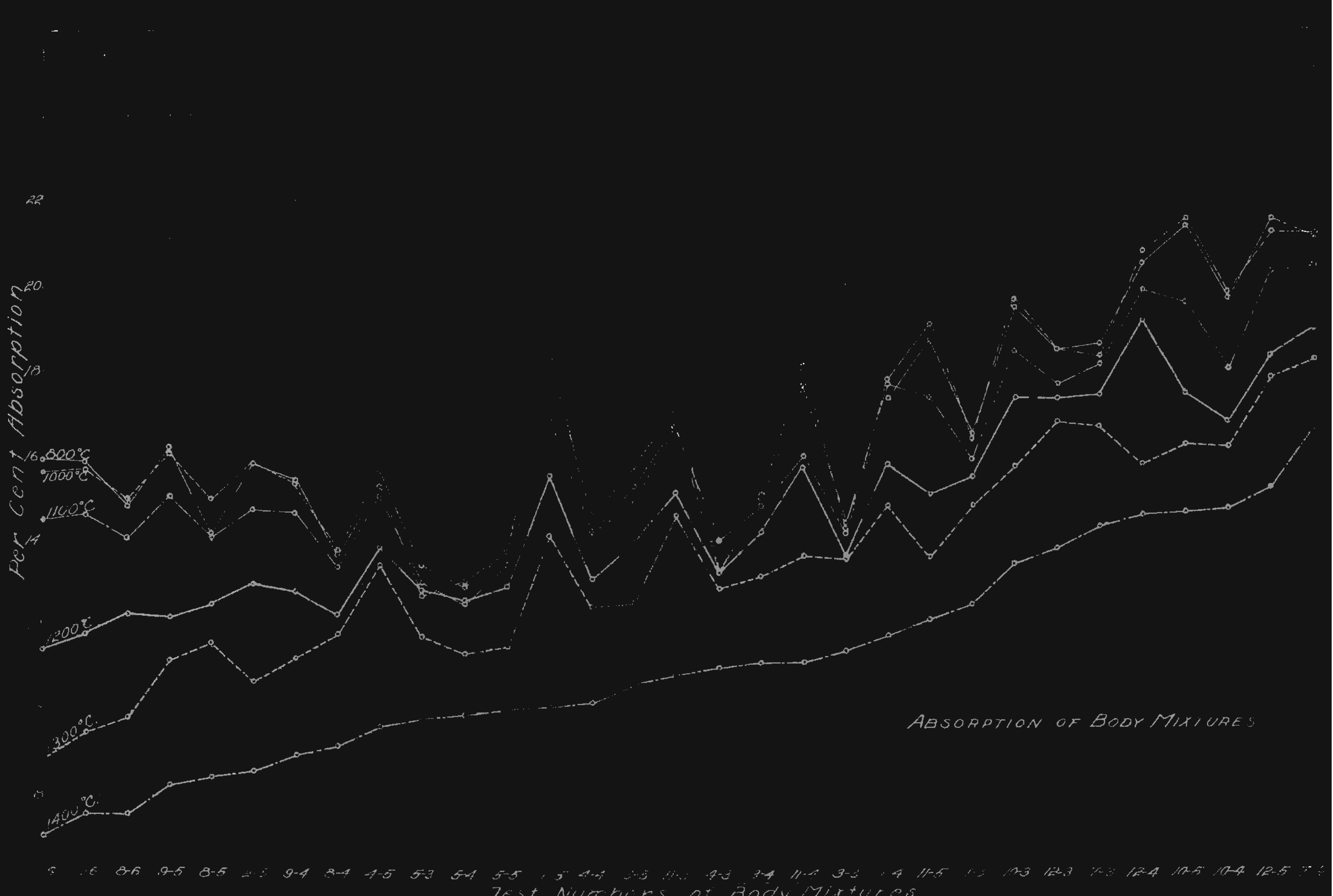

Per Cent Absorption
22
20
18
16
14
1600°C
1000°C
1100°C
1200°C
1300°C
1400°C
Absorption of Body Mixtures
Test Numbers of Body Mixtures

Figure 7.

Porosity of Body Mixtures.

Figure 8.

Absorption of Body Mixtures.

Figure 8.

Absorption of Body Mixtures.

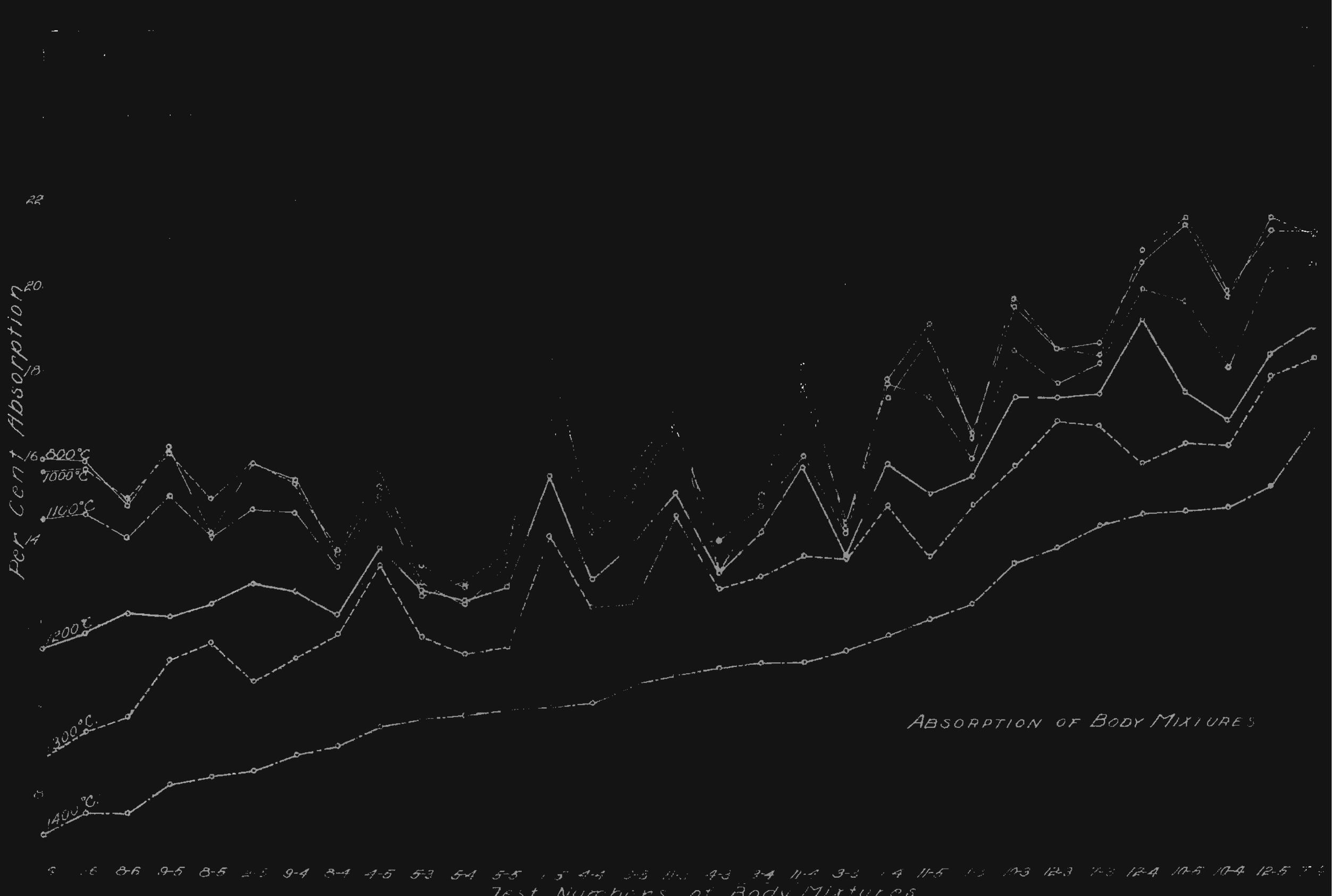

Per Cent Absorption
22
20
18
16
14
1600°C
1000°C
1100°C
1200°C
1300°C
1400°C
Absorption of Body Mixtures
Test Numbers of Body Mixtures

Table V.

Modulus of Rupture of Body Mixtures (Pounds per Square Inch).

Body Mixture	Temperature of Burn			
	800° C.	1000° C.	1200° C.	1400° C.
1 - 3	254	541	1034	1251
1 - 4	262	571	1046	1256
1 - 5	326	615	1062	1477
2 - 5	252	803	1094	1473
2 - 6	246	810	1243	1698
3 - 3	340	794	959	1136
3 - 4	331	630	931	1015
3 - 5	368	720	1062	1127
4 - 3	273	711	1133	1372
4 - 4	257	693	1109	1367
4 - 5	264	601	1245	1361
5 - 3	357	712	1033	1407
5 - 4	350	606	1004	1289
5 - 5	370	595	988	1244
7 - 3	80	225	502	570
7 - 4	91	181	595	839
8 - 4	308	626	1339	1875
8 - 5	359	667	1568	1782
8 - 6	367	501	1432	1841
9 - 4	258	615	1488	1900
9 - 5	269	603	1344	1708
9 - 6	303	771	1672	1959
10 - 3	217	499	764	796
10 - 4	261	487	801	809
10 - 5	236	439	673	698
11 - 3	185	361	899	1149
11 - 4	184	437	836	1089
11 - 5	203	444	997	1358
12 - 3	169	271	589	842
12 - 4	186	368	700	824
12 - 5	189	362	813	930

Modulus of Rupture of Body Mixtures

In the numbers given below for the body mixtures the first number indicates the clay and the second gives the percent of clay used in the mix, the final zero being omitted. e.g. Number "7-3" denotes the body mix made from clay #7, 30% clay by weight and number 2-6 contains clay #2, 60% by weight.

1600
1200
800
400
1400°C. Burn
1300°C. Burn
1200°C. Burn
1100°C. Burn
1000°C. Burn
900°C. Burn
1600
1200
800
400

7-3 10-5 10-3 10-4 12-4 7-4 12-3 12-5 3-4 [illegible] 3-5 3-3 11-3 5-6 1-3 1-4 5-4 11-5 4-5 4-4 [illegible] 5-3 2-5 1-5 [illegible] 9-5 6-5 8-6 8-4 6-4 9-6

Test Number of Body Mixture

Figure 9.

Modulus of Rupture of Body Mixtures.

Modulus of Rupture of Bodies

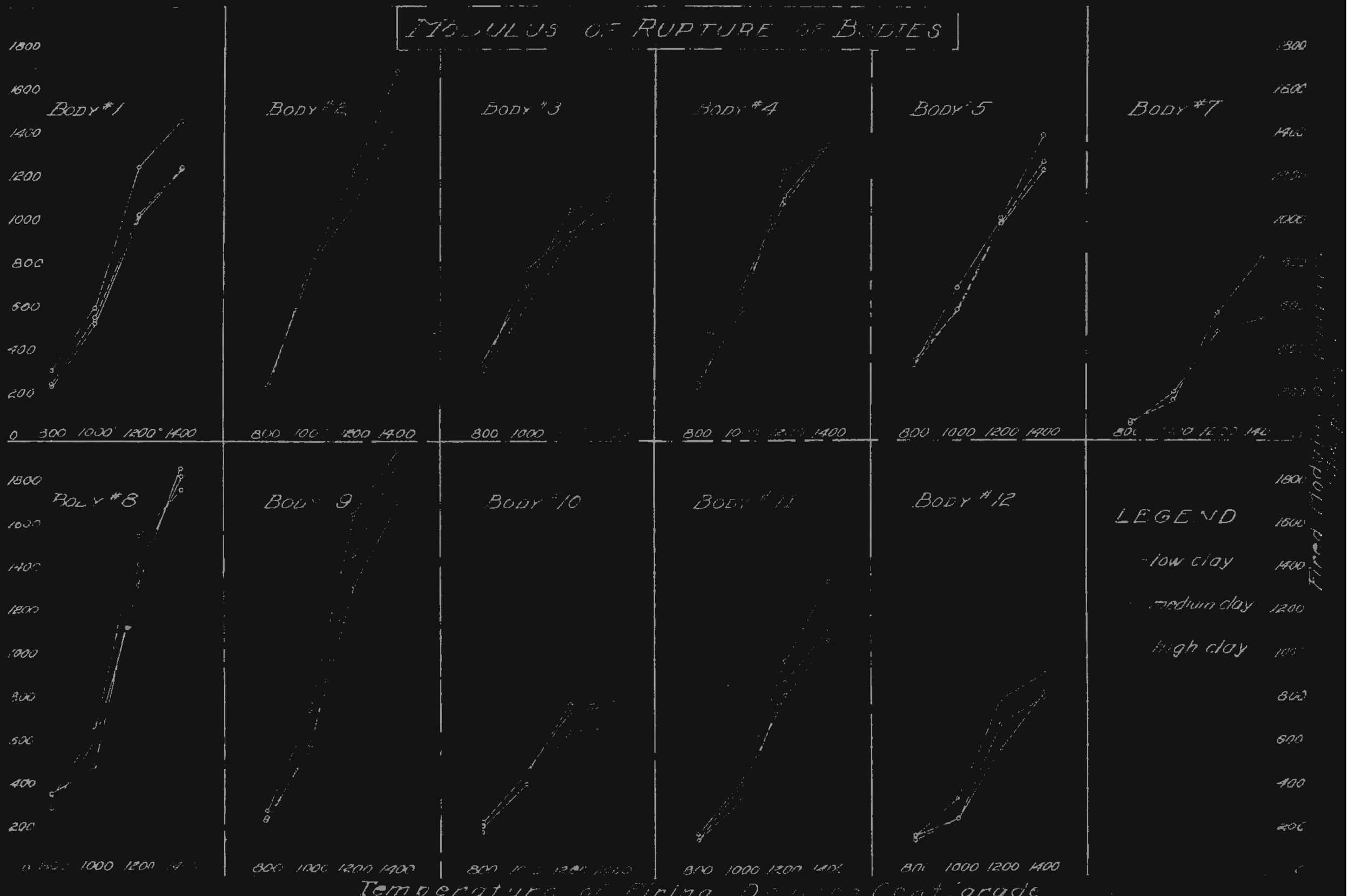


Figure 10.

Modulus of Rupture of Bodies.

Table VI.

Screen Analysis of Grog.

Mesh Number	Per cent	Cumulative Per cent
On 6 mesh	0.58	0.58
On 8	9.59	10.17
On 10	17.30	27.47
On 14	14.27	41.74
On 20	10.37	52.11
On 28	11.30	63.41
On 35	8.50	71.91
On 48	6.37	78.28
On 65	5.17	83.45
On 100	3.94	87.39
On 150	3.15	90.54
On 200	2.10	92.64
Through 200	7.36	

SUMMARY.

The results of the tests that have been described may be summarized under the heads of clays and body mixtures.

C l a y s.

Chemical analyses of the clays investigated show a widely varying alumina-silica ratio, but very little variation in the other constituents. There is no apparent relation between the chemical analyses and the deformation values. The latter range between Cone 27-28 and Cone 33-34.

The plasticity of seven of the clays permitted making the body mixture of lowest clay content of thirty per cent clay. Clays No. 8 and 9 possessed a slightly lower plasticity than the average. Clay No. 2 possessed very little plasticity, necessitating fifty per cent of clay in order that the mixture could be successfully molded. A body mixture made from twenty per cent of Clay No. 7 could be molded but was considered impractical.

Body Mixtures.

There was considerable variation in the water of plasticity required. In the body mixtures of highest clay content it ranged from 14.5 to 24 per cent. Experimental results did not show a proportionate decrease in the water of plasticity for body mixtures of lower clay content in all cases.

The drying shrinkage in the body mixtures of high clay content varied from 8 to 12 per cent with the medium clay content mixtures closely following. However, the drying shrinkage of the body mixtures of low clay content was considerably lower, being between 2 and 8 per cent.

The modulus of rupture of body mixtures fired at 1400° C. ranged from 700 to 2000 pounds per square inch. The values for the same body mixtures fired at 1200° C., 1000° C., and 800° C. were very nearly proportionately lower. The fired modulus at 800° C. never exceeded 400 pounds and averaged about 250 pounds per square inch. Variation of the clay content in the bodies had little effect on the fired modulus of rupture.

The volume shrinkage of body mixtures fired at 800° C. was negligible. Shrinkage became measurable at 1000° C. and increased gradually through the temperatures of 1100° C., 1200° C., 1300° C. and 1400° C. The greatest increase in most cases was between 1300° C. and 1400° C. The values at 1400° C. ranged from 3.6 to 11.2 per cent. One value of 14.6 per cent was probably erroneous.

Porosity and absorption for the various body mixtures followed each other very closely. Both were a minimum on the test pieces fired at 1400° C. and the maximum value came at 1000° C. Porosity at 1400° C. ranged from 14.3 to 30 per cent, while the absorption values at the same temperature were between 7 and 16. 5 per cent.

COMPARISONS.

Since this thesis covers only a part of the investigation—the comparison of various clays for zinc retort manufacture—no conclusions will be drawn. However, several comparisons may be made on the basis of those properties, which have already been determined. Clay No. 3—St. Louis Cheltenham—,due to its widespread use for zinc retorts, was used as a standard of comparison.

1. The deformation values of all clays tested exceeded that of the standard, except Clays No. 5 and 9.
2. The water of plasticity of body mixtures from Clays No. 4, 5, 7 and 8 is equal to or slightly lower than that of the standard. Body mixtures made from Clays No. 9, 2, 1, 11, 10 and 12 require more water in the order given over the standard.
3. The drying shrinkage of body mixtures made from Clays No. 4, 5, and 7 is less than those containing the standard clay, while the remainder of the body mixtures have a greater drying shrinkage.
4. The modulus of rupture of body mixtures fired at either 800° C. or 1000° C. admit of little comparison. However, when fired at 1200° C. and 1400° C. the modulus of rupture of body mixtures made from Clays No. 7, 10, and 12 show a value lower than the standard, from Clay No. 11 approximately equal, and from Clays No. 1, 5, 4, 2, 8

and 9 higher values in the order given.

5. The volume shrinkage of body mixtures made from all clays with the exception of Clay No. 5, in general exceeds that of the standard.

6. The porosity and absorption of body mixtures made from Clays No. 4, 9, 8, 5, and 2 are approximately equal to or less than the standard, while the body mixtures made from Clays No. 1, 11, 7, 10, and 12 are higher than the standard in both porosity and absorption.

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