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VISCOSITY OF PORCELAIN BODIES

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VISCOSITY OF PORCELAIN BODIES

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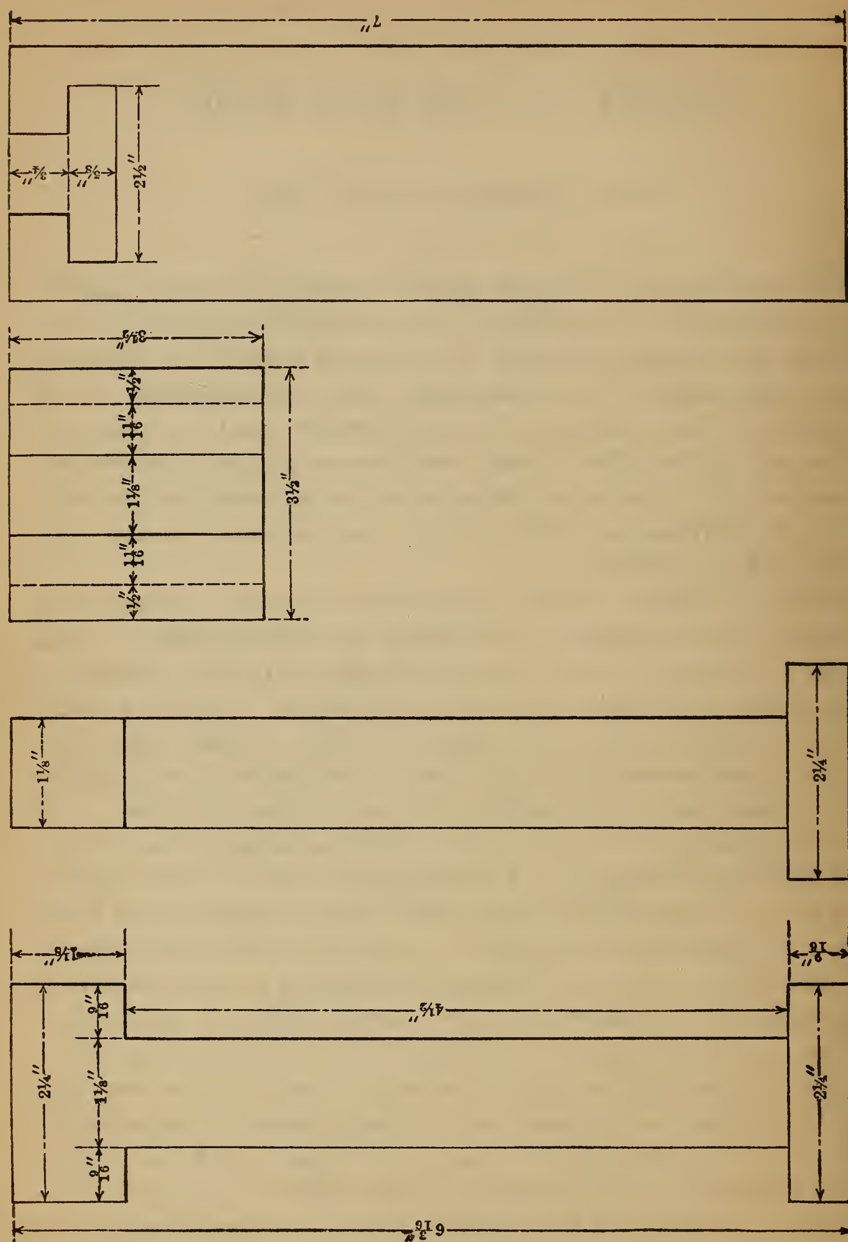
The vitrification of ceramic bodies requires for its explanation two assumptions, the existence of a considerable superficial force tending to contract the mass, and lowered viscosity or softening which will permit the displacement and rearrangement of the molecules. The existence of surface tension must be considered as proven in the light of many well-known physical phenomena. Likewise, there can be no doubt as to the softening of the body, since the deformation observed only too frequently clearly indicates such a condition.

Owing to the fact that no numerical values are available with reference to the degree of softening of ceramic bodies, it was thought desirable to carry on experiments with the purpose of determining the degree of viscosity reached by a series of bodies of the porcelain type. As a measure of the viscosity, the deformation under tensile stress was used. For this purpose specimens of porcelain body were made up of such shape that they could be hung from a fire-clay grid and a weight attached to the bottom. The shape and dimensions of the pieces are shown in the diagrams of Fig. 1. The length of the square bar between the end pieces was 4.5 inches and the width 1.112 inches, mold measurements. It was desired to have specimens possessing a cross section of approximately 1 square inch after burning them to vitrification.

The load was applied to each bar (after firing to cone 10) by means of a fire-clay piece provided with a groove into which fitted the bottom part of the porcelain. It was decided to maintain the tensile load as closely at 5 pounds per square inch as possible. After burning the test bars their cross section was measured accurately by means of a micrometer caliper and the average cross section computed, based upon 10 measurements. For each bar



FIRE CLAY WEIGHT

Fig. 1

Porcelain Test Piece

the weight of the corresponding fire-clay load piece was then adjusted by chipping so that the initial tensile strain was 5 pounds per square inch. The elongation was determined by measuring the distance between two fine lines 9 cm. apart.

The porcelain series embraced composition ranging from 35 to 50 per cent of clay and from 10 to 25 per cent of feldspar. The clay material was introduced as North Carolina kaolin, Georgia kaolin, and Tennessee No. 3 ball clay in the proportions of 5: 1: 1. In Table 1 the chemical analyses of the raw materials are given and in Table 2 the composition of the bodies.

The body constituents were ground together in the slip state in the ball mill for two hours, then screened and filter pressed. After wedging the mass it was pressed into the shape shown. After thorough drying all of the specimens were fired to cone 10 before being subjected to the tension tests. The bars were then suspended from H-shaped fire-clay grids, placed firmly upon fire-brick piers and the proper weight piece attached to each. The firing for the tensile tests was carried to the following temperatures: 1065°, 1100°, 1125°, 1160°, 1190°, 1220°, 1250°, 1280°, and 1310° C. Up to 800° the burning was carried at a convenient rate, but from this point on great care was taken to raise the temperature at the rate of $33\frac{1}{3}°$ per hour. Firing was stopped as soon as the proper temperature was reached. No elongation was observed until the 1160° burn.

The numerical results of the work are compiled in Table 3. The ink test was applied to the bodies after burning them to the maximum temperature, by noting the absorption of ink after washing off the spot with oxalic acid and water.

It will be noted from the table that complete vitrification, as measured by the ink absorption, takes place in no case with less than 19 per cent of feldspar.

It is interesting to observe, also, that softening occurs at as low a temperature as 1160° only in the case of the larger feldspar contents, 22 and 25 per cent, and even these amounts do not lower the viscosity with the maximum clay content.

Small percentages of feldspar, 10 and 13 per cent, bring about softening only with low clay content, 35 per cent, and then only at 1280°. Even with 16 per cent feldspar, elongation does not

appear until 1250° to 1280° has been reached. High feldspar contents, on the other hand, show deformation at as low a temperature as 1160° with 35 per cent of clay. The decreasing effectiveness of the fluxing constituent in bringing about softening with increasing clay is clearly shown, inasmuch as with 50 per cent of clay and 25 per cent feldspar elongation does not begin before 1220°.

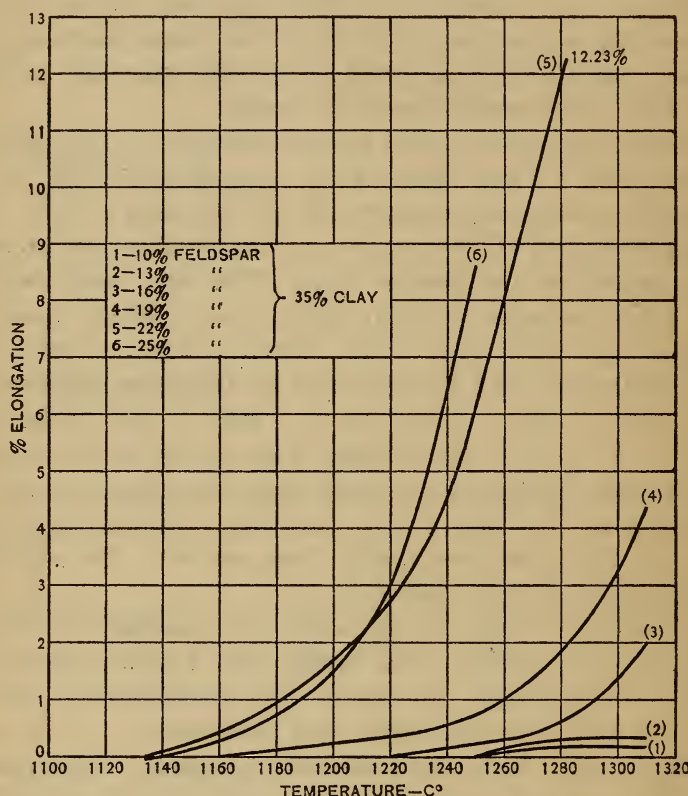


Fig. 2

The diagrams of Figs. 2, 3, 4, and 5 illustrate the elongation behavior of the bodies for the clay contents of 35, 40, 45, and 50 per cent.

In the 35 per cent clay series, Fig. 2, a sudden decrease in viscosity seems to occur between 19 and 22 per cent of feldspar. The latter amount is clearly excessive for this body. It would seem as if up to 19 per cent the feldspar formed a viscous solution

with the other constituents, while at 22 per cent it was in excess and, due to its own low viscosity, caused the body to soften rapidly.

From this it appears that it is rather important to fix the feldspar content at the lowest value consistent with the desired physical properties.

In the 40 per cent clay series, Fig. 3, the curves are grouped together much more closely and no such sharp break in viscosity is observed, for which behavior the increased clay content is undoubtedly responsible. The elongation values also are smaller—

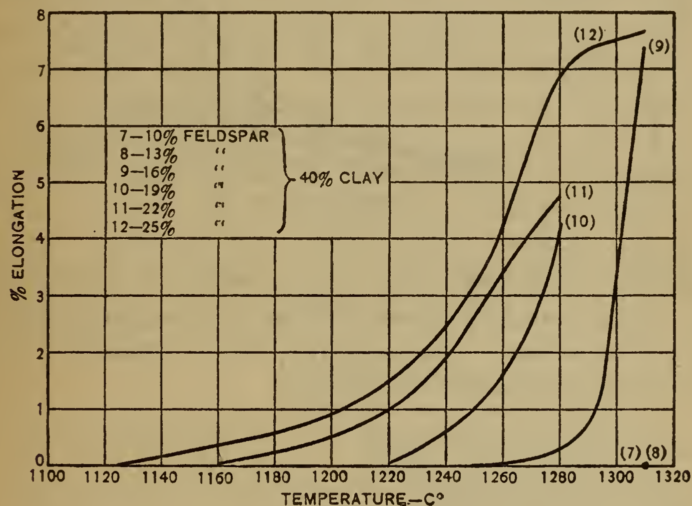


Fig. 3

i. e., the viscosities greater. The curves, however, are quite steep, indicating a rapid decrease in viscosity or softening with temperature which is not a desirable condition.

In Fig. 4 not only is a regular gradation observed between the different feldspar contents of the 45 per cent clay series, but the curves are very much less abrupt and thus indicate more gradual changes in viscosity between given temperatures. The rate of viscosity change is proportional to the feldspar content. The deformation values are considerably lower than for the 40 per cent clay series.

The diagram of Fig. 5 (50 per cent clay series) shows a marked drop in the deformation values from the preceding bodies. The viscosity thus has increased very decidedly, which means lessened

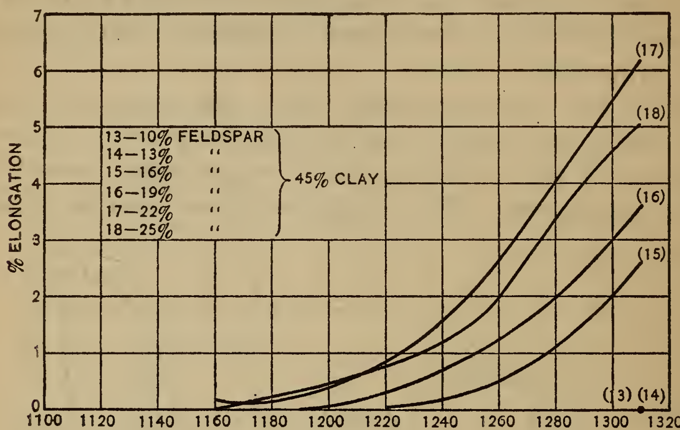


Fig. 4

deformation. It is noted also that the effect of the feldspar increases is very much less marked than in the preceding cases. The rate of decrease in viscosity with rise in temperature also is very much less pronounced in this case.

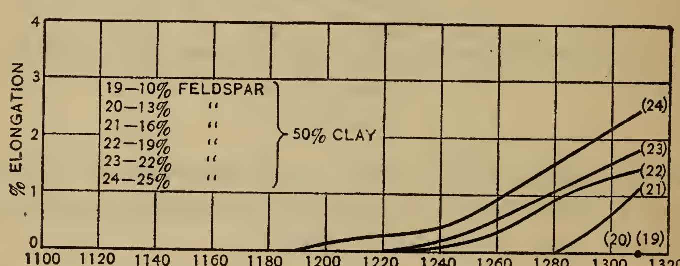


Fig 5.

From the foregoing results it seems, then, that for the temperatures and the raw materials under consideration, complete vitrification is not possible with less than 19 per cent of feldspar. Excess of feldspar is undesirable owing to the lowered viscosity brought about by it.

The higher the clay content the less marked does the effect of feldspar become. A sharp line of demarcation appears between the bodies containing less than 45 per cent clay and those of higher clay content. The former possess a very much higher temperature coefficient of viscosity decrease and hence are more subject to deformation. A lower clay content than 45 per cent is therefore undesirable and may explain the difficulties experienced with bodies of the Seger porcelain type. The strength of porcelain bodies under tensile stress, at the kiln temperatures considered, has been found to be quite low, approaching 5 pounds per square inch quite closely with maximum elongation and is but a small fraction of the tensile strength at ordinary temperatures. As to the permissible numerical elongation value under a load of 5 pounds per square inch, no exact deductions can be made, but it probably lies between 5 and 6 per cent.

This method of studying bodies is capable of producing valuable results and might with advantage be applied to clays and other mixtures. In further work along this line a different style of bar is being used, resembling at the ends the shape of cement briquettes. The length of the straight portion is 4 inches.

TABLE 1

	North Carolina kaolin	Tennessee ball clay	Georgia kaolin	Feldspar	Flint
	Per cent	Per cent	Per cent	Per cent	Per cent
Silica	45.84	50.80	45.69	70.79	99.23
Alumina	38.46	32.09	37.52	16.75	.32
Ferric oxide	.57	1.56	.53	.22	.10
Titanium oxide	.11	1.23	1.61	....	....
Calcium oxide	.19	.18	.18	.24	.08
Magnesium oxide	.08	.40	.25	.18	.13
Sodium oxide	.07	.38	.11	3.29	....
Potassium oxide	.35	1.14	.20	8.26	....
Loss on ignition	14.44	12.49	14.05	.46	.22
Total	100.11	100.27	100.14	100.19	100.08

TABLE 2

Composition of Bodies

Number	Per cent clay	Per cent feldspar	Per cent flint
1	35	10	55
2	35	13	52
3	35	16	49
4	35	19	46
5	35	22	43
6	35	25	40
7	40	10	50
8	40	13	47
9	40	16	44
10	40	19	41
11	40	22	38
12	40	25	35
13	45	10	45
14	45	13	42
15	45	16	39
16	45	19	36
17	45	22	33
18	45	25	30
19	50	10	40
20	50	13	37
21	50	16	34
22	50	19	31
23	50	22	28
24	50	25	25
25 [1]	....	....	....

[1] Commercial porcelain body.

TABLE 3

Number	Per cent elongation at degrees centigrade						Ink test after firing to 1310°	Remarks
	1160°	1190°	1220°	1250°	1280°	1310°		
1					0.13	0.13	Strong stain	
2					.25	.27	do	
3				0.20	.56	2.02	Stained	
4		0.14	0.34	.76	1.83	4.35	No stain	
5	0.39	1.29	2.79	6.17	12.23		do	Partly pulled in two at 1280°
6	.22	1.04	3.02	8.56			do	Partly pulled in two at 1250°
7							Strong stain	
8							Stain	
9					.28	7.40	Strong stain	Partly pulled apart at 1310°
10				.94	4.22		Faint stain	Partly pulled apart at 1280°
11		.36	.93	2.72	4.77		No stain	
12	.34	.62	1.40	3.14	7.01	7.62	do	Pulled apart, 1310°
13							Strong stain	
14							Stained	
15				.28	1.04	2.66	do	
16			.28	.95	1.99	3.65	No stain	Broke, 1310°
17	.17	.25	.85	2.03	4.09	6.14	do	
18		.34	.73	1.52	3.37	5.02	do	
19							Strong stain	
20							Stain	
21						1.15	Faint stain	
22				.17	.96	1.49	No stain	
23				.25	1.01	1.80	do	
24			.26	.59	1.53	2.49	do	
25			.14	.39	2.01	4.08	do	Do.

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