one (1.5 to 3 g) the upper surface, and one (1.5 to 3 g) the lower surface. The object was to determine the content of free alkali and its approximate degree of migration. The dried sample in each case was digested with 200 ml of water on a steam bath overnight, filtered, and the residue leached a second time overnight with the same quantity of water. The filtrate from the two leachings was titrated with 0.1 *N* hydrochloric acid.

(d) SIEVE ANALYSIS

The sieve analysis was made by the wet method [4] on a sample of approximately 200 g of each mortar. United States Standard Sieves Nos. 20, 40, 60, and 100 were used. Sieving of the dried residue was accomplished with a machine.

(e) PYROMETRIC CONE EQUIVALENT

The pyrometric cone equivalents (softening points) were determined according to ASTM standard method, serial designation C 24–35.[5] Cones were made from the mortars both before and after calcining at approximately 1,200° C. In either case, after placing the cones in plaques, they were heated to about 1,200° C and cooled before testing.

(f) FUSION BLOCK

The blocks were of a refractory composition (pyrometric cone equivalent 32). The compartment for holding the test material was made approximately ½ in. deep in some blocks and ⅛ in. deep in others. The mortar was dried, then ground to pass a No. 70 United States Standard Sieve, and wetted slightly with a solution of gum tragacanth before being placed in the compartments. One set of blocks filled with mortar to a depth of ½ in. was heated at 1,425° C for 5 hours and a second set at 1,500° C for 5 hours. One series of blocks filled with mortar ⅛ in. deep was heated at 1,500° C for 5 hours. After the mortars cooled, they were examined for shrinkage, bubbles, glassiness, and flow.

(g) TROWELING

In order to eliminate the personal factor, a machine was built to simulate the motion of the mason's trowel while spreading the mortar on a brick. The machine is shown in figure 1. The brick was fixed in position in the machine, and the mechanical trowel moved backward and forward lengthwise over the brick. The trowel was actuated by two pistons driven by water pressure. A constant speed of travel of the trowel throughout the stroke was assured by a constant head of water acting on the pistons, which were directly connected to the trowel. The machine automatically provided for the two-way motion of the trowel and the thickness of the prospective mortar joint. The minimum automatic reduction in thickness of layer of mortar with each stroke of the trowel was 0.005 in. The trowel, in the form of a trough, was made from 1/16-in. sheet iron and was 6.5 in. long and 1 in. wide. The sides of the trough had an angle of 120° between them. The outside corner of the trowel was nearest the 9- by 4½-in. face of the brick, and the two sides made equal angles (30°) with the face. The trowel was placed so that its axis made an

[4] The manner of conducting the test was in general similar to method C 92–36, p. 31, American Society for Testing Materials, Manual of ASTM Standards on Refractory Materials, 1937.
[5] Described in American Society for Testing Materials Manual of ASTM Standards on Refractory Materials, 1937, p. 53.

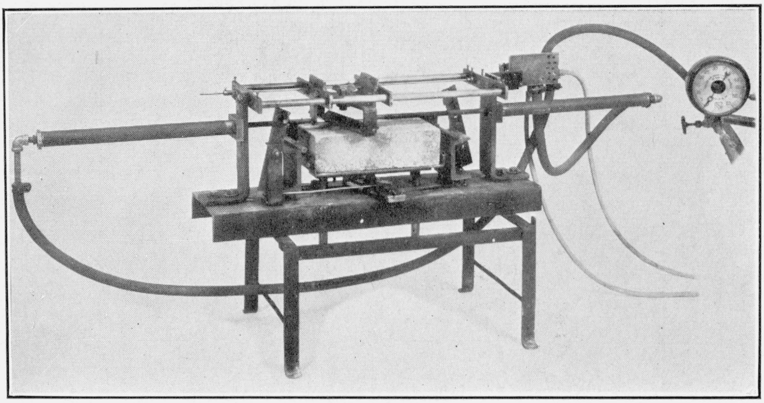

FIGURE 1.—*Machine used for simulating the motion of the mason's trowel while spreading mortar on a brick.*

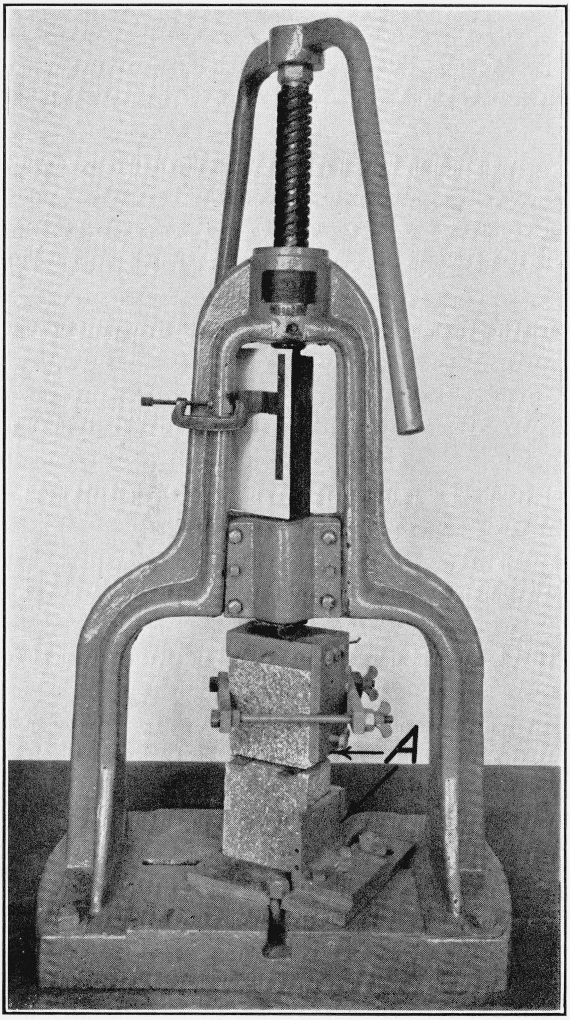

FIGURE 2.—*Screw-press with two half-brick in position, showing the manner in which a brick-and-mortar assemblage was made.*

angle of 10° with the plane of the 2½- by 4½-in. face of the brick. This angle has no special significance as far as the troweling operation is concerned. The trowel operated at a speed of 24 strokes per minute, and the water pressure was maintained at 5 ± 1 lb/in.^{2} during the troweling operation.

Four troweling tests were made of each mortar, as follows: The brick was first placed in a wooden frame, the inside dimensions of which corresponded to the outside dimensions of the brick, except that it was 2¾ in. high. The mortar was spread evenly by hand troweling on the upper 9- by 4½-in. face of the brick and also flush with the edge of the frame, thus forming a uniform ¼-in. coating over that face. The mortar-covered brick was removed from the frame and immediately placed in the machine, preparatory to making the troweling tests. From 2 to 3 minutes were required for placing the mortar on the brick and fastening the brick in the machine. The first test consisted in reducing the ¼-in. layer to a ⅛-in. layer in one stroke. The second test consisted in reducing the ¼-in. layer to a ⅛-in. layer in 25 strokes. The third test reduced a ¼-in. layer to a 1/16-in. layer in one stroke. The fourth test reduced the ¼-in. layer to a 1/16-in. layer in 37 strokes.

(1) *Appearance before drying.*—On completion of the troweling tests, observations were made in each case on the appearance of the layer of mortar, as an indication of whether it had satisfactory or unsatisfactory troweling properties.

(2) *Appearance after drying.*—The mortar-covered brick thus treated were set aside for drying at room temperature under ordinary atmospheric conditions. After drying, the mortar was examined to determine whether it had dried free of shrinkage cracks, had curled, and whether it had separated from the brick.

(h) TRANSVERSE STRENGTH AND LINEAR SHRINKAGE

The transverse strength (modulus of rupture) was determined on bars 6 by 1 by ¼ in., over a 5-in. span. The bars were made in brass molds, which rested on slips of newspaper; these in turn rested on glass plates. The newspaper was used because it adjusted itself more readily than other types of paper to the movements of the specimen during shrinkage. Because of the different consistencies of the mortars as taken from the containers it was necessary to use three different methods for preparing specimens, namely:

1. Casting the mortar into the mold, jolting the mold slightly to level the mortar, and not smoothing it with a spatula.
2. Pressing the mortar into the mold and smoothing it with a spatula on top side only.
3. Pressing the mortar into the mold and smoothing it with a spatula from both top and bottom.

After filling the mold, the specimen in the mold and the attached paper were placed on a fire-clay brick with paper side down. Within a few minutes an initial set would take place, and the mold was then removed from the specimen. A safety-razor blade was used to separate the mold from the specimen. The specimens were covered with a damp cloth until placed in a constant humidity room for the routine drying treatment. To prevent excessive warping during drying, the following drying schedule was followed for each mortar: 48 hours at approximately 60- to 65-percent humidity [6] and at 20 to 22° C; 18 hours (overnight) at ordinary laboratory temperature and humidity; and 27 hours in a drying oven at approximately 105 to 110° C. In several cases it was necessary to heat the specimens slowly up to 105° C to prevent bloating of the specimens. The paper was removed while the specimens were still in the constant-humidity room, but not until they had become sufficiently hard to permit handling without breakage. The side of the specimen originally next to the paper was identified as the "bottom" of the specimen, even though the bars were turned over a number of times to prevent warpage after the removal of the paper. Five specimens were tested with the original bottom on the bottom during the breaking of the specimen, and a second set of five with the original bottom on top during this test.

(1) *Heated and cooled specimens.*—To determine whether any changes in strength took place because of heating and cooling the mortars, the modulus of rupture of the bar specimens was determined after drying and also after heating them for 24 hours at different temperatures and cooling. Different lots of specimens of all mortars were heated for 24 hours at 500, 750, and 1,000° C, and for 1 hour at 1,310 and 1,350° C; specimens of mortars Nos. 1 to 5, inclusive, also received heat treatments for 24 hours at 250, 625, and 850° C. No lot of specimens received more than one heat treatment.

The over-all linear shrinkage of the specimens was measured before they were tested for transverse strength.

(2) *Specimens tested at 750° C.*—Specimens 10 by 1 by ¼ in. were prepared from six mortars for modulus of rupture tests at 750° C. After drying, each test specimen was heated to 750° C and maintained at approximately that temperature for one hour before it was broken in bending over an 8-in. span. After cooling, the two portions of the broken specimen were tested at room temperature for breaking strength over a 3-in. span.

(i) POROSITY AND SOLUBILITY

Specimens of mortars Nos. 1 to 5, inclusive, heated at several different temperatures and cooled, were tested for porosity. The determinations were made in accordance with the test method adopted by the American Ceramic Society.[7]

The relative water solubility of the alkali salts in the specimens tested for porosity was obtained by titrating the liquid (distilled water), in which the porosity specimens had been boiled, against a 0.1 N solution of hydrochloric acid.

2. ASSEMBLAGE OF TWO HALF-BRICK AND MORTAR

The standard size [8] (9-inch) brick used in the tests for the determination of strength of bond and time of set of the various mortars were of the stiff-mud type and had a moderately coarse texture and an absorption of 8.6 percent. They were cut by means of an abrasive wheel into two equal parts and parallel to the 2½- by 4½-in. faces. They were then placed overnight in a drier maintained at approximately 90° C. A laboratory screw press (fig. 2) was slightly changed

[6] These humidity and temperature ranges were conveniently available at all times in one of the rooms at the Bureau, and use was made of those facilities.
[7] J. Am. Ceram. Soc. **11**, 456 (1928).
[8] The effect of strength and total absorption of bricks on the strength of mortar joints was discussed by R. A. Heindl and W. L. Pendergast in the Bul. Am. Ceram. Soc. **15**, 182 (1936).

to accommodate a 9-in. brick on end. A jig, or aligning guide, *A*, and clamp were attached to the frame of the press to prevent lateral motion of the two halves of the brick when they were forced together with the mortar between them. The operation of bonding was as follows: After clamping the two halves of the brick in place with the molded faces in contact,[9] two spacers were placed on the lower half of the brick and the upper half was then brought in contact. These spacers were 1/16 in. thick when joints for bonding strength of mortars were being prepared, and 1/4 in. thick when joints for "time of set" tests were being prepared. With the two half-brick in contact, the reading indicated on a scale was noted, the upper section of the brick was then raised about 3/4 in., and the spacers were removed. Approximately double the amount of mortar required for the joint was placed between the two half-brick, and the upper portion was again lowered until the scale reading corresponded to that first noted. The excess material forced from the joint was then removed and the specimen released from the clamp. The entire operation consumed about 3/4 minute.

A series of specimens was also prepared for the purpose of determining the bonding strength of the mortars when used in a dipping consistency. The end surface of the half-brick was dipped in the mortar and two 1/16-in. spacers placed on it before the dipped end of the second half of the brick was brought in contact. A *C*-clamp was used to squeeze out the excess mortar by forcing the two half-brick together.

(a) SETTING TIME OF MORTAR

The bonded specimen, prepared with the 1/4-in. joint of mortar, after removal from the press was set on end on the floor. After the lapse of 3 minutes from the time the mortar first touched the brick, a 50-lb. weight [10] was gently set on the end of the brick, and it was noted whether the mortar was squeezed from the joint. If the mortar gave no indication of flowing from the joint, a second specimen was tested, the elapsed time between the application of the mortar and load being but 2 minutes. If the result was still negative, then the elaspsed time was reduced to 1 minute for a third specimen. If, on the other hand, the mortar flowed from the joint at the end of the 3-minute period, additional tests on newly prepared specimens were made after longer periods, increasing by 3-minute increments, up to 15 minutes. If the mortar still flowed, the increment was lengthened to as much as 10 minutes, depending on the fluidity of the mortar. When a sufficiently long interval was reached so that no flow was observed, then this period would be reduced by 1-minute decrements until the point was determined to the nearest minute when the mortar ceased to flow. The time elapsing between placing the mortar on the bricks and the attainment of sufficient stiffness to prevent flow when loaded is designated "time of set."

(b) TRANSVERSE STRENGTH

After bonding the two half-brick, the assemblages intended for testing the strength of the mortar joint were stored on end, care being

[9] The original surfaces of the brick were bonded to simulate service conditions.

[10] The decision to use a 50-lb. load and a 1/4-in. mortar joint was reached after experiments with 25-, 50-, and 100-lb. loads and 1/16-, 1/8-, and 1/4-in. joints. The behavior of the chosen combination, with the particular brick used in these experiments, indicated that a reasonably good spread in time-of-set values between the different mortars would be obtained.

taken not to jar them while the mortar was still damp. Those which were to be tested without heat treatment, other than a final drying at 105° C, were stored in the constant-humidity room and given the same drying treatment as that of the bar specimens already described. Those which were to be tested, after having been heated at different temperatures and cooled, were stored in the laboratory. In all cases brick-and-mortar assemblages were heated simultaneously and in the same furnace with the bar specimens from the corresponding mortar. The modulus of rupture of the mortar joint was determined over an 8-in. span.

3. PIER OF THREE BRICK AND MORTAR

A second type of brick-and-mortar assemblage was made which consisted of a pier of two standard size brick and two half-brick. Three of these piers were laid up with a 1/16-in. dipped joint and three with a 1/8-in. troweled joint. The two half-brick with the two original end surfaces toward one another were laid flat between the two full-sized brick. Each pier, therefore, had two horizontal joints and one vertical joint. For the dipped joint, 1/16-in. drill rods were used as spacers, and for the larger joint 1/8-in. spacers. The troweled joint was made entirely with mortar of a troweling consistency.

The piers were examined for defects of the mortar and mortar joint after curing and drying as previously described, again after heating at 750° C for 24 hours, again after heating at 1,425° C for 24 hours, and lastly after heating at 1,500° C for 5 hours. Two piers of each thickness of joint were heated at each temperature. Since three piers only were made, it was necessary to heat some piers at successively higher temperatures.

IV. RESULTS AND DISCUSSION

1. MORTAR

(a) SEGREGATION, CONDITION, AND CONSISTENCY

The difficulty of preventing segregation of the solid material from the liquid in a mortar is indicated by the information on supernatant liquid given in table 1, column 2. Fifteen of the twenty mortars showed an appreciable layer of liquid, one just a trace, and four no liquid on top of the solid material, when the container was opened. The containers had been in storage from 9 to 33 months.

The length of time that a mortar had been in storage would, in some cases, affect its working properties.[11] Not only was it very difficult to remove some of the mortars from the containers, but it would have been practically impossible to recombine the liquid and solids of these mortars by mixing them in a mortar box in the usual manner. However, in the laboratory the kneading machine recombined the liquids and solids within the allotted time. Table 1, column 3, gives the months of storage of various mortars before the containers were opened, and shows that 5 of the 20 mortars were rated as difficult to work [12] after being in storage from 9 to 17 months. Information obtained on 3 of the 5 mortars indicated that they were workable after shorter periods in storage. For the remaining 15 mortars, all of which were

[11] Silicate of Soda Cements (Philadelphia Quartz Co. Bul. 241, p. 4, 1936).

[12] This rating, based solely on the judgment of the investigators, classified these mortars as being commercially unsatisfactory as far as this property is concerned.

rated as workable, the maximum period of storage for any one mortar was 33 months.

As taken from the container, the consistency of each mortar for troweling purposes is given in table 1, column 4. Ten of the mortars were rated good, nine fair, and one poor. A word or two in explanation of the fair or poor classification is given for some mortars. Two ratings are given for mortars 2, 11, and 16, because of variation between containers. The addition of water would undoubtedly have improved the working consistency of some of the mortars rated other than "good," but as will be shown later, this might have been to the disadvantage of other properties. Furthermore, unless the producer specifies the quantity of water which is to be added, it cannot be expected that the properties obtained after the addition of water will correspond to those claimed by the producer for the mortar in a troweling consistency.

Information on the ease of changing the mortar from the as-received condition to a consistency suitable for dipping, and the workability of the latter mixture is given in table 1, column 7. The majority of the mortars could be brought to a satisfactory dipping consistency with less than 15 minutes of mixing. Such mortars were considered as having "mixed readily." Mortars 10, 14, 16, and 18 required approximately one-half hour of mixing, and 3 and 15 approximately 1 hour, to bring these mortars to a dipping consistency. The time required to bring them to a dipping consistency was considered excessive; therefore, it was reported in the table that they "did not mix readily."

The workability of the dipping mixture was considered "good" if the mortar remained in suspension, the excess mortar could readily be forced from between the brick, and the brick had no tendency to slip out of position after laying. It was considered "poor" if the mixture dried so quickly after dipping the brick that it was very difficult to force the excess mortar from between the brick as soon as they were laid. The rapid loss of water in some cases (mortars 3 and 15) may have been due to the presence of the large percentage of material retained on a No. 60 sieve. Mortars 10 and 16 failed to stay in suspension after mixing, but could be used if constantly agitated. Mortar 21 was different from the others in that most of it would slip from the brick as it was withdrawn from the dipping mixture.

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TABLE 1.—*Some properties of air-setting refractory mortars marketed in the wet condition*

Mortar number	Supernatant liquid	Condition after months [1] in storage	Consistency [2] (troweling) after mixing	Loss of water at 105° C. Based on dry weight [3]: As received	Loss of water at 105° C. Based on dry weight [3]: For dipping	(a) Ease of changing consistency; (b) workability of dipping mixture	Alkali as Na_2O: Upper surface	Alkali as Na_2O: Lower surface	Alkali as Na_2O: Cross section	Sieve analysis: Retained on No. 40	Sieve analysis: Passed No. 40; retained on No. 60	Sieve analysis: Passed No. 60; retained on No. 100
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
				%	%		%	%	%	%	%	%
1	Yes	Workable; 16	Fair	26.5	42.5	(a) Mixed readily (b) Good	2.85	2.71	2.79	1.0	1.8	6.2
2	do	Workable; 17	Good Too liquid	28.2 32.8	51.0	(a) Mixed readily (b) Good	2.64	2.33	2.48	1.2	1.3	27.6
3	do	Workable; 16	Fair (short, stiff).	23.1	41.0	(a) Did not mix readily. (b) Dried too fast	1.95	1.94	1.94	.1	13.0	21.2
4	do	Workable; 12	Good	25.5	38.7	(a) Mixed readily (b) Good	3.14	2.97	3.08	0	.5	6.6
5	No	Difficult to work; 9.	do	28.5	30.7	(a) Mixed readily (b) Good	2.08	1.55	1.75	0	.6	4.7
6	do	Workable; 20	Fair (short)	23.7	36.2	(a) Mixed readily (b) Fair	2.26	1.78	2.02	.1	7.3	24.8
8	Yes	Difficult to work; 13.	Good	32.3	34.7	(a) Mixed readily (b) Dried too fast	1.60	.99	1.22	5.7	7.8	10.2
9	do	Workable; 16	do	24.4	37.9	(a) Mixed readily (b) Good	3.00	2.71	2.94	.2	2.2	13.2
10	do	do	Good (sticky)	23.7	28.5	(a) Did not mix readily. (b) Did not stay in suspension.	3.54	3.25	3.40	.1	.4	2.2
11	No	Workable; 23	Fair Good	20.6 25.3	28.5	(a) Mixed readily (b) Good	2.24	1.67	1.88	1.0	6.4	14.9
12	Yes	Workable; 33	Fair (thin)	26.9	26.9	(a) Not changed (b) Slightly thick	2.93	2.52	2.73	0	0	0
13	do	Workable; 16	Poor (short, stiff).	23.9	30.8	(a) Mixed readily (b) Poor	2.75	2.32	2.55	2.6	5.8	12.2
14	Trace	Difficult to work; 17.	Fair (fatty, stiff).	24.3	41.4	(a) Did not mix readily. (b) Good	2.13	1.97	2.03	.1	3.8	10.2
15	Yes	do	Fair (short, stiff).	23.4	42.5	(a) Did not mix readily. (b) Poor	1.64	1.18	1.32	.8	14.6	17.3
16	do	Difficult to work; 16.	Good Poor	29.6 22.9	40.2	(a) Did not mix readily. (b) Did not stay in suspension.	2.61	2.31	2.34	1.7	14.5	19.8
17	do	Workable; 17	Good	20.2	30.7	(a) Mixed readily (b) Good	2.50	2.40	2.45	.3	6.0	9.4
18	do	do	do	21.6	34.6	(a) Did not mix readily. (b) Good	2.60	2.40	2.43	1.4	4.9	20.9
19	do	do	do	20.1	35.4	(a) Mixed readily (b) Good	2.47	2.25	2.37	.3	5.5	13.4
20	do	do	Fair (stiff, fatty).	21.5	34.7	(a) Mixed readily (b) Fair	2.65	2.43	2.52	.1	10.2	19.2
21	No	Workable; 20	Fair (stiff, short).	22.7	39.6	(a) Mixed readily (b) Fair	3.25	2.87	2.99	.6	5.5	6.8

[1] Numerals represent number of months in storage. First containers of mortars 14, 15, and 16 opened after 1, 8, and 2 months, respectively, at which time they were satisfactory for working.

[2] Directions on container implied that most mortars were of a trowelling consistency ready for use. Considerable differences in water content between original and later shipments of mortars 2, 11, and 16 were noted; therefore, the two conclusions are given.

[3] Mortars 22, 23, and 24 were received late; consequently, they were not subjected to all tests. The water content for these "as received" was 20.5, 29.9, and 17.9 percent and for "dipping" 47.2, 31.6, and 36.0 percent, respectively. All three mixed readily to a dipping consistency.

TABLE 1.—*Some properties of air-setting refractory mortars marketed in the wet condition*—Continued

Pyrometric cone equivalent		Troweling. Spreading and reducing layer from—				Appearance after troweling and drying		Time of set (minutes)
Raw	Calcined	¼″ to ⅛″ in 1 stroke	¼″ to ⅛″ in 25 strokes	¼″ to $\frac{1}{16}$″ in 1 stroke	¼″ to $\frac{1}{16}$″ in 37 strokes	Curled	Cracked	
(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Cone 23	*Cone* 23	Fair	Good	Fair	Fair	No	Slightly	*min* 2
20	20	Very good	Very good	Very good	Very good	Moderately	do	60
32	32	Good	Good	Poor	Fair	do	Badly	1
34	34	Very good	Very good	Very good	Very good	Slightly	Slightly	60
33	33	Good	Good	Good	Good	Moderately	Badly	2
32–33	32–33	Fair	Poor	do	Poor	Slightly	Slightly	1
29	29	Good	Good	do	do	do	do	2
30	30	Very good	Very good	Very good	Very good	No	No	48
20	19	do	do	do	do	do	do	90
37	37	Good	Good	Good	do	Slightly	Slightly	1
27–28	28	Very good	Very good	Very good	Very good	No	No	24
32–33	32–33	Poor	Poor	Poor	Fair	do	do	60
28	27	Good	do	Good	Poor	Moderately	Moderately	1
30	30	do	do	do	do	Badly	do	1
26–27	26–27	do	do	do	do	Moderately	Badly	1
31	31	do	Fair	do	Good	Slightly	No	3
18	18	Very good	Good	Very good	do	do	Slightly	2
27	27	do	Very good	do	Very good	No	No	3
14	15	Fair	Poor	Poor	Poor	Slightly	Slightly	1
[4] 29	23–26	Good	do	do	Fair	Badly	Moderately	1

[4] Very difficult to obtain satisfactory end point.

(b) WATER LOSS AT 105° C

Based on the dry weight, the loss of moisture at 105° C of the 23 mortars "as received" ranged from 17.9 to 32.8 percent, and for the material in a dipping consistency the range was from 26.9 to 51.0 percent. The values are given in table 1, columns 5 and 6. The relative water content of the mortars as received was not an indication of their troweling consistency (table 1, column 4). A second shipment of mortar 2 contained 2.6 percent more water than the first, which changed it from a good troweling consistency to a consistency that was considered too fluid, since it would not support the brick. A second shipment of mortar 11, which contained approximately 5 percent more water than the first, was rated "good" compared with a rating of "fair" for the first shipment. The second shipment of mortar 16 was rated "good." It contained about 7 percent more water than the first which was rated "poor." There was a great deal of difference in the quantity of water necessary to change the various mortars from a troweling consistency to a dipping consistency.

(c) ALKALI CONTENT

The total alkali content of the mortars, in terms of sodium oxide, ranged from 1.22 to 3.40 percent (table 1, column 10). The alkali content near the upper surface and that near the lower surface of the dried specimens are given in columns 8 and 9, respectively. The migration of the alkali salts, which it is assumed takes place during the drying of the mortar specimens, varied greatly. For example, in mortars 3 and 17 the migration was negligible, but in mortars 8, 11, and 15 the migration was pronounced. On the whole there appeared to be no relation between migration and water loss when all the mortars were considered. However, a very good direct relation is indicated for all the four mortars (5, 8, 10, and 12) whose consistency was such that the test specimens were made by casting. Since only four mortars are included in this class, the relation may result from chance, even though the range in both water content and migration was great.

(d) SIEVE ANALYSIS

The results obtained in the sieve analyses are given in table 1, columns 11, 12, and 13. The residue on a No. 20 sieve is not given, because 15 of the 20 mortars showed 0.1 percent or less retained on this sieve. Only one mortar (8) showed as much as 1 percent retained. Furthermore, 15 of the mortars showed 1 percent or less residue retained on a No. 40 sieve. The material which would not pass a No. 100 sieve ranged from 0 to 35 percent.

(e) PYROMETRIC CONE EQUIVALENT

The pyrometric cone equivalent (pce, or softening point) of the mortars given in table 1, columns 14 and 15, ranged from 14 to 37 for the uncalcined material, and from 15 to 37 for the calcined mortars. These results indicate that very little difference in pyrometric cone equivalents may be expected between calcined and uncalcined material. However, in a number of cases the end points of the uncalcined materials were much more difficult to obtain than when calcined materials were used, because of the tendency of the cones to twist and curl.

(f) TROWELING

(1) *Appearance before drying.*—The results of the troweling tests are given in table 1, columns 16 to 19, inclusive. The ratings, very good, good, fair, and poor, are used to designate the comparative ease with which the mortars spread with the mechanical trowel, and their appearance on the brick immediately after each of the four tests was completed. As examples (see fig. 3), mortar 12 was rated "very good" and mortars 13 and 21 both rated "poor." A rating of "very

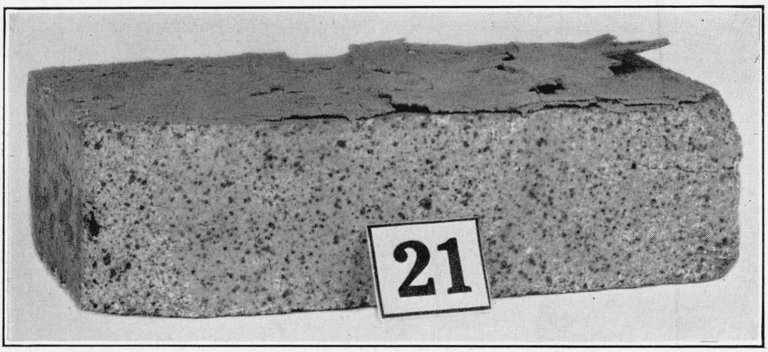

FIGURE 4.—*A case of cracking and curling is illustrated by mortar 21.*

The entire layer of mortar after drying could be easily removed from the brick.

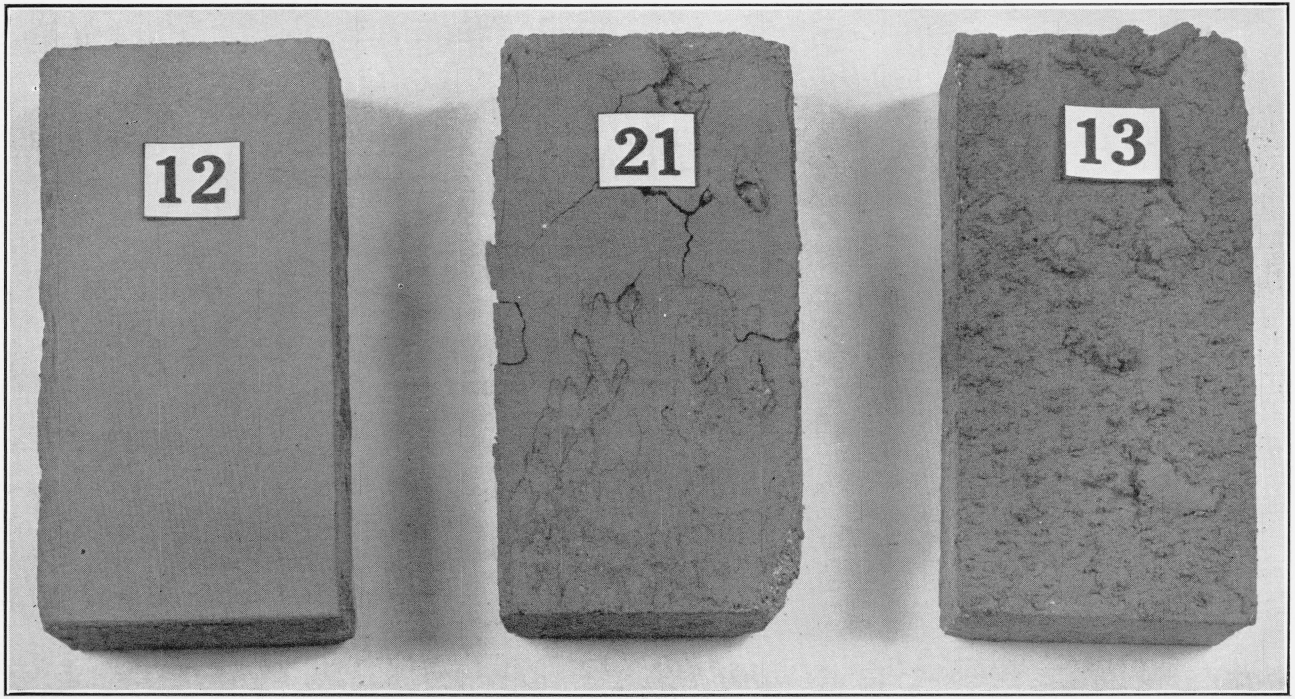

FIGURE 3.—*Appearance of three mortars after having been spread on firebrick, by means of a mechanical troweling device, and dried.*

Mortar 12 spread smoothly and easily; mortar 21 had a tendency to stick to the trowel and consequently pulled from the brick in spots; mortar 13, although sticking to the brick, was so "short" and stiff that it would not spread good" was given if the mortar spread easily and uniformly, without the least indication of pulling from the brick as the trowel traveled over the mortar, and if the surface had a smooth texture. A rating of "good" was given if the mortar spread satisfactorily although the texture was coarse or rough, possibly because of the lack of plastic material or of a sufficiently high percentage of fines. A rating of "fair" indicated that some of the mortar actually pulled from the brick, leaving bare spots, and the mortar showed some tendency to spread unsatisfactorily. A rating of "poor" was given if these conditions were accentuated so that from one-third to one-half of the brick was pulled bare of mortar, or if a very rough surface remained which was apparently caused by the mortar being too stiff or short, so that it would not spread to the desired thinness.

Six mortars (2, 4, 9, 10, 12, and 19) rated "very good" and only one (5) rated "good" in all the troweling tests. Not one of the 20 mortars was rated "poor" in all four tests, although several were given that rating in either two or three of the four tests. Mortar 3 was satisfactory when the layer of mortar was held at ⅛ in., but was unsatisfactory when reduced to a $\frac{1}{16}$-in. layer. Other mortars, for example 14, 15, and 16, rated "good" in the 1-stroke test but were unsatisfactory in the 25- and the 37-stroke tests.

The ratings of mortars 13 and 15 were changed from poor to very good in the 37-stroke test by the addition of water to the mortar. These were the only mortars whose consistency was changed. The 37-stroke test was the only one made with the changed consistency.[13]

(2) *Appearance after drying.*—The following ratings, based on the appearance of the mortar after drying on the brick, were given to differentiate the several degrees to which the mortars were curled or cracked: no, slightly, moderately, and badly. The tendency of the mortar to curl, resulting in the pulling of the mortar from the brick, is given in table 1, column 20, and the tendency to crack, which developed with the drying, is given in column 21. The ratings were based upon the appearance of the mortar on all four brick used in the mechanical troweling tests. The degrees of curling and cracking were not entirely independent.

Four of the mortars which rated "very good" in all the troweling tests showed neither curling nor cracking on drying. Mortar 12, shown in figure 3, comes within that category. None of the mortars were both badly cracked and curled, but five were so rated in either one or the other respect (3, 5, 15, 16, and 21). Mortar 21, shown in figures 3 and 4, curled badly, cracked moderately, and lacked adhesiveness, so that practically the entire top of the brick could easily be brushed free from the dried mortar.

Mortar 13 showed no indication of curling or cracking when the material as received was tested, nor after the consistency was changed, as described in the preceding section. On the other hand, mortar 15 cracked moderately on drying, both with the original and with changed consistency.

[13] The effect of change of consistency on some other properties of these two mortars will be discussed under the section on transverse strength and linear shrinkage.

TABLE 2.—*Transverse strength of neat-mortar bars and two half-brick-and-mortar assemblages, and shrinkage of mortars*

Mortar and molding[1] method	Transverse strength,[2] neat-mortar bars after heating at ° C									Transverse strength, two half-brick-and-mortar assemblage after heating at ° C and manner of failure[3]									Length changes after heating[5] at ° C			
	105	250	500	625	750	850	1,000	1,310	1,350	105	250	500	625	750	850	1,000	1,310	1,350	105	750	1,000	1,350
	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	*lb/in.*²	%	%	%	%
1-*X*	5,165 5,800 5,455	3,175 4,350 3,760	2,185 2,075 2,360	2,350 2,275 2,310	1,725 2,115 1,920	1,820 1,925 1,870	1,865 2,040 1,960	Bloated Bloated Bloated	Bloated Bloated Bloated	505 *B*	285 *B & J*	375 *B & J*	290 *B & J*	310 *B*	330 *B & J*	350 *B*	295 *B & M*	300 *B & M*	4.5	+0.7	2.7	-----
2-*Y*	1,100 1,465 1,265	990 950 975	610 755 670	355 370 365	360 620 490	335 520 430	190 245 215	Bloated Bloated Bloated	Bloated Bloated Bloated	115 *J & M*	95 *J*	30 *J*	10 *J*	5 *J*	30 *J*	15 *J*	320 *B, J, & M*	315 *M*[4]	6.1	+.7	+1.2	-----
3-*Y*	2,850 3,430 3,140	2,795 2,760 2,780	1,930 2,300 2,115	2,175 2,515 2,345	2,010 2,240 2,125	1,965 2,110 2,030	1,805 2,030 1,915	2,810 2,925 2,870	3,065 3,125 3,095	430 *B & J*	295 *B & J*	225 *J & M*	285 *J & M*	230 *J & M*	285 *B, M, & J*	315 *B, M, & J*	370 *B, M, & J*	310 *B, M, & J*	2.2	0	2.7	1.1
4-*X*	6,105 6,830 6,470	5,665 6,890 6,270	3,670 4,340 4,005	2,955 3,490 3,220	2,705 2,645 2,675	2,850 2,750 2,800	3,700 3,575 3,635	Bloated Bloated Bloated	Bloated Bloated Bloated	540 *B*	365 *B & J*	445 *B*	365 *B*	415 *B & M*	375 *B & J*	400 *B*	290 *B & J*	300 *B & M*	4.5	+2.1	0.4	-----
5-*Z*	1,280 1,070 1,155	1,275 1,435 1,330	1,185 1,410 1,300	1,080 1,310 1,215	995 1,255 1,115	1,310 1,670 1,490	2,020 1,820 1,990	1,330 1,635 1,480	1,560 1,565 1,565	245 *J & M*	240 *M*	215 *M*	145 *M*	105 *M*	205 *M*	245 *M & J*	300 *B, M, & J*	300 *B, M, & J*	3.9	.1	.7	1.3
6-*Y*	2,150 2,200 2,175	------ ------ ------	970 1,370 1,190	------ ------ ------	920 1,235 1,070	------ ------ ------	1,255 1,435 1,345	1,910 2,155 2,030	2,600 2,780 2,695	415 *M & J*	------	320 *M*	------	285 *M*	------	390 *B & M*	405 *B & M*	245 *M*	4.6	.8	+.1	3.7
8-*Z*	580 790 685	------ ------ ------	455 665 560	------ ------ ------	445 520 485	------ ------ ------	920 960 940	1,650 1,510 1,585	1,555 1,455 1,505	50 *M*	------	95 *M & J*	------	90 *M & J*	------	70 *M & J*	175 *M & J*	205 *M & J*	4.5	.2	1.3	4.0
9-*X*	3,910 5,000 4,455	------ ------ ------	1,960 2,530 2,245	------ ------ ------	1,850 2,400 2,100	------ ------ ------	1,870 2,405 2,140	1,770 2,480 2,165	2,160 2,455 2,350	460 *B*	------	390 *B*	------	395 *B*	------	360 *B*	330 *B & M*	300 *B & M*	3.8	+1.8	+1.2	.8
10-*Z*	3,485 4,545 4,065	------ ------ ------	2,565 2,315 2,440	------ ------ ------	2,945 3,630 3,290	------ ------ ------	2,555 3,130 2,840	--------- --------- ---------	1,995 2,400 2,195	245 *J*	------	175 *J*	------	140 *J*	------	185 *J*	190 *J*	225 *M*	2.7	.8	.2	+3.1
11-*X*	1,670 2,050 1,815	------ ------ ------	1,600 1,750 1,675	------ ------ ------	1,375 1,910 1,530	------ ------ ------	2,020 2,370 2,195	2,640 2,500 2,560	2,510 2,210 2,360	335 *B, M, & J*	------	220 *J*	------	310 *J*	------	315 *B & J*	280 *B, M, & J*	270 *B & M*	2.0	.5	.1	.8
12-*Z*	2,700 2,725 2,710	------ ------ ------	2,025 2,470 2,275	------ ------ ------	1,430 1,915 1,675	------ ------ ------	2,405 2,435 2,420	Bloated Bloated Bloated	Bloated Bloated Bloated	440 *B*	------	240 *M*	------	240 *M*	------	310 *B & J*	410 *B & J*	360 *B & J*	5.8	+.2	+.1	-----
13-*X*	2,185 3,090 2,640	------ ------ ------	1,720 2,260 2,045	------ ------ ------	1,225 1,910 1,465	------ ------ ------	1,385 2,365 1,875	1,555 2,580 2,295	1,835 2,755 2,255	475 *B*	------	370 *B*	------	395 *B*	------	375 *B*	330 *B & M*	330 *B & M*	1.8	+.2	.2	2.9

14-*Y*	2, 425 2, 980 2, 705	2, 445 2, 720 2, 580	2, 165 1, 975 2, 080	2, 150 2, 670 2, 410	3, 155 3, 260 3, 210	2, 375 2, 735 2, 520	120 *M & J*	------	75 *J*	------	65 *J*	------	135 *J*	140 *J*	85 *J*	8. 3	. 2	1. 3	2. 4
15-*Y*	740 910 830	650 780 715	650 730 690	1, 245 1, 125 1, 185	1, 620 1, 780 1, 700	1, 410 1, 815 1, 595	75 *M & J*	------	85 *M & J*	------	50 *M & J*	------	125 *M & J*	105 *M & J*	95 *M*	5. 3	. 3	1. 5	2. 6
16-*X*	1, 565 2, 455 2, 010	900 1, 205 1, 070	780 945 880	880 1, 440 1, 160	1, 585 1, 470 1, 520	1, 575 1, 470 1, 520	340 *M*	------	85 *M & J*	------	100 *M & J*	------	240 *M & J*	235 *M & J*	240 *M & J*	6. 8	. 9	+. 2	2. 2
17-*X*	3, 640 4, 615 4, 130	1, 795 1, 590 1, 690	1, 065 1, 540 1, 305	1, 315 2, 010 1, 690	2, 125 2, 340 2, 220	2, 020 2, 250 2, 110	360 *B*	------	340 *B*	------	390 *B*	------	400 *B*	355 *B*	300 *B*	4. 2	. 4	+. 4	1. 5
18-*X*	1, 875 2, 705 2, 290	1, 410 1, 565 1, 490	775 680 730	380 455 415	695 695 695	Fused Fused Fused	215 *J*	------	110 *J*	------	115 *M & J*	------	105 *J*	290 *M & J*	325 *M*	6. 0	. 4	+. 9	-----
19-*X*	2, 715 3, 905 3, 310	1, 350 1, 340 1, 345	880 1, 175 950	955 1, 245 1, 085	765 670 720	------	365 *B*	------	300 *J*	------	200 *M & J*	------	210 *M & J*	375 *M*	380 *M*	6. 1	. 3	+. 4	-----
20-*X*	4, 775 4, 845 4, 810	2, 100 2, 565 2, 335	1, 105 1, 315 1, 210	940 1, 085 1, 010	1, 000 1, 080 1, 040	Bloated Bloated Bloated	305 *J*	------	135 *J*	------	170 *J*	------	135 *J*	365 *B & M*	340 *B & M*	7. 6	. 7	+1. 1	-----
21-*Y*	2, 810 2, 970 2, 890	1, 780 2, 190 1, 990	1, 840 2, 200 2, 020	2, 520 2, 740 2, 630	3, 430 2, 810 3, 125	Bloated Bloated Bloated	335 *J*	------	160 *J*	------	195 *J*	------	210 *M & J*	345 *B & J*	370 *B & J*	8. 3	1. 0	1. 7	-----

[1] Neat-mortar specimens molded, (*X*) from 1 side only, (*Y*) from 2 sides, (*Z*) by pouring or casting. Method of molding depended on consistency which varied in some cases with different shipments.

[2] The three values for each mortar at the various temperatures represent, in the order given: (1) The average of 5 specimens broken with the surface on top that was uppermost during drying; (2) the same number of specimens with that surface on the bottom; (3) the average of all specimens.

[3] *B*, *J*, and *M* indicate failure occurred in brick, joint, or mortar, respectively.

[4] Mortar ran from joint.

[5] Except the values for 105° C, which represent the drying shrinkage, the length changes given represent changes between the dry length and the length after heating. "+" indicates expansion.

(g) TRANSVERSE STRENGTH AND LINEAR SHRINKAGE

(1) *Heated and cooled specimens.*—In table 2 are given the transverse strengths (moduli of rupture) of the mortars after they were heated to various temperatures and cooled. In each case three sets of values are given: First, the average for not less than five specimens broken, with the surface that was originally at the bottom on top (hence, in compression); second, a similar average but for specimens with this surface at the bottom (hence, in tension); and third, the average for both positions. It will be noted that with comparatively few exceptions the strength was greater, and in many instances decidedly so, when the original top surface was in tension during the breaking of the specimen. This difference in strength is probably related to the differences in concentration of the alkali salts near the two surfaces (table 1, columns 8 and 9). A few tests of the transverse strength of specimens made of fire clay to which no silicate of soda had been added failed to show a similar difference in strength. Some mortars, however, for example, 1, 3, 14, and 17, showed comparatively little migration of the salts in comparison with some of the other mortars, yet all showed as great a difference in strengths as those in which the migration of the salts was much greater. Since only one specimen of each mortar was tested for alkali content, and since it was quite difficult in many cases to prepare equally thin sections for test in all mortars, it is quite probable that at best the values for the alkali content represent only an approximation of the migration of the salts.

The strengths of the mortar specimens dried at 105° C covered a very wide range, the lowest average for the two positions of test being 685 lb/in.^{2} and the highest 6,470 lb/in.^{2} The change in strength of the mortars heated at higher temperatures and then cooled to room temperature varied with the materials. Such variations in strength between three mortars are illustrated in figure 5. The mortars, in general, may be classed according to loss or gain in strength into three groups, illustrated by the types in figure 5, namely:

1. Those with high initial or air-setting strength which was lowered by heating at intermediate temperatures. The strength increased again, probably because of vitrification, by heating at the highest temperatures.
2. Those of high initial or air-setting strength which was lowered by heating at intermediate temperatures and was not further changed, even after heating at the highest temperature.
3. Those of comparatively low initial strength which changed very little with heating at the lower temperatures but increased progressively with heating at moderately higher and the highest temperatures.

Nine mortars (3, 4, 5, 6, 12, 13, 14, 16, and 21) were of the first type, eight (1, 2, 9, 10, 17, 18, 19, and 20) of the second type, and three (8, 11, and 15) of the third type.

Strength tests could not be made of mortars 1, 2, 4, and 12 after heating them at 1,310° or 1,350° C, because the specimens bloated badly. Although bloating due to overfiring might have been expected in the cases of mortars 1 and 2 because of their low pce, it was rather unexpected in the cases of mortars 4 and 12, which had higher pyrometric cone equivalents. It is somewhat puzzling why mortar 4 should have bloated, since it has a pce of 34. Although it was among the highest in alkali content, the others with comparable alkali content and lower pyrometric cone equivalents did not have the same tendency to bloat.

Fifteen of the twenty mortars had an air-setting strength of over 2,000 lb/in.², and 12 had a strength of over 2,500 lb/in.² Those mortars having an initial air-setting strength exceeding 2,500 lb/in.² continued to have a satisfactory strength after being heated at all

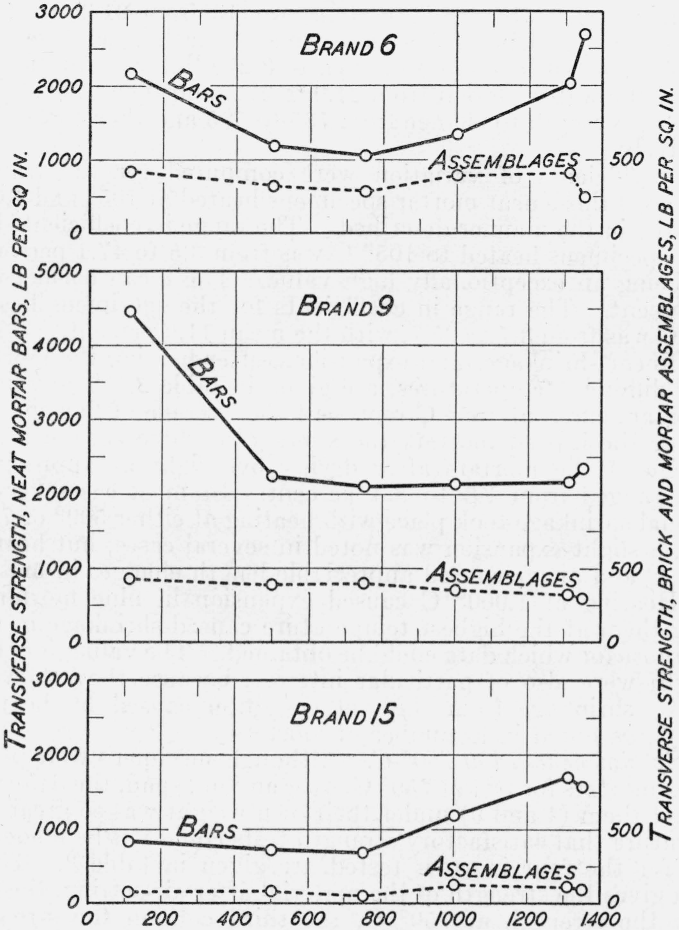

FIGURE 5.—*Changes in transverse strengths with temperatures of heating for bars and two-half-brick-and-mortar assemblages made with mortars 6, 9, and 15, representing three different types of trends.*

succeeding higher temperatures and cooled. Mortars 5 and 11 were exceptions; although they had a rather low initial strength, they retained a satisfactory strength after heating them at all higher temperatures and subsequent cooling. Because of these exceptions, it would appear necessary to test mortars after air-setting, and also after heating at 750° C and cooling. Although not all mortars reached their lowest strength after heating at 750° C and cooling, the values obtained after such treatment are in general close to the lowest obtained after the various heat treatments.

After the mortars were heated at 1,350° C, much glass was observed by a visual inspection of the test specimens. This glass, which in many cases was concentrated near the surfaces, apparently was the result of the large quantities of sodium silicate, which the mortars contain.

Changing the water content of mortar 13 from 21.3 to 24.9 and then 26.6 percent caused the transverse strength to change, respectively, from 4,170 to 4,035 and then to 3,270 lb/in.^{2} For mortar 15, changing the water content from 24.9 to 27.5 and then to 38.5 percent caused the strength to change from 735 to 685 and then to 485 lb/in.^{2}, respectively.

The coefficients of variation were computed for the transverse strengths of those neat mortar specimens heated at 105° and 1,000° C and tested in the manner described. The range in coefficients for the mortar specimens heated to 105° C was from 3.5 to 47.1 percent, the latter being an exceptionally high value. The mean coefficient was 13.6 percent. The range in coefficients for the specimens heated to 1,000° C was from 3.7 to 25.7, with the mean 11.9 percent.

The linear shrinkages and expansions, after heating the mortars at several different temperatures, are given in table 2. The values for the mortars cured at 105° C represent the average of five specimens, those for the heated mortars the average of three specimens. The shrinkage of the mortars after drying overnight at approximately 105° C ranged from 1.8 to 8.3 percent. In most cases very little additional shrinkage took place with heating at either 500° or 750° C; in fact, a slight expansion was noted in several cases, but heating at 1,000° C and above caused appreciable length changes in most mortars. Heating at 1,000° C caused expansion in nine mortars, but heating them at the highest temperature caused shrinkage in all but one of those for which data could be obtained. The values for changes in length were also of particular interest, because they showed the very low shrinkage from the wet condition caused by heating at 1,350° C, as noted in a number of mortars.

(2) *Specimens tested at 750° C.*—Although specimens were prepared from six mortars for test at 750° C, over an 8-in. span, the deformation of two of them (4 and 9) under their own weight was so great at this temperature that satisfactory strength tests could not be made. The values for the four mortars tested are given in table 3. The first column gives the strength of the material after air-setting, the second column the strength at 750° C, the third column the strength at approximately 20° C of the two 5-in. sections that resulted from rupturing the 10-in. specimens at 750° C, the fourth column gives the values for specimens also tested at 750° C, but which had been first heated at 750° C for an hour and cooled to room temperature before testing at 750° C.

The results, based on a limited number of specimens, indicate that at room temperature the modulus of rupture of mortar 18 was somewhat lower than it was at 750° C, and that of each of the other three mortars was somewhat greater. However, a decided decrease in strength was obtained for all four mortars when tested at room temperature after being heated for a short time at 750° C. After heating the mortars to 750° C and cooling to room temperature and then testing at 750° C, the strengths for mortars 19, 20, and 21 (no data available for mortar 18) follow approximately the same trend as those obtained on specimens tested at 750° C without the preliminary heating at 750° C.

TABLE 3.—*Modulus of rupture of mortars tested after different heat treatments*

Mortar number	Tested at			
	20° C, after drying at 105° C [a]	750° C, after drying at 105° C [a]	20° C, after heating at 750° C [b]	750° C, after heating at 750° C and cooling [a]
	lb/in.²	*lb/in.²*	*lb/in.²*	*lb/in.²*
18	2,955	3,660	870	----------
19	4,880	2,925	1,315	2,995
20	4,890	3,450	1,385	3,500
21	4,640	4,535	3,190	3,880

[a] Average of 3 specimens (6 for mortar 19) over an 8-in. span.
[b] Average of 6 specimens (12 for mortar 19) over a 3-in. span.

No explanation for the decrease in strength due to the heating at a comparatively low temperature and cooling is offered. The high strength obtained at 750° C may be explained on the basis of the presence of crystalline silica as shown by the results of studies,[14] reported by R. A. Heindl and W. L. Pendergast.

(h) POROSITY AND SOLUBILITY

The porosities, obtained only for mortars 1 to 5, inclusive, are given in table 4. Each value represents the average of five determinations. It is rather doubtful that the porosity values for the materials heated to 105° C are correct, because of the possibility of partial disintegration of the specimens during their contact with water. As indicated in the table, mortars 1 and 4 disintegrated. Values are given for all five mortars after they were heated at 250° C, but it is doubtful also that any are correct because of partial dissolution of the specimens. The values for mortars 1 and 4 give some indication that this is true.

The values in table 4 are of some interest in that they give an indication of the action of the salts in the different mortars. In this group the highest alkali content was shown by mortars 1 and 4 (see table 1). These two show the greatest changes in porosity after the various heat treatments through 1,000° C. The porosity of mortar 4 was greatest after being heated at 750° C, except after it was heated at 1,310° C, when it showed definite signs of bloating.

Figure 6 shows the relation between porosity and strength of mortar 3 and shows also the effect of heating on these properties.

Solution of the salts, as evidenced by a simple titration test, occurred with all five mortars after they were heated at 250° C, but in no case was solubility evident after the mortars had been heated at 500° C. No attempt was made to determine the relative amount of soluble material of the five mortars after the 250° C heating. Also, it is not known whether contact with water for a longer time than in these tests would cause solution of salts in specimens which had been heated at 500° C.

[14] *Fire clays; some fundamental properties at several temperatures*, BS J. Research **5**, 213 (1930) RP194. *Young's modulus of elasticity at several temperatures for some refractories of varying silica content*, J. Research NBS **13**, 851 (1924) RP747.

TABLE 4.—*Porosity of mortars 1 to 5 after being heated at various temperatures and cooled*

Mortar number	Porosity after heating at °C								
	105	250	500	625	750	850	1,000	1,310	1,350
	%	%	%	%	%	%	%	%	%
1	(a)	11.5	17.5	22.3	22.8	21.9	24.4	(b)	(b)
2	18.2	20.1	25.3	26.5	23.0	24.1	26.3	(b)	(b)
3	19.5	18.3	24.1	22.2	23.8	22.8	19.0	13.6	12.7
4	(a)	10.3	21.6	28.7	35.8	29.3	29.3	43.8	(b)
5	27.9	31.0	33.1	34.1	34.2	35.2	33.5	28.6	29.2

[a] Specimens disintegrated. [b] Specimens bloated badly, no determinations made.

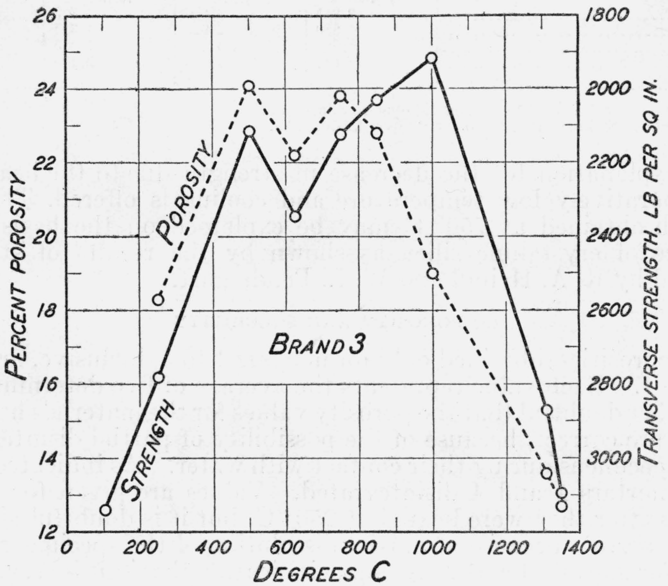

FIGURE 6.—*Relation between porosity and strength of mortar 3 after it was heated at various temperatures.*

2. ASSEMBLAGE OF TWO HALF-BRICK AND MORTAR

(a) SETTING TIME OF MORTAR

The time required for each of the mortars to air-set, or stop flowing under loads when placed between firebrick, is given in table 1, column 22. Figure 7 illustrates the two extremes in time of set as represented by mortars 10 and 11. Sixty minutes had elapsed before the 50-lb. weight was placed on assemblage 10, but, as shown in the figure, the flow of the mortar was still quite high. The time required for this mortar to set under the conditions of the test was 90 minutes. On the other hand, only 1 minute had elapsed before the weight was placed on assemblage 11. A total of eight mortars set within 1 minute and only six had failed to set after 3 minutes. These 6 mortars ranged in time of set from 24 to 90 minutes, leaving a rather wide gap between

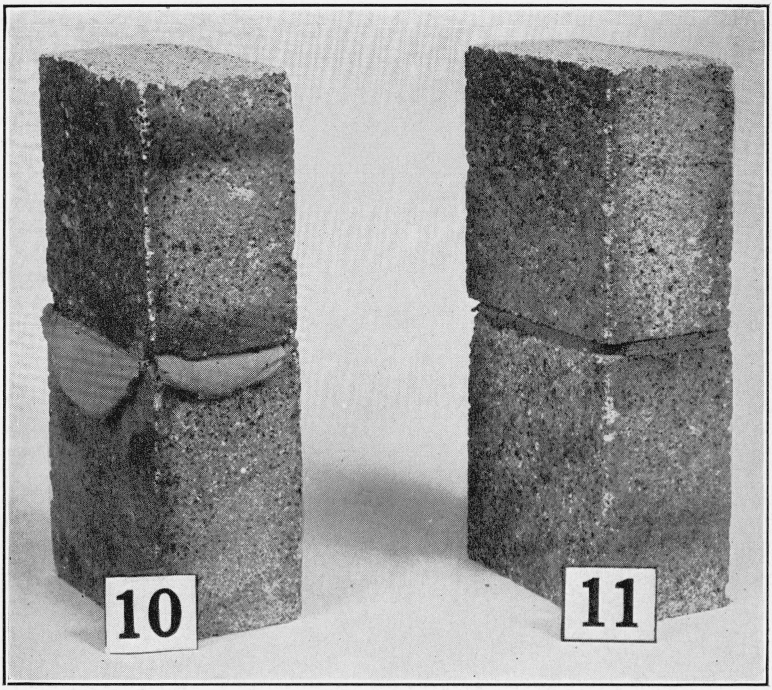

FIGURE 7.—*Appearance of brick-and-mortar assemblages after test for determining the time for mortars to air-set or stop flowing under load.*

Brick-and-mortar assemblage 10 showed high flow of the mortar even after 60 minutes had elapsed before application of the load. Brick-and-mortar assemblage 11 showed no flow after 1 minute under the same conditions.

these and the other 14 mortars, which showed no flow within 3 minutes or less.[15]

No relation between the time of set and the other properties of the mortars is apparent. It is true that the alkali content of all the mortars which require considerable time to air-set is quite high, as is also the air-setting strength. Furthermore, all these mortars, with the exception of mortar 13, were classed "very good" in the mechanical troweling test.

(b) TRANSVERSE STRENGTH

The transverse strengths of the two half-brick-and-mortar assemblages, tested after being heated in the same furnace as, and simultaneously with bar specimens of the neat mortar, are given in table 2. They ranged from 5 lb/in.^{2} (mortar 2) to 540 lb/in.^{2} (mortar 4). The values of strength of assemblage for mortars 6, 9, and 15 are plotted in figure 5 with the strengths of the neat mortars at the corresponding temperatures. On the average, the trends of the cross-breaking strengths of the assemblages, after having been heated at various temperatures and cooled, resembled those of the neat mortars considerably more than the examples shown in figure 5. However, the trends for the assemblages varied considerably more among themselves than did the trends for the bars. Some of the probable reasons for such variations are discussed in the following paragraph.

It was reported by Heindl and Pendergast [16] that the modulus of rupture of the brick (stiff-mud type) used in this study was 745 lb/in.^{2} It was found that in no case did the modulus of rupture of the assemblage of brick and mortar approach this value, though in many cases the brick failed rather than the mortar or the joint. However, as already pointed out, the assemblage was made by joining the two outside end surfaces of the brick. A difference in physical characteristics between the central portion of this particular type of brick and the ends may be a partial explanation for the discrepancy. Some weight can be given this supposition, because tests made by Heindl and Mong [17] showed that considerable differences may exist between specimens cut from different parts of the same brick. There is also the possibility that the silicate of soda, which migrates to the pores of the brick, weakens the structure. With a 20-power binocular it was possible to distinguish in some cases white opaque particles of similar appearance in both the mortar and the brick surface adhering to the mortar. Migration of the liquid from the mortar joint to the brick was also indicated by a dye added to mortar 4.

In general, a high air-setting strength of the neat mortar presages a satisfactory strength of the brick-and-mortar assemblage. Mortar

[15] The porosity of the brick has apparently a considerable effect on the rate at which the mortar with which it comes in contact loses its water. For example, bricks of 1.5- and 8.6-percent absorption when bonded with mortars 3 and 5 and loaded as described, but using a 100- instead of a 50-lb. weight, gave the following information:

Mortar number	Absorption of brick (percent)	Setting time (minutes)
3	1.5	45
3	8.6	2
5	1.5	30
5	8.6	2

[16] *Bonding strength of cold-setting refractory cements*, Bul. Am. Ceram. Soc. **15**, 182 (1936).

[17] *Young's modulus of elasticity, strength, and extensibility of refractories in tension*, J. Research NBS **13**, 851 (1934) RP747.

14 is the only exception; the neat mortar not only has a fairly high air-setting strength, but maintains a high strength after being heated at the various temperatures, yet the assemblage shows only a low strength. This mortar has a shrinkage (see table 2) equal to the highest in the group of 20 mortars. Brands 2, 8, and 15 would be considered as having low assemblage-joint strengths, but all three show the neat mortar to have low air-setting strengths. A high strength of the assemblage of brick and mortar after air-setting usually, but not always, presages a good assembly strength after heating at moderately high temperatures. The assemblage for mortar 16 was one of the exceptions (table 2; assemblages heated at 500 and 750° C).

A brick-and-mortar assemblage for each mortar, except mortar 4, was heated at 1,500° C for 1 hour. After the mortars cooled, the strength was found to range from 345 to 765 lb/in.^{2} The values are not tabulated, because they represent only one specimen in each case.

To obtain an indication of the effect of long-time heating at a low temperature on the strength of the bond in the assemblage of two half-brick and mortar the following test was made: Five assemblages of each of three air-setting refractory mortars selected at random, and, for comparison, five of one high-alumina hydraulic mortar (1 cement, 2 sand) were heated continuously at 260° C for 9 months, cooled, and then tested for transverse strength. The results are given in table 5.

TABLE 5.—*Effect of long-time heating on strength of assemblage*

Mortar number	Strength [a] after heating 18 hours at 105° C	Strength after heating 9 months at 260° C	Loss in strength
	lb/in.^{2}	*lb/in.*^{2}	*Percent*
1	505	275	45.5
2	115	30	74.0
5	245	260	[c] −6.0
Hydraulic	[b] 220	65	70.5

[a] Taken from table 2. [b] Tested after curing (laboratory air) for 9 months. [c] Increase.

The two-half-brick assemblages prepared with the mortar in a dipping consistency were cured and then dried at 105° C. The results of transverse-strength tests on these assemblages are given in table 6.

TABLE 6.—*Modulus of rupture of assemblage of two half-brick and mortar used in a dipping consistency*

Mortar number [1]	Specimens	Modulus of rupture	Failed [2] in	Mortar number [1]	Specimens	Modulus of rupture	Failed [2] in
		lb/in.^{2}				*lb/in.*^{2}	
1	7	205	*J*	13	10	450	*B*
2	10	40	*J*	14	6	50	*J*
3	5	140	*M*	15	10	40	*J*
4	10	320	*B* & *J*	17	10	235	*J*
5	10	140	*J* & *M*	18	10	5	*J*
6	10	270	*J* & *M*	19	8	220	*J*
10	5	430	*B*	20	8	140	*J*
11	8	245	*J*	21	10	25	*J*

[1] Mortars 8, 9, 12, and 16 not tested.
[2] *B*, *J*, and *M* indicate that failure occurred in brick, joint, or mortar, respectively.

All of these values, with the exception of those for mortars 10 and 13, are considerably below those obtained when the mortar was applied in a troweling consistency (see table 2).

The coefficients of variation for the cross-breaking strengths of the assemblages (table 2) heated at 105° C varied from 7.9 to 38.5 percent, and the mean value was 20.2 percent. Information was not obtained on the variation for the assemblages heated at other temperatures.

(c) TYPES OF FAILURE

The four types of failure which occurred in the tests of the cross-breaking strength of the assemblages of two half-brick and mortar were as follows:

1. The brick failed.
2. The assemblage failed in the joint.
3. The mortar failed.
4. Some combination of the foregoing types.

The manner in which the bonded brick specimens failed when the mortar was used as received is indicated in table 2. Considered collectively, no particular type of failure predominates, except that at the highest temperature the partial or complete failure of the brick structure appeared to occur. For any one mortar the type of failure was, in general, the same, regardless of the heat treatment, except as noted above. This was especially true for the heat treatments ranging from 105 to 1,000° C, inclusive.

Of the four types, the failure of the assembly in the joint varied over the widest ranges, namely, from 5 lb/in.^{2} (mortar 2, 750° C heating) to 335 lb/in.^{2} (mortar 21, 105° C heating).

(d) RESISTANCE TO WEATHERING

An approximate indication of the weathering resistance of the two-half-brick-and-mortar assemblages was obtained by exposing one specimen of each to the weather. The specimens were so placed on a parapet that one-half of the assemblage extended over the edge and would drop of its own weight as soon as the mortar bond could no longer support the half-brick. At the end of 16 months' exposure to the rain, snow, and sunshine in Washington, D. C., 10 specimens had failed. The first failure occurred at the end of 17 days (mortar 5) and for all mortars there was, in general, a direct relation between the strength of bond (see table 1) and the number of days before rupture occurred.

3. THREE-BRICK PIER AND FUSION-BLOCK TEST

In table 7 a summary is given of the observations made of the three-brick (two whole and two half) assemblages or piers after being dried, after being heated at 750° C for 24 hours, again after being heated at 1,425° C for 24 hours, and lastly after being heated at 1,500° C for 5 hours. The appearance of the mortars after having been heated at 1,425° and 1,500° C in the fusion blocks is also noted. The conclusions drawn from the appearance of the mortar in the fusion-block tests correlate well with those drawn from an examination of the piers.

Cracks occurring in the horizontal joints are designated " ‖ "; those in the vertical joints "⊥." No differentiation was made as to the direction of the cracks themselves within the joints. Only those cracks designated as "bad" would be considered as affecting the quality of the mortar.

TABLE 7.—*Appearance of mortar in fusion block and*

Mortar No.	Appearance [1] of dry mortar in joint		Appearance [1] of mortar in joint after heating 24 hours at 750° C		Appearance [1] of mortar in joint after heating 24 hours at 1,425° C		Appearance [1] of mortar in joint after heating 5 hours at 1,500° C	
	1/16″	1/8″	1/16″	1/8″	1/16″	1/8″	1/16″	1/8″
1	Good	‖ cracks.	⊥ and ‖ cracks.	‖ cracks.	‖ cracks	Good	⊥ and ‖ thermal cracks.	⊥ and ‖ thermal cracks.
2	‖ cracks	Good	‖ cracks.	Bad ⊥ and ‖ cracks.	Very glassy. Lower joint flowed.	Very glassy. Lower joint flowed.	Bulged. Full of large bubbles. Bricks slipped out of place. Glassy.	Bulged. Full of large bubbles. Bricks slipped out of place. Glassy.
3	Good	do	do	⊥ and ‖ cracks.	Good	Good	⊥ cracks	⊥ shrinkage and thermal cracks.
4	do	do	⊥ and ‖ cracks.	do	do	Good. ‖ thermal cracks. Bulged.	⊥ and ‖ cracks.	Bulged
5	do	do	Bad ⊥ and ‖ cracks.	⊥ cracks in ‖ joint.	do	Good. ‖ thermal cracks.	⊥ shrinkage and ‖ thermal cracks.	⊥ and ‖ shrinkage cracks.
6	‖ cracks	do	⊥ and ‖ cracks.	Good	do	Good	⊥ thermal cracks. Glassy.	⊥ and ‖ shrinkage cracks. Glassy.
8	do	‖ cracks.	do	⊥ and ‖ cracks.	Shrinkage cracks mostly healed. ‖ thermal cracks.	Shrinkage cracks mostly healed. ‖ thermal cracks.	Glassy	Glassy; bulged.
9	do	Good	do	Good	Good	Good	Good	Good
10	Good	do	Good	⊥ cracks.	No bond with brick. All joints badly cracked.	No bond with brick. All joints badly cracked.	Mortar cracked and pulled from brick.	Mortar cracked and pulled from brick.
11	do	do	do	Good	Good	Good	⊥ cracks	⊥ cracks
12	do	⊥ and ‖ cracks.	⊥ and ‖ cracks.	⊥ and ‖ cracks.	do	do	Bulged	Mortar flowed from ⊥ joint.
13	do	Good	Good	⊥ cracks.	‖ thermal cracks.	‖ cracks	‖ and ⊥ shrinkage and ⊥ thermal cracks.	⊥ cracks
14	‖ cracks	do	⊥ and ‖ cracks.	⊥ and ‖ cracks.	⊥ cracks	‖ thermal cracks.	Good	Good. Bulged.
15	⊥ cracks	do	do	⊥ cracks.	‖ thermal cracks.	‖ thermal and shrinkage cracks.	⊥ thermal and shrinkage cracks.	⊥ cracks
16	do	⊥ cracks	Bad ⊥ and ‖ cracks.	⊥ cracks in ‖ joint.	Bad ⊥ and ‖ cracks.	Bad ⊥ cracks.	⊥ cracks	Bulged. Bubbles.
17	Good	Good	Good	Good	Good	⊥ thermal cracks.	Good	‖ thermal and ⊥ shrinkage cracks.
18	do	do	do	do	‖ thermal cracks.	‖ thermal cracks.	Very glassy. Bricks slipped. Flowed.	Very glassy. Bricks slipped. Flowed.
19	do	do	do	do	Good	Good	do	do
20	do	‖ cracks.	do	Bad ‖ cracks.	do	do	Very glassy. Bulged. Flowed from joint.	Very glassy. Bulged. Flowed from joint.
21	⊥ cracks	Good	⊥ and ‖ cracks.	⊥ and ‖ cracks.	⊥ and ‖ cracks.	⊥ and ‖ thermal cracks. Bulged.	‖ thermal and ⊥ shrinkage cracks.	⊥ and ‖ thermal cracks. Bulged.

See footnotes at end of table.

in joints of three brick-and-mortar assemblages or piers

Remarks on general appearance after heating at 1,500° C	Appearance of mortar in fusion block [2] after heating for 5 hours at			Appearance [1] of cap of mortar on brick after heating [4]
	1,425° C (7/16" thick)	1,500° C (7/16" thick)	1,500° C (1/8" thick)	
Good	Bubbles on surface. Fused and flowed to 1. High shrinkage.	Bubbles on surface. Fused and flowed to 1. High shrinkage.	Flow 0. Bubbles. High shrinkage.	Moderately cracked.
Very poor	Flow 1½. Glass	Flow 6. Glass	Flow 2. Glass	Fused [3] and crawled.
Very good	Flow 0. High shrinkage.	Flow 0. High shrinkage.	Flow 0. High shrinkage.	Slightly [3] cracked.
1/16", good. 1/8", poor.	Flow ¾. Bloated. Glassy surface.	Flow ¾. Bloated. Glassy surface.	Flow 0. Bubbles and glassy surface. Shrinkage 0.	
Good	Flow 0. Slight shrinkage. No bubbles.	Flow 0. Slight shrinkage. No bubbles.	Flow 0. Slight shrinkage. No bubbles.	Moderately cracked.
do	Flow ¾. Bloated. Glassy surface.	Flow ¾. Bloated. Glassy surface.	Flow 0. Bubbles. Glassy surface.	
Fair	Flow 0. Few bubbles. High shrinkage.	Flow 0. Few bubbles. High shrinkage.	Flow 0. Few bubbles. High shrinkage.	Badly [3] cracked.
Very good	Bubbles on surface. Fused and flowed to 1.	Bubbles on surface. Fused and flowed to 1.	Flow 0. Bubbles. High shrinkage.	Almost no defects.
Poor	Flow 0. Glassy surface and chalky body.	Flow 0. Glassy surface and chalky body.	Flow 0.	
Very good	Flow 0. Little shrinkage and no glass.	Flow 0. Little shrinkage and no glass.	do	No defects.
Poor exterior. Very good interior.	Flow 1. Bubbles on surface fused to glass.	Flow 1. Bubbles on surface fused to glass.	Flow 0. Bubbles. High shrinkage.	
Fair	Flow 0. Bubbles on surface are glassy. High shrinkage.	Flow 0. Bubbles on surface are glassy. High shrinkage.	Flow 0. No bubbles. Moderate shrinkage.	
1/16", good. 1/8", fair.	Flow 0. High shrinkage. Bubbles on surface are glassy.	Flow 0. High shrinkage. Bubbles on surface are glassy.	Flow 0. High shrinkage. No bubbles.	
Good	Flow 0. High shrinkage. No bubbles.	Flow 0. High shrinkage. No bubbles.	do	Moderately cracked.
1/16", fair. 1/8", exterior poor, interior good.	Flow 0. High shrinkage. Bubbles on surface.	Flow 0. High shrinkage. Bubbles on surface.	Flow 0. High shrinkage. No bubbles.	
Good	Flow ¼. Bloated and glassy surface.	Flow ½. Bloated and glassy surface.	Flow 0. Bubbles. Moderate shrinkage.	Slightly cracked.
Very poor	Flow ¾. Glass	Flow 4. Glass	Flow ¾. Glass	Fused [3] and crawled.
do	Flow 1. Glass	Flow 2. Glass	Flow ½. Glass	Fused to glass.
1/16", fair. 1/8", poor.	do	Flow 6. Glass	do	Fused and crawled.
1/16", fair. 1/8", poor.	Flow 1. High shrinkage. Bubles and glassy.	Flow 1. High shrinkage. Bubles and glassy.	Flow 0. High shrinkage. Bubles and glassy.	Badly cracked and curled.

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TABLE 7.—*Appearance of mortar in fusion block and in*

Mortar No.	Apperance [1] of dry mortar in joint		Appearance [1] of mortar in joint after heating 24 hours at 750° C		Apperance [1] of mortar in joint after heating 24 hours at 1,425° C		Appearance [1] of mortar in joint after heating 5 hours at 1,500° C	
	1/16″	1/8″	1/16″	1/8″	1/16″	1/8″	1/16″	1/8″
22	---do----	-----do----	Bad ⊥ cracks.	---do----	‖ cracks. Glassy.	‖ thermal cracks. Bulged.	-----do-------	‖ and ⊥ thermal cracks. Bulged. Flowed from ⊥ joint.
23	---do----	-----do----	‖ cracks.	---do----	‖ thermal cracks.	-----do-----	⊥ and ‖ thermal cracks.	⊥ and ‖ thermal cracks.
24	Good---	-----do----	----------	----------	Good------	Good------	Good--------	‖ thermal cracks. Slightly glassy.

[1] When cracks carry no identification as to cause, it is intended to be understood that they are shrinkage cracks. Those occurring in the horizontal joint are labeled "‖," in the vertical joint "⊥."

[2] Each division on the fusion block is equal to ¼ inch.

[3] Heated at 1,425° C for 24 hours; the others were heated at 1,500° C for 5 hours.

[4] No information was obtained where no comment is made.

joints of three brick-and-mortar assemblages or piers—Continued

Remarks on general appearance after heating at 1,500° C	Appearance of mortar in fusion block [2] after heating for 5 hours at			Appearance [1] of cap of mortar on brick after heating [4]
	1,425° C (7/16" thick)	1,500° C (7/16" thick)	1,500° C (1/8" thick)	
1/16", fair. 1/8", poor.	Flow 0. Bloated and glassy. High shrinkage.	Flow ½. Bloated and glassy. High shrinkage.	Flow 0. Bloated and glassy. High shrinkage.	Moderately cracked.
Good	Flow 0. Moderate shrinkage. No bubbles. Glazed.	Flow 0. Moderate shrinkage. No bubbles. Glazed.	Flow 0. Moderate shrinkage. No bubbles. Glazed.	Do.
Very good	Flow 0. No bubbles. Glazed. Slight shrinkage.	Flow 0. No bubbles. Glazed. Slight shrinkage.	Flow 0. No bubbles. Glazed. Slight shrinkage.	Almost no defects.

After drying the piers, neither the 1/16-in. nor the 1/8-in. joints had cracked seriously. There was a slightly greater tendency for cracks to occur in the thinner than in the thicker joints. After heating the piers at 750° C, the mortar joints in many units had developed cracks, which were not visible after drying, although only four mortars were classified as having cracked badly. Four mortars did not have cracks after the treatment at 750° C.

One effect of heating at 1,425° C was that many of the cracks visible after the treatment at 750° C had apparently healed in many cases (for examples, see mortars 3, 6, 9, 12, etc.). A number of the units had, however, developed cracks which have been designated "thermal cracks" (for examples, see mortars 4, 5, 8, 15, etc.). In such cases the mortar had become glassy or had reacted with the brick and during cooling had cracked because of stresses which developed. Mortar 2 had become very glassy and full of bubbles, and the mortar in the lower joint of the piers, whether 1/8 or 1/16 in. thick, showed a slight indication of flow. Mortar 10 also appeared to be unsatisfactory for use at high temperatures. The mortar was badly cracked and pulled from the brick in many places, and consequently the bond of this mortar was very weak.

After the soaking at 1,500° C, many changes for the worse had taken place. In three cases (piers 2, 18, and 19) the brick had slipped out of alignment, even though the pier was apparently resting vertically, that is, on a 9- by 4½-in. face. An example of this slippage is illustrated in figure 8, which shows a pier bonded with mortar 2. The photograph was so taken that the extent of the slippage could be readily seen. The apparently glazed appearance of the surface of the brick was caused by shadows. Table 1 shows the pyrometric cone equivalent of this mortar to be only 20. The mortar had apparently become quite liquid at 1,500° C, since very little of it remained in the 7/16-in. deep compartment of the fusion block (see fig. 8), and the flow was quite high also from the compartment 1/8-in. deep.

Mortars 4, 14, 16, 20, 21, and 22 when used in a 1/16-in. joint had a better appearance than when used in the 1/8-in. joint. In none of these cases, however, was even the 1/16-in. mortar joint given the highest rating. On the other hand, mortars 3, 9, 11, and 24 may apparently be used successfully in either 1/16- or 1/8-in. joints, since in either case they are practically free from defects. In figure 9 may be seen the appearance of mortar 11 after being heated at 1,425° C (1/16-in. joint) and at 1,500° C (1/8-in. joint). No defects are visible in the joints, and the excellent appearance of the mortar in the fusion blocks is a good indication that the joints should be of a high quality. Although table 7 indicates that some mortars have cracks in the vertical joints, these cracks were few in number and of hairline magnitude and have no significance.

An example of a somewhat different type of mortar (12) from that just discussed is shown in figure 10 in the pier in which a 1/8-in. joint was used. The mortar had a pce of 28, but, as may be seen, the edges of the joints have bulged badly. The appearance of the mortar after heating in the fusion block was indicative of what might be expected

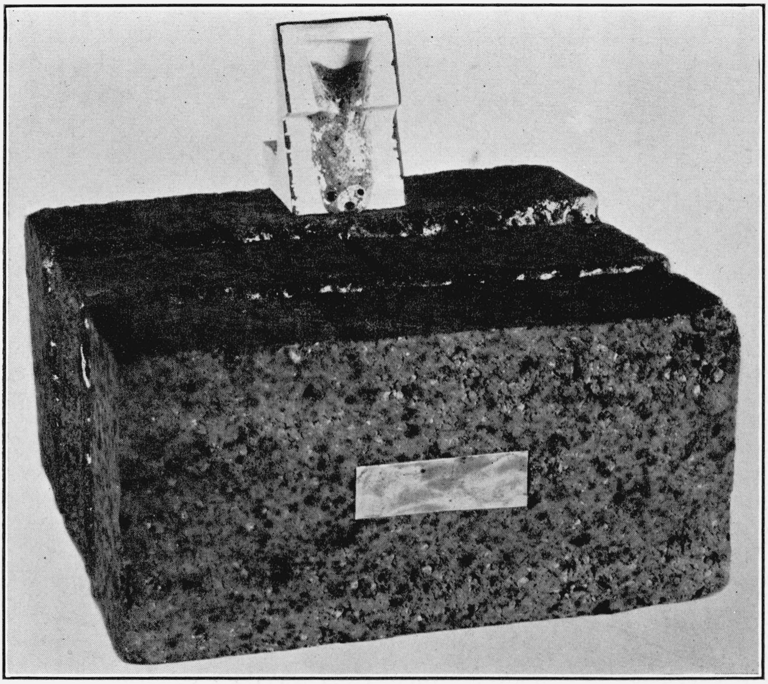

FIGURE 8.—*Mortar 2 had become so fusible at 1,500° C that the bricks laid with a ⅛-in. joint slipped out of position when built into a pier.*

During heating, the pier was approximately vertical, that is, a 4½-by 9-in. face was the bottom. The fusibility of the mortar is illustrated by the extent of the flow from the vertical (2½-in.) joint in the pier as well as the compartment in the fusion block heated simultaneously with the pier.

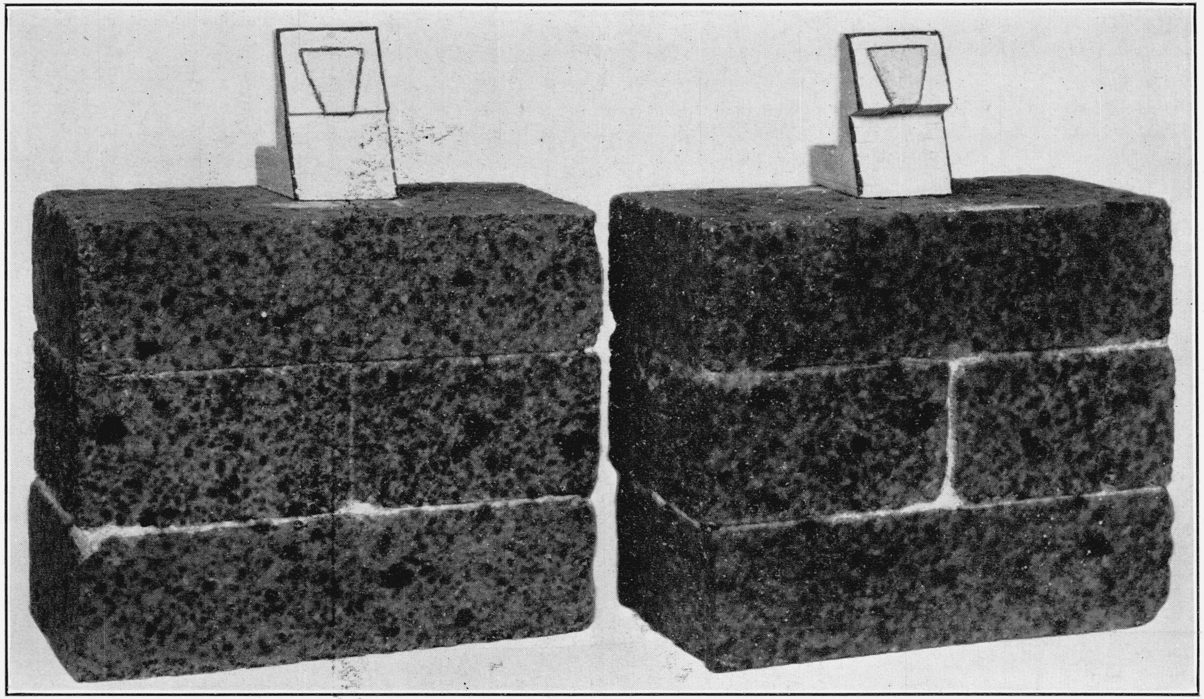

FIGURE 9.—*Mortar 11 gave excellent results in piers regardless of whether a 1/16-in. dipped joint (heated at 1,425° C) or a 1/8-in. troweled joint (heated at 1,500° C) was used.*

The excellent properties of the mortar are further illustrated by its appearance after it was heated in the fusion test blocks. Shrinkage is very low and signs of cracking, curling, or flow are entirely absent.

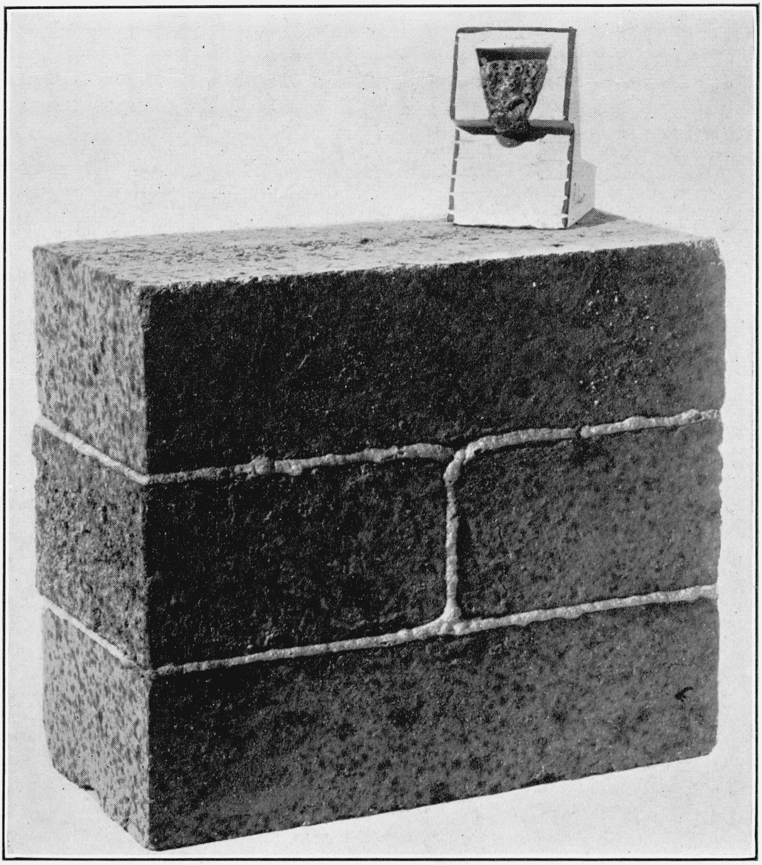

FIGURE 10.—*Mortar 12 used in a pier with ⅛-in. joints and heated at 1,500° C showed bulging.*

The pyrometric cone equivalent of this mortar was 32. However, because the migration of the sodium silicate was high, as was evident both from the edges of the mortar joints and the surface of the mortar in the fusion test blocks, bulging occurred at the edges of the joints.

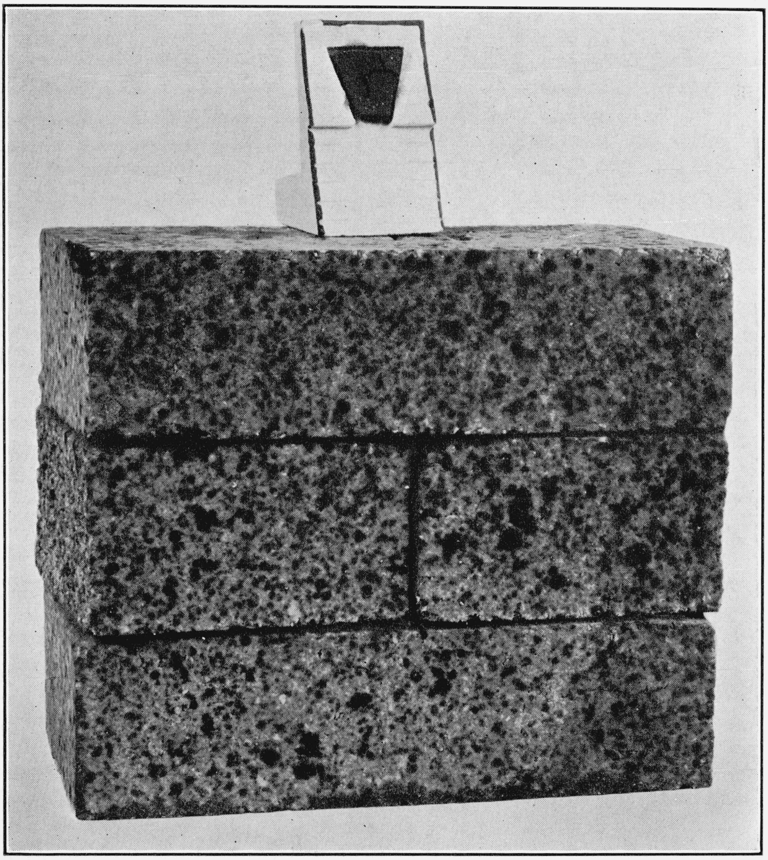

FIGURE 11.—*Mortar 16 showed high shrinkage and cracking after it was heated at 1,500° C in the fusion test block having a ⅛-in. deep compartment.*

The vertical joint in the pier also showed excessive cracking, as did the horizontal joints, although in the latter they are not so apparent.

when it was heated at 1,500° C in a mortar-and-brick assemblage. There is apparently a high degree of migration of the sodium silicate, since there was little indication of fusion below the surface of the mortar in the fusion block. Also, when the brick were separated, the mortar in the interior of the layer showed no visible signs of glassiness. Although the mortar did not flow from the ⅛-in. fusion-block compartment, it did flow as far as the first division from the 7/16-in. compartment in the soaking tests at 1,425° and 1,500° C.

An example of high shrinkage is illustrated by mortar 16 (see fig. 11), in both fusion block (compartment ⅛ in. in depth) and pier, after heating to 1,500° C. In the block the mortar showed both high shrinkage and cracks. A close inspection of the vertical 1/16-in. joint of the pier in the figure will disclose that it is also cracked badly. The ⅛-in. joint was bulged and full of bubbles around the outside of the brick, but the interior of the joint appeared satisfactory.

In some cases a layer or cap of mortar approximately ⅛-in. thick was placed on the outside face of the upper brick to observe the effect of temperature on the exposed mortar. The last column of table 7 describes briefly the appearance of this cap of mortar after the heat treatment. In general, the conclusions reached were in accord with those arrived at regarding the mortars in the piers and in the fusion blocks.

In the fusion-block test, some flow was shown by mortars 4, 9, 12, and 17, the pyrometric cone equivalents of which (see table 1) were 34, 30, 28, and 31, respectively. The flow in these highly refractory mortars was apparently caused by the migration of the silicate of soda to the surface of the mortar, where it reacted with the clay, forming a low-fusing mixture. This surface mixture flowed, but the portion below this surface layer showed very little sign of fusion.

4. STRENGTH TESTS OF SINGLE AND DUPLICATE SHIPMENTS OF MORTARS

It was impracticable to prepare at one time the large number of specimens required for test purposes. Not only were specimens prepared from mortars coming from different containers in the same shipment, but also in some cases, specimens were prepared from shipments of the same mortar received as much as 18 months apart. Since length of storage is generally considered to influence the properties of this type of mortar, it was of considerable interest to learn the extent of the variation in strength between specimens prepared under these conditions. The results of strength tests on such specimens after having been heated at 105° C are given in table 8.

In general, the results are fairly constant for any one brand of mortar, but those of high alkali content appear to show more variation than those of low alkali content. Mortar 21 was especially variable, a considerable difference existing between groups of specimens prepared from the different small containers of the same shipment.

TABLE 8.—*Results of strength tests of the same and duplicate shipments of mortars*

Mortar number	Shipment number	Transverse strength (dried at 105° C)
		lb/in.²
1	1	6,100
1	2	5,125
1	2	5,455
4	1	8,910
4	2	6,470
5	1	1,030
5	1	1,155
6	1	2,260
6	1	2,175
8	1	650
8	2	685
9	1	4,650
9	2	4,455
10	1	4,690
10	1	4,065
13	1	2,640
13		2,700
13		2,960
17	1	4,130
17	1	3,945
19	1	3,440
19	2	3,310
21	1	4,660
21	1	2,890

V. SUMMARY AND CONCLUSIONS

Twenty-three air-setting refractory mortars, marketed in the wet condition and furnished by 20 manufacturers, were subjected to a series of tests, both without the addition of water (troweling consistency) and with the addition of water (dipping consistency), in order to obtain information suitable for preparing a Federal specification covering this commodity. Three of the mortars, received late, were not tested as completely as the other 20, and the summary which follows omits any reference to them.

The condition of the different mortars, after having been in storage for varying periods up to 33 months, was judged by the relative ease with which they could be removed from the container, and with which the segregated liquid and solids could be recombined. Five of the twenty mortars, after having been in storage from 9 to 17 months, had settled to such an extent that remixing them in a mortar box would not have been feasible. After they were remixed, the troweling consistency of 12 mortars was good, 7 fair, and 1 poor. The loss of moisture at 105° C, based on the dry weight of the mortar, ranged from 20.6 to 32.8 percent. The amount of water in the mortars when in a dipping consistency ranged from 26.9 to 51.0 percent. Fifteen of the twenty mortars showed 1 percent or less of residue retained on a No. 40 United States Standard Sieve, and for all the mortars the residue on a No. 100 sieve ranged from 0 to 35 percent. The alkali content, expressed as sodium oxide, ranged from 1.22 to 3.40 percent. The pyrometric cone equivalents of the mortars ranged from 14 to 37. There was very little difference in pyrometric cone equivalents between the calcined and uncalcined mortars, although in some cases the end points of the uncalcined materials were much more difficult to obtain.

A mechanical device was used to classify the mortars as to the comparative ease with which they could be spread or troweled on fire-clay brick. Four tests were made in which both the number of strokes of the trowel and the final thickness of the mortar layer were varied. Six mortars were rated as "very good" in all tests, one "good" in all tests, and the remainder from "very good" through "fair" and "poor," the ratings varying with the individual tests. After drying on the brick, the mortars were rated on their tendency to curl and to crack as follows: "no," "slightly," "moderately," or "badly." Four of the six mortars which rated "very good" in the troweling test showed no cracking or curling on drying. None of the mortars were rated "badly" in both respects, but five rated as such in either one or the other.

The average transverse strengths of the air-set neat mortars ranged from 685 to 6,470 lb/in.^{2} The strength of the test bars was greater in many cases when the surface uppermost during drying was in tension in the breaking test. This effect was caused probably by the concentration of alkali salts (due to migration) near this surface. The change in strengths of the mortars resulting from heating at various temperatures up to 1,350° C and cooling varied with the materials. According to such change in strengths the mortars could be classed as follows: (1) Those of high air-setting strength, which was lowered by heating at intermediate temperatures but raised again, probably because of vitrification, when heated at the highest temperatures; (2) those of high air-setting strength, which was lowered by heating at intermediate temperatures and not further changed by heating, even at the highest temperatures; (3) those of comparatively low air-setting strength, which changed very little with heating at the lower range of temperatures, but increased progressively with heating at moderately higher and the highest temperatures. Most of the mortars were of the first two types. Although not all mortars reached their lowest strengths after being heated at 750° C and cooled, such strengths were, in general, close to the lowest obtained after they were heated over a fairly wide range of temperatures.

The time required for the mortars to air-set, as indicated by their resistance to flow under load, ranged from 1 to 90 minutes when used to bond firebrick of 8.6-percent absorption. Eight mortars set within 1 minute and an additional six set within 3 minutes.

The bonding strength of the mortars in assemblages of two half-brick and mortar was obtained. These assemblages were heated at the same temperatures at which specimens from the neat mortars had been heated. The lowest strength was 5 lb/in.^{2} and the highest 540 lb/in.^{2} In general, a high air-setting strength of the neat mortar presages a satisfactory strength of a brick-and-mortar assembly in cross bending. Failure of the assembly occurred either in the brick, in the mortar, in the joint, or in some combination of these.

Piers of two standard-size brick and two half-brick (making two horizontal and one vertical joint) were made up with ⅛-in. and $\frac{1}{16}$-in. joints. After drying, none of the joints showed serious cracking, but after they were heated at 750° C, four were found to have cracked badly. During the heating at 1,425° C many of the cracks visible before the heat treatment healed, but numerous cases of thermal cracking occurred. Heating at 1,500° C caused slippage of the brick in the case of three mortars. The appearance of five mortars was much better in units made with the $\frac{1}{16}$-in. joint than with the $\frac{1}{8}$-in. one. Four mortars were practically free from defects in either size of joint.

Examination of the mortars after heating at 1,425° C and 1,500° C in fusion-test blocks gave information relative to shrinkage, cracking, migration of salts and flow because of fusion. This information was in good agreement with observations made of piers of two whole and two half-brick and mortar heated similarly.

The results of this study lead to the conclusion that a specification governing air-setting refractory mortars may be prepared with the assurance that a satisfactory commercial product may be obtained readily in the open market.

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PROPERTIES OF AIR-SETTING REFRACTORY-BONDING MORTARS OF THE WET TYPE

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ABSTRACT

Twenty brands of refractory mortars were studied with regard to their tendency to segregate and harden, their water content, fineness, alkali content, pyrometric cone equivalent, suitability for troweling and dipping, drying properties, and strength after heating at various temperatures and cooling. The setting time, strength, types of failure of assemblages of two half-brick and mortar, and tendency of the mortar to shrink, crack, and flow when exposed to high temperatures, both in fusion blocks and in units of three brick each, were also studied.

The results of the tests show a wide range in the properties of refractory mortars of the air-setting type. In general, neat mortars having a high air-setting strength will show good strength after heating and cooling. Although not all mortars reached their lowest strength after heating at 750°C and cooling, that strength was, in general, close to the lowest obtained, after heating over a fairly wide range of temperatures. The materials were all finely ground, very little being retained on a No. 40 sieve. A preliminary calcining of the mortars did not affect the pyrometric cone equivalent but greatly facilitated obtaining the end points. Some of the mortars could be troweled satisfactorily under all of four different conditions of a mechanical-troweling test; others were satisfactory in only some of these tests. If curling occurred with drying of the mortar, it was usually accompanied by cracking. The results of the fusion-block tests correlated well with observations made on the three-brick units in the heat-soaking tests.

CONTENTS

I. INTRODUCTION

The number of new brands of air-setting refractory-bonding mortars marketed in the wet condition in recent years, as well as production statistics, indicate an increasing popularity of this product. This popularity may be attributed to the fact that these mortars usually develop a high strength at ordinary temperatures, and retain a goodly proportion of that strength throughout the lower ranges of moderately high temperatures. At still higher temperatures a strength is developed through partial vitrification of some of the constituents of the mortar. A high strength of the mortar joints is thereby assured over a wide range of temperature. This is in contrast to a mortar prepared from only ground fire clay and water. In most cases very little strength is attained by such a mortar until it has been heated to a sufficiently high temperature to cause some vitrification of the clay. The air-setting mortar, therefore, may advantageously be used in installations where the temperatures reached are moderately high, but not high enough to cause any vitrification of the clay, and also in installations where the range in temperature may vary from close to ordinary temperatures in certain parts of the installation to high temperatures (for example, approximately 1,300° C) in other parts.

Refractory mortars of widely varying properties are on the market, and it is to be expected that certain of these mortars will prove to be more suitable in one type of service than in another, whereas others may prove satisfactory in nearly all types. It is, therefore, essential to evaluate the properties of these mortars by means of laboratory tests [1] as an aid in their selection for specific services. The National Bureau of Standards has been requested to prepare a Federal specification for this commodity; therefore, a study of the properties of a group of such mortars was undertaken.

Air-setting mortars are marketed in both the wet and the dry condition; those of the wet type were studied first, and the results are reported in this paper. It is planned to report the results of a study of mortars marketed in the dry condition in a future paper.

[1] Laboratory tests for evaluating the properties of air-setting mortars have been proposed, among others, by J. F. McMahon, J. Can. Ceram. Soc. 6, 55 (1937); and also by S. M. Phelps, Am. Refractories Inst. Tech. Bul. 60 (September 1935).

II. MATERIALS

Twenty-three[2] air-setting refractory mortars were obtained from 20 manufacturers rather widely distributed throughout the United States. In all cases the mortar was furnished in air-tight containers, and in all but six cases it was furnished in several small (5- or 10-lb.) containers.

III. PREPARATION OF SPECIMENS AND METHODS OF TESTING

1. MORTAR

(a) SEGREGATION, CONDITION, AND CONSISTENCY

Since all the mortars could not be tested simultaneously, and since the different tests were made over a fairly long period, the containers were opened at varying intervals of time after their receipt. Observations were made at the time of opening the container as to whether the solids and the liquid had segregated, and also, whether the condition of the mortar was such that it could be easily removed from the container and remixed without much difficulty. The mortar was churned or kneaded mechanically for 15 minutes before it was used for test purposes. After removing the mortar from the sealed container, it was kept in a pan covered with a wet cloth to retard loss of moisture while the specimens were being made.

Each mortar was classified according to the ease with which it could be spread with a mason's trowel. This property, designated "consistency for troweling", was based solely on the judgment of the investigators.

A joint 1/16 in. or "thinner," obtained by dipping the brick in a slurry of mortar, is usually recommended by the manufacturers when mortars of this type are used for laying brick. Consequently, the desirability of making some observations as to the ease with which mortars, as received from the manufacturers, may be changed to a dipping consistency was important. A quantity of the mortar was placed in a pan and mixed by hand with measured amounts of water until the desired dipping consistency was obtained.

(b) WATER LOSS AT 105°C

The loss in weight, assumed to indicate the water content, was obtained on 200-g samples by drying them to constant weight at about 105°C. The loss was determined at the end of 72 hours, and again at the end of 96 hours, on the mortars as received, and also after changing them to a dipping consistency. If there was a loss in weight during the last 24-hour period, the mortar was dried for another 24-hour period.

(c) ALKALI CONTENT[3]

The alkali content of the mortars was determined on bars 1 in. wide and 1/4 in. thick which were initially dried with the top or finishing surface uppermost, at least until set had occurred. After drying the samples to constant weight at 105°C, three of them were taken for test: One (5 g) representing the entire cross section of the sample,

[2] Because of delayed receipt of 3 mortars, they were subjected to only a limited number of tests. It is specifically stated in the text when the information discussed covers all 23 mortars.
[3] Determined by E. H. Hamilton, of the Bureau staff.