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SOME PROPERTIES OF HEAT-SETTING REFRACTORY MORTARS

By Raymond A. Heindl and William L. Pendergast

ABSTRACT

Twelve brands of the heat-setting type of refractory mortar were studied with respect to sieve analysis, pyrometric cone equivalent, amount of mixing water required, troweling and drying properties, and strengths after heating at various temperatures. The tendency of the mortars to shrink, crack, and adhere when exposed to high temperatures, both in fusion blocks and in units of three bricks each, was also investigated.

CONTENTS

I. INTRODUCTION

There are four materials ordinarily used for bonding fire-clay bricks or refractory shapes. Ground plastic fire clay was the generally accepted medium for many years, but with the improvement in refractories, the heat-setting mortar and the wet and dry types of air-setting mortars were developed and marketed. Federal specifications based on the results of investigations made at the National Bureau of Standards have already been prepared for fire clay and the two types of air-setting mortars. It is planned that the data reported in the present paper will be used for a similar purpose in the case of the heat-setting type of mortar.

II. MATERIALS

Twelve refractory mortars of the heat-setting type were supplied by eight manufacturers. One of these mortars was originally submitted as an air-setting mortar of the dry type, but because it had very little strength after air-setting, it was considered a heat-setting mortar.

III. PREPARATION OF SPECIMENS AND METHODS OF TESTING

1. MORTARS

Each mortar was mechanically mixed with water for 1 hour, during which period the water content was adjusted to obtain the proper consistency for troweling as judged by "feel." After soaking the mortars overnight they were mixed for an additional 4 hours before testing them. All the tests were made on mortars so treated except the sieve analysis test,[1] which was made after the 1-hour mixing. The amount of mixing water was determined by drying samples of approximately 200 g to a constant weight at about 105° C. The pyrometric cone equivalents were determined according to the ASTM standard method.[2] The flow-table test was made as described in Federal Specification SS–C–158,[3] and also in the ASTM standard specifications.[4]

The troweling tests were made with the machine described by Heindl and Pendergast.[5] A ¼-in. layer of mortar was spread evenly by hand-troweling on the upper 9- by 4½-in. face of a brick by means of a template. Using such specimens, two tests of troweling properties were made by reducing this ¼-in. layer to ⅛ in. in 1 stroke, and to ⅛ in. in 25 strokes (0.005 in. per stroke), respectively. The mortar caps were examined before drying for uniformity of thickness and adherence to the brick and, after drying, for cracks.

The modulus of rupture (transverse strength) was determined on mortar bars 6 by 1 by ¼ in. after drying for 27 hours at approximately 105° C. The bars were placed on supports 5 in. apart and loaded midspan. For convenience in reporting the results of the breaking tests, reference hereafter to the "original" position indicates that the surfaces of the bar in the test machine were in the same position as they were when made, that is, the same surface was uppermost on both occasions. Conversely, reference to "inverted" position indicates the surfaces were in reverse position during the tests. Half of the 10 mortar bars were tested in the original position in the cross-breaking machine and the other half in the inverted position.

The linear shrinkage determinations were made on three bar specimens of each mortar after each of three heat treatments, namely at 105°, 1,350°, and 1,500° C, respectively.

Tests of the mortars for adherence and also observations for shrinkage were made by heating each mortar in a fusion block having a compartment ½ in. deep. The heat treatments were identical with those used for the bar specimens.

2. MORTAR AND BRICK

Assemblies of two half-brick and mortar were used for determining the strength of brick-to-mortar bond. The brick were cut parallel to the 2½- by 4½-in. faces into two equal parts. A laboratory screw

[1] In general, the test was similar to that described in Standard Method of Test for Particle Size of Ground Refractory Materials, ASTM Designation C 92–36, Am. Soc. Testing Materials Standards, pt. 2, Nonmetallic Materials—Constructional, p. 195 (1939).

[2] Pyrometric Cone Equivalents of Refractory Materials, ASTM Designation C 24–35, Am. Soc. Testing Materials Standards, pt. 2, Nonmetallic Materials—Constructional, p. 214 (1939).

[3] Cements, Hydraulic, General Specification.

[4] Standard Specifications for Masonry Cement, ASTM Designation C 91–40, Am. Soc. Testing Materials Standards, Supplement, pt. 2, p. 1–7 (1940).

[5] J. Research NBS **23**, 7 (1939) RP1219.

press [6] was used in bonding the two half-brick with mortar. Sections of ⅛-in. drill rod were used as temporary spacers to obtain uniform thickness of mortar joints. The modulus of rupture of the mortar joint was determined after drying the specimen for 27 hours at about 105° C. The specimens were placed on supports 8 in. apart and loaded midspan.

A second type of brick-and-mortar assembly was made, consisting of a pier of two standard-sized brick and two half-brick laid flat to give one vertical joint between the two horizontal joints. Three of these piers were laid up with a troweled joint ⅛ in. thick. The piers dried at 105° C and also heated at 1,350° and 1,500° C, were examined, when cool, for defects of the mortar cap and mortar joints.

The bonding ability of a mortar may be judged by grasping the top brick in a pier made of three brick as described above, and lifting it. If the mortar and brick pier remains intact, it can be assumed that the mortar has reasonably good bonding properties. This simple test was made on piers heated for 1 hour at 1,350° and at 1,500° C and cooled.

IV. RESULTS AND DISCUSSION

1. MORTARS

(a) SIEVE ANALYSIS

The results of the sieve analysis are given in table 1, columns 2 to 7. Less than 1 percent was retained on the No. 20 sieve for 8 of the 12 mortars. In the case of five of the mortars, over 60 percent passed the No. 200 sieve. Mortars *P1* and *Y1*, on the other hand, had the largest percentage of coarse fractions, only 35 percent having passed the No. 200 sieve.

(b) PYROMETRIC CONE EQUIVALENT

The pyrometric cone equivalent of the mortars, listed in table 1, column 8, ranged from 27–28 to 35–36. The refractoriness of the mortars was fairly high, since the pyrometric cone equivalent was above 30 in all but one instance.

(c) MIXING WATER AND FLOW-TABLE TEST

The amounts of water, in terms of percentage of the dry weight of the mortar, used for bringing the mixtures to the proper consistencies for troweling are given in table 1, column 9. The amount of water ranged from 21.2 to 41.5 percent. In general, the mortars which contained greater proportions of coarse particles, as indicated by the total percentage retained on the No. 200 sieve, required the least amounts of water for tempering. The two exceptions to this relation are mortars *N1* and *O1*, which contained the lesser proportions of coarse particles. Both of these mortars showed definite alkaline reaction when tested with 0.2 *N* hydrochloric acid and the deflocculation resulting from this alkalinity no doubt accounted for the low percentages of water required. The other two mortars which gave indications of alkalinity were *P1* and *R1*. Both contained high percentages of coarse-grained material, in fact, *P1* led all others in that respect, and hence any deflocculating action which could have been caused by the alkalies present may have been largely nullified.

[6] J. Research NBS **23**, 7 (1939) RP1219.

TABLE 1.—*Some properties of heat-setting refractory mortars*

Mortar	Sieve analysis [1]						Pyrometric cone equivalent	Water content of neat mortar	Flow-table readings	Troweling properties. Spreading and reducing layer—		Drying properties of troweled caps	
	Retained on No. 20	Passed No. 20. Retained on No. 40	Passed No. 40. Retained on No. 60	Passed No. 60. Retained on No. 100	Passed No. 100. Retained on No. 200	Cumulative total not passing No. 200				From ¼ in. to ⅛ in. in 1 stroke	From ¼ in. to ⅛ in. in 25 strokes	Adhered	Cracked
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Cone*	*Percent*	*Percent*			*Percent*	
J 1	0.0	1.7	16.2	21.0	17.2	56.1	31	25.6	72	Good	Good	100	No.
K 1	.2	1.8	9.3	12.9	14.0	37.2	30–31	36.0	76	do	do	0	Do.
N 1	.0	0.2	4.4	9.9	14.5	29.0	32–33	22.8	82	do	do	95	Do.
O 1	.0	.1	3.3	10.6	15.2	29.2	31–32	25.7	70	do	Poor	35	Do.
P 1	.2	12.2	20.2	16.3	15.7	64.6	31	26.4	75	Fair	Fair	100	Do.
Q 1	.1	0.9	17.2	20.1	19.1	57.4	31–32	32.0	65	Good	Good	100	Do.
R 1	1.9	12.7	21.4	12.1	11.2	59.3	35–36	24.6	77	do	do	95	Do.
S 1	0.1	6.5	20.9	16.1	12.9	56.5	35	22.2	74	do	do	100	Do.
T 1	1.2	8.7	9.0	9.5	9.6	38.0	32	41.5	79	do	Fair	0	Moderately.
U 1	1.5	11.5	9.8	7.7	7.7	38.2	31–32	39.0	57	do	Good	0	Do.
V 1	0.1	2.0	16.5	20.7	15.1	54.4	32	32.2	66	do	do	95	No.
Y 1	2.7	32.1	19.2	5.2	6.5	65.7	27–28	21.2	82	do	do	95	Do.

[1] U. S. Standard Sieve Series.

The results of the flow-table test of the mortars in a troweling consistency are given in table 1, column 10. The values range from 57 to 82, all but three being between 70 and 82, indicating that the initial consistency of most of the mortars was very nearly the same.

(d) TROWELING

The results of the mechanical-troweling tests are given in table 1, columns 11 and 12. These tests gave an indication of the workability of the mortars. In the one-stroke test all mortars except *P1*, which lacked sufficient plasticity, proved satisfactory, but in the 25-stroke test mortars *O1*, *P1*, and *T1* were the exceptions. Mortar *O1* was rated "poor" because of excessive stickiness, resulting in its adhering to the trowel and being partially pulled from the brick.

The condition of the mortar caps on the brick, after troweling and drying, are given in table 1, columns 13 and 14. Mortars *K1*, *T1*, and *U1* showed no indication of adherence to the brick, and mortar *O1* adhered only about one-third. The remainder had good adherence. The degree of adherence of the mortar cap, however, was no indication of the bonding property of the mortar when used in joints. The caps were remarkably free from drying cracks; only 2 (*T1* and *U1*) of the 12 showed any development of cracks and these were not serious.

In table 2 are given the average transverse strengths of the neat-mortar bars after heating them at 105°, 1,350°, and 1,500° C. In each case three values are given: (1) the average for not less than five bars broken in the inverted position, (2) a similar average for bars broken in the original position, and (3) the averages for both positions. The results obtained after heating the bars at 105° C indicate no significant difference in strength with position of specimen during loading. However, the specimens, after heating at 1,350° and 1,500° C, showed strengths averaging about 18 percent greater when tested in the inverted position than when tested in the original position. This relation is the reverse of the findings in tests of air-setting mortars [7] of the wet and dry types.

The average transverse strength of the neat mortars dried at 105° C ranged from 0 to 290 lb/in^2, those heated at 1,350° C from 350 to 4,720 lb/in^2, and those heated at 1,500° C from 1,705 to 5,550 lb/in^2, all the specimens being cooled to room temperature before testing.

The linear shrinkages of neat mortars resulting from heating at 105°, 1,350°, and 1,500° C and cooling are given in table 2. The two mortars, *T1* and *U1*, which show the highest shrinkages after heating at 105° C, were the only ones which cracked on drying after the troweling tests.

2. MORTAR AND BRICK

The results of the transverse-strength tests made on assemblies of the two half-brick bonded with mortar are given in table 2. After heating at 1,350° C, eight of the 12 mortars indicated no significant bonding of the end faces of half-brick, as indicated by lack of cross-breaking strength of the brick-and-mortar units. After heating at 1,500° C, however, all but four of the mortars had good adherence or bonding properties, the strengths of the assemblies ranging as

[7] R. A. Heindl and W. L. Pendergast, *Properties of air-setting refractory bonding mortars of the wet type*, J. Research NBS **23**, 7 (1939) RP1219; *Some properties of dry air-setting type of refractory bonding mortar*, **28**, 401 (1942) RP1461.

TABLE 2.—*Strength and shrinkage of heat-setting mortars after heating at several temperatures*

Mortar	Transverse strength [1] (modulus of rupture) of neat-mortar bars after heating at—			Linear shrinkage [2] of neat-mortar bars after heating at—			Transverse strength (modulus of rupture) of two-half-brick-and-mortar assemblage after heating at—	
	105° C	1,350° C	1,500 C°	105° C	1,350° C	1,500° C	1,350° C	1,500° C
	lb/in.²	*lb/in.²*	*lb/in.²*	*Percent*	*Percent*	*Percent*	*lb/in.²*	*lb/in.²*
	230	1,590	2,765					
J1	240	1,570	2,365	2.4	1.7	3.0	90	520
	235	1,580	2,565					
	210	5,200	3,010					
K1	200	4,235	2,950	6.9	5.9	4.4	0	0
	205	4,720	2,980					
	125	3,885	6,020					
N1	135	2,625	5,090	4.8	3.5	6.3	0	0
	130	3,220	5,550					
	160	4,170	4,750					
O1	150	3,400	4,330	6.3	4.1	6.4	0	0
	155	3,785	4,540					
	165	2,120	3,040					
P1	175	2,035	2,480	2.5	2.9	5.3	25	300
	170	2,080	2,760					
	160	2,680	4,120					
Q1	150	2,355	2,680	6.2	3.1	5.6	0	365
	155	2,515	3,400					
		1,205	2,315					
R1	0	895	2,180	0.9	0.8	1.5	180	665
		1,050	2,150					
	190	1,635	2,990					
S1	180	1,780	2,175	2.5	1.4	3.1	0	[3] 260
	185	1,710	2,580					
	170	2,405	3,115					
T1	180	2,405	2,730	9.2	3.7	5.1	0	0
	175	2,405	2,920					
	300	3,405	3,255					
U1	290	2,920	2,750	7.7	6.4	7.4	0	145
	290	3,160	3,005					
	110	2,075	3,140					
V1	95	2,060	4,530	6.5	3.2	4.8	0	[3] 85
	105	2,070	3,835					
	190	350	1,755					
Y1	205	345	1,655	4.0	1.0	3.9	95	460
	195	350	1,705					

[1] The 3 values determined for each mortar after having been heated at each of 3 temperatures represent, in the order given, the averages for: (1) 5 specimens broken with the surface that was originally at the top during drying in tension ("inverted position"), (2) 5 specimens with the surface that was originally on the bottom in tension ("original position"), (3) all specimens.

[2] Values tabulated in columns for 1,350° and 1,500° C are burning shrinkages.

[3] Average of 2 specimens.

high as 665 lb/in². In all cases the lack of strength in the assembly was due to failure of bonding of the mortar and brick and not due to weakness of the mortar.

The results of the visual examination of the mortars in the joints of the three-brick piers and in the fusion blocks after heating at 105°, 1,350°, and 1,500° C are given in table 3. Only those cracks described as "bad" would be considered as affecting the quality of the mortar. Almost without exception the information relative to the shrinkage and cracking of a mortar, whether obtained from examination of a fusion block or of a cap, correlated with that obtained on the joints. The following exceptions may be cited. (1) The shrinkage of *K1* was less in the joints than in the fusion block or in the cap, (2) the shrinkage of *O1* in the joints and in the fusion block was less than in the cap with comparable heat treatment and, (3) the appearance of mortar *Q1* in the joints of the pier and that in the fusion block heated at 1,500° C did not correlate.

TABLE 3.—*Appearance of mortar in fusion block, cap and in joints of three-brick-and mortar assemblage*

Mortar	Appearance of mortar in ⅛-in. joints [1] of pier after heating at—			Appearance of mortar in fusion block after heating at—			Condition [2] of ⅛-in. cap of mortar after heating at—		Bond in pier satisfactory after heating for 1 hour at—	
	105° C	1,350° C	1,500° C	105° C	1,350° C	1,500° C	105° C	1,350° C	1,350° C	1,500° C
J1	Good	⊥ and ‖ cracks.	Good	Slight shrinkage	Slight to moderate shrinkage.	Slight shrinkage. No adherence.	Good	Good	Yes	Yes.
K1	⊥ and ‖ cracks.	Moderate ⊥ and ‖ cracks.	Moderate ⊥ and ‖ cracks.	Moderate shrinkage.	High shrinkage. No adherence.	High shrinkage. No adherence.	Badly cracked. 75% not bonded.	Badly cracked. 80% not bonded.	No	Do.
N1	do	do	do	Slight shrinkage	Moderate shrinkage	Moderate shrinkage	Slightly cracked	Slightly cracked	do	No.
O1	Moderate ⊥ and ‖ cracks.	do	Bad ⊥ and moderate ‖ cracks.	do	do	do	Badly cracked	Badly cracked. 25% not bonded.	Yes	Yes.
P1	Good	Good	Good	Good	Good	Good	Good	Good	do	Do.
Q1	do	do	Bad ⊥ and slight ‖ cracks.	Slight shrinkage	Slight shrinkage	Slight to moderate shrinkage.	do	Slightly cracked. 10% not bonded.	do	Do.
R1	do	⊥ and ‖ cracks.	Thermal cracks. Fused.	do	do	do	do	Slightly cracked	do	Do.
S1	do	Good	Good	do	Slight to moderate shrinkage.	Slight to moderate shrinkage.	do	Good	do	Do.
T1	Moderate ⊥ and ‖ cracks.	Bad ⊥ and ‖ cracks.	Bad ⊥ and moderate ‖ cracks.	Moderate shrinkage.	High shrinkage. No adherence.	High shrinkage. No adherence.	Badly cracked. 50% not bonded.	Badly cracked. 80% not bonded.	do	Do.
U1	do	do	do	do	do	do	do	do	do	Do.
V1	Good	⊥ and ‖ cracks.	⊥ and ‖ cracks	Slight shrinkage	Moderate shrinkage	Moderate shrinkage	Good	Slightly cracked	do	Do.
Y1	do	Good	Good	do	Good	Slight shrinkage	do	Slightly cracked. 50% not bonded.	do	Do.

[1] Cracks occurring in the horizontal joints are designated ‖; those in the vertical joints ⊥.
[2] No reference to "adherence" indicates that bonding had taken place between mortar and fusion block.

In general, the cracking which occurred in the mortar joints and caps could have been predicted on the basis of selecting from the mortars listed in table 2, those having the highest shrinkage values after drying at 105° C.

The results of the test for judging the bonding ability of the mortars by grasping the top brick of a pier of three bricks bonded with mortar are listed in the last two columns of table 3. All the mortars proved satisfactory in the tests except *K1* and *N1*. Mortar *K1* failed in this test after having been heated at 1,350° C, and mortar *N1* failed both after heating at 1,350° and at 1,500° C.

V. SUMMARY

Twelve refractory mortars of the heat-setting type supplied by eight manufacturers were investigated.

The mortars were finely ground, as supplied, only one contained as much as 2 percent of material that would not pass a United States Standard Sieve No. 20. The refractoriness of the mortars, as indicated by the pyrometric cone equivalent, was high, all but one being above cone 30. The amount of mixing water ranged from 21.2 to 41.5 percent. The consistencies of the mortars, however, as indicated by the flow-table test, were, with three exceptions, within a narrow range. The ease of troweling on brick, determined mechanically, was considered satisfactory except for one mortar. After troweling and drying, three mortars failed to adhere to the brick, but cracking was absent in all but two cases and these were not serious. These two mortars also had the greatest drying shrinkages.

The average modulus of rupture of the neat mortars dried at 105° C ranged from 0 to 290 lb/in.^{2}; of those heated at 1,350° C, from 350 to 4,720 lb/in.^{2}; and of those heated at 1,500° C, from 1,705 to 5,550 lb/in^2. In the transverse tests the bonding strength of the mortars in assemblies of two half-brick and mortar, heated at 1,350° C and cooled, was poor, as indicated by the lack of any significant stregnth of 8 of the 12 mortars. Satisfactory bonding strength was shown, however, by 8 of the 12 mortars after the heat treatment at 1,500° C. On the other hand, when the mortars were tested for their bonding property by grasping the upper brick in a pier made up of three brick and motar and lifting it, the results were very different. In these tests only two mortars were observed to fail when heated at 1,350° C, and but one when heated at 1,500° C and cooled.

The majority of mortars included in this study would be considered of satisfactory quality with respect to the technical requirements in a Federal specification based on the results of this investigation.

WASHINGTON, January 11, 1943.