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STUDY OF EFFLORESCENCE PRODUCED ON CERAMIC WICKS BY MASONRY MORTARS

By T. Ritchie

RESEARCH PAPER NO. 20

Division of Building Research,
National Research Council,
Ottawa, Ontario, Canada

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Study of Efflorescence Produced on Ceramic Wicks by Masonry Mortars

by T. RITCHIE

Division of Building Research, National Research Council, Ottawa, Ontario, Canada

Ceramic wicks (Efflorwicks) were partly embedded in cylinders of masonry mortars of various compositions, and the hardened mortars were alternately wetted and dried, which produced various amounts of efflorescence on the wicks. Portland cement in mortars contributed significantly to efflorescence. The alkaline material of the cementing substance of the mortars appeared to be an important source of the efflorescence.

I. Introduction

UNDER similar conditions of exposure, it has been found on occasion that masonry will develop efflorescence when one type of mortar is used but will be free of it or much less affected when mortar of another composition is used. This situation has been referred to frequently in the literature.¹ The use of Portland cement, particularly, in masonry mortars has been found, on occasion, to result in efflorescence on the masonry, whereas under the same conditions with lime mortar there has been none. The efflorescence has been attributed to alkaline material in the Portland cement.^{1(c), 1(c)}

The purpose of the investigation described in this paper was to compare the capacity of various common mortar materials to produce efflorescence on a particular fired clay material in contact with them.

A large number of mortars, composed of combinations of several types of limes, Portland cements, masonry cements, and sands, was prepared. A standard (for this work) fired clay material, in the form of a wick, was placed in each of the freshly mixed mortars, which had been placed to harden in cylindrical molds. A cylinder of mortar was thus formed,

from the top of which projected the wick of fired clay material, similar in properties to many building brick.

Efflorescence was formed on many of the wicks by alternately wetting and drying the mortar. An arbitrary number (ten) of these wetting and drying cycles was made, after which the wick was broken away from the mortar. It was dried, weighed, washed in water, dried, and again weighed. The difference in weight indicated the amount of soluble salts which had collected in the wick. In this way a comparison was made of the amounts of efflorescence produced under the same conditions by the various mortars used.

II. Mortar Materials

(1) Lime

Three types of lime were used; two were prepared from quicklime and the other was a hydrated lime powder. A chemical analysis of these limes before they were made into putty is given in Table I. Lime A was a high-calcium lime prepared from quicklime. Lime B was a hydrated lime made into putty by soaking in water. It was used after soaking for 24 hours. Lime C was prepared from quicklime in accordance with the procedure recommended by the manufacturer.

(2) Portland Cement

Portland cement from two sources was used. These cements are designated A and E. An analysis of samples of them, with respect to some constituents, is presented in Table I.

(3) Masonry Cement

Two masonry cements were used, designated M and S. An analysis of these cements is presented in Table I.

(4) Sand

Three sands were used, two of which were local sands employed for masonry work in the area. These two are designated A and L. The other sand, designated O, a relatively pure silica sand of uniform particle size, is used as a standard sand in some cement tests.² Sand L conformed in particle-size gradation to the requirements of a standard specification for mortar sands³ whereas sand A did not, being slightly too coarse. No chemical analysis of the sands was made.

III. Fired Clay Wick

A wick of a fired clay material was placed in each mortar as a means of collecting efflorescence. For this purpose Efflorwicks were used, obtained from the Research Department of the New York State College of Ceramics, Alfred University,

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¹ (a) Great Britain Department of Scientific and Industrial Research; Report of Building Research Board with Report of Director of Building Research, 1927.

(b) F. O. Anderegg, H. C. Peffer, P. R. Judy, and Lee Huber, "Indiana Limestone: I, Efflorescence and Staining," *Purdue Univ. Eng. Expt. Sta. Bull.*, No. 33, 84 pp. (1928).

(c) R. K. Robertson, "Efflorescence," *J. Can. Ceram. Soc.*, 13, 40-43 (1944); *Ceram. Abstr.*, 23 [9] 151 (1944).

Table I. Analysis of Mortar Materials (%)

Component	Lime A	Lime B	Lime C	Portland cement A	Portland cement E	Masonry cement M	Masonry cement S
Na ₂ O	(*)	0.02	0.05	0.41	0.09	0.28	0.01
K ₂ O	(*)	0.01	0.06	0.49	0.53	0.41	0.06
SO ₄	(†)	(*)	(*)	3.38	1.9†	1.80	1.26
Cl	(†)	(*)	(*)	(*)	(†)	(*)	(*)
CO ₂	0.05	2.14	0.44	0.24	(†)	25.53	1.57
MgO	0.99	11.64	1.72	2.62	4.1	1.08	1.87
CaO	97.15	64.00	90.50	62.77	62.2	56.72	67.18

* None. † Not determined. ‡ As SO₃.

² "Standard Specifications for Masonry Cement," A.S.T.M. Designation C 91-49; A.S.T.M. Book of Standards, Part 3, 1949.

³ "Standard Specifications for Aggregate for Masonry Mortar," Designation C 144-44; A.S.T.M. Book of Standards, Part 3, 1949.

Alfred, New York, where they have been developed for studies of the tendencies of various masonry materials to produce efflorescence.⁴ These wicks had been made by pressing ground shale into thin slabs, which were fired to a temperature corresponding to that attained in the firing of many structural clay products. This developed a red color in the material, and other properties similar to many fired clay building brick.

The wicks used were about 3 in. long, 2 in. wide, and $\frac{3}{16}$ in. thick, one end being semicircular in shape, the other rectangular. The form of the wicks is shown in Fig. 1.

IV. Preparation and Treatment of Mortar Samples

The mortar materials were proportioned on a volume basis. The amount of dry sand in each mortar mix was 0.05 cu. ft. The amounts of the other materials were measured by weight, the weight-to-volume relationship having been determined previously.

The mortar ingredients were mixed in a small mechanical mixer. The cementing materials were made into a slurry with water and to this was added the sand, and additional water as required to produce a plastic mixture. Ordinary tap water was used. Mixing continued for at least 5 minutes. The flow of the mortar was adjusted by the addition of water so that, when used, the mortar flow was between 100 and 125%.²

Molds designed for the preparation of small cylinders of concrete for compressive strength tests⁵ were used to form the samples of mortar. These molds were 4 in. high and 2 in. in diameter. For this work, however, a wooden plug was placed in the lower part of the mold, so that the cylinder of mortar obtained from the mold was $2\frac{1}{2}$ in. high.

The mortar was placed in the mold immediately after mixing. A wick, wetted in distilled water to improve its contact with the mortar, was placed to a depth of 1 in. in the mortar. On each wick a deep scratch had been made 1 in. from the end, so that when the wick was embedded in the hardened mortar the projecting part of it could be easily broken off at the mortar surface. The mortars were left in the molds for 24 hours, after which they were removed and stored in the laboratory air for at least a week before beginning the tests.

To subject the mortar samples to wetting and drying, each sample was placed in a small jar (capacity, about 7 oz.) and distilled water was added to a level just below the top surface of the mortar. The wick protruded through a hole in the metal cover of the jar; the opening between the wick and the cover was reduced in size by placing thin glass plates on the cover against the wick. Each sample was placed in water in this way for 24 hours. Then it was removed from the jar and allowed to dry in the laboratory air for about 7 hours. It was placed in the original water again for wetting, with more water added to bring its level just below the top surface of the mortar. The cover was replaced and the sample stood in the water for about 17 hours, when the drying procedure was carried out again.

In each 24 hours, therefore, the samples were being wetted for about 17 hours and for about 7 hours were being dried. During the wetting part of this procedure, moisture evaporated from the wick. While drying, however, the whole sample was exposed to the laboratory air, with the wick probably drying out more completely than the mortar in the time allotted.

Fig. 1. Equipment used in preparation and treatment of samples.

The equipment used in preparing the samples is shown in Fig. 1. The central mold space contains one of the wooden inserts and a mortar cylinder with wick attached. The type of jar in which the samples were wetted and one of the wicks are also shown.

Each mortar sample was wetted ten times and dried ten times, after which it was stored for at least a week in the laboratory air. Photographs were then taken of the samples, and each wick was carefully broken away from the mortar in which it had been embedded, at the scratch made previously in the wick.

Each wick broken off in this way was dried in an oven for 48 hours at about 100°C., cooled, and weighed. It was then placed in 50 cc. of distilled water for 24 hours, after which this water was replaced by another 50 cc. After one hour the water was replaced again by the same amount, and this procedure was continued until each wick had been washed in 250 cc. of water. The total washings from each wick were retained for analysis.

After this washing treatment, the wicks were dried for 48 hours at about 100°C., cooled, and weighed. The difference in the weighings, before and after washings, was taken to represent the amount of soluble material in the wicks. A similar washing treatment, made on several unused wicks to determine the soluble material present, showed this to be a very slight amount, but it was subsequently taken into account in determinations of the amounts of soluble material in the wicks broken from mortar samples.

V. Mortar Compositions

The mortars studied consisted of various combinations of the cementing materials and sands, and of various proportions by volume of cementing material to sand.

The materials used in the mortars have been described. The mortars made from them are designated by letter and number. The mortars composed of Portland cement, lime, and sand are listed in Table II, which shows, for each mortar, the types of materials used and their proportions. The mortars composed of the masonry cements and sand are listed in Table III.

VI. Comparison of Amounts of Efflorescence

After the wetting and drying procedure, the mortars were dried in the laboratory air for an additional week or more and then photographed. The wetting and drying treatment had formed extensive deposits of salts on some wicks; others appeared free of the salts, or slightly marked by them.

⁴ C. R. Amberg and L. Washburn, "Wick for Testing Efflorescence Tendencies of Materials," *Am. Ceram. Soc. Bull.*, 25 [1] 7-9 (1946).

⁵ "Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory," A.S.T.M. Designation C 192-49; A.S.T.M. Book of Standards, Part 3, 1949.

Fig. 2. Samples A1, A2, A3, A4, A5, and A6 after wetting and drying treatment.

Photographs of some of the mortars, which illustrate these differences, are shown in Figs. 2 through 6. (Figure 6 is of mortars of the masonry cements and sand; the others are of the lime, Portland cement, and sand mortars.) The com-

position of these mortars is shown in Tables II and III.

The amount of material soluble in water in each wick was determined, in the manner previously described. In Figs. 7 through 11 the weight of soluble material washed from each wick has been plotted against the composition of the mortar with which it was used.

VII. Analysis of Washing Solutions

The solutions obtained from the washings of one series of wicks (mortars A1 through A6), and from other wicks, were analyzed with respect to some constituents. The results of this analysis, which have been expressed as parts per million of the solution, are shown in Table IV.

VIII. Discussion

The capacity of mortars composed of many different ingredients to produce efflorescence under certain conditions has been studied. Ceramic wicks, developed and employed

(Text continued on p. 366)

Fig. 3. Samples AO1, AO3, and AO5 after wetting and drying treatment.

Fig. 5. Samples CO1, CO3, and CO5 after wetting and drying treatment.

Fig. 4. Samples BL1, BL3, and BL5 after wetting and drying treatment.

Fig. 6. Samples M2 and S after wetting and drying treatment.

Table II. Materials Used and Their Proportions in the Portland Cement, Lime, and Sand Mortars

Mortar designation	Type of mortar material			Proportions by vol. of mortar materials		
	Lime	Portland cement	Sand	Lime	Portland cement	Sand
A1	A	(*)	A	1.0	(*)	3.0
A2	A	A	A	0.8	0.2	3.0
A3	A	A	A	0.6	0.4	3.0
A4	A	A	A	0.4	0.6	3.0
A5	A	A	A	0.2	0.8	3.0
A6	(*)	A	A	(*)	1.0	3.0
AL1	A	(*)	L	1.0	(*)	3.0
AL2	A	A	L	0.8	0.2	3.0
AL3	A	A	L	0.6	0.4	3.0
AL4	A	A	L	0.4	0.6	3.0
AL5	A	A	L	0.2	0.8	3.0
AL6	(*)	A	L	(*)	1.0	3.0
AL1A	A	(*)	L	1.0	(*)	2.0
AL2A	A	A	L	0.8	0.2	2.0
AL3A	A	A	L	0.6	0.4	2.0
AL4A	A	A	L	0.4	0.6	2.0
AL5A	A	A	L	0.2	0.8	2.0
AL6A	(*)	A	L	(*)	1.0	2.0
AL1B	A	(*)	L	1.0	(*)	4.0
AL2B	A	A	L	0.8	0.2	4.0
AL3B	A	A	L	0.6	0.4	4.0
AL4B	A	A	L	0.4	0.6	4.0
AL5B	A	A	L	0.2	0.8	4.0
AL6B	(*)	A	L	(*)	1.0	4.0
AO1	A	(*)	O	1.0	(*)	3.0
AO3	A	A	O	0.6	0.4	3.0
AO5	A	A	O	0.2	0.8	3.0
B1	B	(*)	A	1.0	(*)	3.0
B3	B	A	A	0.6	0.4	3.0
B5	B	A	A	0.2	0.8	3.0
BO1	B	(*)	O	1.0	(*)	3.0
BO3	B	A	O	0.6	0.4	3.0
BO5	B	A	O	0.2	0.8	3.0
BL1	B	(*)	L	1.0	(*)	3.0
BL3	B	A	L	0.6	0.4	3.0
BL5	B	A	L	0.2	0.8	3.0
C1	C	(*)	A	1.0	(*)	3.0
C3	C	A	A	0.6	0.4	3.0
C5	C	A	A	0.2	0.8	3.0
CO1	C	(*)	O	1.0	(*)	3.0
CO3	C	A	O	0.6	0.4	3.0
CO5	C	A	O	0.2	0.8	3.0
CL1	C	(*)	L	1.0	(*)	3.0
CL3	C	A	L	0.6	0.4	3.0
CL5	C	A	L	0.2	0.8	3.0
E2	A	E	A	0.8	0.2	3.0
E3	A	E	A	0.6	0.4	3.0
E4	A	E	A	0.4	0.6	3.0
E5	A	E	A	0.2	0.8	3.0
E6	(*)	E	A	(*)	1.0	3.0
EL6	(*)	E	L	(*)	1.0	3.0
EO6	(*)	E	O	(*)	1.0	3.0

* None present.

Table III. Materials Used and Their Proportions in the Masonry Cement and Sand Mortars

Mortar designation	Type of mortar material		Proportions by vol. of mortar materials	
	Masonry cement	Sand	Masonry cement	Sand
M1	M	A	1.0	2.0
M2	M	A	1.0	3.0
M3	M	A	1.0	4.0
ML	M	L	1.0	3.0
MO	M	O	1.0	3.0
S	S	A	1.0	3.0
SL	S	L	1.0	3.0
SO	S	O	1.0	3.0

Fig. 7. Comparison of amounts of salts dissolved from wicks used with mortars of lime A and various sands and Portland cements. (L) indicates lime, (PC) Portland cement, and (S) sand. Proportions are by volume

Fig. 8. Comparison of amounts of salts dissolved from wicks used with mortars of lime B, Portland cement, and various sands. (L) indicates lime, (PC) Portland cement, and (S) sand. Proportions are by volume.

Fig. 9. Comparison of amounts of salts dissolved from wicks used with mortars of lime C, Portland cement, and various sands. (L) indicates lime, (PC) Portland cement, and (S) sand. Proportions are by volume.

Table IV. Analysis of Washing Solutions*

Solution constituent	Mortar											
	A1	A2	A3	A4	A5	A6	E5	EL6	EO6	MO	ML	M2
Na ₂ O	5.0	88.5	160	265	280	250	91	122	105	196	248	248
K ₂ O	6.0	55.0	105	150	210	220	140	253	365	319	229	161
SO ₄	4.2	43.6	23.0	32.1	35.4	80.6	22	49	67	142	84	56
Cl	<2	<2	<2	<2	<2	<2	None	None	None	None	None	None
CO ₃	48.3	194.7	294.0	528.0	572.0	478.0	204	267	438	360	477	474
MgO	2.9	None	None	None	None	6.5	None	None	None	None	None	None
CaO	19.6	4.2	4.2	4.2	4.2	4.2	None	None	None	None	None	None

* Expressed as parts per million of the solution.

elsewhere for similar studies, were used with mortar samples which were subjected to cycles of wetting and drying to produce efflorescence on the wicks. The amounts of such salt deposits have been compared visually and by the loss in weight of the wicks from a washing treatment.

For all the Portland cement, lime, and sand mortars studied, the amount of efflorescence tended to increase as the propor-

tion of Portland cement in the mortar increased (Figs. 7 through 10).

Under the same conditions, mortars containing one type of Portland cement produced greater amounts of efflorescence than those of another (Fig. 7, mortar series A1 through A6 and E2 through E6). The lesser amounts of efflorescence were produced by mortars in which the Portland cement contained less alkaline material (Na₂O and K₂O; see Table I). Similarly, mortars of the two masonry cements differed in the amount of efflorescence produced, under the same conditions, as is shown in Fig. 11. In this case, the lesser amounts of efflorescence were produced by the mortars of the masonry cement which contained less alkaline material (Na₂O and K₂O; see Table I).

For those mortars which gave relatively high amounts of efflorescence, the type of sand used appeared to exert considerable influence on the amount of efflorescence which developed on the wick. Figures 7, 8, 9, and 11 show that, other conditions being the same, the mortars of sand O, the silica sand of uniform particle size, produced the greatest amounts of efflorescence, and mortars of sand A the least. This is probably due to differences in the ease of water movement through the mortar samples, resulting from differences in particle-size characteristics of the various sands.

The analysis of the washing solutions obtained from one series of mortars (A1 through A6, Table IV) indicated for that series that sodium and potassium carbonate predominated in the washings of the wicks used with mortars containing Portland cement, and calcium carbonate in the washings of the wick used with the lime and sand mortar. Sulfate material was present in relatively appreciable quantities in the washings when Portland cement was used in these mortars.

An increase in the proportion of cementing material to sand in the mortars produced a greater amount of efflorescence, as shown in Figs. 10 and 11.

Fig. 10. Comparison of amounts of salts dissolved from wicks, in relation to changes in mortar composition and ratio of cementing material to sand. (L) indicates lime, (PC) Portland cement. Proportions are by volume of lime; ratios by volume of cementing material to sand.

Fig. 11. Comparison of amounts of salts dissolved from wicks used with mortars of masonry cements M and S and various sands for different ratios by volume of cementing material to sand.

IX. Conclusions

Marked differences in amounts of efflorescence occurred on ceramic wicks partially embedded in mortar samples which were subjected to a certain wetting and drying procedure. Sixty mortars were studied, composed of three lines, two Portland cements, two masonry cements, and three sands. The capacity of the cementing materials to contribute to efflorescence appeared to be related to the alkaline material present (expressed in this paper as Na₂O and K₂O). The cementing materials relatively low in alkaline content produced mortars which gave relatively small amounts of efflorescence on the wicks; conversely, the cementing materials of relatively high alkaline content produced mortars which gave relatively large amounts of efflorescence on the wicks.

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