Research Paper 8

Assessment of the Salt Attack Resistance of Fired Clay Bricks

Abstract

This paper reports the findings of a series of experiments designed to help the development of a technique which would provide an indication of the susceptibility of fired clay bodies to deterioration caused by salt attack.

These experiments consisted of the study of the relationship between measurable physical properties of some extruded clay bodies fired at a series of temperatures and their resistance to salt attack as measured by the number of salt cycles they withstood before deterioration was observed.

Good correlations were observed with both cold water absorption and Rockwell Hardness and salt cycles. The relationship between moisture expansion and salt cycling was also investigated.

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Research Paper 8

Assessment of the Salt Attack Resistance of Fired Clay Bricks

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1.0 Introduction

In the selection of any fired clay product for a particular project, one of the main considerations must be the ability of the materials to withstand the damaging affects of the exposure conditions to which they are likely to be subjected during the life expectancy of the structure in which they are to be used.

In Australia where, apart from a small number of ski resorts where frost resistance is also an important consideration, the ability to resist the action of salt attack by these products is the main concern.

Frost and salt attack resistance of fired clay bodies are however not directly measurable properties, as they are dependent not only on the material's own properties, but also on the exposure conditions.

Therefore, the prediction of their performance under all exposure conditions is difficult, if at all possible.

An approach to the solution of this problem is to examine their performance under controlled conditions and hope that the observed behaviour of these materials under test can be related to that displayed under different conditions of exposure.

To evaluate the salt attack resistance of fired clay bodies under controlled conditions, salt cycling is an obvious technique to consider. Its drawback is the length of time required for the completion of the test.

The authors therefore attempted to relate the number of cycles leading to failure to more rapidly assessable physical properties.

2.0 Experimental

A range of raw materials and production blends supplied by two Victorian clay brick manufacturers were selected for this study (see Table 1).

Table 1. Raw materials and production blends used in this study

1. Creswick White
2. Enfield Yellow
3. Pit Shale
4. Enfield Grey
5. Cream Brick Mix 1
6. Red Brick Mix
7. Brown Brick Mix
8. Bacchus Marsh Clay
9. Light Reef Clay
10. Wollert Plastic Clay
11. Cream Brick Mix 2
12. Pink Brick Mix

After appropriate sample preparation, the clays were extruded in a laboratory extruder producing bars with dimensions of 250x25x50 mm. The specimens were dried and then fired at pre- determined temperatures in a programmed small electric kiln adopting a five hour heating period, a five hour 'soaking' period and subsequent cooling to ambient temperature over a total 24 hour cycle.

Temperatures were monitored with No. 27 Buller rings. Full size bars were used to determine the samples accelerated moisture expansion, 24 hours Cold- and five hours Boiling Water absorption values.

For salt cycling tests, smaller (40x15x15 mm) pieces, displaying at least one face, were cut from full size bars.

The most commonly observed efflorescing salts in brickwork, sodium sulphate and sodium chloride, were selected for the salt cycling. The salt solutions were prepared from Na_2SO_4,10 H_2O and NaCl at 14 w/v concentrations.

The absorption properties were determined according to the method given in AS 1226-1980 and the accelerated moisture expansion determination is described in part H of the *BDRI Specification and Methods of Test for Clay Bricks.*

The following procedure for the salt cycling was devised: dried samples (in duplicate) were exposed to cycles of soaking for two hours in 150 ml of the appropriate salt solution followed by subsequent oven drying for 22 hours at 110°C. The cycle number at which the deterioration of the samples began was accepted as the first of three consecutive cycles in each of which there was a significant weight loss.

The Rockwell Hardness tests were carried out using Rockwell Scale E (HRE) employing a 100 kg load and a 3.2 mm diameter indenter. An average of 10 readings was accepted as the mean hardness value.

3.0 Results

A summary of the results of these investigations is given in Table 2.

4.0 Discussion

The cycling procedure outlined in this paper will, without doubt, impose a more severe exposure condition on the fired clay body than it is ever likely to encounter in most buildings. However, the results show that some fired clay bodies are attacked more readily by salts than others. Thus this procedure may be used as an accelerated test to indicate the resistance of fired clay bodies to salt attack under very severe artificially-created conditions.

The nature of this accelerated deterioration test means that the less severe conditions that the product encounters during its lifetime are not being simulated.

The results of these investigations can however be interpreted by assigning durability grades on the basis of the number of salt cycles survived by the specimen tested.

These grades may be designated as materials with high, intermediate and low durability.

5.0 Effectiveness of salt solutions

In these series of tests, as shown in Table 2, of the two salt solutions used, less sodium chloride cycles were needed to cause failure in specimens fired at lower temperatures (900 to 1000°C) than was the case with sodium sulphate. However, in specimens fired at 1050°C, sodium sulphate caused failure in a limited number of cycles while many of the specimens survived a large number of sodium chloride cycles.

Preliminary experiments show that the scale of deterioration of test samples in 14 percent w/v magnesium sulphate and 14 percent w/v potassium chloride is slower than in the case of sodium sulphate. Sodium chloride attack in brickwork is prevalent in coastal regions. However, salt deterioration is frequently noted where sodium sulphate accumulates in the brickwork and the entrance of external water triggers the mechanism of salt attack. These results and observations suggest that either of these salts could be used for an accelerated test, but sodium sulphate is preferred by the authors as it appears to be more effective over the whole firing range.

6.0 Gradings based on salt cycling

From the results given in table 2, it is evident that the samples may conveniently be grouped into three categories.

1. Those that did not fail during these tests.
2. Those that failed rapidly after a small number of cycles.
3. Those that failed after the cut-off mark of category 2.

It is worth noting that the appearance and physical characteristics of specimens in group 2 is similar to fired clay bodies that are often seen failing in exposed locations, whilst those in the first group are never seen to fail even under the most severe exposures to salt attack such as occur in coastal regions.

In terms of the number of salt cycles survived by these specimens, the three classes may be defined as follows:

High Durability: those that did not fail after 30 cycles

Intermediate: those that failed between 12 and 30 cycles

Low Durability those that failed in less than 12 cycles.

Table 2. Summary of test results

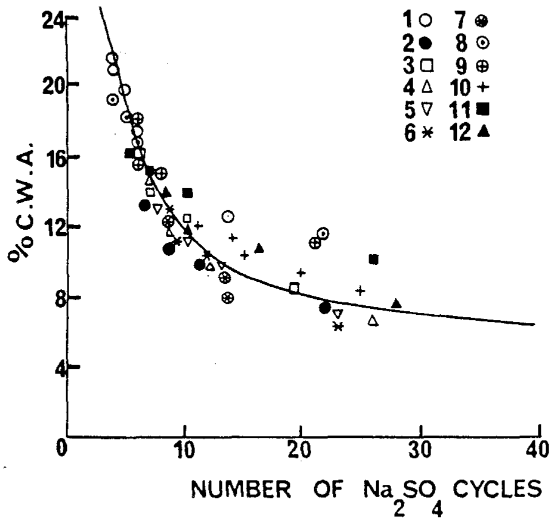
Firing temp. °C	Treatment		Samples											
			1	2	3	4	5	6	7	8	9	10	11	12
900°	Failure after no. of cycles in:	Na2S04	4	7	6	7	8	8	9	4	5	11	5	7
		NaCl	2	N/D	5	5	4	6	5	3	3	6	3	5
	Average C.W.A.(%)		21.5	13.1	16.2	14.2	13.1	13.3	12.1	19.3	18.0	12.0	16.6	14.2
	Average B.W.A. (%)		22.8	13.7	18.4	14.9	14.0	14.7	13.4	21.5	19.9	14.7	18.9	15.7
	Saturation coefficient		.94	.96	.88	.95	.94	.90	.90	.90	.90	.82	.88	.90
	Average R. Hardness(HRE)		19	45	31	37	29	39	47	12	14	53	20	37
	Average Steam Exp.(%)		0.040	0.062	0.056	0.049	0.047	0.067	0.071	0.024	0.037	0.119	0.039	0.065
960°	Failure after no. of cycles in:	Na2S04	4	9	7	9	10	9	13	5	6	14	7	10
		NaCl	3	N/D	7	8	9	8	17	4	4	9	5	8
	Average C.W.A.(%)		21.0	10.9	13.9	11.7	11.2	11.1	9.5	18.2	16.0	11.2	15.0	12.0
	Average B.W.A. (%)		22.4	11.8	16.2	12.6	12.3	12.8	11.4	20.5	18.1	14.2	17.4	14.0
	Saturation coefficient		.94	.92	.86	.93	.91	.87	.83	.89	.88	.79	.86	.86
	Average R. Hardness(HRE)		21	60	57	57	59	65	73	22	30	54	33	56
	Average Steam Exp.(%)		0.093	0.134	0.113	0.140	0.124	0.105	0.095	0.076	0.108	0.127	0.108	0.128
1000°	Failure after no. of cycles in:	Na2S04	5	12	10	12	13	12	14	6	8	15	10	16
		NaCl	4	N/D	9	17	11	13	34	5	6	12	6	12
	Average C.W.A.(%)		19.7	10.0	12.4	9.9	9.9	9.8	7.8	16.6	14.9	10.4	13.9	10.9
	Average B.W.A. (%)		20.6	11.7	14.9	11.1	11.7	11.7	10.0	18.7	17.0	13.8	16.2	12.8
	Saturation coefficient		.96	.85	.83	.89	.85	.84	.78	.89	.88	.75	.86	.85
	Average R. Hardness(HRE)		24	74	62	76	72	73	82	28	43	55	40	64
	Average Steam Exp.(%)		0.135	0.116	0.077	0.128	0.116	0.066	0.055	0.116	0.125	0.084	0.133	0.129
1050°	Failure after no. of cycles in:	Na2S04	6	22	19	26	23	23	+	22	22	20	26	28
		NaC1	5	N/D	24	x	38	x	x	10	16	x	11	x
	Average C.W.A.(%)		17.1	7.3	8.7	6.3	7.1	6.3	4.6	11.6	11.5	9.3	10.1	7.3
	Average B.W.A. (%)		19.3	8.2	11.2	8.3	8.4	7.0	6.2	13.3	14.0	12.8	11.9	9.4
	Saturation coefficient		.89	.89	.78	.76	.85	.90	.74	.87	.82	.73	.85	.78
	Average R. Hardness(HRE)		28	82	77	93	95	96	111	65	66	60	78	86
	Average Steam Exp.(%)		0.127	0.048	0.039	0.066	0.060	0.028	0.022	0.140	0.120	0.020	0.105	0.057
1110°	Failure after no. of cycles in:	Na2S04	14	+	+	+	+	+	+	+	+	25	+	+
		NaCl	14	N/D	x	x	x	x	x	x	x	x	x	x
	Average C.W.A.(%)		12.5	3.8	2.8	0.8	4.0	2.0	1.1	5.6	5.5	8.2	4.9	2.8
	Average B.W.A. (%)		14.7	4.4	4.5	1.5	4.4	3.2	1.3	6.2	7.7	12.0	6.4	3.8
	Saturation coefficient		-85	.86	.62	.53	.91	.63	.85	.90	.71	.68	.77	.74
	Average R. Hardness(HRE)		53	103	111	110	115	115	122	96	98	60	102	110
	Average Steam Exp.(%)		0.073	0.012	0.009	0.009	0.020	0.009	0.006	0.040	0.029	0.009	0.022	0.010

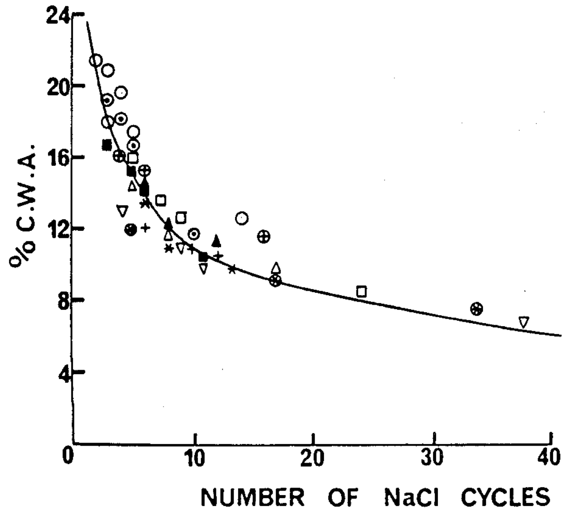
+greater than 80 cycles, x greater than 60 cycles, N/D not determined

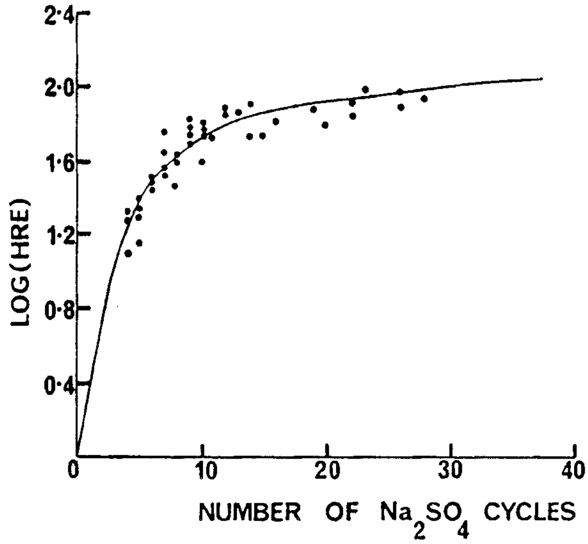
7.0 Relationship between salt cycling and other physical properties

The number of salt cycles in either Na_2SO_4 or NaCl solutions that the specimens withstood correlated well, as shown in figures 1 and 2, with their cold water absorption and there was also a good relationship with the Rockwell Hardness values as shown in figure 3.

No useful correlation was observed between the resistance to salt cycling and either accelerated moisture expansion values or the saturation coefficients calculated from the results of the cold and boiling water absorption tests.







(Top) Figure 1. Number of Na_2SO_4 cycles correlated to cold water absorption

(Middle) Figure 2. Number of NaCl cycles correlated to cold water absorption

(Bottom) Figure 3. Number of Na_2SO4 cycles correlated to Rockwell Hardness values

8.0 24-hours cold water absorption

The fact that none of the specimens with CWA values below 6.3 percent failed and all survived over 80 cycles has mode the statistical evaluation of these results very difficult.

However by determining the line of best fit within the limits of the data where failures did occur, the following relationship has been established between salt cycling and CWA:

$$\% \text{ CWA} = 27.01 - 14.24 \log n$$

where n = number of cycles of failure

From this function:

High Durability: may be defined as those fired clay bodies that have CWA values less than 6 percent.

Intermediate: fired clay bodies with CWA values between 6 and 12 percent.

Low Durability., fired clay bodies with CWA values in excess of 12 percent

The values of 6 percent CWA for high durability is confirmed by the observations of Cole and Pepplinkhouse[1]. They found that roofing tiles with 6 percent CWA or less showed a high degree of salt attack resistance after 19 years at a seaside exposure site.

Another supporting fact is the relatively rare occurrence of salt attack damage in some other parts of Australia. This may be explained by the fact that the CWA values of Victorian bricks (as shown in unpublished data from the Brick Development Research Institute) is usually around or below 6 percent, whilst a large number of bricks made elsewhere have CWA values much in excess of 6 percent.

9.0 Boiling water absorption and saturation coefficient

The boiling water absorption values were determined to enable the calculation of saturation coefficients.

When boiling water values are plotted against salt cycling, a significant relationship between these two tests can be seen.

However values of saturation coefficient calculated from the CWA and BWA tests do not relate to the performance of the specimens in salt cycling.

10.0 Rockwell hardness

The results of the Rockwell Hardness test indicate a good correlation with salt attack when the logs of HRE values are plotted against the number of cycles of exposure to sodium sulphate. Whilst the authors at this stage do not propose the use of this test for dividing durabilities into grades as with CWA, the experimental evidence indicates that HRE values of 100 or greater would seem to ensure a high degree of resistance to salt attack.

11.0 Accelerated moisture expansion

No useful correlation was obtained between accelerated moisture expansion and resistance to salt attack. The reason for this will be that moisture expansion peaks at different temperatures for different clays.

The samples tested reached their expansion peak when fired between 960 and 1000°C. Samples 5, 6, 7, 11 and 12 were actual brick formulations and, under manufacturing conditions, they are fired at temperatures between 1000 and 1100°C. From the data the effect of increased firing temperatures on both durability and moisture expansion is clear. Therefore, when a sudden significant increase in the moisture expansion of these bricks is observed, the data imply that these products will suffer a significant reduction in durability.

12.0 Comments

As indicated earlier, all data in this paper refer to extruded samples and thus conclusions drawn for these experiments can only be related to products manufactured by the same process that are without the addition of materials that would significantly change the pore structure of the final product. An example is the process where saw dust is added to the clay mix to lighten the final product by increasing its porosity.

Other tests, not reported here (unpublished BDRI data), indicate that extruded bricks fired with saw dust additive are highly resistant to salt attack in spite of their high CWA values.

Salt cycling tests on stiff plastic and semi-dry pressed bricks are, at the time of preparation of this paper, being conducted and early indications are that these products show high salt attack resistance at higher CWA values than do extruded bricks.

Study of the pore size distribution of the bricks with the aid of a mercury porosimeter is currently in progress to help gain an understanding of the role pore sizes play in fixing the salt attack resistance of fired clay products.

13.0 Recommendations

The results of these investigation and others indicate that the use of the cold water absorption test or salt cycling could lead to a satisfactory technique for assessing the durability quality of bricks.

However, because of the considerable scatter of the results near the 30 cycle mark, and other observations by the authors not reported here, it is recommended that should the findings of these investigations be adopted as a basis for quality control, a safety margin of 10 additional cycles be added to the High Durability class, that is *High Durability: 40 cycles of exposure in sodium sulphate solution.*

In the meantime testing of a wider range of commercially made products is underway to further test the findings of this paper.

14.0 Acknowledgements

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15.0 Reference

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