9TH CANADIAN MASONRY SYMPOSIUM

ASSESSMENT OF POTENTIAL CRYPTOFLORESCENCE IN CLAY MASONRY

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ABSTRACT

An indication of the presence of cryptoflorescence in clay masonry has been found in the unusually high level of moisture expansion measured in some 13-stack unrestrained clay masonry single-leaf walls. This expansion, which greatly exceeds that which would be expected from the unbonded brick expansion, is referred to as an enlarged expansion.

Considering the unbonded brick properties; clay type, soluble salt level and range, water absorption, compressive strength and irreversible moisture expansion characteristics, it is possible to assess the potential for enlarged expansions caused by cryptoflorescence, in clay masonry. The benefit of using these properties for an assessment is that the majority are readily available from the brick manufacturers.

The paper discusses the background to the choice of these properties to assess cryptoflorescence in clay masonry. Results are presented of tests on single-leaf clay masonry test panels constructed from a wide ranger of brick units, which showed that an enlarged expansion occurred in all of the test panels constructed with units based on the chosen properties.

Key words: Cryptoflorescence Efflorescence Expansion Bricks Movement

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CRYPTOFLORESCENCE

The phenomenon of cryptoflorescence, sometimes referred to as crypto-efflorescence in fired clay products was first mentioned in relevant literature by Cooling (1930), and is a hybrid of the word crypto meaning to lock in and florescence to bloom. The chemistry of the compounds which produce cryptoflorescence are similar to those that produce efflorescence, therefore the formation, behaviour and subsequent results of cryptoflorescence using a chemical analogy with efflorescence is adopted.

Efflorescence in masonry materials occurs when soluble salts contained within the matrix of the brick go into solution in the presence of water, this water may be derived from elemental conditions or during construction. In the case of external walls internal temperatures are usually higher than external and it is likely that the vapour pressure will also be higher internally. The natural flow of water vapour, known as the vapour drive will therefore be through to the outside of the wall, once the moisture reaches the surface it evaporates and the salts resume their crystalline structure (efflorescence).

Cryptoflorescence is also related to the soluble salt content of the brick, but when the rate of movement of the salt solution through the brick pores is lower than the rate of evaporation, the drying zone may form beneath the surface or at the brick/mortar interface. The subsequent crystallisation of these salts in the pores over time at these locations may lead to an expansion in the masonry.

BACKGROUND TO RESEARCH

Creep of masonry is defined as the gradual increase in strain with time under a constant load and total creep as the time-dependent strain after allowing for free moisture movement strain as measured on an unloaded (control) wall. It is apparent therefore that the moisture movement strain generated in the unloaded wall must be representative of that produced within the loaded wall for any meaningful results to be obtained. Research on deformations of unloaded clay masonry walls has highlighted the existence of an expansion in the vertical direction that is in addition to irreversible and reversible moisture expansion as measured on unbonded and bonded bricks (Brooks & Bingel (1988), and is thought to be a result of cryptoflorescence. A recent publication by Forth & Brooks (2000) showed that certain types of brick unit were more likely to produce cryptoflorescence in masonry, mainly due to specific physical and chemical properties. The aim of this investigation was to derive selection criteria based on unbonded brick unit properties that would predict the potential for cryptoflorescence in walls made from those units, using information obtainable from the brick manufacturers.

SELECTION CRITERIA

Twenty units were initially chosen based on previous research by the authors and specific information provided by the brick manufacturer with regard to long-term irreversible moisture expansion (Table 1). The selection criteria was based on the following:

- Soluble salt;
- Clay type;
- Irreversible moisture expansion;
- Water absorption;
- Initial rate of suction;
- Compressive strength.

Soluble salt content

The phenomenon of efflorescence in fired clay products has been well researched and documented over the last 70 years. Early work by Cooling (1930), Brady & Coleman (1931) and Butterworth (1935), published in the Transactions of the British Ceramic Society have lead the way in limiting the visual and material damage caused by efflorescence in fired clay masonry. A test for efflorescence was specified in BS 3921:1974, but the test was deleted because it was found difficult to relate the test results to the brickwork efflorescence, this was due to the fact that the salts could be derived from external sources. Originally the test was intended to predict the durability of bricks with regard to crystallisation damage from magnesium and potassium sulphate. BS 3921:1985 now specifies limits on soluble salts for two categories of brick. Low (L) class with soluble ions of magnesium, potassium and sodium not to exceed 0.03% each and sulphate ions not to exceed 0.5%. Normal (N) class units with the sum of the contents of soluble ions of sodium, potassium and magnesium not to exceed 0.25% and sulphate not to exceed 1.6%. Searle (1956) states the main sources of soluble salts as:

- the clay, shale or ‘earth’ of which the bricks are made;
- kiln atmosphere conditions;
- the water used during manufacture;
- the mortar used to lay the bricks;
- material with which the bricks may come into contact with in wet weather.

Crystallisation of salts in porous bodies has been investigated by many researchers with early tests by Bonnell and Nottage (1939) showing that anhydrous salt (or lower hydrate) may be hydrated (or further hydrated) against relatively high stresses. Expansions generated in their tests showed that hydration within the material pores may exert enough force to bring about disintegration of the material. A review of the processes of crystallisation damage in relation to bricks and stone was undertaken by Caner-Saltik et al (1994). Reviewing research work encompassing the processes of crystal growth, crystal linear growth pressures and durability properties of materials effected, conclusions were reached based on an analogy between rocks, stone and bricks. It was found that pore structure changes were induced in the materials tested due to the expansive pressures generated by crystal growth, even in materials with a low percentage of pores such as bricks.

Clay type

The type of clay used is important because it is within the raw material that the majority of the soluble salts originate. Searle (1956) notes that sufficient amounts of soluble salts to produce efflorescence in the finished bricks occur in some marine clays, particularly those forming part of the Triassic formation (Keuper Marls), the Jurassic formation (Kimmeridge and Upper Oxford clays) and part of the Eocene formation (London clay). Keeling (1963) notes that almost one percent of soluble salts can be water-extracted from most clays, and that these salts are mainly sulphates of calcium, magnesium, sodium and potassium. Their origin is believed to be by precipitation from the water in which the clay was sedimented. Also, iron sulphide present within the clay may oxidise with the sulphur contained within fuel used for firing to form sulphur trioxide, on exposure to water this then reacts with the alkali and alkali earth constituents of the brick to form sodium, potassium, magnesium and calcium sulphate in the brick.

Irreversible moisture expansion

A fired-clay brick begins to expand immediately after leaving the kiln due to the adsorption of moisture from the environment, water is also absorbed from the mortar during construction. These expanded bricks when heated to over a 100^0C lose part of the water and part of the expansion (reversible moisture expansion), but Vaughan & Dinsdale (1959, 1962) have shown that considerably higher temperatures are needed to completely recover the original mass and dimensions (irreversible moisture expansion). Smith (1955) attributed this irreversible moisture expansion to the reduction in surface energy caused by the adsorption of moisture, which releases some of the compressive force on the individual particles caused by intermolecular attraction. A chemical reaction between water and the glassy phase of the fired unit was also found to increase the internal surface area and surface energy making the possible expansion greater. Research by Smith (1993) looked at the effects of firing temperature on irreversible moisture expansion of bricks and found expansions ranging from 0.02% to 0.2% occurred, depending on the type of clay and firing temperature. Table 2 indicates typical values of irreversible moisture expansion of fired-clay bricks resulting from changes in moisture content as given in CP 121: Part 1 (1973).

Water absorption

Brick unit water absorption is measured using the 5 hour boiling water test as stipulated in BS 3921 : 1985 appendix E. Water absorption is the difference in wet weight and dry weight divided by the dry weight and is expressed as a percentage of water absorbed (total porosity). The importance of the unit water absorption as regards the tensile strength of masonry is recognised by BS5628: Part 1 (1990) which relates three percentages of water absorption (< 7 %, > 7% < 12% and > 12 %) to characteristic flexural strengths for design purposes. BS3921 only stipulates water absorptions for Engineering Class A (< 4.5%) and Engineering Class B (≤7.0%). Bonnell & Butterworth (1940) looked at the characteristics of many brick clays and found that those made with, Brickearth, Lower Oxford, Keuper marl (middle/upper) and Gault clays produced fairly porous bricks regardless of the process of manufacture. Bricks made from carboniferous clays such as the coal measures and shales produced bricks of low porosity.

Initial rate of suction

The BS 3921 : 1985 Appendix H test measures the ability of the first 3mm of brick unit surface, to pull water from the mortar. This suction is mainly dependent upon the pore structure of the masonry unit and its surface texture. The pore size distribution and the properties of the mortar connected with the retention and loss of water are also limiting factors in this suction, Cooling (1930), Sneck (1982), Lawrence & Cao (1987). Forth et al (2000) used a Fletton common brick with a Class (ii) mortar and showed that during a moist curing period under polythene an initial absorption of water from the mortar by the unit occurred, this was followed by a re-absorption of water from the unit by the mortar. This back and forward transference of water and salts in solution between the unit and mortar occurs early on during the setting of the mortar and depending on the solubility of the salt controls the amount of salts deposited at the brick/mortar interface. For brickwork subject to environmental conditions the wetting and drying processes would substantially increase these deposits.

Compressive strength

The BS 3921 : 1985 Appendix D test defines the compressive strength as the stress corresponding to the maximum failure load. The test provides an indication of the bricks properties such as density and water absorption, and information on the brick manufacture such as the effectiveness of raw materials, degree of initial compaction and effectiveness of the firing process.

EXPERIMENTAL DETAILS

Twenty brick unit types were used to construct thirteen course high by two brick wide single-leaf masonry panel walls. Fifty per cent of the units, namely, units 8, 10, 12, 13, 15, 16, 17, 18, 19 and 20 were selected to produce an enlarged expansion when constructed within a masonry wall. The remaining ten units were chosen based on properties which were thought would not produce an enlarged expansion. A class (ii) 1: ½ : 4½ mortar (cement : lime : sand) by volume was used for all the walls. The mortar had a consistency of 10mm as determined using the dropping ball test, as specified in BS4551 (1980), and the water/cement ratio by mass for the mortar was 0.83. All the test panels were constructed and tested within environment rooms controlled to a relative humidity of 65 ± 5% and a temperature of 21 ± 1°C. Masonry panels were sealed in polythene immediately after construction for a seven-day moist curing period, after which time the panels were exposed to the controlled environment conditions. Strain measurement of test panels, unbonded units and mortar prisms using Demec gauges commenced at the age of one day and has been covered in detail by Forth & Brooks (1995).

Irreversible moisture expansion values, clay type, soluble salt levels, brick compressive strength, initial rate of suction and water absorption values provided by the respective brick manufacturers are presented in Table 1. These values were also confirmed by tests carried out by the authors.

Compressive strength tests were carried out on 100x100x100mm mortar cubes at 7, 14 and 28 days. The average compressive strengths and standard deviations at 7, 14 & 28 days were 11.4(0.70), 13.3(0.74) and 15.5(0.44) MPa respectively.

RESULTS AND DISCUSSION

Practical restrictions mean that measurements taken across the bed face of the units are limited to the central 50mm section covered by the 50mm length of the Demec gauge. No enlarged expansion is found across the bed face as measured using the 50mm Demec gauge. As the units measure 65mm nominally there is a total of 15mm or 7.5 mm either side of the gauge which is not measured. When brickwork vertical strain measurements are taken using a 750mm length Demec gauge the enlarged expansion is measured. The implications of this are that the enlarged expansion must be occurring within:

1. the 7.5mm unmeasured section of the unit either side of the 50mm Demec gauge measurement positions (phase 1)

2. the mortar joint (phase 2)

3. the brick/mortar interface (phase 3)

It is unlikely that the expansion occurs within phase 2 as measurement tests on mortar prisms show shortening, which would be expected due to drying shrinkage. The enlarged expansion therefore occurs within phase 1, phase 2 or a combination of both.

From Table 3 it can be seen that an enlarged expansion was found in panels constructed with the pre-selected units 8, 10, 12, 13, 15, 16, 17, 18, 19 and 20, however there is a large variation in the level of enlarged expansion exhibited by the different brick types. From the results of this investigation it is apparent that there is not one single property of the brick unit that is directly related to the enlarged expansion, but rather an interaction of many different properties (figures 1,2,3&4).

Correlation of the salt content of the brick with its water transport characteristics shows that for a unit to produce an enlarged expansion in masonry the controlling factor may not be the amount of salt contained within that unit but the amount of salt that can be mobilised. For example, units 12, 15 and 20 which had a Class N soluble salt content and initial rate of suction ≥ 1.5 kg/m^2/min produced an enlarged expansion, whereas units 5, 6, 7 and 9 with a Class N soluble salt content and initial rates of suction ≤ 0.9 kg/m^2/min showed no enlarged expansion. The only exception to this was produced by unit 8, which had a Class N soluble salt content and an initial rate of suction of 0.7 kg/m^2/min. This could possibly be explained by the magnesium salt content of this unit which is 0.09% (the highest of all the units tested). Magnesium and potassium sulphate have been shown to be particularly aggressive in terms of crystallisation damage because of their relatively high solubility (Table 4) compared to other typical sulphates commonly found in clay bricks, Bowler and Fisher (1989). For Class L soluble salt content bricks with initial rates of suction ≥ 1.0 kg/m^2/min an enlarged expansion was found in units, 10, 13, 16, 17, 18 and 19. For Class L soluble salt content bricks and initial rates of suction ≤ 1.0 kg/m^2/min no enlarged expansion was found, units, 1, 2, 3, 4, 11 and 14.

When looking at Table 3 it is apparent that the majority of bonded units exhibit higher expansions than the unbonded units. This could simply be caused by the inherent variability of clay units or due to the addition of water to the bonded brick possibly accelerating the irreversible moisture expansion, Vaughan & Dinsdale (1959). Table 3 also shows that the bonded Fireclay units (units 3, 7, 8, 13 and 16) exhibit a higher level of expansion than the unbonded Fireclay units. The brick manufacturers long-term IME tests have shown that there is a wide range of possible expansion for Fireclay bricks (0.030 – 0.100%). Research by Edgell (1993) also found that the Fireclay units used in their tests produced a high expansion of 0.8mm/m at 400 days and 1.43mm/m after steam treatment.

CONCLUSIONS

1. An enlarged expansion in masonry that is in addition to irreversible and reversible moisture expansion as measured on unbonded and bonded bricks, has been found in walls constructed from different brick unit types and is thought to be due to cryptoflorescence at the brick/mortar interface.

2. A selection criteria derived from previous research has been established based on standard measured brick unit properties which will predict the potential of cryptoflorescence occurring in masonry built from those types of unit. However, as part of the selection criteria, the general soluble salt level classifications of N and L are not sufficient to allow the assessment of potential cryptoflorescence. Knowledge of the individual soluble salt content is required from the manufacturer.

3. Generally, units with relatively high porosity, high initial rates of suction and low compressive strength are susceptible to cryptoflorescence.

4. An interaction can occur between the unit and mortar which facilitates the transfer of soluble salts from the mortar to the unit as reported by Bettzieche (1994) and Forth et al (2000). The possibility exists therefore, for cryptoflorescence to occur in test panels with a brick having a low soluble salt content as was the case for some of the wall panels tested.

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Table 1. Brick Manufacturers Information for Brick Unit Properties

Brick Unit	A.I.R.S. ($kg/m^2/min$)	A.W.A (%)	I.M.E.	Strength (N/mm^2)	Clay Type	Class
1	<1.0	< 11.0	L	> 50	Coal Measure shale	L
2	<1.0	< 11.5	M	> 56	Coal Measure shale	L
3	<1.0	< 7.0	L	> 50	Fireclay Mixture	L
4	0.70	< 8.0	0.40	> 45	Mudstone shale	L
5	0.50	< 12.0	0.45	> 42	Weald	N
6	0.90	< 12.0	0.50	> 35	Ball Clays/Shale	N
7	0.70	< 10.0	0.50?	> 50	Coal Measure Fireclay	N
8	0.70	< 10.0	0.95	> 40	Fireclay shale	N
9	0.30	< 7.0	0.20?	> 50	Etruria Marl	N
10	3.6	< 36.0	?	> 9	Brick-earth/Chalk Breeze	L
11	0.8	< 18.0	0.525	> 15	Wadhurst	L
12	1.5	AWA 21	L/M	ACS 20	Lower Oxford	N
13	> 1.0 < 2.0	AWA 9.0	H	ACS 68	Fireclay shale	L
14	< 1.0	AWA 5.5	M	ACS 120	Coal Measure shale	L
15	1.6	AWA 18.5	M	ACS 17	Weald	N
16	> 1.0 < 2.0	AWA 7.0	L	ACS 86	Fireclay Mixture	L
17	3.2	AWA 27.0	M	ACS 13.5	Brick-earth	L
18	3.0	AWA 29.5	M	ACS 22	Keuper Marl (lower)	L
19	2.4	AWA 26.0	M	ACS 30.5	Keuper Marl (lower)	L
20	1.5	AWA 27.0	M	ACS 13.5	Gault shale	N

AWA = Average water absorption - ACS = Average compressive strength - AIRS = Average initial rates of suction - IME = Irreversible moisture expansion (values expressed relative to those established by Lomax (1983), Low, Medium and High or as a % of the original length)

Table 2 Expansion of fired clay bricks resulting from changes in moisture content CP121:Part 1: 1973

Clay from which units are made	**IME (%} calculated on original dry length) for bricks fired to average works temperature**		**Wetting movement (%)**
	Kiln hot to 2 days	**3 days to 128 days**	
Lower Oxford	0.03	0.03	Generally less than 0.02 unless under-fired
London Stock	0.05	0.02	
London clay	0.02	0.02	
Keuper marl	0.03	0.02	
Weald clay	0.08	0.04	
Carboniferous shale	0.04	0.07	
Devonian shale	0.03	0.05	
Gault	0.02	0.01	

Table 3 One-Year Vertical Moisture Movement Strain (x10^{-6})

Brick Unit	**Unbonded 50**	**Bonded 50**	**Wall 750**	**Brick Unit**	**Unbonded 50**	**Bonded 50**	**Wall 750**
1	-346	-377	-139	11	-235	-381	-35
2	-272	-293	-38	12	-386	-419	-903
3	-444	-621	-102	13	-376	-535	-680
4	-259	-356	-37	14	-172	-220	19
5	-275	-356	-34	15	-306	-384	-537
6	-263	-321	-130	16	-220	-252	-545
7	-288	-327	-273	17	-237	-199	-843
8	-429	-556	-632	18	-275	-303	-558
9	-182	-260	-206	19	-202	-217	-918
10	-288	-280	-856	20	-197	-247	-478

The sign convention for movement is taken as expansion being negative and contraction as positive.

Table 4 Relative solubility of sulphates found in clay bricks Bowler & Fisher (1989)

Sulphate	**Approx. values of solubility (%)**	
	0°C	**20°C**
Magnesium	26.0	35.0
Sodium	4.8	25.0
Potassium	8.5	12.0

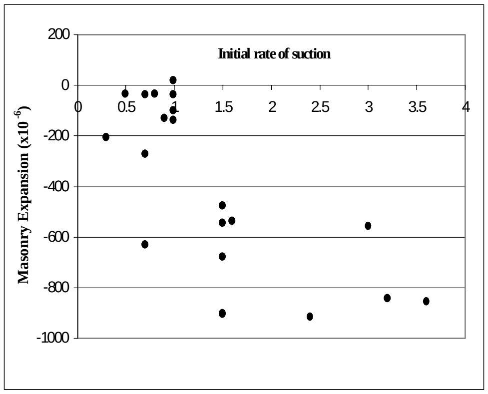

Fig. 1 Masonry expansion v AIRS

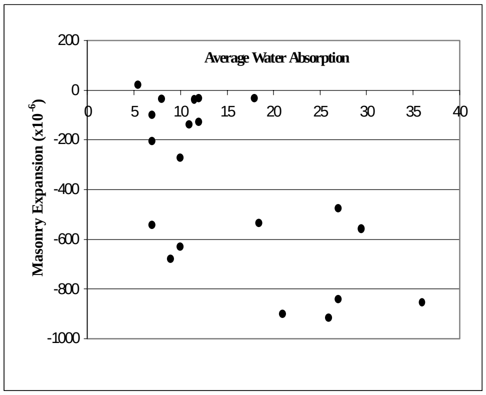

Fig. 2 Masonry Expansion v AWA

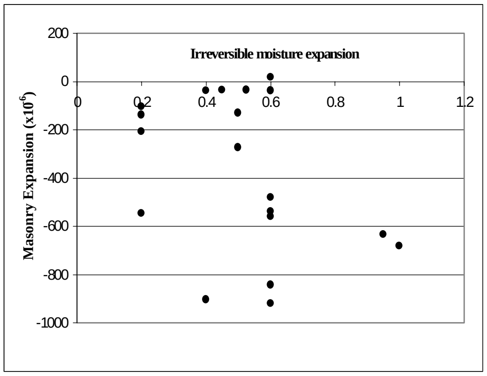

Fig. 3 Masonry expansion v IME

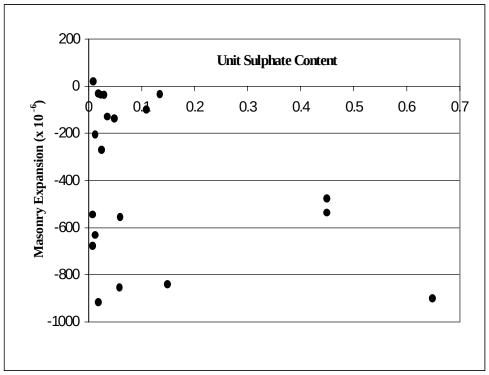

Fig. 4 Masonry expansion v SO_4 Levels