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Research Paper 0

# Predicting the Long-term Moisture Expansion of Fired Clay Products

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## ABSTRACT

The literature on moisture expansion of fired clay bodies is briefly reviewed. Details are given of a method for accelerating the rate of expansion, which can be completed in 24 h or less, and gives results which correlate well with the behaviour of similar bricks exposed to ambient conditions for periods up to 4 years. Correlation of accelerated and natural expansion is based on 1479 observations of 378 pairs of bricks drawn from all over Australia, and the results are used to provide a basis for predicting the long-term size change of bricks. Sources of variability in the results are investigated and confidence limits are established for the predictions of long-term growth. The methods developed are thought to be valid for measurements made at or near sea-level, on Australian bricks which have a range of moisture expansion from zero to 0.25% in 5 years exposure to ambient conditions. Some modification to the conversion factors used may be needed in other localities. The practical implications of the work for brick manufacturers and for designers of brick buildings are briefly outlined.

## 1.0 Introduction

It is well known that bricks may undergo permanent expansion as a result of a reaction between water and the fired clay body.[1,2] The amount of expansion observed varies from place to place, and within one locality there may be considerable differences in the expansions of different products, because of differences in the chemical and mineralogical composition of the raw materials used.

Cole[3] has reviewed attempts to relate expansion behaviour to composition and shown that, although some broad generalisations are possible, there are not yet sufficient data to control the expansion characteristics by selection and blending of raw materials.

Moisture expansion of brickwork can lead to cracking in buildings if appropriate action is not taken to accommodate potential movements. The measures usually adopted are storage of bricks for a period between manufacture and building in, provision of movement joints in the brickwork, or a combination of both. If these measures are to be fully effective it is necessary to have details of the magnitude of expansion to be expected, and the rate at which it will occur. This information can be obtained from long-term measurements, or by accelerating the expansion by a method which can be related to the long-term growth under natural exposure conditions.

Evidence is presented to show that moisture expansion can be accelerated by treating the bricks in saturated steam at atmospheric pressure, and that there is a high degree of correlation between the accelerated and the natural expansions for periods up to 4 years.

## 2.0 Acceleration of moisture expansion

Many workers who have investigated the effect of moist atmosphere on fired clay products have made use of autoclave treatments to accelerate the rate of expansion. This work has been reviewed by Hosking and others,[2] who have also reported their own extensive work in this field.[2,4] This concluded that, although the rate of moisture expansion is accelerated in the autoclave by amounts which depend on the temperature reached, the reactions which occur at elevated temperatures include some which would not occur at lower temperatures. For this reason moisture expansion in the autoclave cannot be reliably correlated with expansion under natural exposure conditions.

The possibility of accelerating moisture expansion of clay products by milder treatments, such as boiling water or steam at atmospheric pressure, has received little attention. Cullen, Klucis and McDowall[5] compared the natural expansion of bricks with the amounts of expansion produced by short treatments in saturated steam atmospheres at 100°, 150° and 225°C. They showed that the amount of expansion increased as steam temperature dropped from 225° to 100°C, and that the ratios of 30-day and 90-day natural expansions to 4-h steam expansion were fairly constant. Freeman and Smith[6] have reported a good correlation between natural exposure for 128 days and steaming at 100°C for 6 h.

Measurements made since 1964 have confirmed earlier observations that treatment in saturated steam at 100ºC accelerates moisture expansion of fired clay bricks. It has also been found that correlation with natural expansion is sufficiently good to permit the use of the accelerated-expansion results to guide decisions on the size and spacing of movement joints in buildings.

## 3.0 Experimental

All the work was carried out on bricks from normal commercial production. The majority were stiff-plastic pressed and extruded bricks made in Victoria, but some came from other states, particularly Queensland, Tasmania and Western Australia. Sampling was carried out over a period of several years, so that more information was available on some bricks than on others.

A sample, taken from the kiln, consisted of ten specimens, two adjacent bricks being taken from each sampling position. The sample was divided into two groups, one group of bricks was steam treated, the other was stored indoors at
17–25°C and 55–70% relative humidity, for measurement of size changes at 1, 3, 6 and 12 months, and then annually. One brick from each sampling position was put in each group so that each group represented, as nearly as possible, an equal cross-section of the range of firing treatment in the kiln. The samples were selected while the bricks were still sensibly warm, and were transported to the laboratory as soon as possible after sampling. In all, 1479 observations based on 378 pairs of bricks, were available for analysis.

Limited programs were undertaken to establish the variability of steam expansions of bricks from two different types of brick plant, to check the growth characteristics of bricks subsequent to steam treatment and to establish the inter-laboratory reproducibility of steam treatment results.

Actual lengths of bricks were measured to 0.025 in. with a slide caliper. Changes of length were measured with a frame of the type described in BS 1180:1944.[7] The frame was equipped with a micrometer measuring to 0.0001 in., and hardened-steel conical seats were fixed to the shaft of the micrometer and the base of the frame.

Reference points were established in smooth dense bricks by using a ¼-in. tungsten carbide drill to form a conical depression at the centre of each end face. These depressions formed seats for ¼-in. steel balls. For rough textured or friable bricks, steel drive screws of the type described by Hosking and others[2] were used.

All differential length measurements were carried out in a constant-temperature room at 25 ±1°C, changes in the length of the measuring frame being corrected by use of a plane-ended invar-steel reference bar, which was placed in the frame between the same ¼-in. steel balls as were used with the bricks. Measurements were reproducible to ±0.0003 in. between operators, and to ±0.00015 in. for a single operator.

After the initial length measurements were completed the bricks in one set were treated for 4 h in saturated steam at 100°C, cooled to equilibrium in the constant-temperature room and measured. The boiler was insulated and the temperature of the bricks was kept as close as possible to 100°C.

## 4.0 Results

### 4.1 Analysis of data

In order to minimize the possible effects of brick length on expansion, only those pairs of bricks whose initial length differed by 0.025 in. or less were considered for analysis.

The range of expansions of bricks treated in steam for 4h was 0–0.16%. In the preliminary analysis of the steam and natural expansions, plots indicated that a linear relationship was likely to hold. At each time of measurement, *t*, a function of the form

$Y = a+bx$ ........................................................ (1)

was fitted to the data where

y = natural expansion at time *t*(%)

*x* = 4-h steam expansion (%)

At all times of measurement *y* and *x* were found to correlate well (see Table 1). The constant *a* was found to be relatively small compared to the measured expansions, and on only one occasion was it significant at the 5% level of probability. In view of these results, and also as it is reasonable to consider that if the steam expansion is zero the natural expansion will be zero or negligible, the relationship between the two variables can be well represented by the model

$y = bx$ ........................................................ (2)

Further work showed that the variability of *y* at each time of measurement was not constant over the range of values of *x*, the standard deviation of *y* being almost directly proportional to the value of *x*. This meant that further analysis of the data would be most appropriately carried out on a variable

$z = y/x$ ........................................................ *(3)*

and the value of *b* in eqn. (2) would be estimated by *z*, the mean value of *z*. The values of *b* thus calculated and the standard deviations of the variable *z* at each time of measurement are given under the heading by in Table 1.

Plotting the values of *b* against *t* indicated that functions of the form

$z = k_1 + k_2 ln\,(t + k_3)$ ............................................. (4)

or $z = k_1 + k_2/(t + k_3)$ ............................................. (5)

could be expected to fit the data, but it was not possible to discriminate between the two functions on the basis of their ability to represent expansion behaviour up to 48 months. These findings are in agreement with those of Cole and Birtwistle[8].

Measurements reported by Johnson[9] and discussed by Cole[10] suggest that expansion of fired clay bodies can continue for a very long time, and therefore the logarithmic function is preferred in the present work.

The parameters in eqn. (4) can be estimated by combining the data for all bricks over all times of measurement. From these results an estimate of *b* for any expansion time *t* can be obtained, and from this the expected natural expansion at that time can be calculated for observed values of 4-h steam expansions.

It will be noted from Table 1 that the variability of *z* varies with time. The standard deviation of *z* was found to be approximately proportional to $ln\ (t + k_3)$ thus enabling a relatively simple weighting factor to be used to adjust for the non-homogeneity in variability. As mentioned above, data for all seven recording times were not available for all bricks, and appropriate steps were taken in the analysis to remove biases due to this lack of orthogonality.

After taking the above points into consideration the usual iterative procedures were used to obtain the parameters in eqn. (4). The expansion function for *z* was found to be

$$z = -0.1929 + 0.6013\ ln\ (t + 2.2977) \qquad (6)$$

The expected values of b as obtained from eqn. (6) for various times are given in Table 1 under the heading $b_2$. No direct comparison should be made between the values of $b_1$ and $b_2$; because the former contain biases due to non-orthogonality which have been compensated in the latter.

## Table 1. Relationships between natural and steam expansions at various times in the expansion period

| *t* (months) | No. of pairs of observations | *r* | Standard deviation of *z* | $b_1$ | $b_2$ | Standard error of $b_2$ | 99% confidence limits for $b_2$ |
|---|---|---|---|---|---|---|---|
| 1 | 343 | 0.900 | 0.2587 | 0.5041 | 0.5246 | ±0.0121 | ±0.0312 |
| 3 | 347 | 0.915 | 0.3028 | 0.8033 | 0.8096 | ±0.0121 | ±0.0312 |
| 6 | 335 | 0.925 | 0.3479 | 1 .0848 | 1 .0794 | ±0.0144 | ±0.0372 |
| 12 | 246 | 0.921 | 0.5009 | 1.4416 | 1 .4066 | ±0.0184 | ±0.0474 |
| 24 | 115 | 0.885 | 0.5115 | 1.8162 | 1.7731 | ±0.0340 | ±0.0877 |
| 36 | 53 | 0.889 | 0.6433 | 2.1186 | 1.9991 | ±0.0479 | ±0.1233 |
| 48 | 40 | 0.852 | 0.6438 | 2.2135 | 2.1630 | ±0.0590 | ±0.1520 |
| 60 | – | – | – | – | 2.2917 | ±0.0682 | ±0.1757 |

*r* = correlation coefficient between natural and steam expansions
$b_1$ = mean value of z from observed data
$b_2$ = expected value of z from the regression equation
$z = -0.1929 + 0.6313\ ln\ (t + 2.2977)$

### 4.2 Variability of steam expansion values

Measurements of expansion on bricks receiving the 4-h steam treatment are subject to variability originating from a number of sources. The most important are the inherent variability of the population, sampling variation and treatment or experimental variation. These were investigated in two series of measurements on day-to-day variation of moisture expansion of bricks from production kilns.

The first series of samples was taken from a plant firing extruded bricks in a tunnel kiln. Two cars were sampled on each of 4 successive days, and five bricks were selected to represent the range of firing on each car. In the second series twelve bricks were sampled from each of four chambers around an oil-fired, fork-lift set Hoffman kiln firing stiff-plastic pressed bricks.

Analysis of the results obtained shows that for the tunnel kiln case, sampling of five bricks per day and two cars per day for 4 days is quite adequate if we require the 90% confidence limit of the mean to be within ±10%. For the same interval with 95% confidence, sampling of five bricks from two cars per day for 8 days would be required. Changes in the number of bricks per car, or the number of cars sampled, have little effect on the precision of the estimate.

The sample of bricks taken from the Hoffman kiln indicates that for the 90% confidence range to be within ±10% of the mean, a sampling scheme would be needed very different from the one used. The most economical arrangement would be a sample of seventy bricks obtained two at a time from thirty-five successive chambers.

### 4.3 Subsequent growth of steam-treated bricks

Several sets of steam-treated bricks were subsequently exposed to ambient conditions and remeasured at intervals. The steam-treated bricks at first expanded more slowly than did their companion untreated bricks, but after 12–18 months the total expansions of the two sets were comparable. A few typical sets are shown in Table 2 (over page).

**Table 2. Comparison of natural expansion of untreated (U) and steam (S) treated bricks (%)**

| Brick type and colour | 4h | Period of natural exposure (months) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | | 3 | | 6 | | 12 | | 24 | |
| | (S) | (S) | (U) | (S) | (U) | (S) | (U) | (S) | (U) | (S) | (U) |
| Extruded, grey | 0.049 | 0.051 | 0.020 | 0.061 | 0.039 | 0.074 | 0.055 | 0.091 | 0.081 | 0.113 | 0.109 |
| Extruded, cream | 0.020 | 0.023 | 0.010 | 0.024 | 0.016 | 0.027 | 0.020 | 0.031 | 0.032 | 0.041 | 0.039 |
| Extruded, red | 0.016 | 0.018 | 0.010 | 0.021 | 0.016 | 0.021 | 0.018 | 0.028 | 0.028 | 0.033 | 0.034 |
| Extruded, red | 0.050 | 0.056 | 0.027 | 0.066 | 0.041 | 0.075 | 0.052 | 0.087 | 0.076 | 0.110 | 0.102 |
| Stiff plastic, pink | 0.031 | 0.035 | 0.018 | 0.043 | 0.024 | 0.047 | 0.039 | 0.054 | 0.053 | n.d. | n.d. |

## 5.0 Quantitative prediction of long-term moisture expansion

### 5.1 General considerations

The long-term moisture expansion of bricks can be allowed for in building work, provided that the amount of growth to be expected is known before the bricks are built in. The necessary information can be obtained either from long-term measurements, or by extrapolation of results from accelerated treatment, but it is also necessary to fix a limit to the time over which the expansion will be considered to have practical effects in buildings.

It is known that moisture expansion of bricks continues for a very long time. Johnson [9] has reported continuing size change in a brick-measuring base built in 1908, but field observations in Australia suggest that in buildings, damage which can be attributed to moisture expansion almost always occurs in the first few years after erection.

Cole[10-13] has shown that moisture expansion of fired clay is linear with a function of log time, a relationship which provides a useful basis for extrapolation of short-term measurements. Freeman and Smith [6] have presented data which do not seem to support the hypothesis that expansion is proportional to log $t$, but Cole and Birtwistle [8] have shown that the apparent discrepancy can be removed if the starting date for the measurements is taken from the time of first exposure to atmosphere, rather than from the time of removal from the kiln at 200°C. It will be noted that the methods of sampling and handling up to first measurement which have been used in the present study record movements starting 12–24 h after the bricks reach temperature equilibrium with ambient air. This procedure avoids complications due to very rapid early expansion, which is irrelevant in building applications.

The characteristics of the logarithmic scale, especially when viewed in the light of field observations of the incidence of building damage caused by moisture expansion, suggest that the small amount of growth which will occur after 5 years is unlikely to have much practical effect, and the expansion can be considered to be complete in this time.

### 5.2 Predicting expansion from accelerated tests

Taking moisture expansion as a linear function of log time, up to the maximum of 5 years, the figures given in Table 1 provide a basis for predicting long-term dimensional changes from the results of the accelerated test, e.g. for a 4-h steam expansion of $x$% the expected mean expansion at 60 months would be 2.2917$x$%. The 99% confidence limits for the expected expansion are 2.4674$x$% and 2.1160$x$%, and it is not unreasonable to take the upper limit as representing the maximum mean expansion likely for a steam expansion of $x$%. The corresponding upper level for individual bricks would be 4.2854$x$%.

Eqn. (6) and the derived values of $b_2$ given in Table 1 can be taken to represent the average for Australian bricks measured at or near sea level. The assumption has been made that the rate of change of $y/x$ with time is of the same order for all brick types, i.e. there is no brick-time interaction. This may not be so, but the present data do not lend themselves to examination of this question.

The errors in the estimation of the natural expansion from a sample of bricks subjected to accelerated expansion by steam treatment are dependent to a large extent on the accuracy of estimation of the steam expansion. As shown in Section 4, a sampling scheme can easily be established for any particular kiln to give a satisfactory estimate of the accelerated expansion.

Inter-laboratory comparisons have shown that there is some danger of the steam expansions being underestimated when measurements are made under works conditions. Before the constants given in Table 1 are used to predict long-term expansion from accelerated tests, care is necessary to ensure that the temperature of the bricks is maintained at 100°C for the full period of the treatment, and that no bias enters into the differential length measurements.

## 6.0 Practical implications

The work reported here has practical significance in the fields of manufacture and use of bricks. For the manufacturer it provides a basis for selection of materials and offers guidance for the control of a property that may affect the practical utility of his product. For the user it gives a method for estimating the long-term size change of bricks, with an accuracy which is adequate for building work.

## 7.0 Conclusions

1. The moisture expansion of fired clay bricks can be accelerated by treatment in saturated steam at atmospheric pressure.
2. The results of steam accelerated expansion tests correlate well with natural exposure expansion tests on similar bricks.
3. Steam accelerated expansion tests provide a basis for practical prediction of the moisture expansion potential of freshly fired products.
4. When predicted expansion values are based on adequate samples of the brick population, their accuracy is sufficient for building work.

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