Research Paper 11

Determination of the Expansion of Non-Kiln-Fresh Bricks

Abstract

The standard test[1], for predicting the moisture expansion of fired clay bricks, developed by the Brick Development Research Institute, requires testing to have commenced between 24 and 36 hours after the bricks have been drawn from the kiln. However, it is often difficult to deliver samples to the testing laboratory in this state, and on some occasions the information required may be either the residual or the past expansion of the bricks. Thus there is a need for a test method where the age of the test specimens is not as crucial as it is in the existing method.

This paper concludes that it is possible to estimate the past and future expansion of a clay brick of any age by refiring specimens at 915°C, measuring the shrinkage induced by that refiring, and then conducting the standard accelerated expansion test.

A series of experiments was carried out on brick specimens that had been subjected to the accelerated expansion test in the past and were subsequently stored in our laboratory. It is shown that on refiring these bricks at temperatures between 900 and 1000°C , they are returned to a "kiln-fresh" state and may be used again in the accelerated expansion test.

The age of the test specimens before refiring was found to have little influence on the relationships investigated.

The refiring temperature was found to significantly influence the magnitude of the shrinkage, but not the subsequent expansion on steam treatment.

The best relationship between past expansion and shrinkage on refiring was found to occur when the bricks were refired at 915°C.

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Determination of the Expansion of Non-Kiln-Fresh Bricks

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1.0 Introduction

The expansion of fired clay products is the result of the changes in volume associated with the adsorption of compounds containing polar hydroxyl groups, such as water, by certain constituents of the ceramic body[2].

This process of adsorption of water by fired clay bodies begins at reasonably high temperatures during the cooling stage of the manufacturing process[2,3] and continues for a long time thereafter. The rate of adsorption was found to be related to the age of the fired ceramic body, the amount of moisture present, the available internal surface area and the temperature[4,5,6,7,8]. The rate and the total amount of expansion varies considerably from body to body[9], making generalizations difficult.

Ideally, a test method should provide an estimate of the future growth of the fired clay product, or in the case of bricks taken from a damaged building, the amount of expansion that has already taken place.

Three methods have been tried to assess the expansive potential of bricks:

1. the development of an index of moisture expansion to relate growth after x days to growth after y days[9],
2. short term tests where the growth is accelerated by some means[l0,11,12],
3. the use of prediction curves to relate expansion to time[l3].

The test method developed by BDRI, now an Australian Standard[1], is based on a short-term test which accelerates moisture expansion. Predictions of the long-term expansion are then made by the use of the relationship between these short term test results and natural expansion found by McDowall and Birtwistle[12].

The usefulness of this method is limited by the fact that only samples of fixed age (24 to 36 hours ex-kiln) may be used, and the method can not be used to determine expansion that has already taken place.

Earlier attempts by the principal author[14] to use the relationship proposed by McDowall and Birtwistle[12] to relate the results of the Standard accelerated test on samples older than 36 hours to their long term natural expansion failed to produce results of adequate accuracy.

All previous attempts to measure past expansion were based on refiring test specimens at a given temperature followed by a direct measurement of the shrinkage. The hope was that the loss of the water adsorbed by the fired clay body was the only cause of the shrinkage.

The major difficulty with this technique has been that the adsorbed water is released by the fired clay body over a range of temperatures, but to be certain that all the water has been released, the body needs to be reheated to near its original firing temperature[15]. At this temperature, further firing shrinkage, or indeed expansion (probably due to cracking), may also occur, and the two effects may become confused. For these reasons it was concluded by Hosking [10] that this method of determination of past growth is not reliable.

2.0 Scope of investigation

The objectives of this investigation were:

(a) to re-examine the question of shrinkage of bricks refired at a range of temperatures close to the original firing temperature and;

(b) to study the relationship between refiring temperature and the subsequent accelerated expansion produced by four hours steam treatment.

The samples used were stiff plastic pressed, semi-dry pressed and extruded bricks (both solid and perforated) taken from various parts of Australia.

Data on the expansion characteristics, both four hours steam and natural expansion for periods up to 16 years, were available.

Two series of tests were conducted. The first series explored the relationships between firing temperature and shrinkage after refiring, the steam expansion after refiring, the age of the brick, and the method of manufacture. Twenty sets of five bricks were used.

The second series of tests used seventeen sets of five bricks. These were refired at the temperature (915°C) which had given the most promising results in the first series of tests. Again the results were analysed to explore the relations between shrinkage after refiring, steam expansion after refiring, sample age and method of manufacture.

3.0 Experimental

Five refiring temperatures were evaluated, namely; 900, 915, 950, 980 and 1000°C. The non-uniformity of the intervals between refiring temperatures arose from limitations of the available equipment.

In the first series of tests one brick from each sample was fired at each temperature. In the second series of tests all five bricks in each sample were refired at 915°C.

The firing cycle was designed to provide a slow rate of increase in temperature, taking 10 to 12 hours to reach the desired value. The temperature was then held constant for five hours, after which the sample was allowed to cool slowly to room temperature over the period of 7 to 9 hours. It was hoped that the slow rate of increase in the refiring temperature would reduce the shock suffered by the bricks during refiring and that this would minimise internal cracking that could interfere with the measurement of shrinkage.

In spite of these precautions, most if not all the specimens, suffered some damage by cracking during the refiring process but this did not appear to affect the results of the subsequent accelerated moisture expansion test. It therefore appears that, as long as the specimen stays in one piece before and after the steam treatment involved in the accelerated expansion test, the results are quite reliable within the limits of error determined in these investigations.

It was also reassuring that neither age nor brick type were found to be significant factors in the values obtained for shrinkage, or in accelerated expansion of the refired bricks.

The length of each specimen selected for refiring was measured (a) before and after the original accelerated expansion test, (b) immediately before refiring and (c) before and after the second accelerated test. All lengths were measured using a micrometer comparator conforming to AS 1226.5 to the nearest 0.0001 inches (0.002 mm), in a constant temperature room, kept at 24 ± 2°C. They were then subjected to the Standard accelerated test described in AS 1226.5 which consists of a saturated steam treatment of the measured specimens at 100°C in a loosely covered steam bath for 4 hours.

4.0 Results

4.1 The relationship between total expansion and shrinkage

The first series of experiments was carried out on bricks of various ages and modes of manufacture, that were refired at different temperatures. It was possible therefore to investigate the influence of these three factors on the relationship between the total expansion of bricks (as measured from 24-36 hours after the original refiring) and the shrinkage caused by refiring.

It was found that refiring temperature had a major influence on the relationship, brick type had virtually no influence at all while the effect of age was applicable only for bricks refired at 1000°C. The influence of temperature is indicated in Figures 1(a) to (e) in which total expansion (y) is plotted against shrinkage (x) for each refiring temperature. Also given are the least-squares regression lines (dotted lines), the line y = x (solid line),and the correlation coefficient. For the temperatures 900, 915, and 950°C the slopes of the regression lines are not significantly different from 1.0 whereas those for the temperatures 980 and 1000°C are significantly less than 1.0.

From the values of the correlation coefficents it would appear that there is little to choose between the temperatures 900 to 980°C. These correlations are however somewhat inflated by the data from one sample of bricks that were very much older than the other bricks (11 years and 3 months compared with the next oldest of only 7 months) and which had much larger expansion and shrinkage values than any of the other bricks. The values of correlations between total expansion and shrinkage without these older bricks is given in Table 1 from which it appears that the lower refiring temperatures 900 and 915°C are to be preferred, with the latter producing slightly better results.

Table 1. Correlations between total expansion and shrinkage with "old bricks" omitted.

Refiring temperature (°C)	Correlation
900	0.96
915	0.97
950	0.92
980	0.93
1000	0.86

For refiring temperature 915°C , the regression of total expansion (y) on shrinkage (x) was estimated to be:

$$y = 0.012 + 1.003\ x$$

where the slope of the line is not significantly different from 0. Now, since total expansion and shrinkage are similar types of quantities and since the slope of the regression line was not significantly different from 1.0, it is both reasonable and simpler to consider a model of the form:

$$d_t = \mu_t + e_t$$

where $d_t = y - x$ is the difference between total expansion and shrinkage, μ_t is a constant and e_t is a random error with mean 0 and variance σ_t^2. The parameters μ_t and σ_t^2 were estimated to be 0.012 and 4.15×10^{-5} respectively from which a 95 percent prediction interval for d_t is given by:

$$0.012 \pm 0.014$$

For the second series of experiments, all bricks were refired at the same temperature, namely 915°C . Again it was found that the age of the bricks had no significant influence on the relationship between total expansion and shrinkage, and that the slope of the regression line was close to 1.0.

The data and fitted regression line are given in Figure 1(f). It was found, however, that the differences between total expansion and shrinkage differed significantly between samples, so that it was appropriate to consider a model of the form:

$$d_t = \mu_t + s_t + e_t$$

where s_t denotes the effect of the sample and is taken to be a random quantity with mean 0 and variance σ^2_{st}.

With now obvious outliers omitted the estimates of the parameters for this model were $\hat{\mu}_t = 0.013$, $\hat{\mu}_{st} = 7.0 \times 10^{-5}$ and $\hat{\mu}_t^{\,2} = 1.3 \times 10^{-5}$ from which an appropriate 95 percent prediction interval for dt is given by

$$0.013 \pm 0.019$$

which is in close agreement with the prediction interval found using the data from the first series of experiments.

This means that the past expansion of a brick can be determined by refiring at 915°C and that, in 95 percent of cases this estimate can be expected to lie within ±0.019 of the true value.

4.2 The relationship between the accelerated moisture expansion tests before and after refiring

The form of the data was the same as for the total expansion v. shrinkage part of the experiment, and the data from the two series of experiments were again analysed separately.

From the first series of experiments it was found that, while the relationship between the two accelerated moisture values varied from sample to sample, it did not depend on the type of brick, the age of brick or the refiring temperature. Since it was hoped to be able to-predict the original (before refiring) accelerated moisture expansion results from those obtained after refiring, the original accelerated moisture expansion values were regressed on those obtained after refiring. For each of the refiring temperatures it was found that the slope of the regression lines was close to 1.0, as indicated in Figure 2, so that it was again appropriate to consider only the difference between the two expansion values for each brick.

Since the refiring temperature had no significant affect, it was possible to consider the variation between and within samples for both series of experiments by fitting a model of the form:

$$d_a = \mu_a + s_a + e_a$$

where d_a denotes the difference between the two accelerated moisture expansion values (original – after refiring), μ_a is a constant, s_a denotes the effect of the sample, which is taken to be a random quantity with mean 0 and variance σ_{sa}^2 and e_a is a random error with mean 0 and variance σ_a^2.

The constant μ_a is included to allow for a possible bias between the two sets of expansion values. However it was found that for both series of experiments, μ_a was not significantly different from 0 so that it was appropriate to use the simpler model:

$$d_a = s_a + e_a$$

When fitting this model, it was found that large values of d_a were associated with bricks that had very large accelerated expansion values, and as a consequence, it was decided to omit from the analysis those bricks for which either value of the accelerated moisture expansion was in excess of 0.070 percent. A total of six samples, three from each series of experiments, and the conclusions below apply only to bricks whose accelerated expansion is less than 0.070 percent.

Based on the bricks with accelerated expansions less than 0.070 percent, the parameters σ_{sa}^2 and σ_a^2 were estimated to be 9.0×10^{-6} and 5.7×10^{-6} respectively, using the data from the first series of experiments, and 9.6×10^{-6} and 4.3×10^{-6} respectively, using the data from the second series of experiments. These two sets of estimates are in very good agreement with each other and lead to the conclusion that, for about 95 percent of the samples with an accelerated expansion of less than 0.070 percent, the difference between the original accelerated expansion value and that obtained after refiring the brick will be less than 0.008.

For bricks with an accelerated expansion value in excess of 0.070 percent the difference between the two accelerated expansion values is likely to be greater than for those with smaller values. An estimated 95 percent prediction interval of 0.018 for the difference is based on very few observations and may not be particularly accurate.

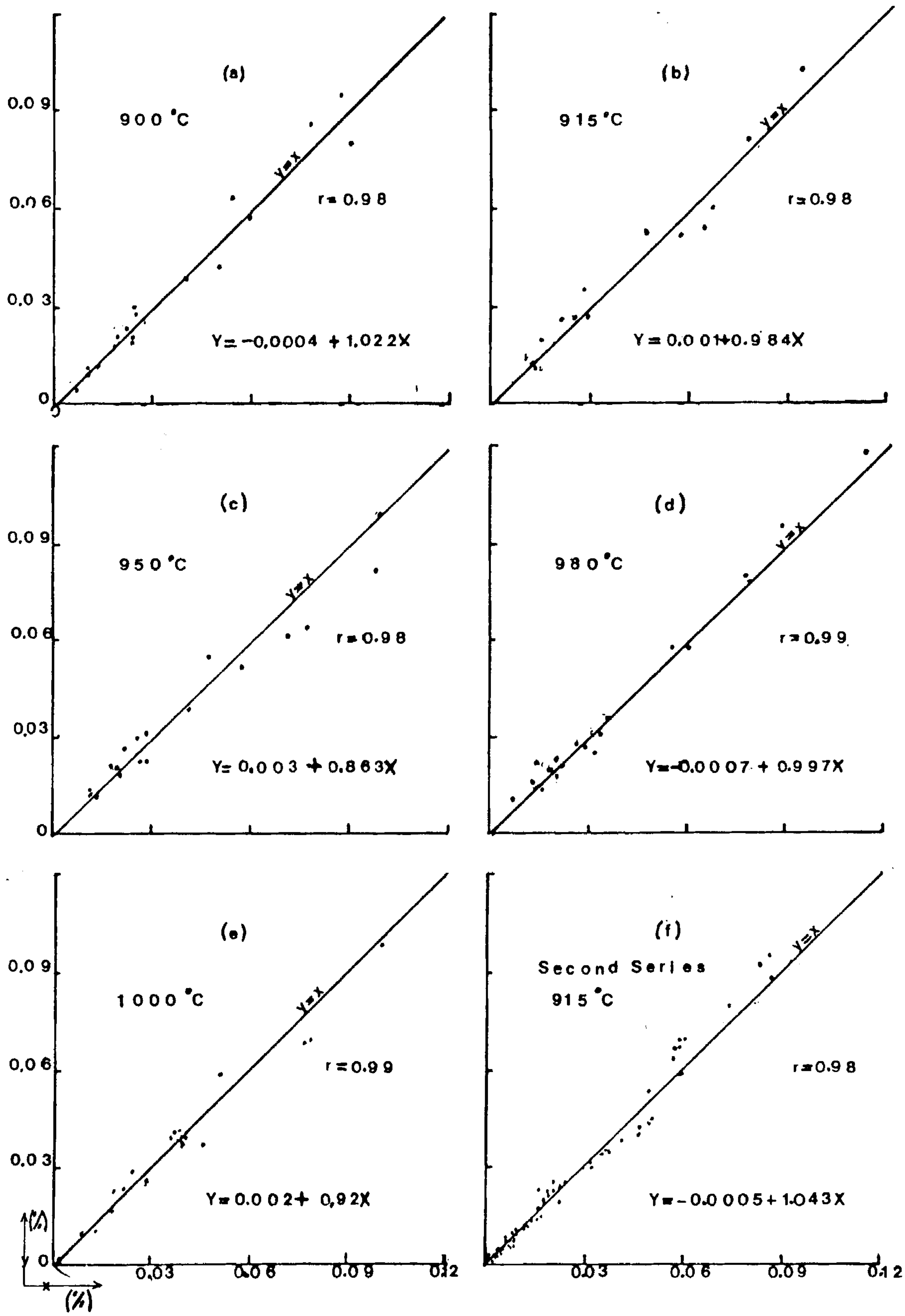

Figure 1. Shrinkage (x%) v. total expansion (y%)

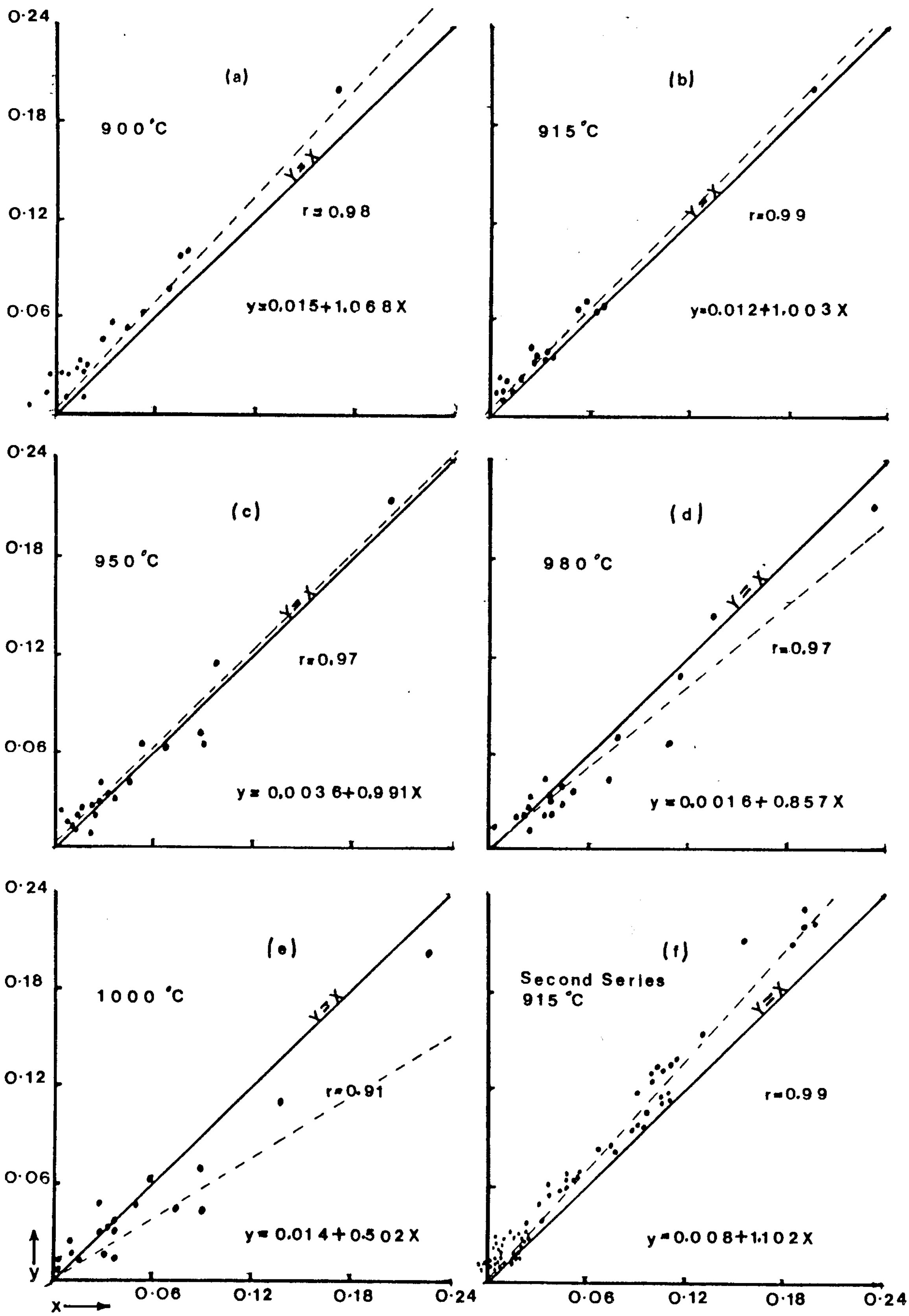

Figure 2. Steam expansion after and before refiring

5.0 Discussion

5.1 Determination of the past growth from the observed shrinkage due to refiring

The relationship between the past growth and the shrinkage was found to be highly significant at each of the refiring temperatures evaluated. However, as expected, this relationship varied with the refiring temperature. The reasons for this are discussed below.

It was found that the best correlation between total growth and shrinkage occurred when the samples were refired at 915°C. At this temperature the shrinkage was found to be less than the total expansion by 0.013 percent on average, therefore, by adding 0.013 percent to the measured shrinkage, an estimation of the past growth can be made.

The findings of this investigation confirm earlier conclusions by Cole[15] that it is not advisable to refire bricks at temperatures more than 50°C below the original firing temperature as, in this region, additional shrinkage may occur that is not related to the loss of adsorbed water. Cole also concluded that, to return bricks to their original dimensions, they need to be refired within 100°C of their original firing temperature.

The original firing temperatures of the samples in this investigation were not known, but it appears that by refiring them at 915°C they did not undergo shrinkage in excess of their past growth. This indicates that this temperature was safe to use with these samples. However, it is reasonable to assume that, should any one of the samples used in this investigation have been originally fired at temperatures in the close vicinity of 915°C, our estimation of the past growth of such bricks would have been in excess of the true value.

In Australia most well made bricks are fired at temperatures well in excess of 1000°C, but as there are exceptions to this generalisation, the future use of this technique requires care.

5.2 Determination of the accelerated expansion value of bricks after refiring

The correlation between the accelerated expansion values before and after refiring was found to be very high at all of the refiring temperatures investigated. The obvious conclusion is that refiring within the range of temperatures used in this investigation renders the bricks suitable for the Standard accelerated moisture expansion test. From the range of temperatures tried, 915°C was found to be the most appropriate, as it matches the best refiring temperature for the measurement of the past expansion by refiring. There are also other considerations, such as avoiding the possibility of exceeding the original firing temperature, which favour a low refiring temperature.

The relationships between accelerated expansion before and after refiring were better with some samples than others. This lead to the relatively large estimate of error of determination. Particularly when low expanding (less then 0.4 mm/m) bricks are being considered, the error may equal or exceed the determined value of accelerated expansion. Application of this large correction factor on low expanding bricks is not likely to cause problems when the results of these tests are used for the calculation of the spacing between movement gaps in brickwork; provided the characteristic expansion does not exceed 0.5 to 0.6 mm/m there is no need to provide a movement gap in walls less than 12 to 15 m in length[18].

Because of the uncertainties involved in the refiring of bricks, it is recommended that in the calculation of the characteristic expansion from the results of the accelerated expansion test on refired samples, the upper limit of the 95 percent confidence interval be used by adding 0.007 to the accelerated expansion value.

5.3 Series two, refiring full sets of five bricks at 915°C

The highly significant relationships previously found between shrinkage past growth, and accelerated expansion before and after refiring, were confirmed.

The availability of the extra data allowed a more accurate determination of errors involved in these tests.

6.0 Conclusion

The results of the investigations described in this paper show that it is possible to estimate the past and accelerated expansion of non-kiln fresh fired clay bricks by refiring them at 915°C, and following this by the application of by the Standard accelerated expansion test. Certain values were determined that give an estimate of the differences between the known values of past natural and accelerated expansions. By using these values, a reasonable estimate of the past growth can be made.

7.0 Acknowledgements

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