Research Paper 7

Determining the Compressive Strength of Clay Bricks

Abstract

The authors are of the view that for structural brickwork a determination of brickwork prism strength provides a direct measure of brickwork compressive strength that is to be preferred to its assumption from a knowledge of brick compressive strength and mortar type. However it is acknowledged that both the brick user and brickmaker require a quick test on which to base acceptance or otherwise of bricks delivered to the site. A test for the compressive strength fulfils this need and having a reliable method for its determination is of importance.

The paper examines the need to test whole bricks as opposed to half or other portions of the brick. This is a matter of importance because machines with the capacity to test whole bricks with a compressive strength above 65 to 70 MPa are scarce and expensive in Australia where many extruded bricks are above this level in their compressive strength.

The conclusion from the presented data is that pressed bricks must always be tested whole. With extruded bricks exact halves produce reliable results as do other fractions provided a correction is made for differences between the perforation proportion of the whole brick and that of the tested fraction.

Further work is needed and is in progress.

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Research Paper 7

Determining the Compressive Strength of Clay Bricks

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1.0 Introduction

The Australian method for the determination of brick compressive strength[1] requires that a half brick be tested using plywood caps. Any frog it may have must be filled with a *ciment fondu* mortar. Such a method means that those machines most commonly available - with a maximum capacity of around 1800 kN – will be adequate for all Australian bricks, but no evidence has been found to support the view that a half brick represents a whole brick.

Morgan[2] examined three different extruded bricks and three pressed bricks, two of fired clay and one calcium-silicate. Among his conclusions were the following:

1. Specimen size has a significant effect on measured brick compressive strength, whole bricks giving higher test results than half bricks.
2. The effect of specimen size was observed to be minimal in the case of highly perforated brick types.

The work reported here confirms that for pressed bricks the first of these two conclusions is valid, but the results support the view that the second conclusion understates the smallness of the difference caused by specimen size when perforated extruded bricks are being tested.

It is acknowledged that only two extruded brick types are reported here, but an analysis of a much larger body of data that is almost complete so far confirms the conclusions of this paper.

A total of 426 specimens was tested.

2.0 Equipment and methods

2.1 Testing machines

The compressive strength measurements of the Type 2 extruded bricks were carried out on an Avery 7112 CCG machine with a maximum capacity of 2700 kN (Machine B). All other compressive strength measurements were obtained from a similar Avery machine except that it has a maximum capacity of 1800 kN (Machine A). Both had been checked to ensure compliance with the accuracy provisions for Grade A machines of AS B128 *Methods for the Verification of Testing Machines*.

2.2 Test method

All specimens were immersed in water for 24 hours prior to testing and pressed bricks had their frogs filled with a *ciment fondu*, all in accordance with Australian standard methods[1]. The specimens were placed in the machine with single sheets of nominal 4.5 mm plywood interposed between both their upper and lower bed faces and the platens or packing plates of the machines. The size of the plywood caps complied with the recommendations of Beech, Everill and West[3] in that all projected between 5 and 15 mm beyond the specimen in all directions. The loading rate was maintained at approximately 45 MPa/min.

3.0 Brick types and test specimens

3.1 Extruded bricks

Two types of perforated brick were tested; Type 1 being multi-hole soft extruded and Type 2 hard extruded with three holes. Both had been extruded in a direction normal to their bed faces and both were fired in tunnel kilns using natural gas. All brick cutting was done with a diamond saw.

3.1.1 Extruded brick type 1 Five sets of 10 bricks were selected at random from a large sample. Those in the first set were tested as whole bricks; the second as two sets of opposite halves, HI and H2; the third gave fractions FI and F2; the fourth, fractions F3a, F3b and F4 and the fifth F5, F6, F7, F8, F9 and F10. Figure 3.1.1 illustrates the plan geometry of the various specimens, all of which were between 75 and 77 mm high.

A total of 140 specimens was tested.

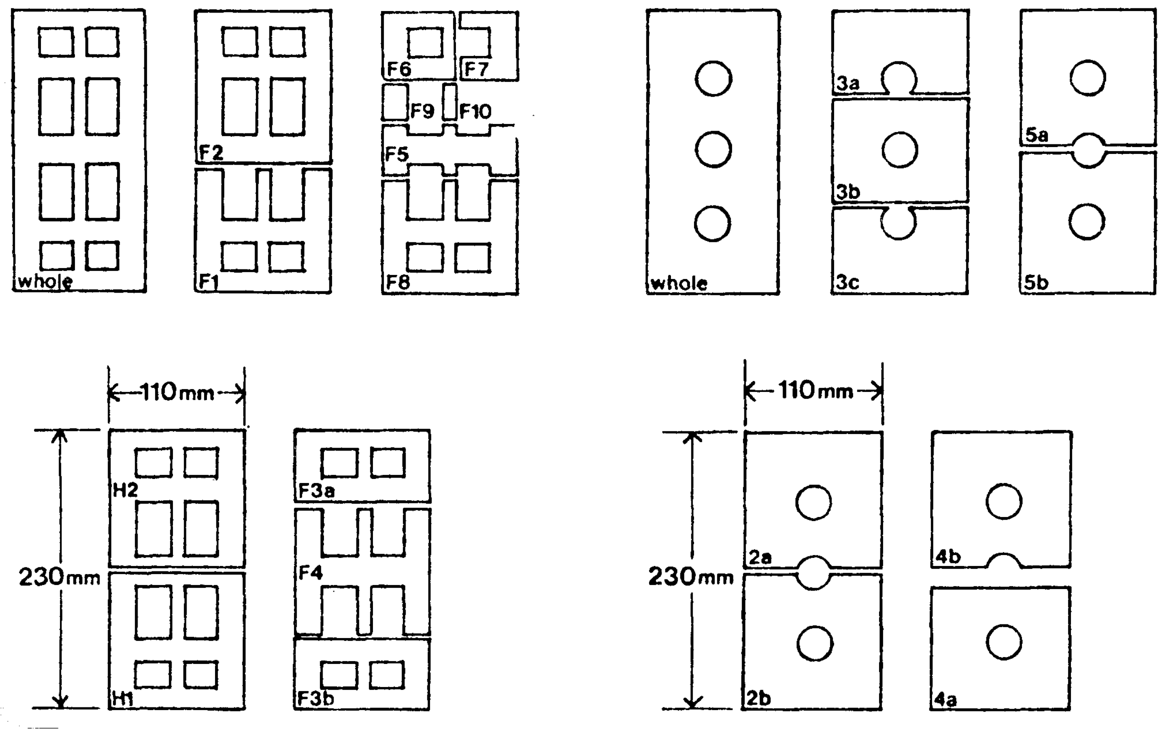


Figure 3.1.1 & 3.1.2. Wholes and fractions extruded bricks type 1 (left) and type 2 (right)

3.1.2 Extruded brick type 2 Again five sets of bricks were selected with the bricks in the first set being tested as whole bricks and the others as halves or fractions as shown in Figure 3.1.2. Samples 1 to 4 all contained 10 bricks each, but there were 12 bricks in Sample 5. In this instance all specimens had an almost identical perforation proportion with not more than 4 percent difference between the highest and lowest. Again all specimens were between 75 and 77 mm high.

A total of 122 specimens was tested.

Because of the high strength of this brick it was necessary to use the larger capacity machine. In order to provide some indication that this practice did not introduce results different from those that might have been obtained from the lower capacity machine, the opposite halves of the fifth set - Samples 5(a) and 5(b) - were tested in the two different machines using the same operator. The results (see Appendix A) indicated that there was no significant difference between the values obtained from the two machines.

3.2 Pressed bricks

Three pressed bricks of different colours were tested, all were made by the stiff-plastic pressed process and were fired using natural gas. The grey bricks were fired in a Hoffman kiln and the creams and reds in a tunnel kiln.

3.2.1 Grey colour A total of 22 specimens was randomly selected from a large sample; 12 were tested whole and the remaining 10 were sawn into 10 halves, 10 quarters and two sets of 10 eighths. A total of 52 specimens was tested.

3.2.2 Cream colour From a total of 30 specimens 10 were tested whole, 10 were sawn into two sets of 10 halves and the remaining 10 were broken down into 10 three-quarter and 10 quarter bricks. A total of 50 test specimens.

3.2.3 Red colour 30 of these bricks were treated in exactly the same manner as the cream bricks. A total of 50 test specimens.

4.0 Results

The compressive strength of a brick is:

$$X = \frac{L}{A_g} \qquad ①$$

where, X = compressive strength per unit of gross area;

L = load to cause failure; and,

A_g = gross area.

If, with extruded bricks, a correction was applied for the perforations, then:

$$X^1 = \frac{L}{A_n} \qquad ②$$

where, X^1 = compressive strength per unit of net area; and,

A_n = net area.

Substituting L from ② into ① we find that:

$$X = X^1 \frac{A_n}{A_g} \qquad ③$$

If we introduce the perforation proportion, P_c and express it as:

$$P_c = \frac{A_g - A_n}{A_g} = 1 - \frac{A_n}{A_g}\ ;$$

i.e. $\frac{A_n}{A_g} = 1 - P_c$,

we can, by substitution in ③, obtain the expression:

$$X = X^1(1 - P_c) \qquad ④$$

4.1 Extruded bricks

4.1.1 Extruded brick (type 1) The results of tests on Type 1 extruded bricks are given in Column 2 of Table 4.1.1.

4.1.1.1 Regression of X on P_c. Using the full data set to calculate the line of best fit via the method of least squares, we obtain the expression:

$$\hat{X} = 82.04 - 86.38 P_c = 82.04(1 - 1.05929 P_c)$$

where $\hat{X}$ is the compressive strength calculated from the regression line.

A plot of residual versus perforation proportion, P_c, indicates that the error variance σ^2 increases as the perforation proportion decreases (see Figure 4.1.1). A weighted linear regression[4] was therefore performed with each observation being weighed by the inverse of the observed variance at that value of the perforation proportion.

This gave the least-squares regression as

$$\hat{X}_1 = 81.80 - 84.10 P_c$$

$$= 81.80(1 - 1.0281 P_c) \qquad ⑤$$

The calculated correlation coefficient r = 0.7443. The t-statistic:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} = 13.09$$

which, when compared with the t-distribution on 138 degrees of freedom, gives a descriptive level of $\delta < 0.1$, this indicating a significant linear relationship. A plot of residuals versus perforation fraction (Figure 4.1.2) shows that the use of the weighted regression has stabilized the variance. The observed compressive strength is plotted against the perforation proportion P_c in Figure 4.1.3.

The net compressive strength, X' , of each specimen was calculated and gave an average value of 80.65 (see Column 6 of Table 4.1.1) which, when substituted into equation 4, gives:

$$X_2 = 80.65(1 - P_c) \qquad ⑥$$

Equation ⑥ is very similar to equation ⑤ and the differences in X obtained from the two ranges from +1.4 to -3.3 percent (see Column 9 of Table 4.1.1).

To calculate the compressive strength of the whole brick (*X*") from the results of tests on fragments, we use the expression:

$$X'' = \frac{x(1 - P_{cw})}{1 - P_{cf}} \qquad ⑦$$

where X is, as before, the measured compressive strength per unit of gross area of the fragment and P_{cw} and P_{cf} are respectively the perforation proportion of the whole brick and of the fraction that has been tested.

Using ⑦, the values for *X*" given in Column 10 of Table 4.1.1 were obtained. As can be seen, the X" values compare well with the measured average compressive strength of the whole brick (58.44 MPa), the difference ranging from -4 to +10 percent.

4.1.1.2 Conclusion. From this exercise it is evident that, provided a correction is made for variations between the perforation proportion of the fraction under test (P_{cf}) and that of the whole brick (P_{cw}), fractions sawn from extruded bricks can be used to determine the unit compressive strength of the bricks.

4.1.2 Extruded brick (type 2) The results of the tests on Type 2 extruded bricks are given in Table 4.1.2.

4.1.2.1 Comparison within samples. Since observations from different fractions of the same brick will not be independent, we cannot simply compare the nine sets of observations. We first compare the compressive strength of the bricks within each sample.

In Sample 2, the identical halves were compared using the Wilcoxon signed rank test. This resulted in a value of W = 33, where W is the sum of the signed ranks. The descriptive level of this result is $\delta = 0.098$, and so we accept the hypothesis of no difference in the compressive strength of the halves.

The fragments in Sample 3 were compared using the Friedman two-way analysis of variance[5, 6]. This gave a value of $x^2 = 4.2$, which, when compared with the chi-square distribution of two degrees of freedom, gave a value of $0.1 < \delta < 0.2$. The data thus provide little reason to reject the hypothesis of equality of compressive strengths.

(The Friedman two-way analysis of variance tests whether k related samples could probably have come from the same population with respect to mean ranks.)

A Wilcoxon signed rank test was used to compare the fragments in Sample 4. We obtained $W = 35$, where W is the sum of the signed rank. The probability of obtaining a value as extreme as 35 is $\delta = 0.0768$, and thus we conclude that the measured compressive strengths are not significantly different.

4.1.2.2 Comparison between samples. A Kruskal-Wallis one-way analysis of variance[7, 8] was used to compare the compressive strength of the samples. For those samples where there was more than one measurement obtained from a brick, the average of the measurements from that brick were used. Thus for Samples 2 and 4 each observation is the average of two readings, and for Sample 3 the average of the three readings. This was done so that all observations were independent.

The Kruskal-Wallis test gave a value of $H = 7.66$. When compared with the chi-square distribution on four degrees freedom, we find that $0.1 < \delta < 0.2$. We thus conclude that there is no significant difference in the measured compressive strength of the samples.

4.1.2.3 Conclusion. The above tests showed that there is no significant difference in the compressive strength of fragments from the same sample and also that the compressive strengths of the five samples do not differ significantly from each other.

4.1.3 Conclusion for extruded bricks For perforated bricks extruded in a direction normal to the bed face, brick fractions can be used to represent a whole brick for the measurement of brick compressive strength. The testing of exact halves saves the need to apply a correction for differences that may exist between the perforation proportions of the test specimens and that of the whole bricks.

4.2 Pressed bricks

The results of these tests are tabulated in Table 4.2.

4.2.1 Linear regression. A linear regression was fitted to the data. As the brick samples were of different compressive strengths, the observations from each brick sample were standardized by the average compressive strength of the whole bricks. This resulted in the following relationship:

$$X = 0.6351 + 0.001749\ A,$$

where X is the compressive strength of the brick and A is the area of the brick. The relationship is shown in Fig. 4.2. The calculated coefficient of correlation, $r = 0.6446$. The slope coefficient, $b = 0.001749$, is significantly greater than zero ($t = 10.32$, descriptive level, $\delta < 0.005$). This indicates that for pressed bricks the compressive strength increases as the area of the specimen increases, the relationship being approximately linear within the range of fractions from eighth to whole bricks.

4.2.2 Conclusion for pressed bricks. It is evident that measured values for the compressive strength of pressed bricks are sensitive to the area of the specimen under test with a tendency for smaller fractions to produce lower results.

Table 4.1.1. Extruded bricks type 1: observed and calculated compressive strength values and other data

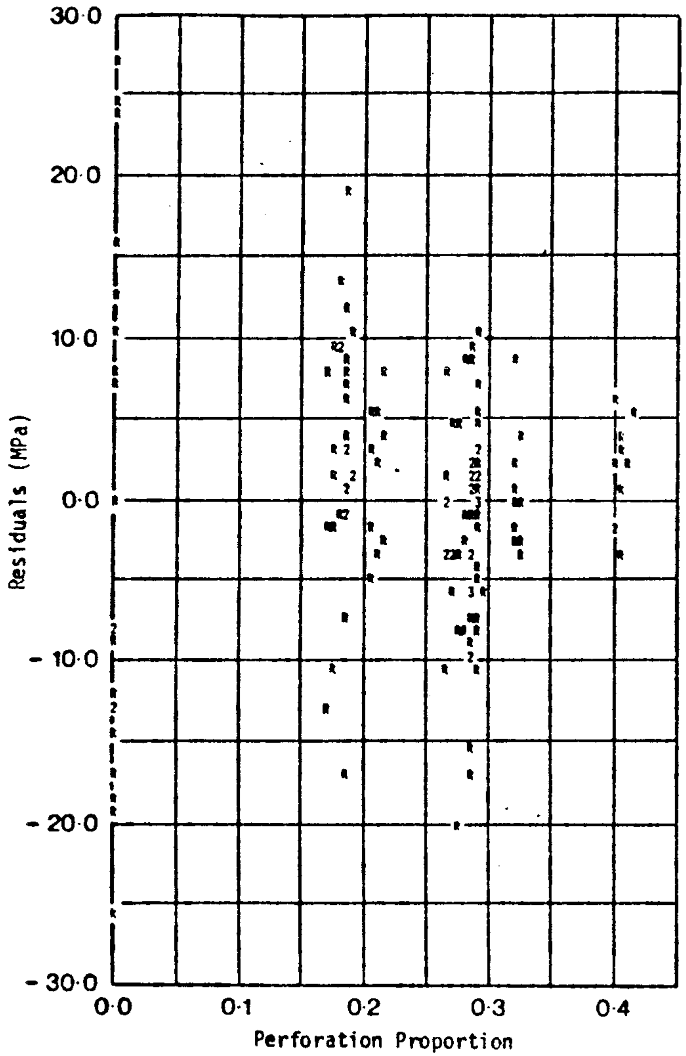
1	2	3	4	5	6	7	8	9	10
Test piece	Observed average compressive strength (MPa)	Standard deviation (MPa)	Area tested (cm^2)	P_{cw} or P_{cf}	Net compressive strength: X^1 from 2 (MPa)	Fitted value: $\hat{X}_1$ from 5 (MPa)	Calculated compressive strength: $\hat{X}_2$ from 6 (MPa)	Percentage difference $\frac{5-6}{5}\times 100$	Calculated compressive strength: X'' from 7 (MPa)
Whole	58.44	2.56	268	0.288	82.07	55.57	57.42	-3.3	58.44
Halves									
HI	52.55	7.28	135	0.288	73.57	57.81	57.65	+0.3	52.39
H2	53.79	6.96	135	0.287	75.43	57.65	57.50	+0.3	53.71
Fractions									
FI	54.79	3.68	120	0.323	80.87	54.67	54.64	+0.05	57.58
F2	57.93	5.18	144	0.267	79.03	59.34	59.12	+0.4	56.27
F3a	58.52	7.82	72	0.186	85.58	66.12	65.62	+0.8	60.93
F3b	69.47	7.67	73	0.185	85.19	66.28	65.77	+0.8	60.65
F4	48.88	3.08	124	0.406	82.24	47.58	47.94	+0.8	58.55
F5	55.85	8.67	56	0.278	77.41	58.40	58.21	+0.3	55.12
F6	68.86	8.92	38	0.175	83.44	67.12	66.57	+0.8	59.41
F7	65.73	4.31	32	0.208	83.03	64.27	63.85	+0.7	59.12
F8	56.60	4.91	107	0.290	79.75	57.38	57.24	+0.2	56.78
F9	80.06	14.58	6.9	0	80.06	81.80	80.65	+1.4	57.00
F10	81.45	18.68	3.4	0	81.45	81.80	80.65	+1.4	57.99
Overall	$\bar{X}$ = 62.43 S = 12.82				$\bar{X}'$ = 80.65 S = 10.11	$\bar{\hat{X}}_1$ =62.71 S = 9.29	$\bar{\hat{X}}_2$ =62.34 S = 8.911		$\bar{X}''$ = 57.43 S = 7.20

Table 4.1.2. Compressive strengths of extruded bricks (type 2)

	Average compressive strength (MPa)	Standard deviation (MPa)
Sample 1	89.87	10.06
Sample 2		
a	95.75	11.13
b	88.89	8.00
Average	92.32	7.70
Sample 3		
a	93.39	12.06
b	82.20	7.83
c	88.57	10.00
Average	88.05	5.87
Sample 4		
a	81.97	9.84
b	93.08	12.77
Average	87.53	7.88
Sample 5b	82.68	6.77

Table 4.2. Pressed bricks – compressive strengths of wholes and fragments

	Area (cm^2)	Average compressive strength (MPa)	Standard deviation (MPa)
Grey stiff plastic pressed			
Wholes	247.13	54.61	7.31
Halves	125.21	41.08	6.15
Quarters	64.30	33.50	6.55
Eighths - a	31.85	30.72	6.15
Eighths - b	30.01	26.93	5.33
Cream stiff plastic pressed			
Wholes	258.22	43.24	3.96
Three-quarters	191.32	43.49	5.17
Halves - a	128.43	41.10	6.23
Halves - b	126.20	42.80	5.52
Quarters	63.44	38.24	4.95
Red stiff plastic pressed			
Wholes	243.52	55.60	3.54
Three-quarters	183.85	57.56	8.32
Halves - a	120.32	54.77	4.62
Halves - b	122.04	50.61	5.29
Quarters	59.78	47.17	6.32



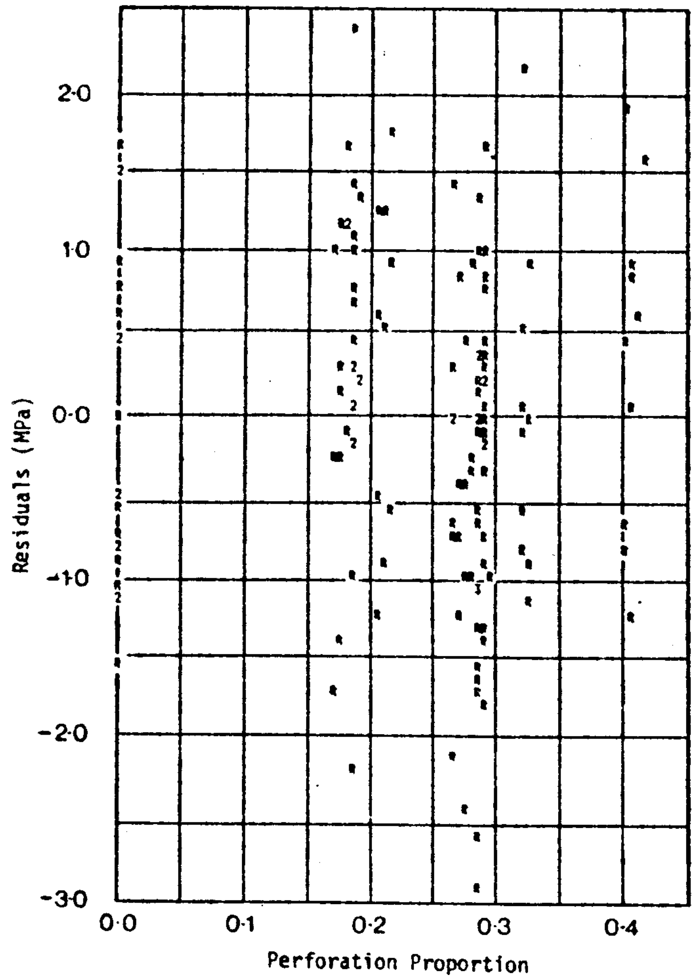


Figure 4.1.1 & 4.1.2. Residual plots: Extruded bricks (left) and After weighted regression (right)

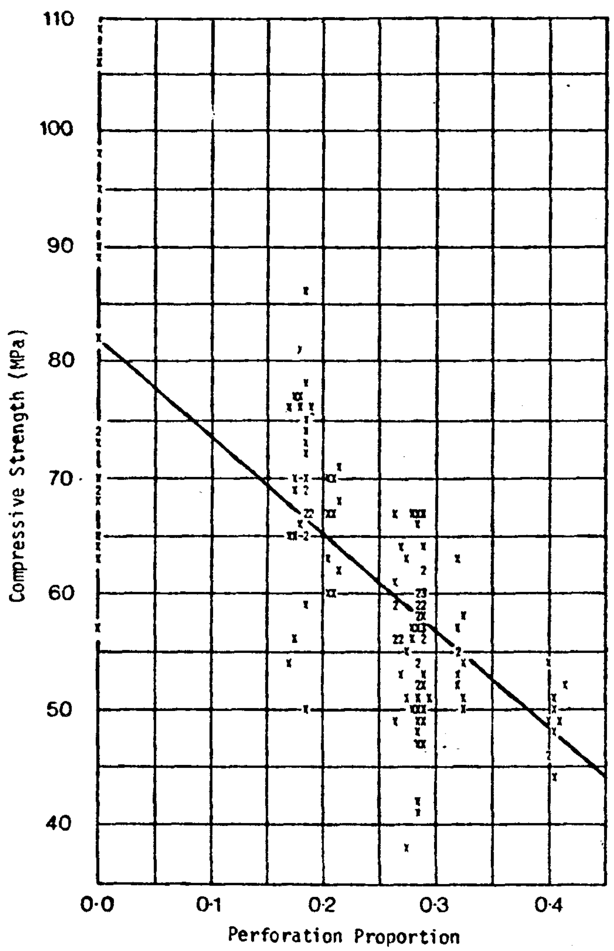


Figure 4.1.3. Plot of observed compressive strengths: Extruded bricks type 1

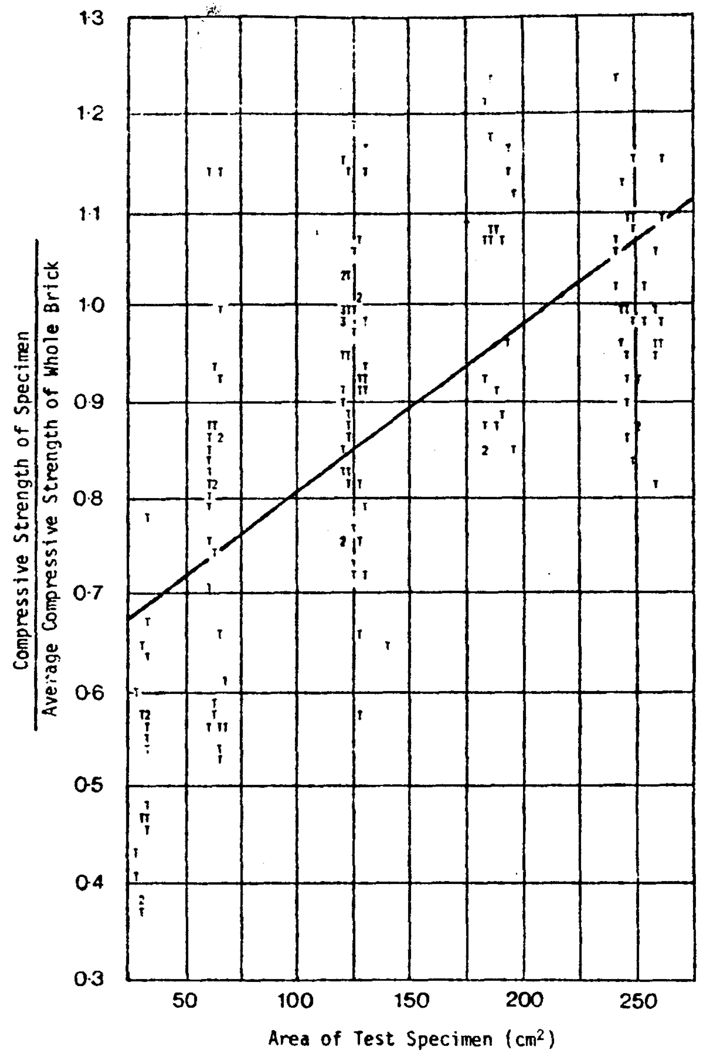


Figure 4.2. Plot of standardised observed data: Pressed bricks

5.0 Discussion

In testing for the compressive strength of concrete it seems to be accepted, by Neville[9] for example, that given reasonably constant aspect ratios the larger the test specimen the lower will be the achieved result. No similar tendency was observed with the extruded bricks described in this paper and, with pressed bricks, the opposite effect was observed in both this series and that reported by Morgan[2].

That no size effect appears to exist with bricks similar to that observed for concrete is probably to be expected. With concrete the test specimen is made to a particular size, either large or small, whereas with bricks we either test the whole unit as it was manufactured or we produce smaller specimens by cutting. It seems probable that the reported size effect with concrete would disappear or reduce if the different sized test specimens under test were cut from a larger block of cast concrete.

In the case of the pressed bricks there is a tendency, that is particularly marked in the grey colour group where quarters and eighths were tested, for measured compressive strength to decrease with the cross-section area of the specimen under test. This suggests that aspect ratio is an influencing factor even though the relationship of height to the least lateral dimension, (d), was never greater than about 1.4d. For a (concrete) compression specimen Neville[10] suggests that height needs to be more than a 1.7d in order for at least the centre portion of the specimen to be free from the laterally restraining effect of the platens. However, Neville is speaking of a concrete specimen laterally restrained through rigid plaster or sulphur caps and the critical ratio of height to depth could be expected to be very much lower for compression specimens such as those reported in this paper where plywood packers were used at both ends of all test pieces. Such a practice would markedly reduce the lateral restraint offered by the platens and could create a situation where the difference in aspect ratio or, more particularly ratio of height to cross-sectional area between wholes and fractions causes the observed difference in results. It is interesting to speculate that this difference may disappear if the US method of plaster or sulphur capping compression specimens were substituted for the British and Australian method of using plywood packers.

The argument above does not work as an explanation for the behaviour of the extruded bricks where height to lateral dimension ratios can be seen to have had no effect on the compressive strength result (X^1 in column 6 of Table 4.1.1).

The following theory is offered as an explanation of why smaller fractions cut from extruded bricks can be used to reasonably represent the compressive strength of whole bricks. In the process of the manufacture of extruded bricks the flat plate-like particles of clay become oriented with their long axes in the same plane as the direction of extrusion thus giving such bricks a grain which, as in timber, has low tensile strength in the directions at right angles to the flow of that grain. Under compression such a brick is thus acting as a series of weakly connected columns each of which has a cross sectional area at least as small as the smallest specimen tested in this series (3.4 cm^2) and probably smaller.

6.0 Conclusion

a) The results given in this paper support the view that when measuring the compressive strength of clay bricks:

i) pressed bricks must always be tested whole; but,

ii) a fraction of an extruded brick may be tested and the result, corrected for any difference greater than about 4 percent between the perforation proportion of the tested fraction and that of the whole brick, will give a reliable measure of the strength of the whole brick.

b) Further work is needed to provide positive confirmation of the correctness of the conclusions in this paper because they are drawn from measurements on a limited range of products.

7.0 References

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Appendix A. Influence of testing machines – See Section 3.1.2

Table A. Compressive strength (MPa) of extruded half bricks tested on different machines

Brick no.	Machine A (1800 kN) sample 5a	Machine B (2600 kN) sample 5b	Difference (d = A-B)	Signed rank
1	74.60	72.56	3.84	4
2	80.72	94.94	-14.22	-10
3	87.69	98.32	-10.63	8
4	87.69	85.60	2.09	1
5	90.75	81.52	9.23	6
6	80.47	88.50	- 8.03	- 5
7	79.81	76.53	3.28	2
8	91.55	101.37	- 9.82	- 7
9	69.59	91.39	-21.80	-12
10	85.00	98.40	-13.40	- 9
11	75.22	91.26	-16.04	-11
12	87.29	83.67	3.62	3
	$\overline{X}_A$ = 82.68 S_A = 6.77	$\overline{X}_B$ = 88.67 S_B = 9.02	$\overline{d}$ = -5.99 S_d = 9.94	W = -46

Wilcoxon signed rank test was used to compare the two samples. This gave value of W = -46. The descriptive level of this result is δ= 0.0742, which indicates that there is no significant difference in the operation of the two testing machines.