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DEVELOPMENT OF THE WATER ABSORPTION FROM FRESH MORTAR TEST

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Abstract

The flexural strength is one of the important design considerations for masonry. It depends primarily on bond strength between masonry units and mortar. Several methods have been used to measure absorption properties of brick units with attempts to relate it to the expected flexural strength: the IRA test, the total absorption test, and the sorptivity test. It was shown that results of all these test methods do not correlate satisfactorily with the results of flexural strength tests. This could be because all these methods are based on the bricks absorbing pure water from the reservoir with unlimited water supply. This paper details the development of a new test method – the Water Absorption from Fresh Mortar test and presents preliminary results of tests on four types of bricks: dry pressed clay, extruded clay, concrete, and calcium-silicate.

Key Words

Brick masonry, water absorption tests, flexural strength.

1 Introduction

The strength of the bond developed between masonry units (bricks) and mortar is one of the most important parameters in the design of masonry, in particular for the design of un-reinforced masonry. One of the most common causes of failure in masonry is out-of-plane loading, such as earthquake or wind loads, which induced tensile forces in masonry walls. In un-reinforced masonry the bond between brick and mortar plays a critical role in resisting these tensile forces. Thus having a test that could accurately predict the developed bond strength for a brick and mortar combination would be a useful tool for both safe and efficient masonry design. The development of bond strength in masonry is very complex and still to this day not well understood. However,

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after many years of research it has been shown to be influenced by two main factors: (i) the absorption properties of the brick units and (ii) the retention properties of the mortar used. There are of course many other factors that influence the developed bond strength, but they can be categorised into one of the two factors mentioned above or they can be due to construction techniques, this however falls outside of the control of laboratory testing. The three most common tests currently used to determine the absorption properties of brick units are:

- Initial rate of Absorption Test
- Total Absorption Test
- Sorptivity Test

However, as shown by previous research and the results of this study, these brick absorption tests do not correlate satisfactorily with the developed bond strength.

We assume that the major reason for this unsatisfactorily correlation between the absorption tests mentioned above and bond strength is the following: the conditions the brick units are subjected to during testing are fundamentally different from the conditions experienced during masonry construction. As all three absorption tests provide the tests specimens with a constant and unlimited supply of water free of any material that may impede its ingress, whereas in actual masonry construction conditions the flow of water from mortar to brick is impeded by clogged pores and ultimately the source of water is limited and not constant due to chemical reactions taking place within the mortar.

Therefore the primary aim of this study was to develop a new brick water absorption test that better simulates actual moisture flow conditions experienced during masonry construction. The correlation of test results with the bond strength was studied to assess accuracy and efficiency of this new test.

2 Standard tests and results

Four types of masonry units were initially tested to determine their flexural bond strength properties and absorption properties:

- Dry Pressed Clay Units - D
- Extruded Clay Units - E
- Concrete Units - C
- Calcium Silicate Units - S

All masonry units were solid bricks (except calcium silicate units, which had three circular perforations) with nominal dimensions 230x110x70 mm.

All tests requiring mortar used the standard 1:1:6 mortar (1 part of cement, 1 part of lime and 6 parts of sand by volume). The consistency of the mortar was kept between 140 –150mm average flow.

Once the properties of the masonry units had been determined, comparisons between absorption properties and corresponding flexural bond strength were made to evaluate whether there was any correlation between them. This was done by fitting a linear trend line to an absorption/flexural strength plot. A linear trend line was chosen, as there was not any data to suggest otherwise. For a correlation to be considered good its trend line must have a positive gradient, and the square of the correlation coefficient should be greater than 0.96.

Once the initial tests had been completed, all the available data was then analysed to determine time lengths of testing for the newly developed Water Absorption from Fresh Mortar (WAFM) test.

2.1 Flexural strength tests

2.1.1 Bond wrench test

The bond wrench test is the standard test for flexural strength of masonry used in Australia, and is described in AS3700 (2001).

In this test all joints of a specially constructed masonry pier are tested one after another by the bond wrench apparatus. The loading handle grips the top brick of the prism; the force applied to the loading handle induces a moment on the joint; the force is increased until failure of the joint occurs. The maximum force recorded is then used to calculate the flexural bond strength of masonry.

Two prisms, six units high (ten joints in total) were constructed for each masonry type. The prisms were then wrapped in plastic and allowed to cure for seven days before testing. Note that one day prior to the construction of the prisms the perforations in the calcium silicate units were filled with mortar and air cured to prevent errors in the calculation of the flexural bond strength due to the additional interlocking action normally achieved when mortar flows into perforations.

Results of bond wrench tests are summarised in Table 1.

Table 1 Flexural bond strength

Masonry Type	Mean Flexural Strength (MPa)	Standard deviation (MPa)
D	0.92	0.13
C	0.85	0.23
E	0.62	0.13
S	0.26	0.08

2.1.2 Beam test

The beam test is another standard test for flexural strength of masonry described in AS3700 (2001).

In this test a specially constructed masonry pier is tested horizontally in pure bending until failure. This test is less favourable and practical than the bond wrench test because (i) only one joint of the prism is tested, therefore requiring more time and materials to gather sufficient amount of data for statistical analysis and (ii) tends to underestimate the flexural strength, as the only joint that fails tends to be the weakest of the test specimen (Krauklis 1993).

Beam tests were not performed. They are described here for completeness of the background information.

2.2 Water absorption tests

2.2.1 Initial rate of absorption test

The Initial Rate of Absorption (IRA) test is the standard brick absorption test used in Australia, and is described in AS/NZS 4456.17 (1997). The IRA is a measure of the amount of water absorbed through the bed face of a brick in one minute.

As a guide, lower IRA units match better with a mortar having fewer fines (low water retention) and higher IRA units match better with a mortar having higher water retention. In extreme cases of higher IRA the units might need to be wetted before laying, although it is preferable to adjust the mortar characteristics to suit.

Research has shown that the IRA of a masonry unit is one of the important factors affecting the flexural bond strength of masonry (Goodwin and West 1982, McGinley 1990). However further research has shown the limits of the usefulness of the IRA test for predicting the flexural bond strength in masonry due to the arbitrary nature of the one minute time length chosen (Reda Taha et al. 2001), and its failure to simulate the interaction between the unit and the mortar (Sugo et al. 2001).

The notes in AS/NZS 4456.17 state: "…in experienced hands, the IRA of a unit, is an important factor in the design of mortars that will bond strongly with the units. It is not an absolute measure of bond strength".

Ten units of each brick type were tested. Results of IRA tests are summarised in Table 2. Plot of IRA versus flexural strength is shown in Figure 1.

Table 2 Initial rate of absorption

Brick Type	Mean IRA ($kg/m^2/min$)	Standard deviation ($kg/m^2/min$)
D	3.47	0.89
C	3.28	0.46
E	1.70	0.38
S	1.27	0.17

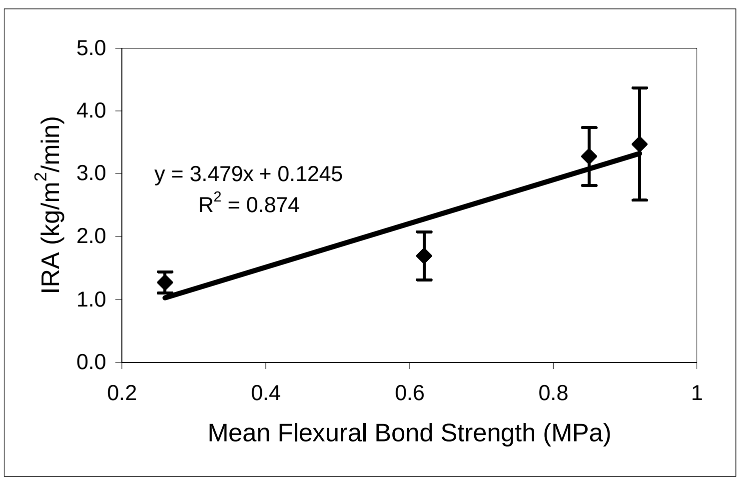


Figure 1 IRA/Flexural strength correlation

2.2.2 Total absorption test

The total absorption test is another test used for determining the absorption properties of masonry units. It is not commonly used in Australia and hence there is no Australian Standard. It is used in America along with the initial rate of absorption test, and is described in ASTM C 67-03 (2003).

The total absorption is a measure of the water absorbed by a brick unit saturated in water at room temperature for 24 hours, and also the water absorbed by the saturated brick unit after being boiled for another 5 hours.

There is no mention in ASTM C 67-03 of the use of the total absorption of a masonry unit for predicting the flexural bond strength of masonry.

Results of 24 hours absorption tests are summarised in Table 3. The plot of total absorption versus flexural strength is shown in Figure 2.

Table 3 24 hours cold water absorption

Brick Type	Mean 24hr. absorption (% of dry weight)	Standard deviation (% of dry weight)
D	9.17	1.36
C	7.85	0.24
E	7.95	1.02
S	12.78	0.51

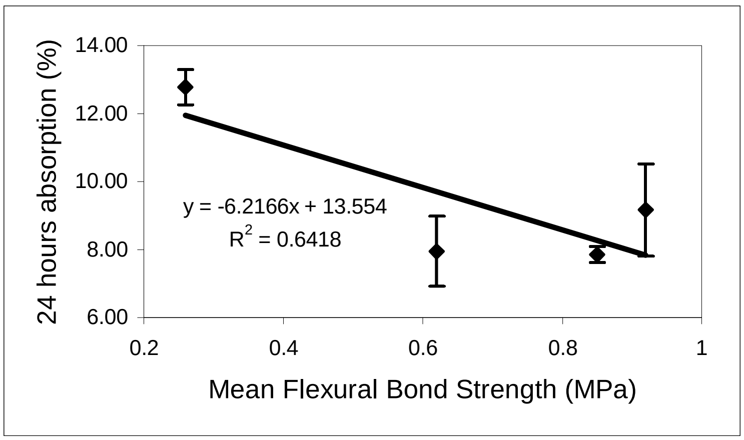


Figure 2 Total absorption/Flexural strength correlation

2.2.3 Sorptivity test

The sorptivity test of a masonry unit is a recently developed test, not yet incorporated by any Standards body to the author's knowledge. A description of the sorptivity test is given in the paper by Reda Taha et al. (2001).

An apparatus setup for this test is similar to the IRA test apparatus. The sorptivity of a masonry unit is a measure of the rate of water absorbed by a masonry unit over a time period of 25 minutes. More exactly, it is the gradient of the straight line fitted to the plot of water absorbed by the masonry unit against the square root of time. A major objective in the development of the sorptivity test was to better account for the critical period in masonry bond development, namely the first few minutes when the free water in the mortar can migrate to the brick pores carrying the early hydration products (Goodwin and West 1982, Lange et al. 1996). This process cannot continue for the 24 hours allowed for in the total absorption test, nor can it be represented by a 1 minute time period of the IRA test (Reda Taha et al. 2001).

Results of sorptivity tests are summarised in Table 4. The plot of sorptivity versus flexural strength is shown in Figure 3.

Table 4 Sorptivity results

Brick Type	Sorptivity ($mm/min^{1/2}$)
D	1.900
C	0.884
E	0.596
S	0.630

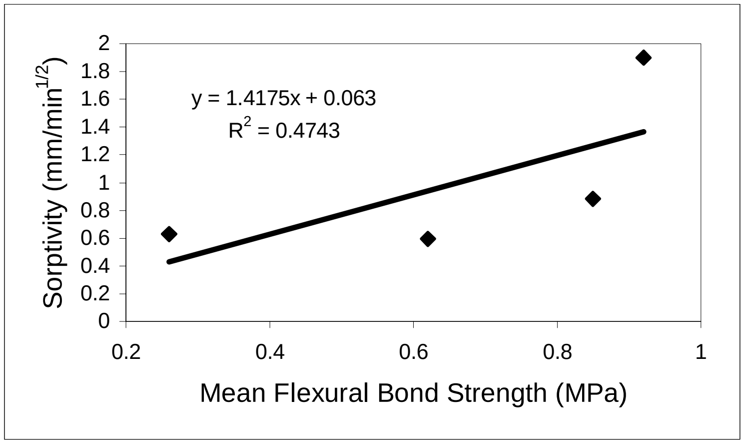


Figure 3 Sorptivity/Flexural strength correlation

2.3 Water absorption data from standard tests

All the raw data from standard absorption tests was converted into g/min format and compiled in the following plot

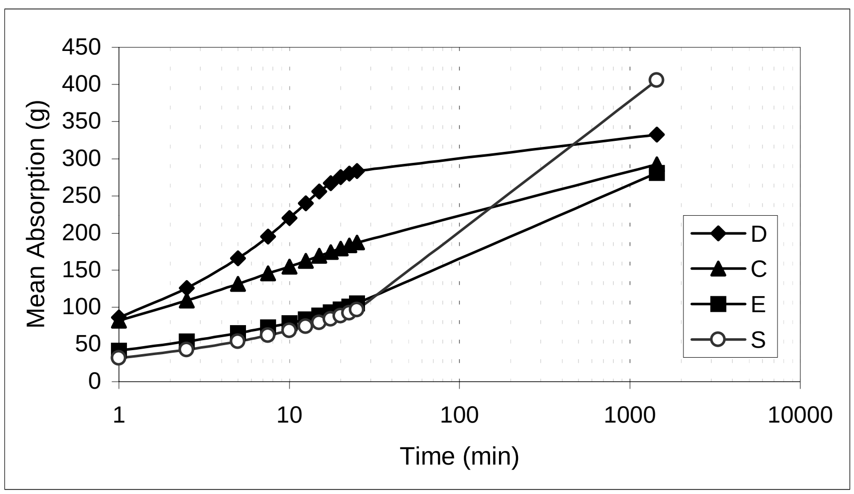


Figure 4 Water absorption by bricks

The plots shown in Figure 4 confirmed well known absorption properties of bricks. Calcium silicate bricks have the lowest 20min and the highest 24hr absorption. Extruded clay bricks have 20min absorption properties similar to those of calcium silicate bricks but the lowest 24hr absorption. Concrete bricks have average 20min absorption and 24hr absorption properties similar to those of extruded clay bricks. Dry pressed clay bricks have the highest 20min absorption and the slowest absorption rate after that, which may suggest that unlike others these bricks do not have a uniform pore structure but pores of two distinct sizes.

Provided that the first minutes are critical in establishing masonry bond strength and that the water absorption patterns do not show any abnormalities during the first 20 minutes, it was decided to perform testing of water absorption by brick from fresh mortar at 2, 10, and 14 minutes after brick came in contact with mortar.

3 Water absorption from fresh mortar test

3.1 Test method

- Cut masonry units in half along the mid height of the unit, discarding any beds containing frogs, ensure there are at least 10 specimens with whole, original bed surfaces.
- Oven dry the specimens to a constant mass, then allow to cool to room temperature.
- Record the initial mass of the specimens, m_1, and bed area, A.
- On a specimen's bed surface place a 10mm thick layer of the standard mortar mix, then lay another specimen on top of the mortar bed, recording the position of each specimen as top or bottom and time of contact with mortar.
- After t minutes has elapsed from when each specimen came in contact with mortar, separate the specimen from mortar, scrape the excess mortar off with a small trowel and clean excess fines with a stiff brush.
- Record the final mass, m_2, of the specimen.
- Repeat the last two steps for various other values of t.

The mortar absorption of each specimen can be calculated from the following equation:

$$AFM_t = 1000(m_2 - m_1) / A \quad , \tag{1}$$

where AFM is the Absorption from Fresh Mortar (kg/m^2);
t is the test time (min);
m_1 is the initial specimen weight (g);
m_2 is the final specimen weight (g);
A is the bed area (mm^2).

3.2 Test results

Ten or more specimens of each brick type were tested with three different test times. Results of water absorption from fresh mortar tests are summarised in Table 5. The typical plot of absorption ($m_2 - m_1$) versus flexural strength in 2min tests is shown in Figure 5.

Table 5 Absorption from fresh mortar

Brick type	2 min test		10 min test		14 min test	
	Mean AFM (kg/m^2)	St.deviation (kg/m^2)	Mean AFM (kg/m^2)	St.deviation (kg/m^2)	Mean AFM (kg/m^2)	St.deviation (kg/m^2)
D	1.103	0.09	1.509	0.13	1.569	0.19
C	0.959	0.09	1.280	0.13	1.359	0.13
E	0.737	0.12	1.233	0.13	1.254	0.17
S	0.846	0.08	1.412	0.10	1.530	0.19

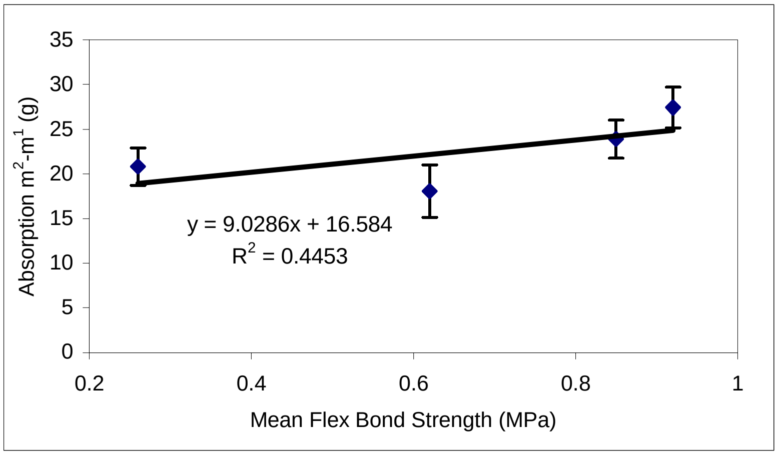
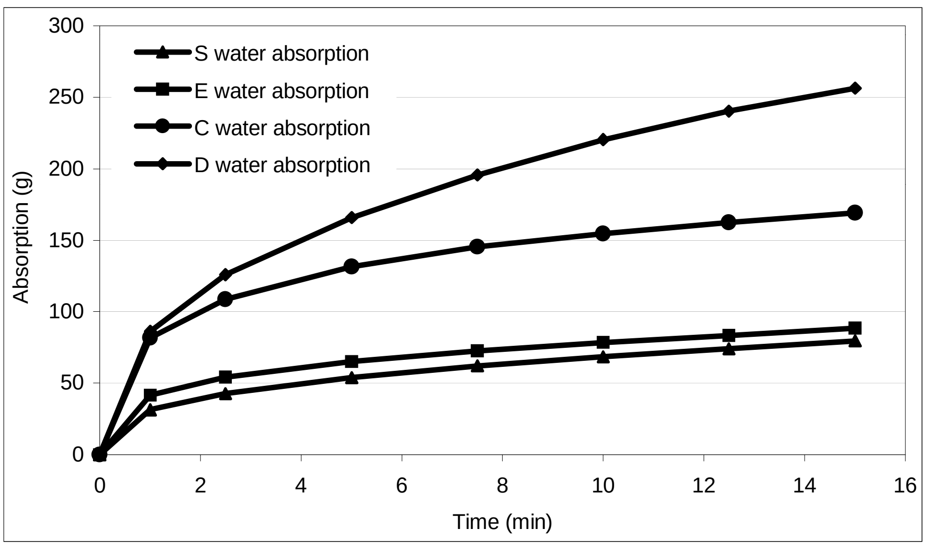


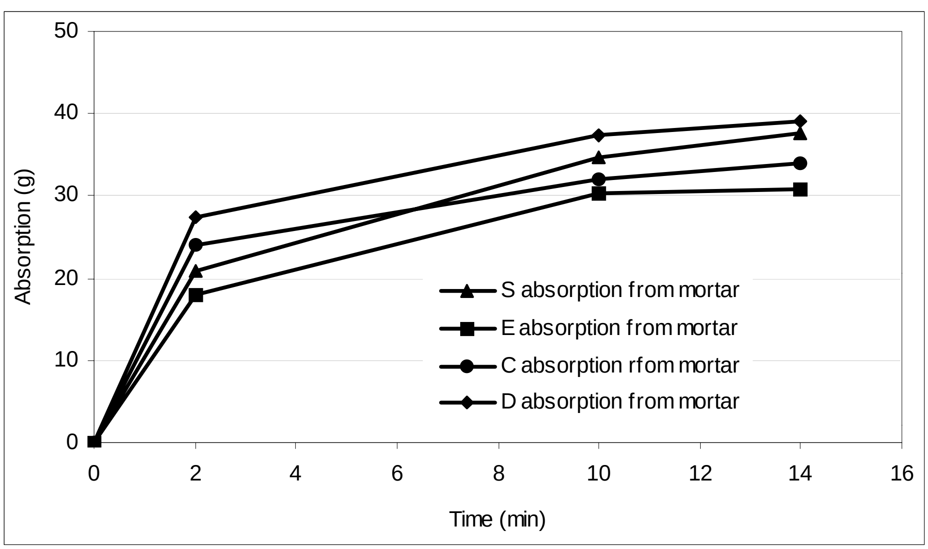
Figure 5 2 minutes absorption/flexural strength correlation

4 Discussion

Results of all water absorption tests converted to the absorption in grams are plotted against time in Figure 6.



a).



b).

Figure 6 Brick absorption from a). water and b). mortar

As it can be seen in Figure 5, the linear trend line fitted to the results has a positive gradient, but its correlation coefficient is quite low. This demonstrates that the AFM test at the current stage of development do not correlate satisfactorily with the flexural strength of masonry. We see several possible reasons for this.

- Firstly, it was assumed that some mortar residue on the brick surface would introduce insignificantly small and systematic error in the (m_2-m_1) absorption, as calculated in Equation 1. Contrary to our assumption the mortar residue was found to be comparable in weight to the water absorption especially during the first minutes. Conveniently the mortar residue is also to a large extent controlled by absorption properties of brick and maybe as (if not more) important for the bond strength development as the water absorption. It is not difficult to separate measurements of the absorbed water from the absorbed mortar paste. In the new series of tests, which are currently underway at the University of Newcastle, new formulae are being used instead of Equation 1

$$WAFM_t = 1000(m_2 - m_3) / A \quad , \tag{2}$$

$$PAFM_t = 1000(m_3 - m_1) / A \quad , \tag{3}$$

where WAFM is the Water Absorption from Fresh Mortar (kg/m^2);
PAFM is the Particle Absorption from Fresh Mortar (kg/m^2);
t is the test time (min);
m_1 is the initial oven dry specimen weight (g);
m_2 is the wet specimen weight after absorption(g);
m_3 is the final oven dry specimen weight (g);
A is the bed area (mm^2).

It is our intention to correlate the flexural strength to a combination of WAFM and PAFM.

- Secondly, it was wrongly assumed that the flexural strength of masonry, as measured by the bond wrench test, could be taken as the strength of an interface between brick and mortar. Several different failure modes were observed including interface failure, mortar failure and various combinations of them. It is not obvious, that process of water absorption has same effect on all of those failures. In current testing we attempt to separate results with different failure modes.

Despite the lack of success with first lot of AFM tests, the analysis of the plots in Figure 6 let us believe that a test method based on measuring water absorption from fresh mortar has some potential. The total amount of water contained in the mortar between two bricks is less than 100g; therefore water absorbed by a brick through one bed surface in reality is less than 50g. AFM, unlike other absorption tests, operates on the correct scale of absorption. It appears that even IRA test, which shows at the moment the closest correlation with flexural strength results, does not reflect realistic water absorption by bricks from fresh mortar one minute after they come in contact. It appears that realistic rates of initial absorption from fresh mortar by different brick types are more consistent than IRA test results. It is also clear from Figure 6b that timing for AFM test plays a critical role because the order of brick types by absorption capacity is different at 2 and 10 minutes. Current set of AFM tests are performed at 2, 6, 10 and 14 minutes to better capture this effect.

5 Acknowledgement

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