EXPERIMENTAL IDENTIFICATION OF MOISTURE TRANSPORT PARAMETERS FOR BRICK AND MORTAR

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ABSTRACT

Moisture transport between bricks and mortar during construction and curing plays a key role in establishing bond between mortar and brick. Current empirical masonry construction practices are based on a superficial understanding of this phenomenon. A research project at the University of Newcastle is aimed at developing a fundamental understanding of the moisture transport process enabling hydraulic compatibility to be obtained between bricks and mortar, thus maximising the bond strength. The hydraulic properties of typical Australian bricks and mortar have been studied experimentally using a WP4 Dewpoint Potentiometer. This paper describes the experimental techniques used and discusses the major hypotheses tested. One of these hypotheses is that the moisture absorption characteristics of bricks during the wetting and drying process are different. Another hypothesis is that the moisture hysteresis effect exhibited during wetting and drying is insignificant in masonry. A water absorption suction curve for brick and drying suction curves for brick and fresh mortar are presented.

Key words: brick, mortar, masonry, bond, moisture transport, suction, potentiometer

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INTRODUCTION

Moisture transport between bricks and mortar during construction and curing plays a key role in establishing bond between mortar and brick. Current empirical masonry construction practices are based on a superficial understanding of this phenomenon. A current joint research project at the University of Newcastle and University of Technology, Sydney is aimed at developing a fundamental understanding of moisture transport between fresh mortar* and bricks in masonry during construction and curing. The importance of moisture transport in establishing bond has been identified in previous research projects at the University of Newcastle on masonry bond strength (Sugo et al. (1997), Sugo (2000). In that investigation, moisture transport from the plastic mortar to the brick on placement, and hypothetical subsequent moisture transport back into the hardened mortar were identified as key factors influencing the process of bond creation between bricks and mortar. The aim of the current research project is to fundamentally investigate these mechanisms. The first part of this project is to study the hydraulic properties of typical bricks and mortar. From these studies a representative computer model of moisture transport between mortar and bricks will be developed, and once verified, will be used to carry out an in-depth study of bond processes. In particular, the hydraulic compatibility of various brick/mortar combinations will be assessed and optimised to allow bond strength to be maximised and the performance of the masonry structure to be enhanced. The focus of this paper is on the establishment of the hydraulic properties of bricks and mortar during drying and of bricks during water absorption. These characteristics are critical factors in defining the mechanism of moisture transport.

BACKGROUND TO THE STUDY

Masonry is a composite material consisting of masonry units (“bricks or blocks”) and mortar joints. The achievement of an effective bond between mortar and brick is the most important aspect of masonry construction. If adequate bond is not achieved, the mortar joints will act as planes of weakness, and cracking along these planes will occur due to wind or minor earthquake tremor. The 1989 Newcastle earthquake provided graphic evidence of the importance of masonry bond strength. Damage in excess of $1.5 billion was caused to buildings. The bulk of this damage was to masonry structures and in many cases the damage was severe because of the low bond strength exhibited by masonry. Good bond strength is also required for the adequate performance of masonry under normal service loads. Significant stresses can be introduced in masonry by

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* The term fresh mortar refers to the mortar from the moment of coming into contact with bricks to the time when the moisture transport between the mortar and bricks becomes insignificant in relation to bond development.

foundation soil movements, mine subsidence, and differential movements caused by temperature effects or moisture.

The fundamental mechanism of bond creation between fresh mortar and brick has been studied both in Australia and overseas (Lawrence et al. (1987), Grandet (1973). One of the most systematic studies in this area by Sugo (2000) was the firs part of an on going project on bond in masonry at the University of Newcastle. All these studies agree that bond is mainly physical in nature and is achieved by mechanical interlock between bricks and hardened mortar. Some chemical bonding may also occur. It is generally agreed that this interlock is created by brick suction acting on the mortar paste, which carries small particles from the fresh mortar into the pores of the brick. This process also creates a cement-rich layer at the brick-mortar interface as shown in Fig. 1.

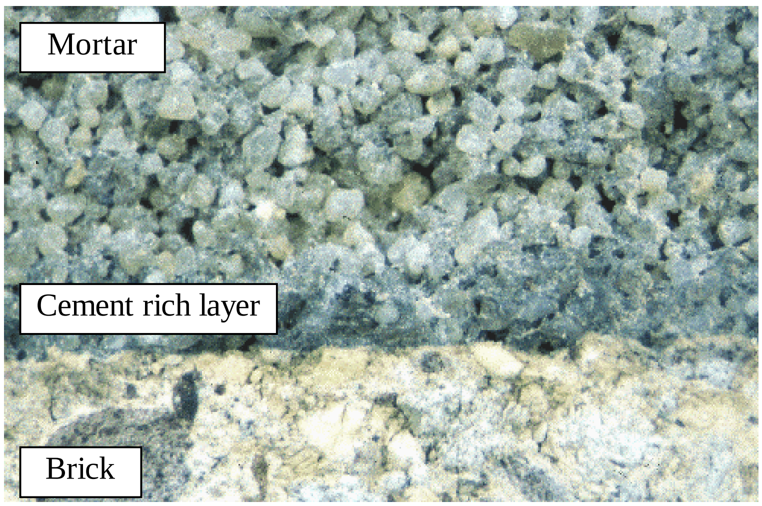

Figure 1. Cement-rich Layer at the Brick-Mortar Interface

The effects of moisture on bond and moisture transport across the brick-mortar interface have been studied experimentally by Groot (1991), Pel et al. (1997), Brocken et al. (1997), Totoev (1999), Jennings (2000)) and also combined with analytical attempts to model this phenomenon using Unsaturated Flow Theory (UFT). Results of these studies show that the suction curves vary widely in shape for different bricks. It is likely that the suction curves established previously overseas will be inappropriate for studying the moisture transport phenomenon in Australian bricks. No reliable suction curve has been reported in the literature for fresh mortar. This project therefore requires establishment of the hydraulic properties of the dry pressed clay bricks and masonry mortar used in the project.

The brick suction curves in previous studies were obtained mostly using the pressure membrane apparatus (PMA). Although, the PMA technique is one of the most reliable experimental methods for establishing drying hydraulic properties of porous materials in the practical range, it does not allow the establishment of the water absorption suction curve. It is usually assumed that brick-water hysteresis either does not exist, or is insignificant in bricks. Based on this assumption, the drying suction curves were previously used in modelling the moisture absorption of bricks. However, water in newly built masonry flows mostly from the fresh mortar into the brick. Therefore, it is more appropriate to use the wetting suction curve for brick in modelling of this process.

Fresh mortar undergoes rapid structural changes as within a period of a few minutes it is transformed from a dense liquid to a solid. The PMA technique unfortunately requires a much longer time for measurements and hence is not appropriate for establishing the drying suction curve for fresh mortar paste.

The objectives of the study reported in this paper are:

- to establish the water absorption suction curve and the drying suction curve for a typical Australian dry pressed clay brick;
- to assess any differences between these two curves and to test the hypothesis that brick-water hysteresis in brick is negligible for purposes of modelling the water absorption;
- to establish the drying suction curve for a typical Australian masonry mortar (1 part of cement, 1 part of hydrated lime, 6 parts of sand by volume).

EXPERIMENTAL METHODS AND TECHNIQUES

In order to establish the suction versus water content curves for a porous material, both the parameters have to be measured. The moisture content was determined gravimetrically from the difference between the wet and the dry weight of a sample. For the suction or the water potential measurements the Dewpoint Potentiameter WP4 (2000) was used. The WP4 apparatus, unlike the PMA method, can be used to measure the water potential of a sample regardless of whether the sample is drying or wetting. A suction measurement can also be taken in only a few minutes. Using the WP4 apparatus was an experiment itself, since it has not been used previously for measuring the water potential of brick.

Brick samples

Brick samples (see Fig. 2) were cores 40 mm in diameter and 10 mm high. Initially 70 mm high cores were taken vertically through the brick using a custom built diamond tipped coring drill developed in a previous Newcastle bond project. Full details have been reported elsewhere (Sugo (1996)). Two samples were then sawn off the top and the bottom of the core using a standard diamond tipped brick saw so that each sample represented the brick at its interface with the mortar. The pressed clay bricks used in this project had been previously studied by Sugo (2000). Some material properties of the brick are listed in Table 1.

Table 1. Material Properties of Brick

Bulk density	1925.9 (kg/m3)
Solid density	2494.7 (kg/m3)
Porosity	22.8 (% of total volume)
Pore ratio	0.295 (m3 pores/m3 solid)

Figure 2. Brick Sample and Sealed Sample Cup

Mortar samples

As can be seen from Fig. 3, an edge form on a brick was used to produce a uniform mortar bed of 5mm thickness. This was equivalent to half a normal joint thickness, thus providing the paste volume appropriate to one bed joint. The mortar samples were taken from this mortar joint after a range of curing periods (from 30 seconds to 10 days). The first sample of fresh mortar was taken before the mortar was placed on the brick.

Figure 3. Mortar Bed

Measurements of water potential using the WP4 apparatus.

The water potential is an indicator of the energy status of the water in the material. It indicates how tightly the water is bound, structurally and chemically, within a brick or mortar sample. Measurements are taken of the vapour pressure of air, which is brought to equilibrium with the capillary water pressure of a sample in a sealed measurement chamber. The WP4 apparatus (see Figure 4) uses the chilled-mirror technique to measure the water potential. A dew-point instrument contains a mirror in a sealed chamber together with a means of detecting condensation on the mirror. A thermoelectric cooler precisely controls the mirror temperature. An internal fan circulates the air within the sample chamber to reduce the time to equilibrium. A photoelectric cell detects the exact point at which condensation first appears on the mirror by sensing the change in reflectance when condensation occurs on the mirror. The final water potential and temperature of the sample is then recorded and displayed.

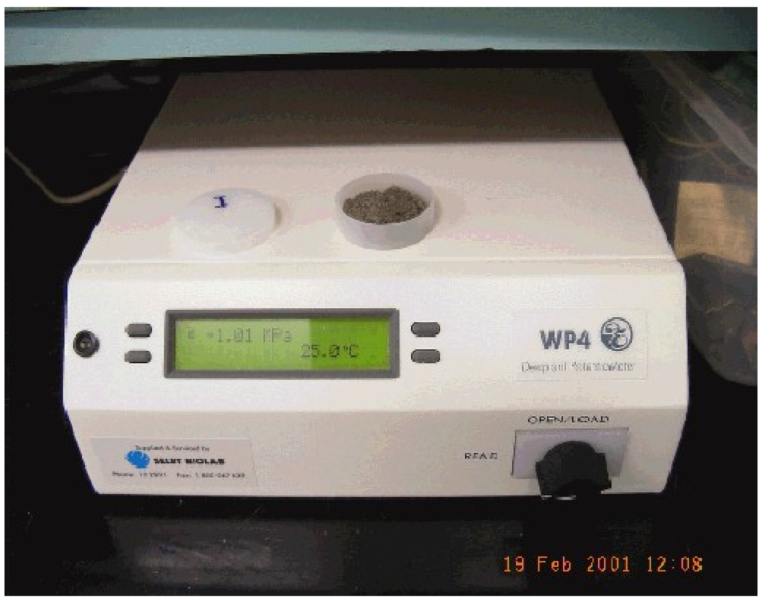

Figure 4. Dewpoint Potentiameter WP4 and Mortar Sample

GENERATING THE SUCTION CURVES

Brick

Suction curves where obtained by measuring the water potential on a set of brick samples which had a range of water contents. Twelve samples were used, with the range of gravimetric water content ranging from 0.1% to 12.5%. Oven-dry samples are dryer than 0.1%, but their suction is greater than –70MPa, which is outside the working range of the WP4 apparatus (0 to –40MPa). Consequently the water content at saturation of approximately 12.5% was determined after 6 hours of boiling in water. It is important that for the drying suction curve this range of water contents is reached progressively by samples drying from the saturated state. Similarly, the water absorption suction curve should be obtained by considering samples wetting from the oven-dry state. For the drying curve, the samples were first brought to saturation, then dried in an oven for various lengths of time to reach the target water content. The samples were then sealed in sampling cups for a period of two to three days to allow a uniform water content over the sample volume to be reached, and finally the water potential was measured in the WP4 apparatus. The average of six readings (three on each side of a sample) was recorded as the water potential.

For the water absorption curve, the samples were first dried for 24 hours in an oven, then various amounts of water were introduced to the surface of the samples to reach the target water content. The samples were then sealed in sampling cups for a period of four to five days to reach a uniform water content over the sample volume, and finally the water potential was measured in the WP4 apparatus.

The resulting drying and water absorption suction curves are shown in Fig. 5, with each point on the curve representing the mean of six readings.

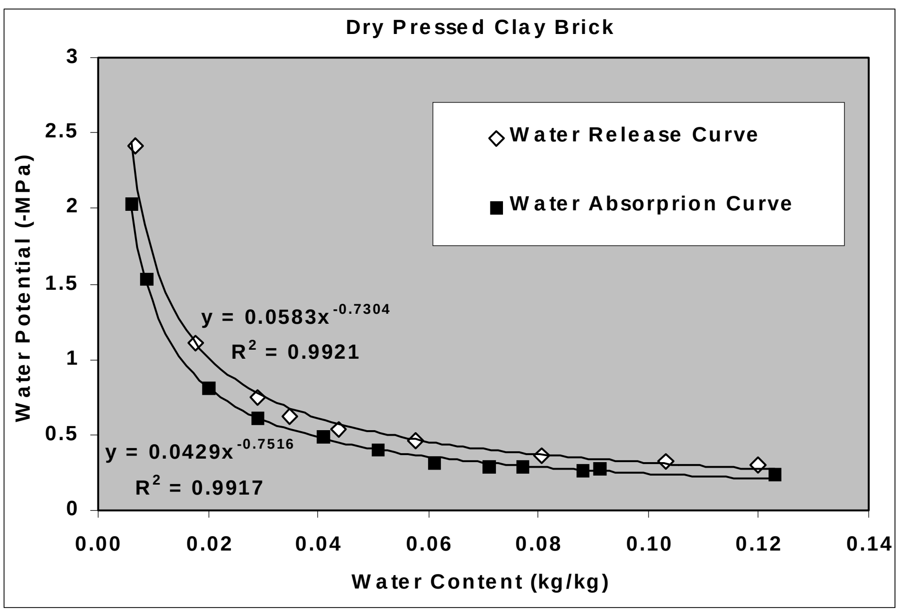

Figure 5. Water Absorption and Drying Suction for Brick

<u>Mortar</u>

The drying suction curve was generated for mortar “in-situ”. The water potential was measured in the WP4 apparatus. Some preliminary tests were performed to establish the necessary drying time of four hours (at 100°C) for mortar samples. If a sample is over-dried, its weight can increase due to carbonation. The gravimetric moisture content was calculated from the difference between the "in-situ" weight and the oven-dry weight of a sample. The resulting drying suction curve for mortar is shown in Fig. 6, with each point on the curve representing the mean of four readings. This curve combines results of three separate tests.

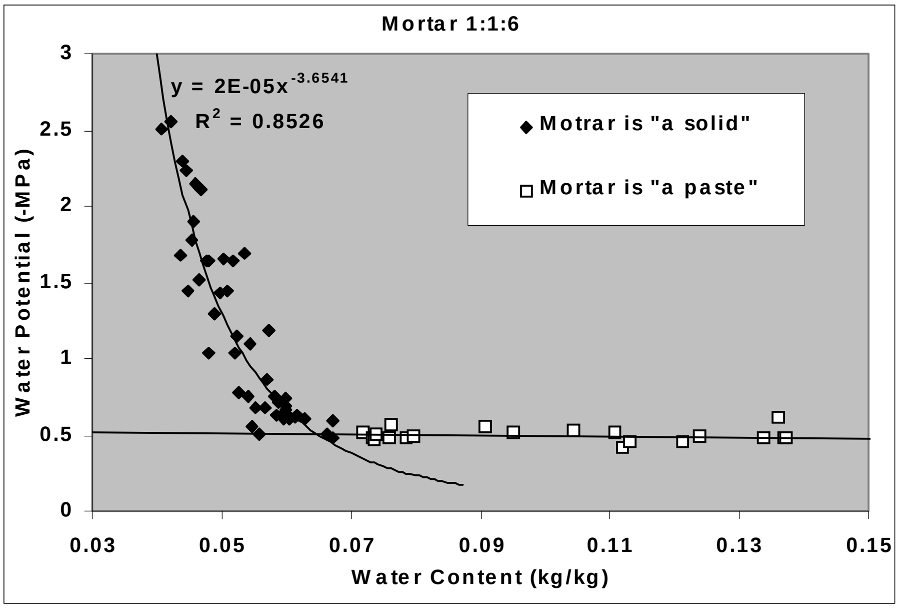

Figure 6. Drying Suction for Mortar

DISCUSSION

The brick suction curves demonstrate that the brick moisture characteristic is hysteretic. At a given water potential, a brick which has reached that water potential in a wetting process, will have lower water content than one which has reached the same moisture content by drying. Overall, the curves in Figure 5 are similar and close. However, at the low water contents, the difference in the water potential is up to 20% of the typical spectrum of brick water potential (which in the practical range is from 0.3 to 1.8 –MPa). The difference in water content between the wetting and drying curves is even greater, particularly for wet bricks. For example, at a water potential of 0.3 –MPa, there is approximately 60% difference in water content.

It can be seen from the drying suction curve for mortar that that there are two phases of mortar drying. In the first stage the mortar loses water from >16% water content to ~7% water content without any apparent increase in the water potential. This suggests, that during this first phase of drying, mortar does not have the porous structure of a solid substance and remains in the state of a thick liquid or a paste. Depending on the brick suction this stage lasted for about 10 minutes. As solidification of mortar progressed, mortar has continued to lose water to the brick, but during this stage the water potential of mortar has progressively increased at a high rate. As a solid, mortar has lost water from ~7% to ~4% with the water potential increasing from about 0.5 -MPa to approximately 2.5 -MPa. This distinctive "two phase" behaviour has significant implications in the mathematical modeling of the moisture transport process, as until the mortar has hardened, the water potential can be assumed to remain constant.

CONCLUSIONS

This paper has described the first stage of an experimental study to establish the moisture transport parameters of typical Australian bricks and mortar. This work is continuing, but several conclusions can be drawn from this preliminary study:

- the dewpoint technique appears to be an acceptable method of measuring the water potential of brick and can be used to establish both the drying and the wetting suction curves;
- the dewpoint technique also appears to be an acceptable method of measuring the water potential of fresh mortar and can be used to establish the "in-situ" drying suction curve;
- ignoring the brick-water hysteresis and using the drying suction curve to model brick water absorption could lead to significant errors and is not recommended;
- the water potential of dry solid mortar could reach higher values than the water potential of brick at the same level of water content. This could potentially cause the reverse of moisture flow from brick into mortar. However no measurable increase in the water content of mortar was recorded during first 10 days of curing;
- two phases of mortar drying have been identified: (i) when mortar is a liquid and (ii) when mortar is a solid. The mechanism of water loss from mortar is different for each phase and should be modeled separately in future moisture transport simulations.

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