



**SORPTIVITY: A SURFACE ABSORPTION CRITERION FOR BRICK UNITS:
A PROPOSAL FOR THE CANADIAN MASONRY STANDARD**

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ABSTRACT

Surface absorption of brick units has a significant effect on masonry bond. Therefore, a reliable and reproducible method should be used to measure the surface absorption of masonry units and establish acceptability criteria. Some codes assess absorption properties through the initial rate of absorption (IRA); others use total absorption. During the last 50 years, different research work has revealed that IRA is an inconsistent measure of the surface absorption of masonry units in relation to subsequent bond. Current measurements of the surface absorption of brick units are therefore reviewed critically. The theoretical basis of sorptivity as a measurement of surface absorption is presented. An experimental programme, incorporating different brick units, was executed to examine the sorptivity of masonry brick units. Analysis of the experimental results showed sorptivity to be a reliable and a reproducible engineering measurement for predicting the surface absorption performance of brick units. Statistical analysis and comparisons to other surface absorption measurements are developed. Sorptivity should be considered for the Canadian masonry standard as the surface absorption criterion for masonry brick units.

Key words: Masonry Bond, Surface Absorption, Sorptivity, Permeation and Total absorption

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INTRODUCTION

Several interdependent factors including mortar composition, mortar water retentivity, unit surface texture, unit moisture content and unit absorption affect masonry bond strength. Of these, unit surface absorption has been shown to have a pronounced effect on the bond that subsequently develops between the unit and the mortar (Goodwin and West 1982). This is because water absorption, in conjunction with mortar water retentivity, determines the amount of water which travels from the mortar to the brick at the mortar-unit interface. This migration allows the formation of an interwoven network of hydration products that links the mortar and the brick unit surface pores, providing mortar-unit bond through mechanical interlocking (McGinley 1990).

Although early studies (Voss 1933) showed the total amount of water absorbed by the brick to correlate with the developed bond strength, Anderegg (1942) showed that it is the early rate of water absorption rather than the total absorption that has a significant effect on mortar hydration and consequently bond strength. Therefore, the initial rate of absorption (IRA) was promoted as a measure of initial brick suction. IRA measures the weight of water absorbed in 1 minute by the bed face of the brick unit when immersed in 3 mm deep water. Using combinations of IRA and mortar retentivity, Lawrence and Cao (1988) showed that it is possible to achieve good bond strength by limiting IRA to a specific range for each water retentivity. This is because bricks with low IRA do not allow enough hydration products to migrate towards the unit surface, while bricks with high IRA extract too much water, reducing the degree of hydration and the amount of hydration products deposited in the pores of the unit. Bricks with high IRA will also induce shrinkage cracks that will weaken the mortar-unit interface.

In contrast Jansson (1965) showed that IRA describes only part of the phenomenon due to the limited testing time. Morgan (1977) proved that IRA is misleading when applied to calcium silicate bricks as the rate of water absorption of this type of brick changes significantly with time. Sneek (1978) measured the rate of water suction for a period of time and showed that straight line relationships between the square root of time and the rate of water absorption exist over time periods longer than the 1 minute used for IRA. Examining water equilibrium in the interface using thermal neutron quantitative analysis, Groot (1991 and 1997) proved that different pore distributions can result in the same IRA values and proposed that testing times of about 15 minutes rather than one minute are required to simulate water equilibrium at the mortar-unit interface. Therefore, the one minute testing time used in the IRA test is an arbitrary rather than scientific choice. However, IRA is still an absorption measure permitted by many standards including the Canadian Masonry Standards (CSA-A 82.1-M87, 1987).

Theory of Sorptivity

The flow of water from the mortar to the brick can be considered to be governed by Darcy's equation for one dimensional unsaturated flow:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \left(-D(\theta) \frac{\partial \theta}{\partial x} \right) \quad (1)$$

θ is the moisture content with upper and lower bounds of saturation and zero. Philip (1957) solved equation (1) by using the Boltzmann transformation such that unsaturated flow becomes dependent on the time function $\phi(\theta)$ and equation (1) becomes:

$$2 \frac{d}{d\phi} \left(D(\theta) \frac{d\theta}{d\phi} \right) + \phi(\theta) \frac{d\theta}{d\phi} = 0 \tag{2}$$

Philip (1957) calculated the cumulative volume of water absorbed per unit volume of brick (i) as:

$$i = t^{1/2} \int_{\theta_i}^{\theta_1} \phi(\theta) d\theta \tag{3}$$

Defining θ_1 as the moisture content at saturation and the initial moisture content, θ_i , to be zero for oven dried specimens, the value of the integration can be determined over any time period t . Philip (1957) defined this integral as the “sorptivity” S , simplifying equation (3) to equation (4).

$$i = S t^{1/2} \tag{4}$$

From equation (4), it can be concluded that the one-dimensional absorption of water is linearly related to the square root of time. Hence, prior to saturation of the bricks, a plot of the volume of absorbed water per unit area of suction surface versus the square root of the absorption time should be linear. The slope of that line defines the sorptivity (S) of the material. The cumulative volume of absorbed water (i) is therefore measured experimentally over a period of time (t). Using the method of least squares, the data points can be used to produce the relationship shown in Fig. 1, expressed in equation (5).

$$\tag{5}$$

$$i = a + S t^{1/2}$$

Jansson (1965) attributed the existence of the intercept to the storage of the water taken up by the specimen at the first contact at the near pore surface while Hall and Yau (1987) and Hall (1989) attributed it to the filling of the open porosity on the inflow surface. The linearity of the experimental results is confirmed by requiring the correlation coefficient of the linear regression (r) to be more than 0.98 ($r^2 > 0.96$). The failure to satisfy this requirement indicates a weak correlation and therefore the sorptivity should not be derived from that set of data (ASTM draft 1996).

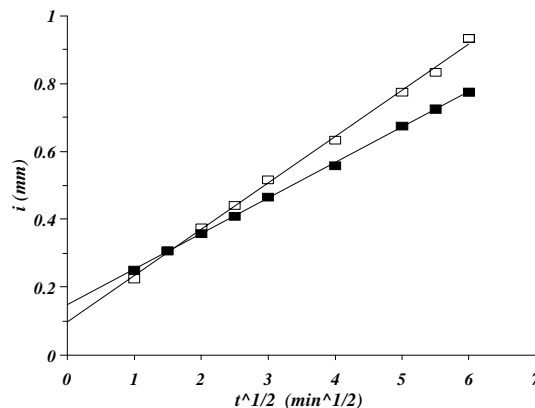


Figure 1. Typical sorptivity plot for two porous materials.

Applications

The principles of sorptivity have been widely applied to different porous materials in the last two decades, especially concrete and masonry. Gummerson et al. (1980) showed that sorptivity can accurately describe water absorption performance of concrete and masonry. Kelham (1988), Hall (1989), Hooton et al. (1993) and Hooton and El-Dieb (1994) examined the sorptivity of concrete and proved that sorptivity correlated very well with water permeability measurements in concrete. The researchers used sorptivity further to examine the efficiency of concrete curing. Without naming sorptivity, Groot (1991) showed that a linear relationship existed between the square root of time and the rate of water absorption from bricks. He proposed using the square root of time versus specific mass increase to measure water absorption of brick units. Shaker et al. (1997) showed the sorptivity to be able to represent the durability of latex modified concrete (LMC). In spite of its wide acceptance as a reproducible measurement with a reliable theoretical basis, sorptivity has not yet been proposed as a measurement for masonry absorption in any specification.

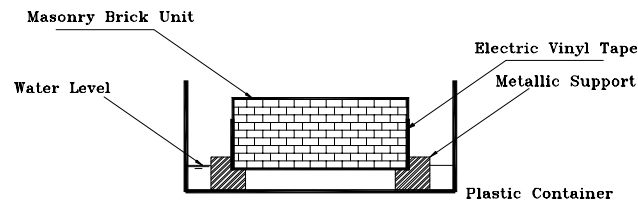


Figure 2. Schematic representation of the sorptivity testing (ASTM Draft 1996).

SORPTIVITY TESTING

The sorptivity test measures the rate of capillary water absorption through dry or partially dry materials (Hall and Yau 1987, Ho and Lewis 1987 and Hall 1989). ASTM Committee C09.03.12 Task Group on Permeability Testing drafted a standard sorptivity test method in 1996. The specimen is first dried and the sorptivity test is carried out by contacting one surface of the specimen with water. Fig. 2 shows a schematic diagram of the test configuration provided by the ASTM draft (1996). The sides of the specimens are sealed with a bituminous coating or vinyl electrician's tape in order to achieve the conditions of one-dimensional flow through the specimen. The mass of the specimen is determined at fixed intervals of time during the test.

$$S = \int_{\theta_i}^{\theta_f} \phi(\theta) d\theta \quad (6)$$

From the definition of sorptivity in equation (6), the sorptivity is dependent on the initial moisture content of the testing unit. Therefore drying the test specimen is a critical part of the test (DeSouza et al. 1997). If the specimens are randomly dried, the test results will be a function of the drying process rather than the material quality. De Souza et al. (1997)

examined several drying methods for concrete including oven drying at 110 °C for a fixed time period, using a solvent replacement for 3 days followed by oven drying at 50°C for 4 days, oven drying the specimen at 50°C for 7 days, or finally drying at 50°C for 3 days followed by placing the specimen inside a sealed container inside the oven for another 4 days to allow moisture redistribution. The last method was found to yield moisture contents similar to those encountered in the field. Oven drying at 110 °C was found to introduce microcracking which will influence the test results. However, oven drying to achieve a certain change in mass per time, rather than for a fixed period of time was found to yield consistent moisture content such that the drying method does not become a variable (Hooton and El-Dieb 1994).

EXPERIMENTAL WORK

Testing Programme

Eight different clay bricks were examined. The experimental programme included three different water absorption tests for masonry units. These are the initial rate of absorption test (IRA), the total water absorption test, and the sorptivity test.

Initial rate of absorption, total water absorption, and water sorptivity tests

All the specimens were dried in 110 °C oven for 24 hours and then left to cool for the following 24 hours in dry conditions. The initial rate of absorption (IRA) test and the total water absorption test were carried out in accordance with ASTM C 67 -86 (1986). Five dry units of each brick type were tested for each test.

Water sorptivity tests were carried out using the guidelines provided by the ASTM draft (1996) for measuring the initial rate of absorption of hydraulic cement mortars and concretes. The whole brick unit was used as the testing specimen. The specimens were oven dried in 110 °C for different drying periods so that all the specimens showed similar change in mass per day (0.5 %) and then the specimens were left to cool in dry conditions for the following 24 hours.

Rectangular aluminum supports with two side holes were used to allow water contact with the specimen surface. The water depth underneath the specimen was kept at 5 mm depth by keeping the outside water level at 3 mm above the hole level. This allows continuous contact between the specimen surface and the water without changing the water depth during the testing time. The sides of the test specimens were sealed with strips of electric vinyl tape. The weight of the specimen was recorded at fixed time intervals to a total time of 25 minutes. The time intervals used are recommended by ASTM draft (1996) and Sabir et al.(1998). All the masonry brick types were tested in triplicate for sorptivity.

RESULTS AND DISCUSSIONS

The average test results and the standard deviations for the total absorption and the IRA for each masonry group are provided in Table 1 and Table 2 respectively. Although the IRA results showed the pressed brick units (group I) to have the highest rate of surface absorption, these bricks did not have the highest total absorption.

Table 1. Average values for total absorption (TA)

Group	I	II	III	IV	V	VI	VII	IIIX
TA %	6.9	8.3	6.8	9.5	6.9	7.8	6.6	11.6
Std Dev.	0.5	0.8	0.3	0.2	0.9	0.25	0.12	0.14

The sorptivity was determined by calculating the volume of water absorbed per unit area of the brick (i) as determined using equation (7) where ΔM is the change of specimen weight, ρ is the water specific gravity and A is the specimen contact surface area.

$$i = \frac{\Delta M}{A \cdot \rho} \quad (7)$$

i is plotted against $t^{1/2}$ and regression analysis performed for each specimen. The coefficient of correlation (r) was determined for each regression. A sample sheet representing the calculation of the sorptivity for a single brick unit is provided as appendix.

Table 2. Average values for IRA

Group	I	II	III	IV	V	VI	VII	IIIX
IRA (gm/cm ² /min)	57.3	33.7	19.8	39.5	6.5	41.9	19.4	33.3
Std Dev.	10.5	0.9	4	2.3	4.2	2	0.6	1.2

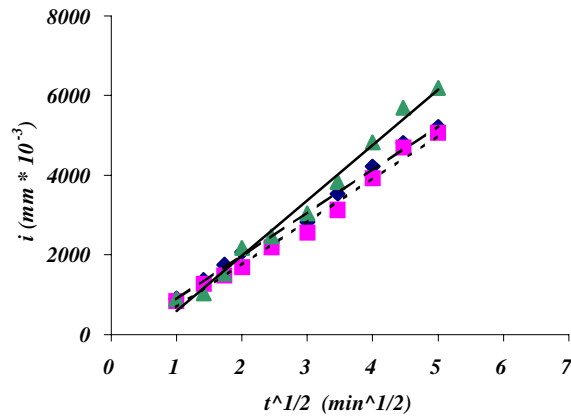


Figure 3. Typical sorptivity plot for the three masonry bricks of group V.

As previously mentioned the validity of the method for regression is limited to correlation coefficients greater than 0.98 ($r^2 > 0.96$) (ASTM draft 1996). This is because lower

regression coefficients do not satisfy the linear relations described in equations (4) and (5). Five of the brick types showed acceptable linear correlations with correlation coefficients greater than 0.98 over the 25 minutes of the test and three did not. Fig. 3 shows data of brick type V as a typical of the five. Fig. 4 shows a typical plot of the data from one of these groups where the unsaturated flow conditions are not fulfilled over the total testing time. The bricks become saturated within the 25 minutes of the test and the curves flatten off. There is thus a low coefficient of correlation associated with linear regression. Therefore, the complete sets of data of these three brick types can not be used to calculate the sorptivities of these bricks.

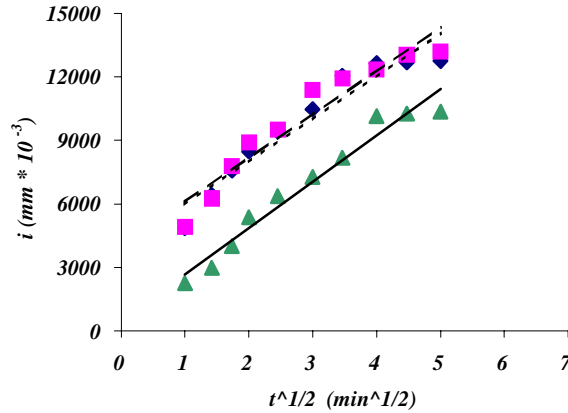


Figure 4. Typical sorptivity of the three masonry bricks of group IV with ($r < 0.98$).

To utilize these data in determining the sorptivity, the conditions for unsaturated flow should be fulfilled. Re-performing the regression analysis can establish the limits of the linear relation. This was done by determining t_{total} (the time to saturation) by repeating regression analyses, as the “horizontal” portions of the data are removed, until the required level of correlation is obtained. The saturation time for the three bricks are presented in Table 3.

Table 3. Saturation time for group I, IV and VI

Group	I	IV	VI
t_{total} (minutes)	6	9	6

Fig. 5 shows the regression analysis of the reduced set of data for group IV with the total regression time as (t_{total}). The process of limiting the testing time is acceptable practice with concretes where the sorptivity of a concrete is frequently determined from the slope of the early time periods up to 9 minutes (ASTM draft 1996). The average sorptivities of all brick types along with the standard deviations are presented in Table 4.

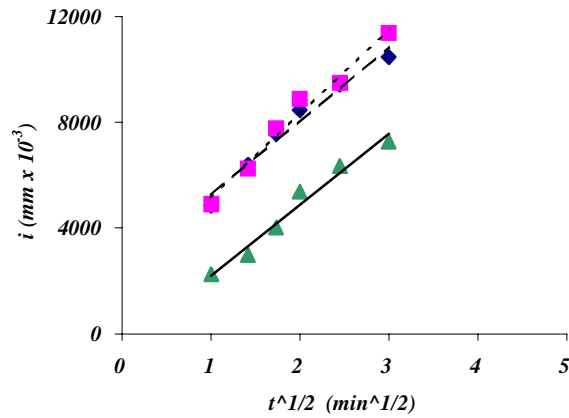


Figure 5. Typical sorptivity of adjusted masonry bricks of group IV with ($r > 0.98$).

Table 4. Average values for Sorptivity

Group	I	II	III	IV	V	VI	VII	IX
S (mm/min ^{1/2})x 10 ⁻³	2370	1684	685	2894	1187	2682	1071	2260
Std Dev.	165	61	26	270	178	197	100	150

The experimental programme showed sorptivity to be a reproducible measurement for masonry brick units with relatively low standard deviations. In addition to being easy to determine, sorptivity has a sound theoretical basis. While the testing time in IRA is arbitrarily chosen and limited to one minute, sorptivity testing time is dependent on the material being tested. This is because the testing time is constrained to being that of unsaturated flow from dry to saturated states. To compare between the three absorption criteria, a descending ranking (i.e. the highest value is the first value) evaluation of the eight bricks was performed for the three absorption criteria. This ranking is presented in Table 5.

This comparison between the examined masonry brick units does not show any agreement between the three criteria. This can be attributed to the difference in physical meaning between the three criteria. While the total absorption represents the total amount of water the brick can absorb, the IRA represents the rate of surface absorption when the brick just contacts the water, whereas the sorptivity represents the rate by which water is absorbed in the brick until the brick gets saturated. It is well established that the critical period in masonry bond development is the first few minutes through which the free water in the mortar can migrate to the brick pores carrying the early hydration products (Goodwin and West 1982 and Lange et al. 1996). This process can not continue for 24 hours (the total absorption testing time), neither can it be represented by the 1 minute time period of the IRA test. Sorptivity has the advantage over other absorption criteria that it describes the absorption performance of the masonry brick units during the most critical period of interaction between the brick unit and the mortar.

However, the sorptivity alone can not define the amount of water migrating from the mortar to the masonry brick unit. This amount is dependent on the availability of water from the mortar (water retentivity), the amount of moisture initially available in the brick

(moisture content), the rate by which the brick unit sucks water (sorptivity), the brick unit absorption capacity (total absorption), the mortar sand gradation (fine particles can block the pores of the unit and change the rate of absorption) and any additives to the mortar which affect hydration (e.g. retarders).

Table 5. Descending ranking of the brick types based on its absorption criteria

Ranking	1	2	3	4	5	6	7	8
TA	IIX	IV	II	VI	I	V	III	VII
IRA	I	VI	IV	II	IIX	III	VII	V
Sorptivity	IV	VI	I	IIX	II	V	VII	III

As these factors are interdependent, experimental design using factorial analysis should be used to examine the effect of these factors on masonry bond strength. Equation (8) represents the anticipated format of the mathematical expression correlating the mortar water retentivity “*R*” brick sorptivity “*S*”, total absorption “*T*” and moisture content “*θ*” to masonry bond strength “ σ_{bond} ”.

$$\sigma_{bond} = f \left(\frac{R S T}{\theta} \right) \quad (8)$$

This mathematical model is based on preliminary results of on-going experimental research work correlating the masonry bond strength to the previously mentioned parameters. The function of this correlation is to allow the selection of a suitable mortar mixture to provide a specific water retentivity required for a specific brick type and construction conditions. The brick type would define the sorptivity, and the total absorption while the construction conditions would determine the possible moisture content of the units at the time of construction. Establishing such correlation could help reduce the inherent weakness of masonry bond.

CONCLUSIONS

- The theory of sorptivity of water is introduced together with its recent application to different porous building materials including concrete and masonry. An experimental programme to examine the application of such a measurement to masonry brick units is described. A simple test rig and procedure is discussed and utilized.
- To avoid violating of the theoretical assumptions of the unsaturated water flow, the total sorptivity testing time may need to be shortened for some masonry brick types. The total testing time should be limited to the time to saturation (6 and 9 minutes for three brick types here).
- Sorptivity has the advantage over other absorption criteria of being able to describe the water absorption performance of masonry bricks over the most critical time period in the development of the mortar-unit interface bond strength.

- Sorptivity is a reliable, reproducible, engineering measurement for predicting the surface absorption performance of brick units. Sorptivity should be considered for the Canadian masonry standard as the surface absorption criterion for masonry brick units.
- Research work examining the relationship between sorptivity and masonry bond strength is on-going. A mathematical model correlating mortar water retentivity, brick sorptivity, total absorption, and brick moisture content to masonry bond strength is being examined.

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APPENDIX

Unit No: II-2

Brick Type and Colour: Group II- Extruded Clay - Yellow

Unit conditioning: Oven cured at 110 °C - Moisture content change < 0.5%

Mass of dry unit: 1593.8

Dimensions: 190 mm x 90 mm

Thickness: 55 mm

Number of cores: 10 holes - 20 mm diameter each

Unit Contact Area: 13958 mm²

t	0	1	2	3	4	6	9	12	16	20	25
√t	0	1	1.414	1.732	2	2.449	3	3.464	4	4.472	5
M	1594	1623	1633	1643	1651	1662	1675	1686	1697	1707	1712
ΔM	0	28.9	38.9	48.7	57.2	68.4	80.8	91.8	103.5	113.4	118
i	0	2070	2787	3489	4098	4900	5789	6577	7415	8124	8454

t (min), √t (min^{1/2}), M (gm), ΔM (gm), i (mm x 10⁻³)

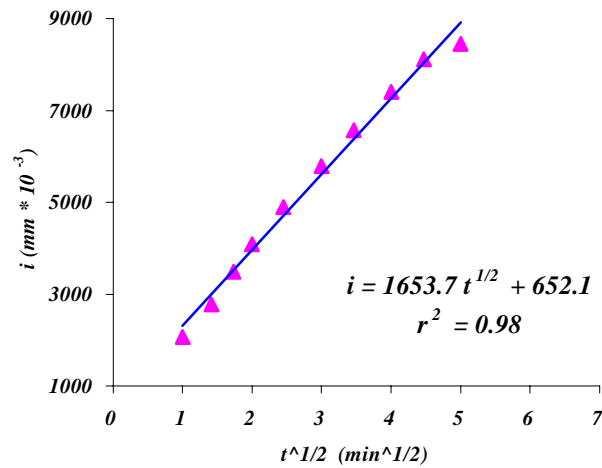


Figure A.1. Sorptivity plot for masonry unit II-2.

$$S = 1654 \cdot 10^{-3} \text{ mm/min}^{1/2}$$

$$r = 0.989$$