FACTORS AFFECTING TRANSFER SORPTIVITY OF LIME AND CEMENT MORTARS IN THE FRESHLY-MIXED STATE

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ABSTRACT

The sorptivity, $S$, is a measure of the ability of a porous material to absorb and transmit water by capillary action. Transfer sorptivity, $A$, is a measure of the ability of an absorbent substrate to withdraw water from a wet mortar mix. Desorptivity, $R$, on the other hand, is the parameter that quantifies water retaining ability of freshly-mixed natural hydraulic lime and cement mortars. The measurement of transfer sorptivity is essentially identical to that of sorptivity except that the brick is placed in contact with a wet mortar mix rather than with water. This paper concerns the combination of wet mortar and brick substrate and the interaction between them. The purpose of this paper is to investigate the influence of hydraulicity, mix water content and sand grain size on the transfer sorptivity of a range of freshly mixed hydraulic lime and PC mortars and to investigate the relationship between transfer sorptivity and desorptivity for the case a substrate material of constant sorptivity. The measurement of transfer sorptivity is not straightforward. Before such measurements could be carried out, it was necessary to confirm that the substrate material to be used was highly homogeneous. To this end, two types of bricks are first investigated to establish their suitability as substrate materials for these measurements. A methodology for the measurement of transfer sorptivity is developed. The results have been shown that the transfer sorptivity increases systematically with increasing hydraulicity; that the transfer sorptivity increases systematically as the water content of a mix is increased; and that the transfer sorptivity of a given mortar increases as the sand grain size is increased. These parameters have important practical consequences, not only in the initial adhesion of the mortar to the substrate but also in the strength of the set material. The ability to monitor the water retaining properties can also allow efficiency in masonry construction.

Keywords: Desorptivity, mortar, sorptivity, transfer sorptivity.

1. INTRODUCTION

In masonry construction jointing mortars are applied to absorbent brick, concrete or stone masonry substrates in the freshly mixed wet state. As these substrates readily absorb water from the wet mix, the water retentivity of the wet mix as well as the suction of the substrate are important parameters which have significant influence on the properties of the resultant set mortar [3].

The substrate removes water from the mix by suction which assists adhesion but quickly reduces workability. Normally brick laying and plastering occur quickly so that the mortar is pushed into its final shape whilst still very soft. Then further water is drawn out by the substrate. An excessive rate of withdrawal of water by the substrate is undesirable. It can result in rapid stiffening of the mix so that even rapid bricklaying / plastering is difficult. Furthermore excessive loss of water from the mix during initial setting can affect the quality of the final set mortar.

The sorptivity is defined as the ability of a porous material to absorb and transmit water by capillarity [6, 7]. The desorptivity describes the water retaining ability of a wet mix. Transfer sorptivity is a measure of the ability of an absorbent substrate to withdraw water from a wet mix and is involving two competing processes: the sorptivity of the substrate acts to remove water from the wet mix; and the water retaining ability of the wet mix opposes this. Sorptivity $S$, desorptivity $R$ and transfer sorptivity $A$, are related by

$$\frac{1}{A^2} = \frac{1}{R^2} + \frac{1}{S^2}$$

A full derivation of this equation is given in [6] and has been experimentally validated for the practically important case of the absorption of water from wet mortar mixes by fired clay bricks [4].
2. MATERIALS AND MIX DESIGN

Mortars were prepared with Natural Hydraulic Limes (NHLs) and Portland cement (PC) as binders. The constituents of the mortars examined were NHLs or PC, fine aggregate (sand), water. NHLs were obtained from Hanson Cement Ltd and comply with BS EN 459-1:2010 [2]. PC (CEM I 52.5N) was manufactured by the Hanson Cement Ltd and complies with BS EN 197-1: 2000 [1].

Desorptivity and transfer sorptivity measurements were carried out on freshly mixed mortars of mix proportions 0.78:1:2 water: binder: sand by volume using ordinary Portland cement (PC) and the range of natural hydraulic limes (NHLs) as binders. Additional mixes of alternative mix proportions were prepared to measure variations in desorptivity and transfer sorptivity with changes in binder, water: binder ratio and sand grading.

The mortars were prepared with pre-dried concreting sand. This was a single source (Croxden) sand having 98.9% of particles<1.18 mm. Mortars were also prepared using the 150 - 300 μm size fraction, referred to in this paper as "sieved sand". In addition a series of NHL 2 mortars was prepared with three other sand particle size fractions. The masses of binder and sand needed to produce the required mix proportions by volume were calculated from carefully determined values of density. To ensure consistency, a standard mixing regime was followed. The water was placed into the bowl of an orbital paddle mixer and the binder added and mixed for 1 minute. Without stopping the mixer, sand was then added gradually over the following 1 minute and the resultant mortar mixed for a further minute. The mixer was then stopped and all unmixed solids scraped from the paddle and the sides of the mixing bowl. Mixing was then continued for a further 7 minutes giving a total mixing time of 10 minutes. Between 1.2 and 2 kg of mortar was prepared in each batch, which provided sufficient material for three to five consecutive desorptivity measurements.

3. EXPERIMENTAL PROCEDURE

3.1. Measurement of Desorptivity

The desorptivity of each mortar was measured following the method described in [5]. Briefly, a known volume of freshly mixed mortar was placed into the pressure cell in several layers, each being tamped thoroughly to eliminate voids before the addition of the next. Having added the wet mix, the cell was sealed and pressurized to the required value before opening the tap. The desorbed water was collected in a flask on a top loading balance connected to a computer. The mass of the desorbed water was recorded at 10 s intervals until gas-breakthrough occurred. The desorptivity of the mix was determined from the gradient of a graph of the cumulative desorbed volume of water per unit area, \( i \), plotted against the square root of time.

3.2. Measurement of Sorptivity

The sorptivity is a measure of the ability of a porous material to absorb and transmit water by capillary action. The measurement of sorptivity is fully described in [7]. The dimensions of the bricks were approximately 215 x 102.5 x 65 mm. Each brick was dried to constant weight at 105 °C in an air oven and the exact area of the bed face measured. The sorptivity was measured by placing the bed face in contact with a shallow layer of water and removing and weighing it at intervals. The sorptivity was determined from the gradient of a graph of the cumulative absorbed volume of water per unit area of absorbing surface versus time.\(^{12}\)

3.3. Uniformity of substrate materials

Sorptivity variations in two different substrate materials were investigated, namely Leicester Buff and Golden Purple bricks manufactured by Ibstock limited. For these experiments, one of each brick type was cut into approximately equal slices perpendicular to the bed face using a masonry saw. The slices were then dried to constant weight and the sorptivity of each slice measured perpendicular to the bed face as previously described.

The results from six slices are plotted in Figure 1(a). It can be seen from Figure 1(a) that the Golden Purple brick has a highly non-uniform sorptivity across its length. In contrast, Figure 1(a) shows that the Leicester Buff brick exhibits a relatively uniform sorptivity across the middle sections. Both Leicester Buff and Golden Purple bricks show very high sorptivity at each end. Since both types are pressed bricks the ends represent less densely compacted clay. The purpose of investigating different bricks was to obtain samples of a uniform enough sorptivity to be able to carry out transfer sorptivity measurements confidently. From previous research it was discovered that variations in sorptivity across a single substrate unit produced major difficulties in transfer sorptivity measurements. The variation in sorptivity across a single Leicester Buff brick is shown in Figure 1(b).
3.4. Measurement of Transfer Sorptivity

The transfer sorptivity, \( A \), is a function of both \( R \) and \( S \) and characterises the ability of a porous material to absorb water from a freshly mixed mortar rather than a free water surface. The measurement of transfer sorptivity is identical to that of sorptivity except that the dried substrate material is placed in contact with a freshly mixed mortar rather than with water. The transfer sorptivity is defined as the gradient of a plot of the cumulative absorbed volume of water per unit area of material in contact with the mortar versus the square root of time. As shown, these parameters are related by Equation 1 has recently been validated experimentally for the case of clay brick withdrawing water from freshly mixed hydraulic lime and cement mortars [4].

Full experimental details of the measurement of transfer sorptivity together with a description of the experimental difficulties are described in [8]. The principle of the measurement of transfer sorptivity is shown in Figure 2(a). Since it is not possible to remove and weigh the brick at intervals without loss of hydraulic continuity, the method shown in Figure 2(b) was used. This method overcomes the problems of loss of hydraulic continuity. The fresh mortar is placed in a compartmentalised mould, and slices of brick of known sorptivity are placed in contact with the fresh mix in each compartment. The brick slices are removed consecutively at appropriate intervals and weighed. Each brick slice is therefore used only once.

4. EXPERIMENTAL RESULTS

4.1. Desorptivity

Desorptivity results are summarised in Table 1. It can be seen from Table 1 that PC mortar (most hydraulic) is less water retaining than equivalent mixes incorporating hydraulic limes (less hydraulic), which in turn are much less water retaining than mortar made with hydrated (air) lime (non hydraulic). These results clearly demonstrate that for a range of mortars of the same composition, the desorptivity increases dramatically with increasing hydraulicity. The results in Table 1 also show that the desorptivity increases as the proportion of mix water increases. Four different sieved fractions of sand were taken to investigate the effect of sand particle size on desorptivity. A decrease in sand grain size caused a progressive decrease in desorptivity and this effect was seen for mortars in general. Smaller particles of sand provide a greater surface area for wetting (thus reducing the availability of free water) and also provide a greater surface.
area for bonding with the binder material. Both these effects are likely to be responsible for the increase in the water retaining ability.

Table 1: Desorptivity values versus mortar hydraulicity; water content; sand grain size.

<table>
<thead>
<tr>
<th>Mortar Hydracity</th>
<th>Desorptivity (mm/min$^{1/2}$)</th>
<th>Water Content</th>
<th>Desorptivity (mm/min$^{1/2}$)</th>
<th>Sand Grain Size</th>
<th>Desorptivity (mm/min$^{1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>2.54</td>
<td>0.78</td>
<td>2.23</td>
<td>75-300 μm</td>
<td>0.79</td>
</tr>
<tr>
<td>NHL5</td>
<td>1.65</td>
<td>0.90</td>
<td>3.85</td>
<td>150-300 μm</td>
<td>1.42</td>
</tr>
<tr>
<td>NHL2</td>
<td>1.33</td>
<td>1.00</td>
<td>6.33</td>
<td>300-600 μm</td>
<td>1.56</td>
</tr>
<tr>
<td>CL90</td>
<td>0.97</td>
<td>1.10</td>
<td>8.78</td>
<td>600-1800 μm</td>
<td>2.12</td>
</tr>
</tbody>
</table>

4.2. Transfer Sorptivity

4.2.1 Hydraulicity

Measurements of transfer sorptivity were carried out on NHL 2, NHL 5 and PC mortars all made with the same volume fractions of binder, water and sand. The hydraulicity of these mortars increases from NHL 2 to NHL 5 then greatly to PC. Since the water releasing ability of a mortar increases with hydraulicity it would be expected that, all other things being equal, PC would produce the highest value of transfer sorptivity and NHL 2 the lowest. Figure 3 shows the results of transfer sorptivity measurements carried out on the three mortars described. These results give transfer sorptivity values of 1.256, 0.992 and 0.987 mm / min$^{1/2}$ for PC, NHL 5 and NHL 2 mortars respectively.

These results correlate well with the desorptivity results given in Table 1. Equation 1 defines the relationship between $A$, $R$ and $S$. Since the sorptivity $S$ is constant throughout the experiment, there is a proportional relationship between desorptivity $R$ and transfer sorptivity $A$. Increasing hydraulicity results in an increase in desorptivity. Desorptivity values of the same three mortars obtained from pressure cell measurements are shown in Table 1 for comparison. This results shows that an increase in hydraulicity causes both $R$ and $A$ to increase as predicted by Equation 1. These results are summarised in Table 1 and 2.

Figure 3: The results of transfer sorptivity measurements carried out on ♦, PC; ■, NHL 5; ▲, NHL 2.

4.2.2 Water content of the mix

NHL 2 mortars made with increasing water: lime ratios were used to examine the effect of varying water content on transfer sorptivity. The water: lime ratios used were 0.78:1, 0.89:1 and 1:1 by volume. The results of these transfer sorptivity measurements are shown in Figure 4 which shows that increasing the water content of NHL 2 mortars resulted in an increase in transfer sorptivity. Increasing the water content of these freshly mixed mortars was also shown to cause an increase in desorptivity as shown in Table 1.

These results once again show the proportional relationship between $A$ and $R$ in Equation 1 and show that increasing the water content of fresh mortars results in an increase in both desorptivity $R$ and transfer sorptivity $A$. 
4.2.3 Sand grain size

The effect of sand grain size on transfer sorptivity was investigated by carrying out measurements on NHL 2 mortars made with the following grades of sieved sand: 150–300 μm, 300–600 μm and 600–1800 μm. The transfer sorptivity results are shown in Figure 5. The results in Figure 5 show that increasing the sand grain size resulted in an increase in the transfer sorptivity. A probable explanation for this is that as the grain size increases, the total surface area of particles decreases, therefore creating an easier passage for the water to be removed from the freshly mixed mortar. These results are consistent with the results summarised in Table 1 where it was shown that an increase in sand grain size results in increased desorptivity and once again demonstrates the proportional relationship between $R$ and $A$.

5. DISCUSSION AND CONCLUSIONS

The sorptivity characteristics of Leicester Buff and Golden Purple bricks were examined with the aim of finding a suitably homogeneous material for the purpose of transfer sorptivity measurements. Golden Purple bricks were found to exhibit large variations in sorptivity across a number of slices cut from the same brick. Leicester Buff bricks on the other hand, with the exception of their ends, were shown to be highly uniform, not only across slices cut from the same brick but also between different bricks from the same batch. This step is essential in any attempt to determine transfer sorptivity. Leicester Buff bricks were therefore chosen for use in experiments to measure transfer sorptivity.

The experimental results are summarised in Table 2. It has been shown that the transfer sorptivity increases systematically with increasing hydraulicity with $A_{PC}>A_{NHL 5}>A_{NHL 2}$, that the transfer sorptivity increases systematically as the water content of a mix is increased; and that the transfer sorptivity of a given mortar increases as the sand grain size is increased.
Table 2: Summary of transfer sorptivity results. Bold indicates the systematic variable examined.

<table>
<thead>
<tr>
<th>Binder</th>
<th>Water : Binder</th>
<th>Grain Size (μm)</th>
<th>A (mm/min^{1/2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHL 2</td>
<td>0.78:1</td>
<td>150-300</td>
<td>0.987</td>
</tr>
<tr>
<td>NHL 5</td>
<td>0.78:1</td>
<td>150-300</td>
<td>0.992</td>
</tr>
<tr>
<td>PC</td>
<td>0.78:1</td>
<td>150-300</td>
<td>1.256</td>
</tr>
<tr>
<td>NHL2</td>
<td>0.78:1</td>
<td>150-300</td>
<td>0.987</td>
</tr>
<tr>
<td>NHL 2</td>
<td>0.89:1</td>
<td>150-300</td>
<td>1.183</td>
</tr>
<tr>
<td>NHL 2</td>
<td>1:1</td>
<td>150-300</td>
<td>1.327</td>
</tr>
<tr>
<td>NHL 2</td>
<td>0.78:1</td>
<td>150-300</td>
<td>0.987</td>
</tr>
<tr>
<td>NHL 2</td>
<td>0.78:1</td>
<td>300-600</td>
<td>1.108</td>
</tr>
<tr>
<td>NHL 2</td>
<td>0.78:1</td>
<td>600-1800</td>
<td>1.281</td>
</tr>
</tbody>
</table>

The transfer sorptivity results shown here are entirely consistent with the desorptivity results given in Table 1 and demonstrate the proportional relationship between $R$ and $A$ indicated in Equation 1 for the case of constant $S$.

6. REFERENCES


