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The effects of lime and admixtures on the water-retaining properties of cement mortars

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Abstract

The water-retaining properties of wet mortar mixes are examined. The desorptivity is defined as a parameter characterising the water-retaining properties of such mixes. A test method based on the American Petroleum Institute filtration cell is described for measuring the desorptivity of wet mixes. Experimental results are reported for a range of wet cement mortars including mixes containing lime and air-entraining and water-retaining admixtures. These show that 1:3 cement:sand and equivalent mixes containing lime all have very similar water-retaining characteristics, but are all much less water-retaining than a 1:3 lime:sand mix. These results therefore demonstrate the strong water-retaining characteristics of lime. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The water-retaining properties of mortars and plasters in the soft state are of considerable practical importance in the construction industry. These particular materials form a distinct subgroup of construction materials because they are applied in a soft, freshly mixed state to absorbent substrates either as renders or bricklaying mortars. Thus the properties of the mortar or plaster are determined not only by the original mix design but also by the extent to which the wet mix is changed by water being withdrawn from it by capillary suction.

The properties of wet mixes have been little studied, although there is a large amount of published work on the hydraulic properties of these materials in the hardened state [1,2]. Water absorption and transport by capillarity in these latter materials is described by the extended or unsaturated Darcy equation. A similar theoretical model may be used to describe the filtration and sedimentation properties of wet slurries. Philip and Smiles [3] and Smiles and Kirby [4] have shown that the filtration of a suspension is described by exactly the same nonlinear diffusion equation as that used in unsaturated flow theory. This model has been applied to the examination of muds and clays in the oil- and mineral-processing industries [5–7].

The compositions of traditional mortar mixes are typically one part cement or fine material to three parts of sand, giving standard mixes of 1:3 cement:sand or 1:1:6, 1:2:9, and so forth, of cement:lime:sand [8]. It is common in practice for the 1:1:6 mix to be replaced by a 1:5 mix containing an air-entraining admixture. BS 4551 [9] describes an empirical test to assess the water retentivity of cement mortars. This test measures the amount of water absorbed in a fixed time interval by filter papers under an applied load placed in contact with the mortar. The mass of water retained by the mortar is expressed as a percentage of that originally present. This is a purely comparative test and does not measure any fundamental material property of the wet mix. Described as a suction test, it is actually a hybrid suction-pressure test, although the pressure associated with the applied load, 254 Pa, is much less than the capillary suction pressure of the filter paper, which will be of the order of several kPa [10]. However, both these pressures are several orders of magnitude less than the capillary suction pressures associated with masonry materials such as clay brick.

In this paper we propose a quantitative measurement technique using a simple pressure filtration cell. We have used a standard American Petroleum Institute (API) filtration cell [11] designed for measuring the filtration properties of drilling fluids and well cements [12]. The wet mix is placed in the cell and the amount of water expelled from the mix under the action of a pressurised gas is measured as a function of time. It is assumed that the expulsion of water

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by this means is equivalent to the suction of water from the mix by an absorbent substrate exerting a capillary suction pressure equal to that of the gas. By using appropriate gas pressures, we take into account the magnitude of the capillary suction forces associated with typical substrate materials such as brick.

The variation of capillary suction with water content for any porous medium is called the "water characteristic." There is hysteresis between wetting and drying due to the way in which pores fill and drain. This results in two water characteristic curves—one obtained by increasing the water content of the initially dry solid (the wetting curve) and the other obtained by pressure draining the initially saturated solid (the drying curve). Typical water characteristic curves for a clay common brick are shown in Fig. 1 [13], which indicate the capillary suction pressures associated with this material.

2. Theory

It is already well established that the sorptivity [1,2] is the most useful parameter to describe the water absorption properties of a porous solid. To characterise the water-retaining properties of a wet mix, we use a related parameter, the desorptivity [14].

Consider an enclosed column of wet mix being caused to dewater under the action of an applied gas pressure, P (Fig. 2). As the mix dewaters, a filter cake of increasing thickness forms at the outflow end of the column. From Terzaghi's law [14] the cumulative desorbed volume of water per unit area of the column, i, is given by Eq. (1):

$$i = Rt^{1/2} \tag{1}$$

where R is the desorptivity of the wet mix and t is the elapsed time. It should be noted that Eq. (1) arises from the theory of one-dimensional filtration and is exact.

Clearly, for a given wet mix the desorptivity will be a function of the applied pressure, P. Desorptivity and pressure are related by the empirical expression seen in Eq. (2):

$$R = CP^n \tag{2}$$

where C is a constant term and the value of the exponent, n, indicates the compressibility or otherwise of the filter cake [15]. For an incompressible cake the hydraulic permeability of the cake remains constant with variations in applied pressure and $n = 0.5$. Values of n less than 0.5 indicate cake compressibility, with decreasing values of n signifying increasing compressibility and hence decreasing cake permeability with increasing applied pressure.

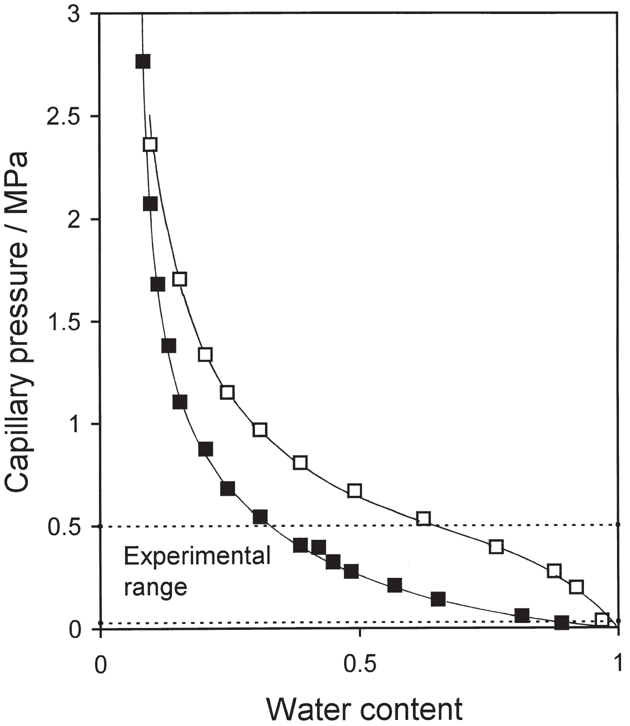

Fig. 1. Wetting (■) and drying (□) characteristic curves for a typical clay common brick [13]. The water content scale is from 0 (dry) to 1 (saturated).

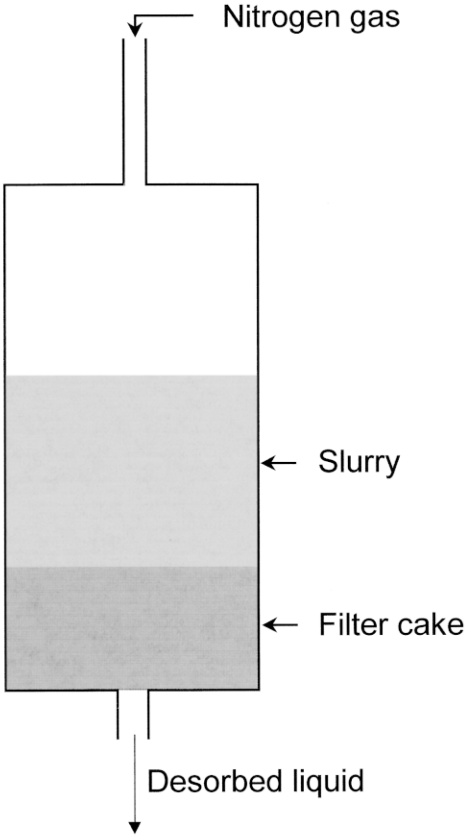

Fig. 2. Schematic diagram of the American Petroleum Institute pressure cell used in the measurement of desorptivity.

3. Methods

3.1. Preparation of the wet mixes

Standard mixes were used in the experimental work to include cement:sand, cement:lime:sand, and cement:sand mortars containing admixtures. Both air-entraining and water-retaining admixtures were used. The air-entraining admixture used was an aqueous solution based on lignosulphonate, and the water-retaining admixture a methylcellulose-based water-soluble polymer in the form of a dry powder.

Two types of mix were examined. In the first all the mixes were of the ratio 1:3 fines:sand by volume. Each mix contained 100 g of water and 300 g of dry, sieved sand comprising of the fraction that passed through a 600-μm sieve. The required masses of the other mix constituents (either cement or cement and lime) were calculated so that the total volume of fines in each mix was constant. This ensured comparable mixes of the same workability.

The second type of mix was based on a 1:5 ratio of fines:sand by volume. Again 300 g of sand and an appropriate mass of fines calculated to give the required volume ratios were used. However, for these mixes a reduced quantity of water (90 g rather than 100 g) was incorporated so that the ratio of the total volume of solids to water in the 1:5 mixes was the same as that in the 1:3 mixes. Both types of mix therefore had the same workability.

Where used, the quantity of admixture corresponded to the manufacturer's maximum recommended concentration. In the case of the liquid lignosulphonate-based admixture this was a concentration equivalent to 560 ml per 100 kg of cement, and in the case of the powdered methylcellulose-based admixture, a concentration equivalent to 0.15 to 0.25% of the mass of cement was used.

3.2. Mixing regime

Because all the experiments were carried out on freshly mixed mortars, it was important to follow a precisely defined mixing regime to ensure that the mixes were reproducible.

A 3-l capacity orbital paddle mixer was used to prepare the mortars. Water was added to the mixer first, followed by lime, cement, and sand in that order. For the mixes containing liquid admixture the liquid was added to the mix water before adding the cement. After liquid was added, the cement was allowed to mix for 1 min before the lime and sand were added. For the mixes containing powdered admixture, the dry powder was mixed with the cement before it was added to the water. This was left to mix for 1 min before addition of the sand.

3.3. Measurement of desorptivity

Measurements of desorptivity were carried out using an API filtration cell [11], which is illustrated schematically in Fig. 2. The cell had an internal diameter of 54 mm and a length of 210 mm. Whatman No. 50 filter paper was placed at the outflow end and the inflow end was connected to a pressurised nitrogen supply. This filter paper has a particle retention size of 2.7 μm. Analysis of the mix constituents showed 85% of the lime and 82% of the cement had particle sizes >2.7 μm. The measured resistance of the filter paper was found to be negligible compared to that of the wet mix.

A known volume of wet mix was placed in the cell, which was then pressurised. The eluted liquid was collected at measured time intervals and weighed using an electronic balance that was connected to a computer. (The eluted liquid was slightly cloudy for the first few seconds of desorption before suddenly becoming clear.) The experiment was continued until gas breakthrough occurred. The experiment was repeated several times on fresh samples of the same mix at different applied pressures. For the mixes investigated in this paper, pressures varying from 0.03 to 0.5 MPa were used. These pressures are compared to the capillary suction pressures associated with a clay brick in Fig. 1 [13]. Data collection times varied from 1 to 30 min, depending on the mix and the applied pressure. The experiments were repeated on identical volumes of other wet mixes.

4. Results and discussion

Fig. 3 shows the cumulative volume of water per unit area desorbed at a range of different pressures from a 1:3 cement:sand mix. The gas breakthrough point is clearly seen in each case as a departure from linearity at long times. The slight departure from linearity of the early time data is due to the time taken for damping to occur in the electronic balance. From Eq. (1) the gradient of the linear portion of

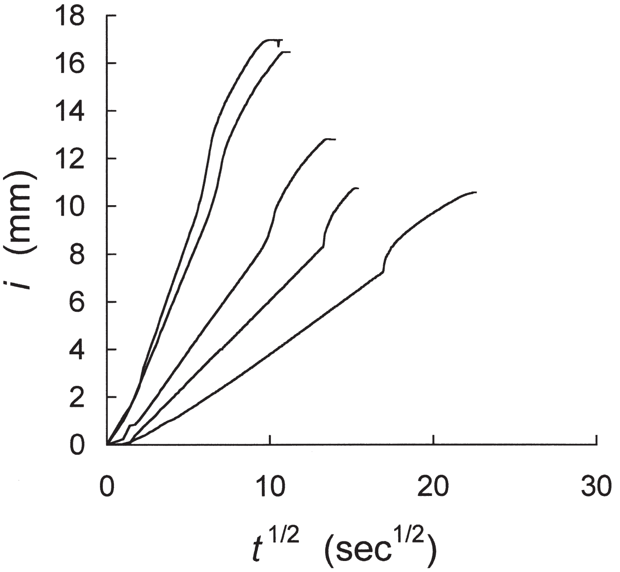

Fig. 3. The cumulative volume of water per unit area desorbed from a 1:3 cement:sand mortar at pressures of 0.03 (lower line), 0.07, 0.13, 0.33, and 0.5 (upper line) MPa. The gradient of each line gives the desorptivity of the wet mix at that pressure.

each line (taken between $t = 5$ s and gas breakthrough) gives the desorptivity of the wet mix at that pressure.

Graphs showing the variation in desorptivity with pressure for a range of wet mixes are shown in Fig. 4. Least squares fits to Eq. (2) show the values of the exponents to be approximately 0.5, indicating cake incompressibility.

Fig. 4 shows a number of interesting results. The 1:5 cement:sand mortar, with or without air-entraining admixture, is much less water-retentive than the 1:3 cement:sand mortar. This is probably because there is a greater proportion of coarse material in the 1:5 mix. It is also shown that the addition of air-entraining admixture, while not having a large effect on the water retentivity of the 1:5 mix, does decrease somewhat the water retentivity of this mix. Also, the 1:5 cement:sand mix with or without air entrainer is much less water-retentive than the equivalent mix of 1:1:6 cement:lime:sand.

Fig. 4 also illustrates the effect of incorporating increasing proportions of lime into the mortar mix. Thus in the 1:1:6 mix, half the cement in the original 1:3 cement:sand mix is replaced by lime; in the 1:2:9 mix, two thirds of the cement is replaced by lime; and in the 1:3 lime:sand mix, all the cement is replaced by lime. Since the ratio of total fines to sand in these mixes is identical and the manufacturers' data indicated that the distribution of particle sizes in the cement and lime were similar, it might be expected that all these mixes would have similar water-retaining properties. However, this has not been found to be the case. Although the water-retaining properties of the 1:1:6 and 1:2:9 cement:lime:sand mixes and the 1:3 cement:sand mixes are about the same, the 1:3 lime:sand mix is much more water-retentive than the other three. These results show that the addition of only a small amount of cement to a lime:sand mix causes a significant reduction in water retentivity.

The pressure cell was also used to assess the effects of different concentrations of methylcellulose-based water-retaining admixture on the water retentivity of a 1:3 cement:sand mortar. It was found that adding methylcellulose at the manufacturer's recommended concentration had little effect on the desorptivity of the mix and that significant changes in desorptivity were not observed until the concentration exceeded a certain critical limit. This effect is clearly shown in Fig. 5: although concentrations up to 1% resulted in some reduction in mix desorptivity, the desorptivity approaches zero at concentrations exceeding ~1%, which is equivalent to four times the recommended concentration.

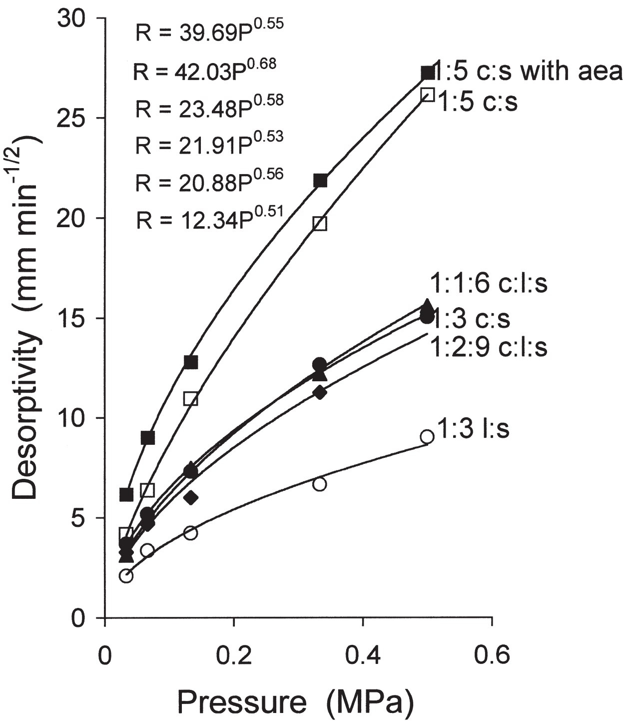

Fig. 4. Graphs showing desorptivity vs. pressure for a range of mortars: (■) 1:5 cement:sand mix with lignosulphonate air-entraining admixture; (□) 1:5 cement:sand mix; (●) 1:3 cement:sand mix; (▲) 1:1:6 cement: lime:sand mix; (◆) 1:2:9 cement:lime:sand mix; (○) 1:3 lime:sand mix. The solid lines, the equations of which are shown on the figure, are least squares fits to Eq (2).

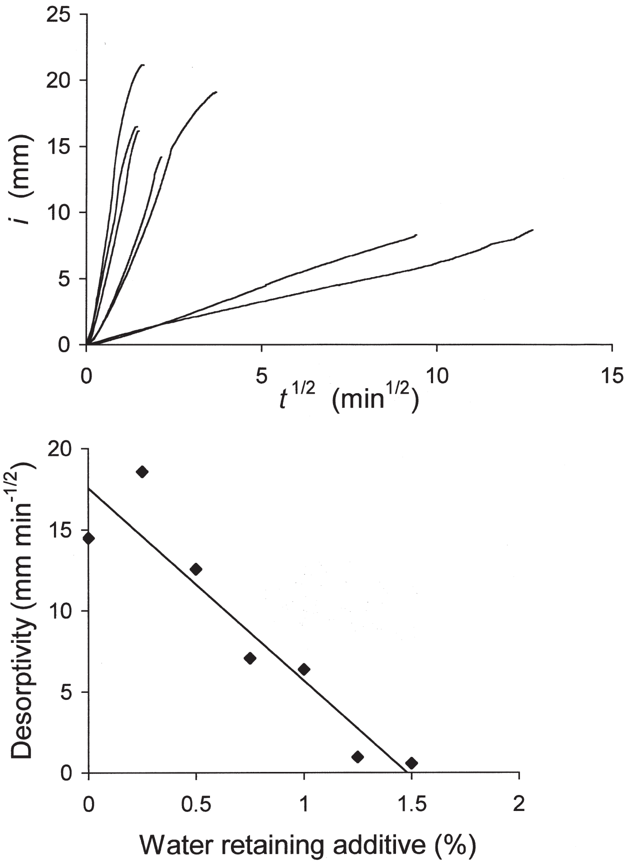

Fig. 5. Graphs showing the effect of a range of concentrations of methylcellulose-based admixture on the water retentivity of a 1:3 cement:sand mortar at an applied pressure of 0.33 MPa. Top graph: cumulative desorbed volume of water per unit area at admixture concentrations of 0.25 (upper line), 0, 0.5, 0.75, 1.0, 1.25, and 1.5% (lower line) of mass of cement used. Bottom graph: the same data plotted to show the dependence of desorptivity on admixture concentration.

5. Conclusions

The most significant result of this work is that 1:3 cement:sand and equivalent mixes containing lime all have very similar water-retaining characteristics, but are all much less water-retaining than 1:3 lime:sand mix. These results demonstrate the strong water-retaining characteristics of lime—characteristics that have long been widely appreciated but not previously quantified. This may explain some of the excellent performance characteristics of lime mortars on historic buildings.

The results also demonstrate the effect of the common trade practice of using a 1:5 cement:sand mix with air-entraining admixture in place of a 1:1:6 cement:lime:sand mix and show that the mix containing lime is much more water-retaining.

Methylcellulose-based water-retaining admixture can reduce desorptivity to very low levels. However, it was found that the performance of this type of admixture is strongly concentration dependent with no appreciable effect below a certain critical concentration.

The filtration method described here provides a useful way of assessing the water-retaining effects of admixtures. We suggest that the pressure cell be used as an aid to mix design and quality control. A version of the cell would also be useful in concrete technology where water-retaining admixtures are used as pumping aids.

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