

## Hall's Notes and Queries

### NQ7

#### **Seven long years: Extended test of the Gummerson effect in Clipsham limestone**

Quantitative experiments of long duration are hard to fund and unappealing to research students. Even so, they provide invaluable information about building materials and performance, where of course processes of alteration may occur slowly over many years. Here I report (unfunded) observations on two specimens of Clipsham limestone extending over more than seven years.

**Preamble** When water is absorbed by dry porous materials such as brick, stone and concrete some air is invariably trapped. The amount of trapped air varies greatly from material to material: the fraction of the open porosity occupied by trapped air (which we denote by  $\lambda$ ) may be as much as 0.5 or as little as 0.04, but appears never to be zero. The fact that air is trapped in capillary absorption is well established. As noted in NQ4, it was shown to be the case by Julius Hirschwald more than 100 years ago in his comprehensive work on building stones. The quantity  $h$ , the fraction of the open porosity occupied by water at the end of initial imbibition, is known as the fractional Hirschwald coefficient. Therefore  $\lambda = 1 - h$ .

The  $h$  values usually quoted are those found in laboratory tests on

small samples. It is likely that for any given material  $\lambda$  is scale-dependent and is also affected by the rate of advance of the wetting front. However, there is almost no information on the influence of these factors. It is also likely that the extent of air trapping depends on the geometry of the water absorption: for example, is  $\lambda$  different if water invades a block of material through one face or if it invades through all faces, as occurs when the block is totally immersed? In the first case, the air is (largely) displaced ahead of the advancing water front (so called co-current imbibition); in the second case, the air can only be lost by moving upstream against the advancing water front (counter-current imbibition). It is to be noted that although the *volume* of trapped air can be estimated accurately by weighing the amount of water in the block, the *pressure* of the trapped air has proved elusive, and therefore the mass of trapped air is not generally known.

The trapped air is not trapped for ever, but is slowly lost. When this was first realised is not clear. It was certainly known by 1976 to Hugo Hens<sup>1</sup> that the amount of water absorbed (or imbibed) by brick materials continues to slowly increase after primary imbibition if they remain in contact with water.

The slow loss occurs because the air trapped by a wetting liquid such as water is compressed by capillary forces. Therefore pockets of trapped air are at a pressure greater than atmospheric pressure. Although the air and water are at mechanical equilibrium, they are not at diffusional equilibrium. Since the solubility of air in water increases with pressure (Henry's law), the concentration of dissolved air at interfaces between the water and the trapped air is greater than its concentration at the external surface. The phenomenon of air dif-

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<sup>1</sup>H Hens (1976) Die hygischen Eigenschaften von Ziegel. Proceedings of the 4th International Brick Masonry Conference, Bruges, Belgium.

fusion in porous concretes was investigated in some detail later by G Fagerlund,<sup>2</sup> who emphasised the beneficial effect of trapped air as a defence against frost damage. Fagerlund developed models of the diffusion process to estimate timescales for the loss of trapped air.

The gradual loss of trapped air by diffusion may be expected to continue until all the air has disappeared, but the process is extremely slow. This is because the solubility of air in water is low, and because diffusion through the pore system is itself slow. As far as I know, it was only in 1980 that it was first shown<sup>3</sup> that a porous material does eventually reach saturation by continued imbibition. Bob Gummerson in a simple but patient experiment showed that a fired-clay brick (porosity 0.30) imbibing water through a header face reached saturation after about 22 months. In this case  $\lambda$  after the initial imbibition was about 0.18 but eventually the water content was indistinguishable from that reached in a vacuum saturation test – in other words, the entire open porosity was water filled. We now call the process of reaching saturation by slow air diffusion the *Gummerson effect*.

**Clipsham limestone** Clipsham, a village in Rutland near the town of Stamford, has produced building stone since at least the fourteenth century.<sup>4</sup> Schaffer<sup>5</sup> calls Clipsham a ‘shelly limestone’. Several different quarries have been worked at different times, so the physical properties are variable. This NQ reports capillary absorption data on specimens supplied by Fairhaven Stone at Bottisham, Cambridge, in 2015. At that time, the stone would have come from the Clipsham Medwells Quarry. Standard tests on several 50 mm

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<sup>2</sup>G Fagerlund (1993), The long time water absorption in the air-pore structure of concrete, Report TVBM-3051, Lund University.

<sup>3</sup>R J Gummerson, C Hall & W D Hoff (1980), Capillary transport in masonry structures: Building construction applications of Darcy’s law. *Construction Papers*, **1**, 17–27.

<sup>4</sup>D Purcell (1967), *Cambridge stone*, Faber.

<sup>5</sup>R J Schaffer (1932), *The weathering of natural building stones*, HMSO.



Figure 1: Clipsham limestone blocks C10, C12  $150 \times 50 \times 50$  mm for long-term imbibition tests.

cubes gave the volume-fraction porosity as  $0.211 \pm 0.002$ , with solid density  $2720 \pm 10$ , close to the crystallographic density of mineral calcite,  $2709 \text{ kg/m}^3$ .

**Test procedure and results** Tests were carried out on two rectangular bars of Clipsham stone  $150 \times 50 \times 50$  mm (Fig 1), imbibing water through a  $50 \times 50$  mm end-face. The bars were housed in a closed box, with their lower inflow faces in contact with water. Changes in the water content of the bars were monitored by occasional weighings on an external balance reading to 0.1 g. Fig 2 shows

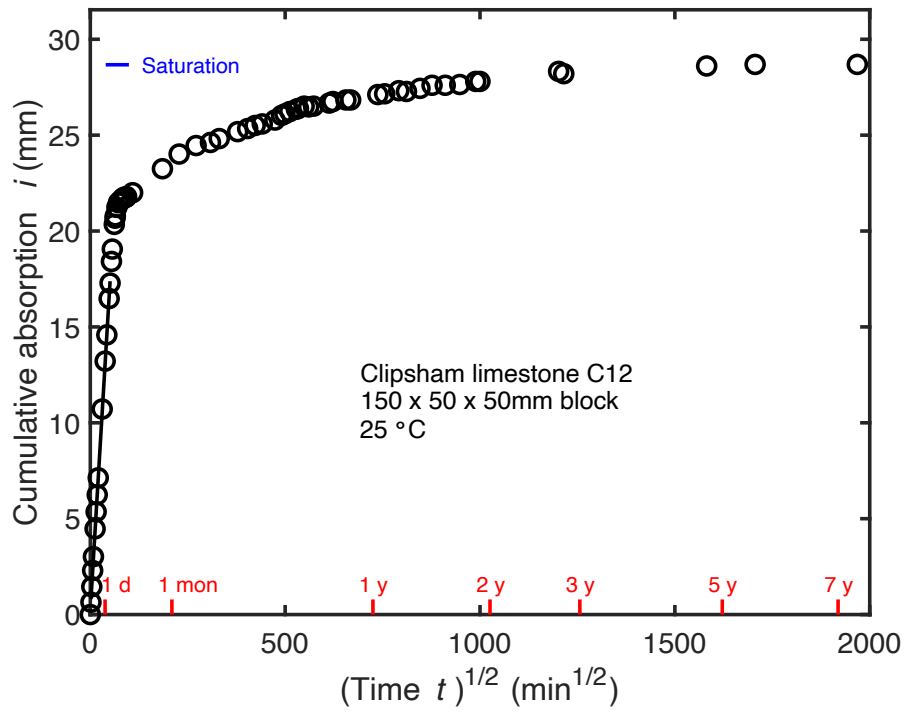
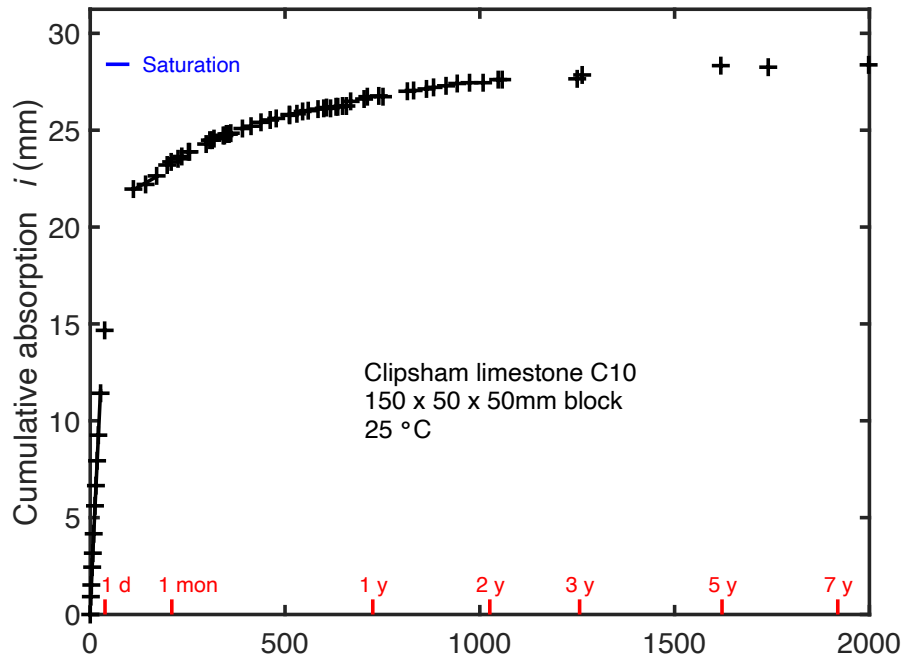


Figure 2: Long-term water imbibition into two Clipsham limestone blocks C10, C12, imbibing through a 50 × 50 mm face in a closed box at 25 °C. Tests run from Feb 2017 to Sep 2024

the long-term capillary absorption of water into these bars. Saturation is reached after about 5 y. The two  $i(t)$  datasets are essentially identical. Here the Hirschwald coefficient  $h$  is 0.74 (both blocks), significantly lower than the values of  $0.80 \pm 0.01$  measured on 50 mm cubes of Clipsham stone from the same delivered batch.<sup>6</sup> This difference is perhaps a tentative indication of the effect of sample size on the extent of air-trapping.

**Comment** An important consequence of the Gummerson effect is that brick, stone and concrete materials that are in contact with water for long periods of time without drying tend inexorably to become saturated. This in turn has two further consequences: first, such saturated materials are then susceptible to severe mechanical frost damage; and second, in such materials the rate of capillary absorption (or effective sorptivity) is increased. The latter effect may then lead to an increase in the height of capillary rise in walls.<sup>7</sup> I consider that the laboratory evidence although sparse is now clear, but field studies do not yet provide any confirmation of the practical effects.

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<sup>6</sup>C Hall & V Pugsley (2020), Spontaneous capillary imbibition of water and nonaqueous liquids into dry quarry limestones, *Transport in Porous Media* **135**, 619—631.

<sup>7</sup>C Hall & W D Hoff (2007), Rising damp: capillary rise dynamics in walls, *Proceedings of the Royal Society* **A463**, 1871–1884