EXPERIMENTAL STUDY OF THE DRYING OF CELLULAR CONCRETE

V.P. de Freitas, J. Castro

Experimental Study of the Drying of Cellular Concrete

Vasco Peixoto de Freitas *

José Castro **

1. INTRODUCTION

There is a growing use of cellular concrete in the Portuguese building construction, executed "*in situ*", used as form layers of flat roofs and filling layers over concrete slabs inside the buildings. The advantages of this material are its low density, easy application and low cost.

The drying of the cellular concrete, especially in case of layers of a great thickness, is very complex and long. The application of waterproofing systems or coverings (wood, linoleum, etc...) on not fully dried cellular concrete, has resulted in the occurrence of pathologies.

At the Building Physics Laboratory – LFC of the Faculty of Engineering of the University of Porto, we have carried out an experimental study with the aim of measuring the drying process of cellular concrete, under laboratory and outdoor conditions *[1]*. The measurement of the moisture content profiles of the tested material was performed by means of a gamma-ray attenuation device. In this paper, we present the experimental results of the study and give some practical recommendations on the hygrothermal implications of the use of cellular concrete.

2. THE DRYING OF BUILDING MATERIALS

The drying of materials can be expressed as a function of the differences in the vapour concentration at the surface of the material and in the atmosphere, by means of the following expression *[2]*:

$$g_v = \beta \cdot (C's - C'a) \qquad (1)$$

* Associate Professor and Head of the Building Physics Laboratory.

** Master of Science.

Faculdade de Engenharia da Universidade do Porto, Rua dos Bragas, 4099 Porto, Portugal – *vpfreita@fe.up.pt*

where

g_v - moisture flow .... kg/m^2.s

β - surface transfer of moisture coefficient .... m/s

C's - concentration of water vapour at the surface .... kg/m^3

C'a - concentration of water vapour in the atmosphere .... kg/m^3

When the surface is saturated, the drying flow is constant. Later, when the amount of water carried from inside the material to its surface is lower than the amount of vapour released during the drying process, the vapour concentration at the surface decreases and the drying flow tends to zero. In this phase, the water vapour is carried to the surface of the material, by means of vapour diffusion, through a layer of "dry" material. This layer of "dry" material increases during this phase *[3]*.

3. PROPERTIES OF THE CELLULAR CONCRETE BEING STUDIED

The cellular concrete being studied is made of a cement paste, with air introduced in the form of bubbles approximately 1 mm in diameter. The air is introduced by means of a chemical reaction during the preparation of the material *[4]*. The percentage of air in this type of material is around 50% of its volume. The original value of water content (saturation) can reach about 1,2 kg/kg.

Twelve cubic samples were moulded in order to determine the apparent density and to evaluate resistance to compression of the material. The density for compositions of Type I and Type II in the dry state are 440kg/m^3 and 600kg/m^3, respectively. The values obtained for resistance to compression ranged from 0,66 and 2,06 MPa.

The hygroscopic moisture content of the cellular concrete was evaluated, by placing a sample of material in a saturated atmosphere (RH $\cong$ 98%), where the moisture content was 0,21 kg/kg. A sample of dry material was also placed in an atmosphere with a relative humidity of about 50%, which reached a moisture content 0,08 kg/kg.

4. EXPERIMENTAL DETERMINATION OF THE MOISTURE CONTENT PROFILES

The experimental device used to measure moisture content by gamma-ray attenuation was built and calibrated at the Faculty of Engineering of Porto University – LFC and consists of a radioactive source (Americium), a detector of sodium iodide, an electronic unit made up of a voltmeter, a temporiser, a counter, a device for measuring the counting rate and high- and low-voltage feed as well as a computer terminal with the respective software for automatically introducing and obtaining data.

The physical principle that is the basis of this measuring technique consists of the attenuation or absorption of emitted radiation when a given material is placed between the radioactive source and the detector (gammametry). The attenuation of the radiation depends on the energy of the photons, the chemical composition of the absorber and the distance between the source and the detector. It is possible to establish the relationship between the emitted (I_0) and transmitted radiation (I), depending on the value of the thickness (χ) of the specimen, the attenuation coefficient (μ) and the density of the material (ρ).

$$I = I_0 \cdot \exp.(-\mu \cdot \rho \cdot \chi) \quad [\text{counts/s}] \tag{2}$$

The value of water content can be calculated since the mass attenuation coefficient of the water (μ_w), the transmitted radiation of dry sample (I_0*) and the density of the dry material (ρ_0) are known:

$$\theta = -\text{Ln}\,(I/I_0^*) \,/\, (\mu_w \cdot \rho_w \cdot d)\ [m^3/m^3] \quad \text{or} \quad W = (\theta/\rho_0) \cdot \rho_w \ [kg/kg] \tag{3}$$

The calibration of the equipment consists of the comparison between the mass variation of the samples obtained by weighing (gravimetry) and the mass variation calculated by the integration of the experimental profiles of moisture content, at the same moment of the drying process. Good agreement of the results shows that gamma-ray attenuation equipment may be considered valid for the determination of moisture distribution profiles (see figure 3).

4.1. Configuration of Samples

Cellular concrete is normally applied in constructions with one side in contact with the support, while the other side – the drying side – is exposed to climate conditions. Thus, the adopted physical model is a prismatic system that is open on one side (drying side) and "waterproofed" on the remaining five sides, so as to make sure that the drying flow in these directions is null.

The physical model was produced by a quadrangular Plexiglas mould of 3,5 mm with heights of 100, 200 and 300 mm and the interior section of 100 x 100 mm^2.

The heights chosen for the samples represent the thicknesses of cellular concrete normally used in Portugal when executing moulded layers of coverings and in filling pavements.

4.2 Drying Process

The samples of cellular concrete, with the dimensions mentioned above, were exposed to the following conditions:

- Drying in the laboratory (T = 22°C ± 2°C and RH = 50% ± 5%);
- Drying outdoors (sheltered from the rain and solar radiation).

Figure 1 shows the variation in the intensity of radiation in the dry state, by three 200-mm-high samples, which showed that density increases with depth, because the number of counts decreases. The samples are not homogeneous.

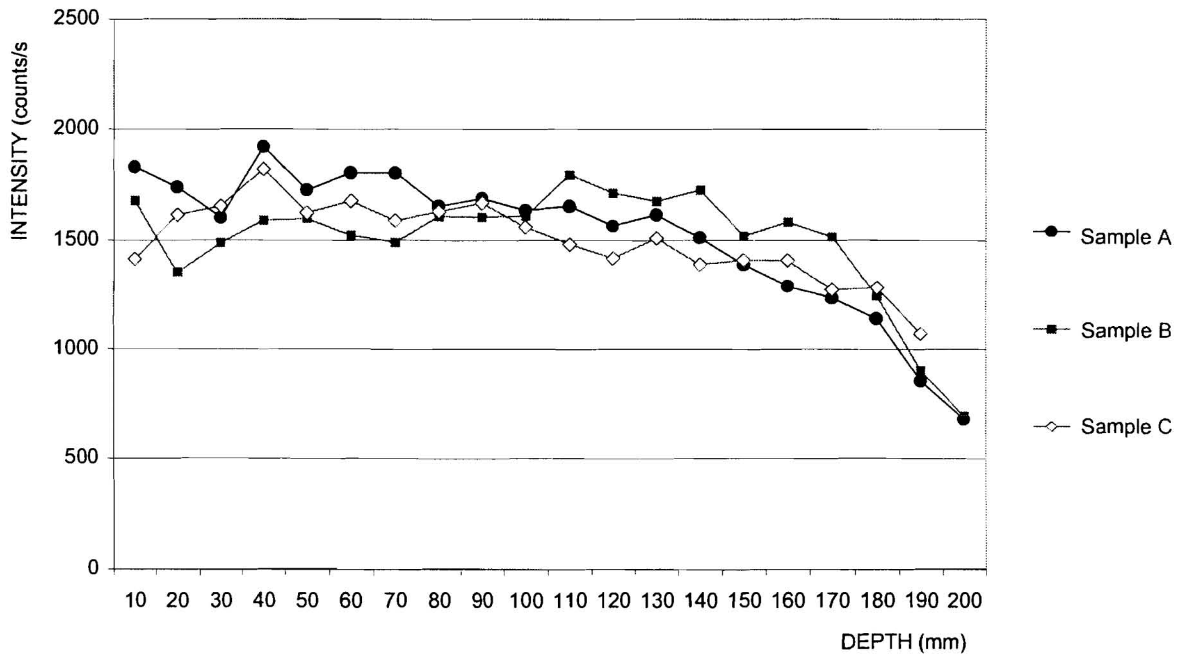

Figure 1 Variation of the intensity of radiation along the sample.

Figure 2 shows the evolution of the profiles of the moisture content in cellular concrete, obtained by means of gammametry, for 100-mm-thick samples dried in the laboratory.

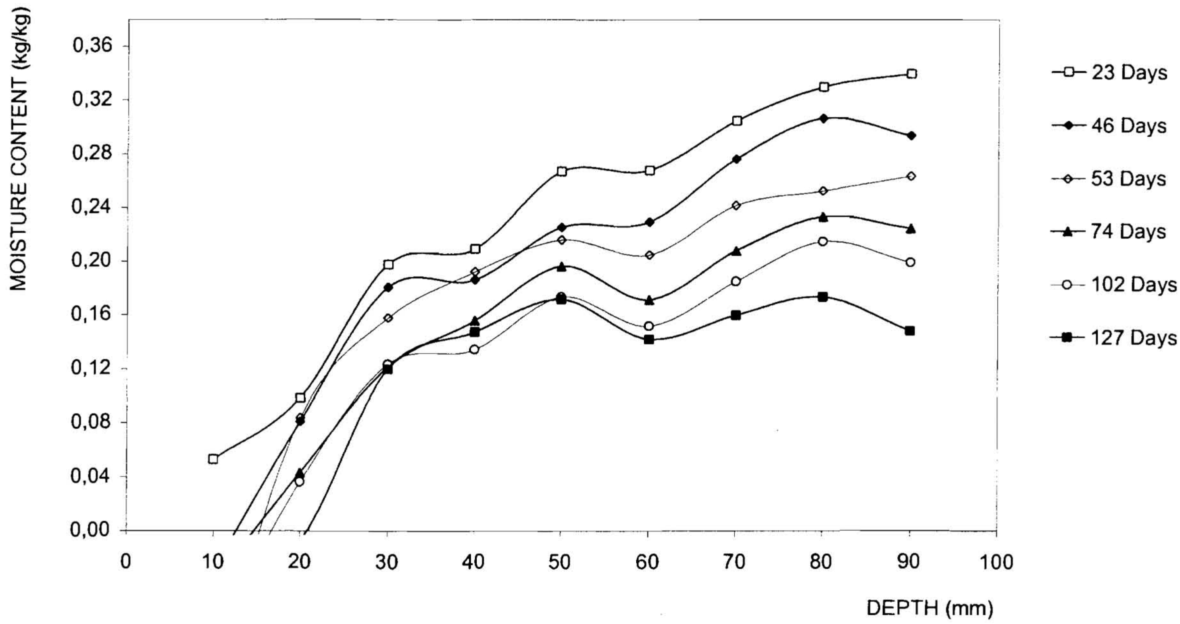

Figure 2 Profiles of the moisture content of 100-mm-thick samples when dried in the laboratory.

At the end of the drying period in the laboratory (127 days), the samples were placed in an oven at 60°C for 52 days, then for another 6 days at 105°C, until it reached the dry state. The variation of mass during the drying process, as a function of the square root of time, is shown in figure 3. In this figure, one can see the agreement between the values for the variation of mass, obtained by means of gammametry and by gravimetry.

Figure 4 shows the evolution of the profiles of the moisture content in a 100-mm-thick sample of cellular concrete dried outdoors. It should be noted that, after 68 days of drying, sheltered from rain and radiation, the samples were left exposed for 12 days, which led to a big increase in moisture content.

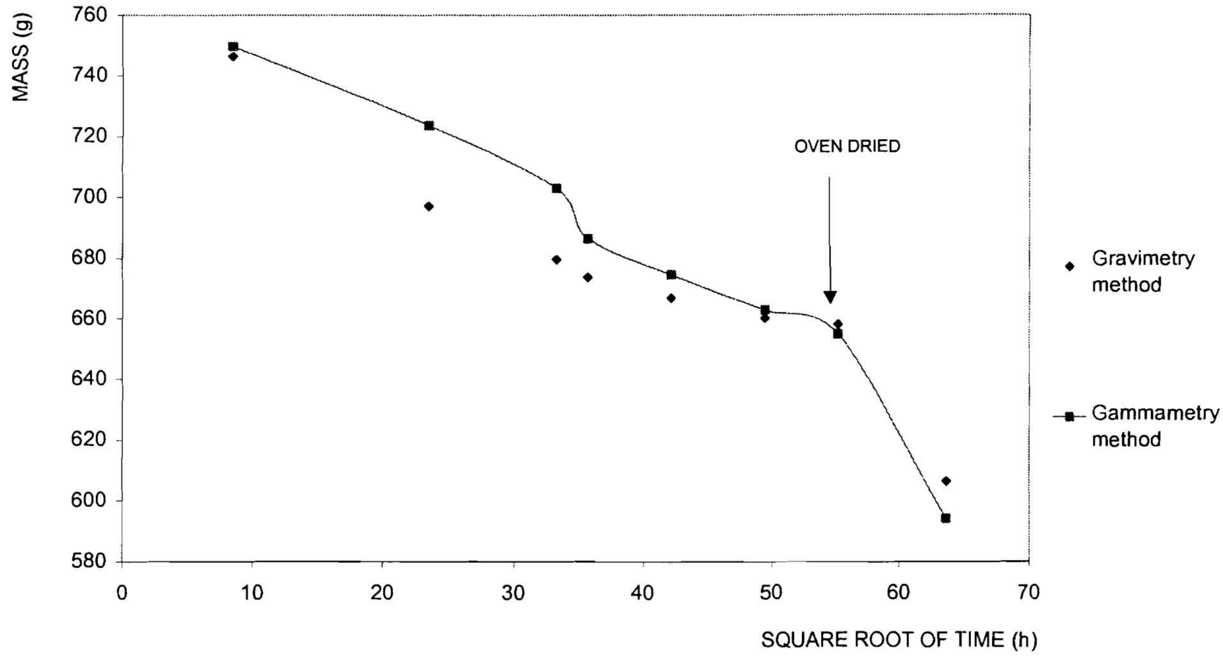

Figure 3 Comparison of the variation of the mass of a 100-mm sample calculated by gammametry and gravimetry.

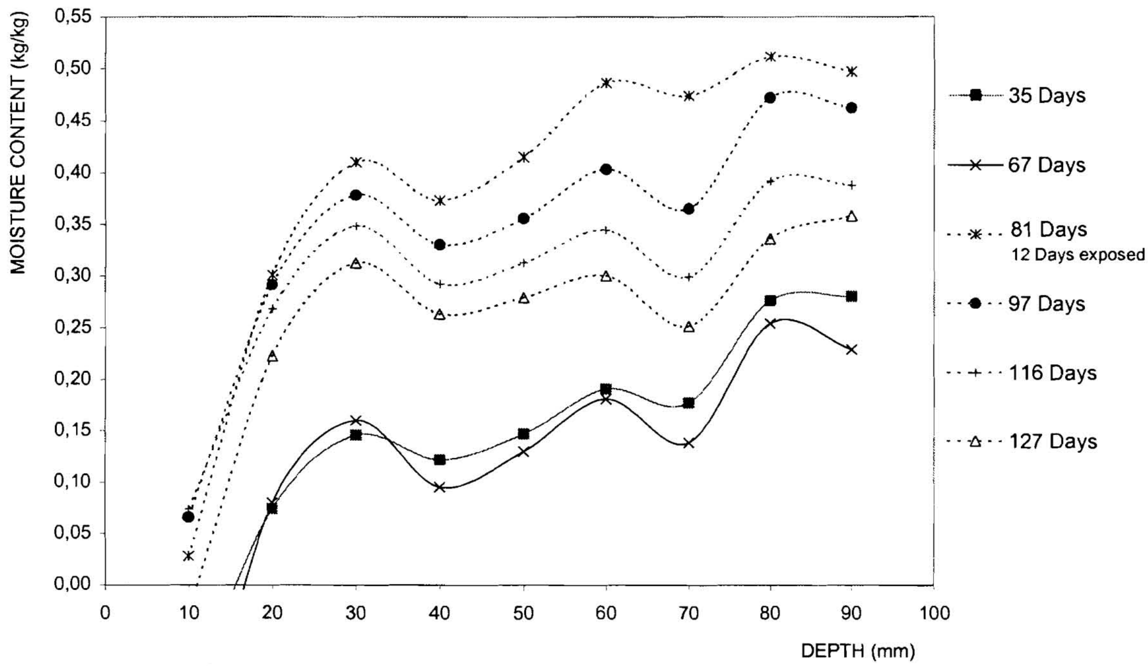

Figure 4 Profiles of the moisture content when drying in outdoor conditions of the 100-mm-thick sample (600kg/m^3).

4.3 Discussion of the Results

The average values for moisture content obtained when drying in laboratory conditions for 100- and 200-mm-thick samples are shown in Table 1. The 300-mm-thick samples are excluded from the table because the drying process is much longer.

Table 1 Values of water content of samples dried in laboratory conditions.

DENSITY (kg/m³)	LAYER THICKNESS (mm)	MOISTURE CONTENT (kg/kg)						
		23 (days)	*30 (days)*	*46 (days)*	*53 (days)*	*74 (days)*	*102 (days)*	*127 (days)*
440	200	--	0,32	0,28	--	0,27	0,26	0,22
600	100	0,23	0,17	0,15	0,14	0,12	0,10	0,09
	200	0,23	--	0,22	0,22	0,21	0,18	0,17

For a cellular concrete of 600 kg/m^3 and thicknesses of 100 and 200 mm, after drying for 102 days, the amount of water found within it exceeds the values for the amounts of water corresponding to hygroscopic equilibrium (50% RH) by 1,2 l/m^2 and 12 l/m^2, respectively.

The moisture content observed in the samples dried in outdoor conditions were considerably higher. As an example, one should note that the average values for moisture content, measured in 100-mm-thick samples (600kg/m^3), 81 days after exposure without rain and sun between the 1st and the 69th days and under the influence of sun and rain between the 69th and 81st days, the values for moisture content exceed 0,40 kg/kg; that is, they exceed by 19 l/m^2 the values for the amount of water corresponding to the hygroscopic equilibrium.

5. PRACTICAL RECOMMENDATIONS FOR THE APPLICATION OF THIS MATERIAL

The application of cellular concrete, as a moulded layer for flat roofs or as a layer for filling pavements, executed "in situ", requires recommendations in what concerns its drying process so that it will not interfere with the hygrothermal behaviour of the construction elements in which the cellular concrete is inserted.

The thicknesses of the layer of cellular concrete to be adopted should be chosen by keeping in mind the drying time. As an example, one can refer to the fact that in the application of a 100-mm-thick layer of cellular concrete, the value of water content found in the material, after being dried for 23 days, is some 10 litres of water per m^2. To us, it seems inadvisable that one should use layers of cellular concrete over 20 cm thick when the possible drying times, without rain, are less than 120 days.

The use of cellular concrete is very complex when it is not sheltered from rainfall. Therefore, the use of protection devices is recommended, during the drying period. A cellular concrete with a density of around 440 kg/m^3 and with a thickness of 200 mm can contain over 25 litres of water per m^2 after exposure to rain for a short period.

The most common forms of protection consist of devices placed on the layer of cellular concrete. This will avoid humidification and, at the same time, allow for the development of the material's drying process.

Another type of constructive drying devices consist of making holes in the layer of cellular concrete, whose length should be greater than half its thickness, and then place perforated tubes, inside these holes to ensure the drying at different levels. These holes are later covered before the waterproofing system is placed. However, protection from the direct rain is required.

6. CONCLUSIONS

As a result of this experimental study, the following conclusions can be obtained:

- The drying of cellular concrete is a long and complex process lasting several months;
- The drying period is increased by the increase in the thickness of the applied material;
- The development of the drying process is deeply influenced by climate conditions and by the physical characteristics of the cellular concrete;
- The tested material is not homogeneous;
- The occurrence of rainfall gives rise to an increase of the drying time;
- In paragraph 5 recommendations are given to the practical application of this material.

7. REFERENCES

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