GAS PERMEABILITY OF CONCRETE: DEFINITION OF A PRECONDITIONING PROCEDURE FOR MEASUREMENTS AND CROSSOVER TRIALS

Gas permeability of concrete

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Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 236-245.

Abstract

This paper describes the main results obtained jointly by a number of French laboratories within the framework of a group under AFREM (Association Française de Recherches et Essais sur les Matériaux et les Constructions).
The objectives of this group were to define a preconditioning process which would result in a better distinction between the various types of concrete with an acceptable test length, and to draft a recommendation for measuring the gas permeability of concrete.
The procedure for measuring the gas permeability of concrete provides good reproducibility. However, the equipment used does not allow the measurement of permeability values greater than 10^{-19} m².
A conditioning procedure for predrying a test sample before measurement was defined. This conditioning procedure is the result of a compromise among the necessary attributes of a test, which should be easy to apply and as rapid as possible, while not degrading the test sample excessively. A drying temperature of 80°C was selected, with two permeability measurements (at seven and 28 days).
It was noted during the tests that the moisture content of the material had a considerable impact on gas transfer, and consequently that measuring permeability alone was not sufficient to distinguish between concrete types. It is absolutely essential that this test be accompanied by a measurement of mass loss, and a graph representation of permeability as a function of mass loss seems to be the only effective way of distinguishing between types of concrete.

Keywords: permeability, concrete, drying, measurements, mass loss, saturation

1 Introduction

The permeability of concrete to gases is one of its basic durability indicators. Accordingly, permeability measurements must follow a well-defined procedure to produce values which can be considered reliable.

The "permeability" subgroup of the AFREM "concrete durability" group has therefore worked to establish a procedure for conditioning concrete before measurements are taken, in order to better distinguish among types of concrete within an acceptable period of time (Quenard and Carcasses, 1997).

The moisture content of the material has a considerable influence on gas transfer and was taken into account.

2 Materials and equipment

2.1 Materials

Two concrete formulations were studied in four trials: a high-performance concrete (HPC) and a plain concrete (B40), the properties of which are given in Table 1. The concrete pourings were kept under static conditions for a day at 20°C, then removed from their moulds and kept in a humid room (20°C, 95% RH) until old enough for testing to begin, or 28 days. Between the 14th and 28th days, core samples were taken and sawn to obtain disks 15 cm in diameter and 5 cm high.

Before the start of testing, the side of each sample was covered with an aluminum cling film to achieve unidirectional drying.

Table 1: Composition of the two concrete types in the crossover trials

Composition	HPC	B40
cement	400 kg	400 kg
type of cement	CEMII 52.5	CEMI 52.5
sand 0/5	660 kg	844 kg
fine gravel 5/12.5	415 kg	1153 kg
gravel 12.5/20	865 kg	/
plasticizer	20 kg	/
water	125 kg	196 kg
slump	17 cm	
S28d	75 MPa	41 MPa
W/C	0.31	0.65
porosity	8.5%	14.6%

2.2 Porosity, mass loss, water content and degree of saturation

2.2.1 Porosity

The porosity ε is defined by the following equation:

$$\varepsilon = \frac{M_{ctd} - M_{dry}}{M_{air} - M_{wtr}}$$

where M_{ctd} = mass in air of the saturated, coated test piece
M_{air} = initial mass in air of the saturated test piece
M_{wtr} = initial mass in water of the saturated test piece
M_{dry} = mass of the coated test piece dried at 105°C

2.2.2 Mass loss

The mass loss ΔM, for a measurement time X in days, is calculated using the following equation:

$$\Delta M = \frac{M_{ctd} - M_X}{M_{ctd}}$$

where M_X = mass of the test piece for a measurement time X.

2.2.3 Degree of saturation

The degree of saturation S is calculated using the following equation:

$$S = \frac{M_x - M_{dry}}{M_{ctd} - M_{dry}}$$

During the different tests, the dry mass M_{dry} was not always measured. Nevertheless, considering the low variability of porosity (Table 1), M_{dry} can be estimated from the test sample volume V_t fixed by the measurement method (diameter of 15 cm, thickness of 5 cm).

2.3 Equipment

The instrument used was a constant-head permeameter of the CEMBUREAU type (Fig.1) with a range of absolute pressures from 1to 6.10^5 Pa (1 to 6 bars).

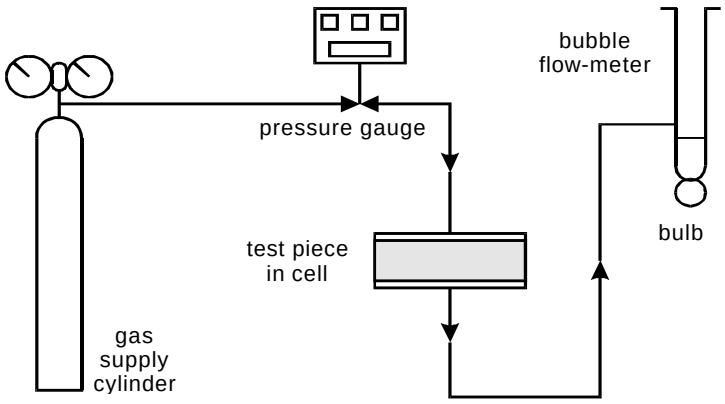

Fig. 1: Flow diagram of permeameter operation

3 Tests and results

3.1 Preconditioning of HPC at 50°C, 80°C and 105°C

When the concrete is 28 days old, preconditioning starts with drying in a ventilated oven (at different temperatures depending on the trial). When drying is completed, the test sample is kept for one day in a sealed bag at 20°C to allow it to return to thermal equilibrium. The mass losses of the samples are monitored at each stage of preconditioning.

At the end of preconditioning, the gas permeability is measured. The samples are then returned to the oven for another period of drying.

Three trials corresponding to three drying temperatures (50, 80 and 105°C) were carried out with the HPC described in Table 1.

To begin with, drying in an oven regulated to 50°C, 80°C and 105°C in turn, in a laboratory regulated to 23°C and 50% RH, results in corresponding relative humidity values surrounding the test sample of approximately 11%, 8% and 3%. Thus the drying conditions are very severe.

The drying curves in Figure 2 show the good reproducibility obtained among the laboratories for drying at 50°C for three months. These curves are more scattered for

The drying kinetics increase with temperature, as temperature plays its usual role as a kinetics accelerator. Equilibrium thus seems to be reached quite quickly (between 10 and 20 days) when drying is performed at 105°C, while at 80°C and 50°C the drying curves are still changing substantially after 50 days of drying.

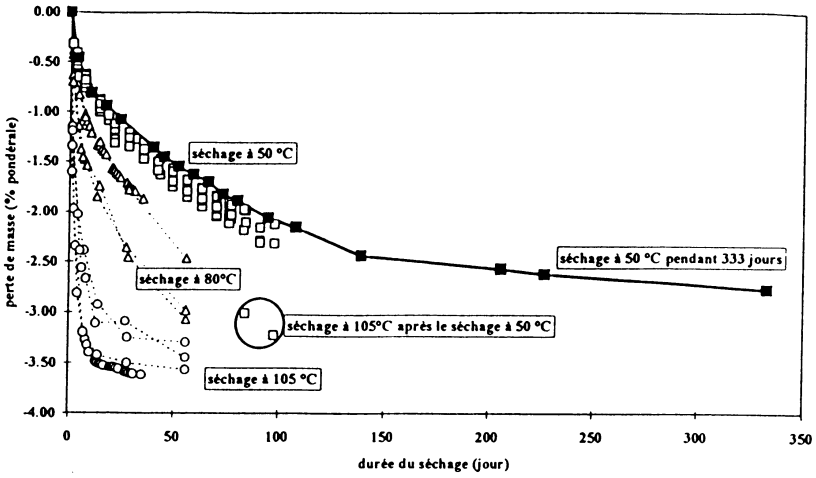

Fig. 2: Weight loss as a function of duration and temperature of drying

It is also interesting to note that drying at 50°C, continued over a very long period of about one year, results in a mass loss approaching the value obtained at 105°C. This development is explained by the fact that, for the three drying temperatures (50, 80 and 105°C), the surrounding relative humidity is very low

(between 3% and 10%) and the drying power of the air is almost identical in all three cases.

Another observation is that, when certain samples are dried at 105°C after drying at 50°C, their mass losses tend toward those obtained by an initial drying at

During the drying process, moreover, the distribution of water through the material is not homogeneous: there is a water content gradient. The moisture content profile was monitored by gammametry during drying (Fig.3). This gradient was not disregarded but, since a homogeneous redistribution of the water in the sample could not be expected within a reasonable time, the permeability measurements were taken with a non-homogeneous distribution of moisture and the average saturation level was considered representative of the condition of the material.

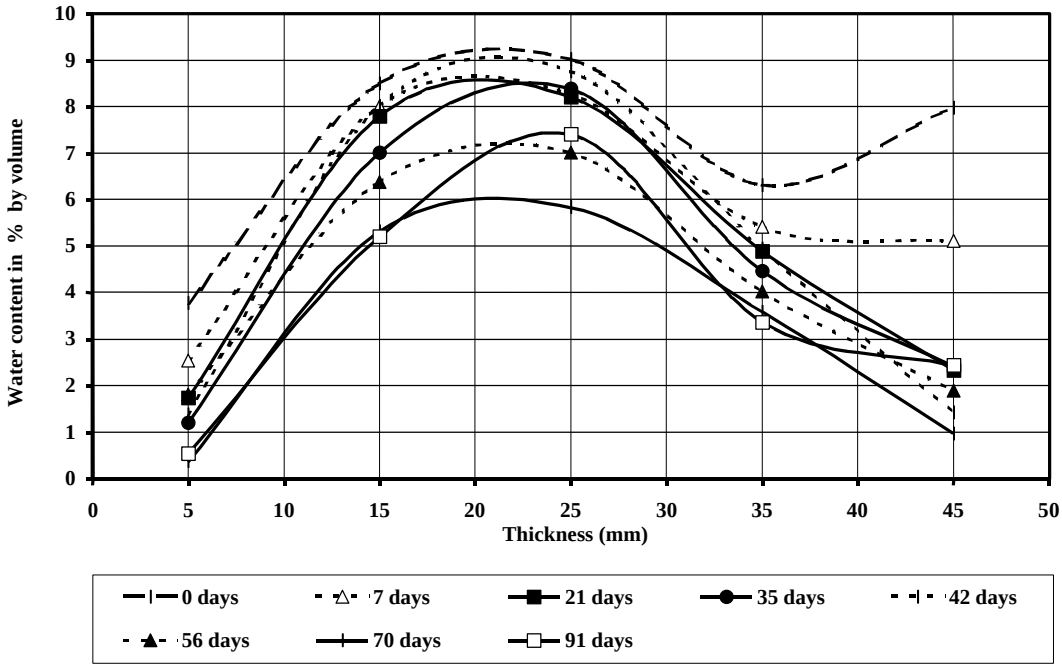

Fig. 3: Water content profiles for different drying times at 50°C

3.2 Permeability of the HPC

At 50°C, the permeability was measured every seven days for three months. In addition, for the sample on which drying was extended to approximately one year, the permeability was also measured during that period.

For conditioning at 50°C, the permeability was measured with a gauge pressure of 5 bars, while for 80°C and 105°C this pressure was no more than 1 bar.

The results for permeability as a function of drying time and degree of saturation of the samples are given in Figure 4. It can be seen that the permeability varies markedly with drying time. It increases by about two orders of magnitude (from 10^{-19} to 10^{-17}m²) between 20 et 100 days of drying, or for a reduction in saturation from 70 à 30%. Moreover, the permeability values measured after drying the samples at 105°C increase by yet another order of magnitude. Finally, continuing the measurement of

permeability for drying times of about 300 days at 50°C shows that the permeability tends toward the value obtained by drying at 105°C (Fig. 4).

Figure 4 shows that scattering is greater for the permeability measurements than for the drying curves, and that it increases with shorter drying times (less than 50 days) (Fig. 4). This suggests that there is a threshold value for saturation below which it is impossible to measure any gas flow with sufficient accuracy: there is no percolation path allowing the flow of gas. In this zone, a small variation in mass loss can result in a pronounced variation in permeability.

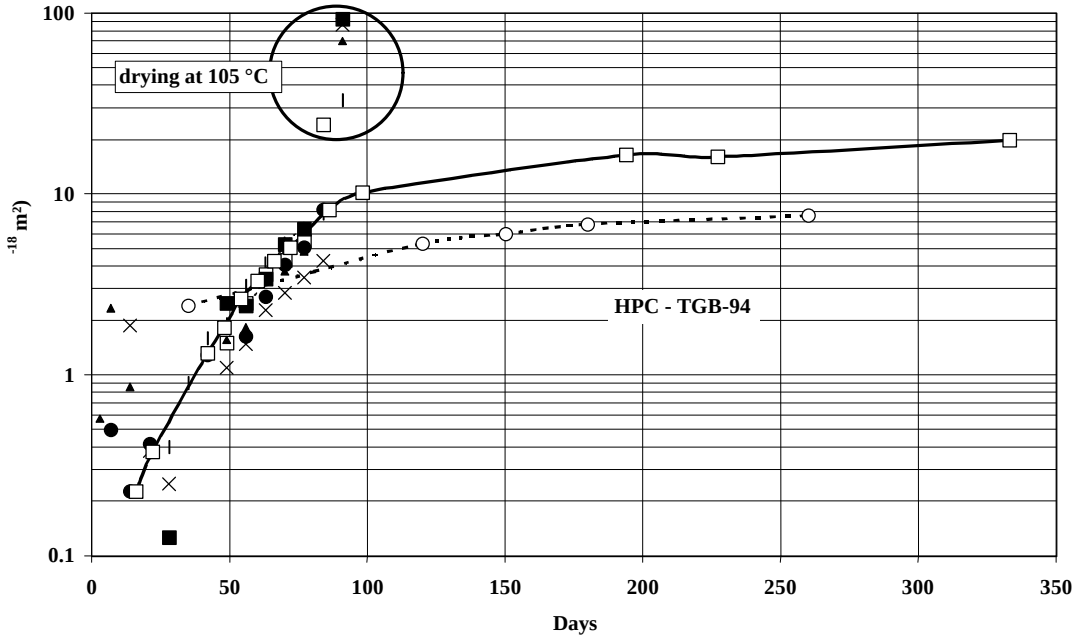

Fig. 4: Permeability as a function of drying time at 50°C

A series of values obtained during an earlier study on concrete prepared with an identical formulation (curve marked "HPC-TGB94") has been included in Figure 4. Although these values are lower, they show the same trend as a function of drying time.

3.3 Preconditioning of the HPC and B40 at 80°C

In the final trial, the two concrete formulations described in Table 1 were tested.

The B40 lost more water (Fig. 5), as its porosity is greater (Table 1). In addition, its mass loss was more rapid, as the pores in this concrete are definitely larger in size.

When permeability is shown as a function of the degree of saturation of the material (Fig. 6), it is apparent that, for high saturation levels, the measurements for the HPC are very scattered, with a maximum difference greater than one order of magnitude (Fig. 6). This scattering may also be related to a percolation effect: a small variation in water content can result in a significant change in the connectivity of the porous network. Moreover, it is very important to mention that this representation does not allow us to distinguish between the two types of concrete.

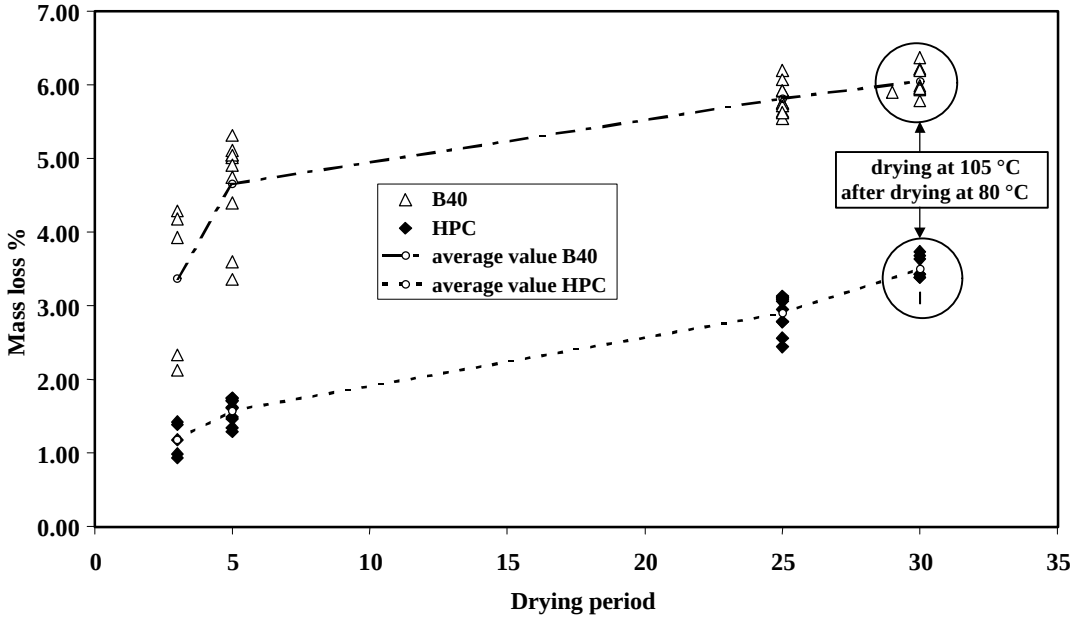

Fig. 5: Mass loss as a function of drying time

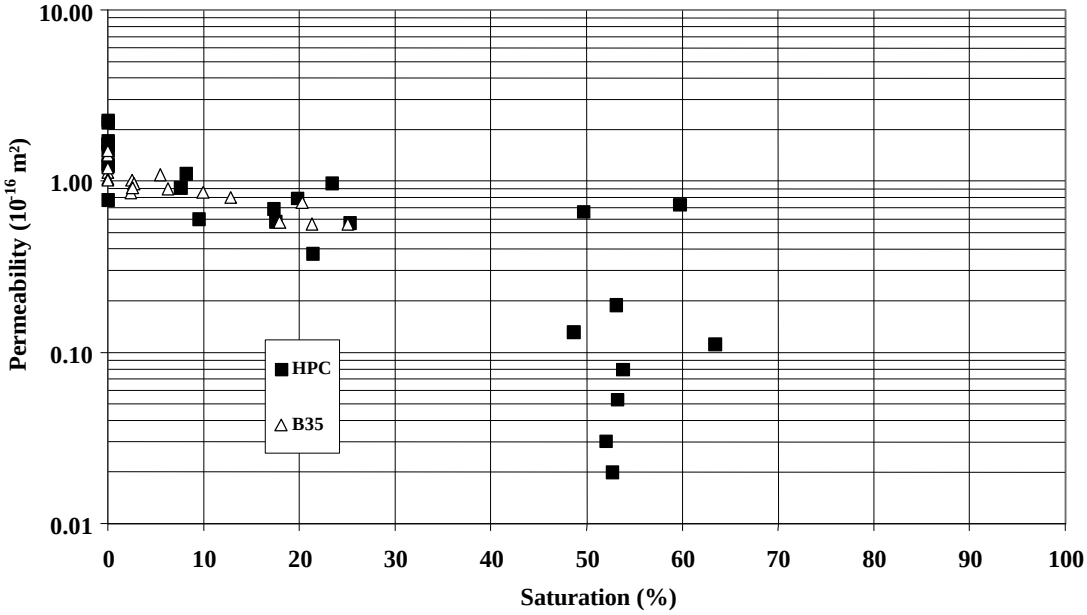

Fig. 6: Permeability as a function of degree of saturation – 4th trial

Comment: In this section, permeability values are expressed in 10^{-16} m² and no longer in 10^{-18} m² as in the preceding sections.

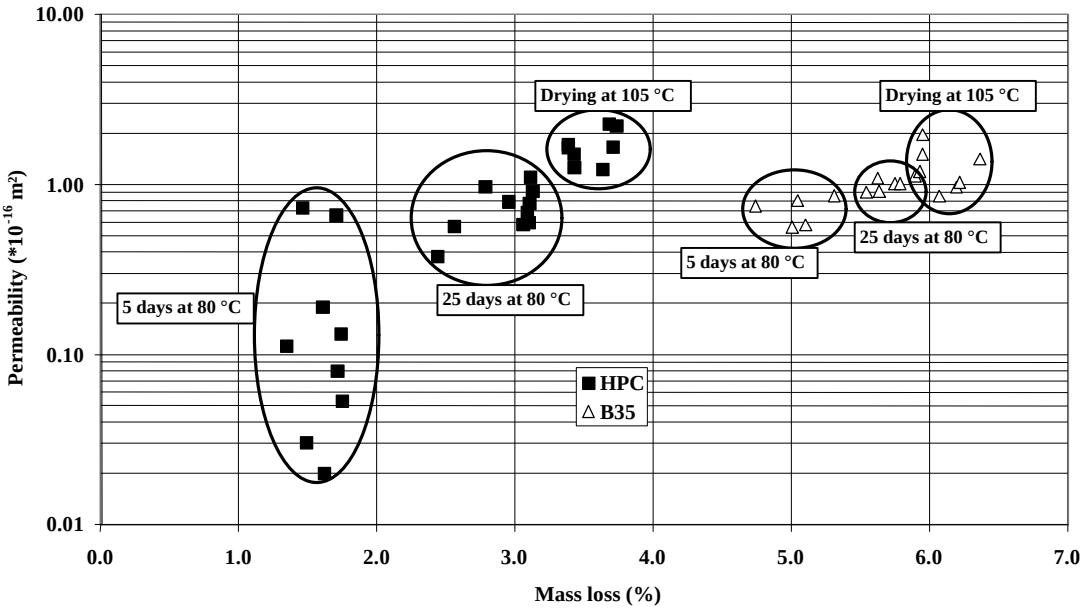

Fig. 7: Permeability as a function of weight loss: HPC and B40.

This is why, in Figure 7, the change in permeability is plotted as a function of mass loss: this type of representation allows us to differentiate between the two types of concrete studied.

In fact, for a given saturation level, the HPC and B40 show similar permeability values, but a given saturation level does not correspond to identical mass losses.

At this point, it is important to point out that plain concrete (PC) which is close to its water saturation point can have a gas permeability value lower than HPC in the "dry" state.

Figure 8 shows most of the permeability values for the HPC obtained during the four trials. We see that the points are all clustered in a beam showing a variation of about three orders of magnitude between the "dry" state and a saturation level close to 80%. It is interesting to compare this tendency to that obtained by C. Gallé (Gallé, 1997) for cement pastes. Finally, Garboczi and Bentz (Garboczi and Bentz, 1991) obtained a percolation threshold of 18% for porosity using a simulation model for the hydration of cement.

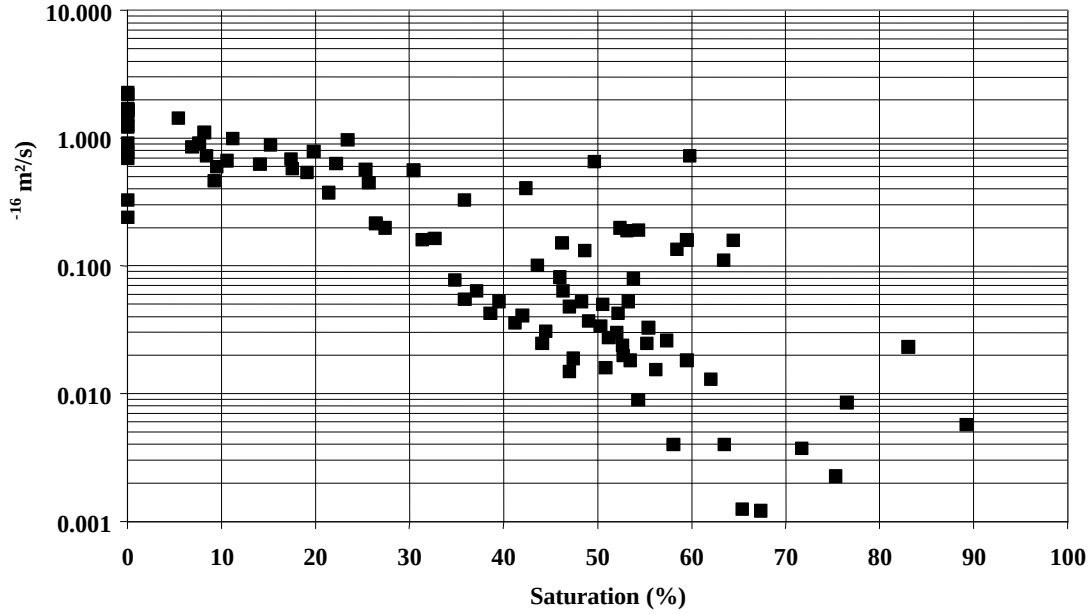

Fig. 8: Permeability as a function of degree of saturation for the HPC

4 Conclusion

The work by the permeability subgroup enabled it to draft a recommendation for the measurement of gas permeability. An essential element of this recommendation is the definition of a conditioning procedure for predrying test samples before measurements are taken. This conditioning procedure is the result of a compromise among the necessary attributes of a test, which should be easy to apply and as rapid as possible, while not degrading the test sample excessively. A drying temperature of 80°C was selected, with measurements at two points in time (seven and 28 days).

Moreover, measuring permeability alone is not sufficient to distinguish between concrete types; it is absolutely essential that this test be accompanied by a measurement of porosity to calculate the degree of saturation and loss of mass. The representation of permeability as a function of mass loss seems to be the only effective way of distinguishing between types of concrete.

5 Acknowledgements

The authors would like to thank all the partners in the "permeability" working group for their effective participation:

- CERIB: Ms C. Dubois, Mr R. Bodet
- CTG (Ciments français - Italcementi): Ms S. Morgano and Ms B. Bourdette, Mr F. Demars.
- EDF - CEMETE: Mr A.Ponsonnet.
- CEBTP: Mr Tran .

- LCPC: Ms V. Baroghel-Bouny.
- LERM: Mr H. Hornain; Mr B. Quénée, Mr Rajnak
- LMDC: Prof. J.P Ollivier, Ms N. Ruscassier
- CSTB: Mr P. Kalifa, Mr H. Sallée and Ms M. Tsimbrovska

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