



RILEM TC 116-PCD: Permeability of Concrete as a Criterion of its Durability

Recommendations

The texts presented hereafter are drafts for general consideration. Comments should be sent to the TC Chairman: Prof. Jörg Kropp, Hochschule – Bremen, Labor für Baustofftechnologie, Fachbereich3- Neustadtswall 30, D-28199 Bremen, Germany Fax: +49 421 590 53 02; e-mail: kropp@fbb.hs.bremen.de, by 31 October 1999.

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TESTS FOR GAS PERMEABILITY OF CONCRETE

A. PRECONDITIONING OF CONCRETE TEST SPECIMENS FOR THE MEASUREMENT OF GAS PERMEABILITY AND CAPILLARY ABSORPTION OF WATER

1. SCOPE

The present draft standard describes a standard method to precondition separately cast concrete test specimens for the measurement of the gas permeability as well as of the capillary absorption of water in routine laboratory tests at an age of the concrete of 28 days or more. The preconditioning shall install a defined pre-drying of the concrete test specimens to an intermediate average moisture concentration, which is in equilibrium with 75 +/- 2 percent relative humidity of the ambient air at a temperature of 20 +/- 1°C and with a uniform distribution of the evaporable water in the test specimens. The preconditioning procedure itself consists of a pre-drying step and a subsequent redistribution phase.

2. TEST SPECIMENS

The test specimens considered in this guideline are circular discs with a diameter of 150 mm and a height of 50 mm. They are separately cast in molds of appropriate size and cured after pouring according to a specified method and duration. Subsequent to the curing, the pre-conditioning of the specimens for either permeability or absorption experiments starts up.

3. DETERMINATION OF THE EQUILIBRIUM MOISTURE CONCENTRATION

For each test series, the moisture concentration of the concrete in equilibrium with an atmosphere of 75 +/- 2 percent relative humidity at 20 +/- 1°C must be determined from a desorption experiment.

3.1 Measurement of total evaporable water content W_e

The total evaporable water content W_e at the end of the curing regime is measured by oven drying the test specimen at 105°C. Drying shall continue until the observed weight loss is less than 0.5 g between two consecutive readings at a time interval of 24 hours.

$$W_e = m_o - m_d \quad (1)$$

W_e = total evaporable water content [g]
 m_o = mass of specimen at the end of curing [g]
 m_d = mass of specimen after oven drying [g].

The evaporable moisture concentration w_e is calculated from the evaporable water content W_e and the dry mass of the specimen by:

$$w_e = W_e / m_d \quad [-] \quad (2)$$

3.2 Measurement of the intermediate equilibrium moisture concentration

The moisture concentration of the tested concrete in equilibrium with 75 +/- 2 percent relative humidity at 20 +/- 1°C, $w_{e,75}$, is measured in a desorption experiment. At the end of the curing regime, the concrete under investigation is subjected to an atmosphere of 20 +/- 1°C and 75 +/- 2 percent relative humidity until moisture equilibrium is attained.

3.2.1 Exposure climate

The ambient climate may be installed in a climate-controlled chamber with a controlled temperature of 20 +/- 1°C and a relative humidity of 75 +/- 2 percent, or in a sealed glove box over a saturated solution of sodium chloride (NaCl) containing excess solid salt, with the glove box being kept at a controlled temperature of 20 +/- 1°C. Sufficient air circulation in the climate chamber or in the glove box must be provided in order to control the boundary conditions of the test specimens.

3.2.2 Preparation of the specimens

A high surface-to-volume ratio of the tested concrete accelerates the necessary drying to equilibrium. The hardened concrete may be cut into thin slices approximately 5 mm in thickness or may be crushed into grains of an equivalent diameter. Because of the high surface area, carbonation of the concrete must be avoided. Therefore, the climate chamber must be operated with carbon dioxide-free air; if a glove box is used, weighing of the samples in the sealed box is preferred.

3.3 Measurement of the evaporable water content $W_{e,75}$

A minimum of 500 g of the concrete prepared according to Section 3.2.2 are used for the desorption test. The concrete is placed in an open container or rig to allow free access of the ambient air, but care must be taken to ensure that no material is lost during subsequent weighing during the course of the experiment.

The water content $W_{e,75}$ of the concrete is measured by oven drying at 105°C after equilibrium has been reached at 75 +/- 2 percent relative humidity. With sufficient accuracy, equilibrium conditions may be assumed if the weight change of the specimens is less than 0.1 g between two consecutive readings after a time interval of 24 hours. The evaporable water content at equilibrium is calculated after oven drying from:

$$W_{e,75} = m_{e,75} - m_d \quad (3)$$

$W_{e,75}$ = equilibrium water content at 75 +/- 2 percent relative humidity [g]

$m_{e,75}$ = mass of concrete at equilibrium with 75 +/- 2 percent relative humidity [g]

m_d = dry mass of concrete [g].

The equilibrium moisture concentration $w_{e,75}$ is calculated by:

$$w_{e,75} = W_{e,75}/m_d \quad (4)$$

4. DETERMINATION OF THE NECESSARY WEIGHT LOSS DURING PRE-DRYING

The necessary weight loss during pre-drying Δm is calculated from the original mass of the test specimen at the end of the curing, its initial evaporable moisture concentration w_e and the equilibrium moisture concentration $w_{e,75}$:

$$\Delta m = \left(\frac{w_e - w_{e,75}}{1 + w_e} \right) m_o \quad (5)$$

Δm = weight loss [g].

5. PRE-DRYING

The drying of the concrete specimens is accelerated at an elevated temperature of 50°C in a ventilated climate chamber where the test specimens are kept until the pre-set weight loss of each of the test specimens Δm is attained. In order to prevent the formation of radial moisture gradients, the circumferential surfaces of the test specimens are sealed with an impermeable and tight material. Free air circulation at the exposed surfaces of the concrete discs must be assured.

The pre-drying shall continue until the required calculated loss of water Δm is attained within a 5 percent level of accuracy:

$$\frac{\Delta m_{obs} - \Delta m_{cal}}{\Delta m_{cal}} < 0.05$$

Δm_{obs} = observed weight change during experiment [g]

Δm_{cal} = required weight change according to equation (5) [g].

During the drying process, the weight loss of the specimens must be monitored by repeated weighing over short time intervals. For ordinary concrete mixes, the necessary drying time depends on the water vapor diffusivity of the concrete and may vary between several hours and approximately two weeks.

6. MOISTURE REDISTRIBUTION PHASE

Subsequent to the pre-drying, the concrete specimens are sealed or stored in small sample containers at an ambient temperature of 50°C. Since no moisture exchange with the environment is possible, the elevated temperature will accelerate the redistribution of the axial moisture gradients towards a homogeneous distribution. The redistribution phase continues until an age of 27 days, but with a minimum duration of 14 days. Then, the specimens attain temperature equilibrium under the

laboratory condition, (20 +/- 1°C) in the sealed state in order to prevent against further drying while cooling during a minimum of 24 hours before the measurement of permeability or absorption commences.

7. TEST REPORT

The test report contains information on the type of concrete tested, such as the type of cement, aggregate grading, mix proportion and curing conditions. The hygric characteristics of the concrete are described by the following parameters:

w_c = initial evaporable moisture concentration at the end of curing

$w_{e,75}$ = equilibrium moisture concentration with 75 +/- 2 percent relative humidity at 20 +/- 1°C.

For each test specimen, the following values are also recorded:

m_o = mass of specimen at the end of curing [g]

Δm_{cal} = calculated necessary weight loss during pre-drying [g]

Δm_{obs} = observed weight loss at the end of pre-drying [g]

t = observed drying time until equilibrium was reached [hours].

8. LIMITATIONS

Based on experimental evidence, the described procedures will lead to a homogeneous distribution of the equilibrium evaporable water content at 75 +/- 2 percent relative humidity in specimens of normal grade concretes in the described size and shape, provided the preconditioning is performed at the end of curing.

These procedures may also be applied to specimens of different sizes and shapes, to concretes with special composition or to specimens taken from existing structures which have been re-wetted in order to run a second drying process. In these cases, the effectiveness of the preconditioning must be evaluated by an experimental determination of the remaining moisture profiles at the end of the preconditioning.

This preconditioning method may also be used for other purposes than permeability or absorption experiments, *i.e.* if a uniform moisture distribution in the concrete specimen is sought.

B. MEASUREMENT OF THE GAS PERMEABILITY OF CONCRETE BY THE RILEM - CEMBUREAU METHOD

1. SCOPE

The described test method covers the determination of the gas (O₂, N₂) permeability of separately cast concrete specimens. This method can be applied to ordinary concrete grades for structural applications as well as for similar cement-based materials used in construction.

2. DEFINITIONS AND SYMBOLS

Symbols	Units	Definitions
A	m ²	cross-section of the specimen
D	m	diameter of the specimen
L	m	thickness of the specimen
K_i	m ²	gas permeability coefficient at pressure stage i
Pa	Pa	atmospheric pressure, absolute (1 bar = 10 ⁵ Pa)
P_i	Pa	applied test pressure, absolute
Q_i	m ³ /s	flow rate at pressure stage i
μ	Pa.s	gas dynamic viscosity at 20°C +/- 2°C

V_i	m ³	measured volume at pressure stage i
t_i	s	time for the bubble to cross the measuring volume V_i .

3. APPARATUS

The test must be performed in a room with a controlled temperature of 20°C ± 2°C without excessive air circulation close to the test apparatus.

The apparatus consists of:

- a tool to measure the specimen dimensions with a precision of 0.1 mm,
- a CEMBUREAU permeameter with a pressure cell to accommodate concrete discs with a diameter of 150 mm and a thickness of 50 mm, a gas supply with a pressure regulation (0.1 to 0.6 MPa) and with a precision of ± 0.01 MPa,
- calibrated soap bubble flow meters, *e.g.* 150 ml, 15 ml, 5 ml, 1 ml,
- a chronometer sensitive to 0.1 s,
- oxygen or nitrogen bottles.

The schematic layout of the experimental set-up is shown in Fig. 1. The permeameter cell is given in Fig. 2 [1].

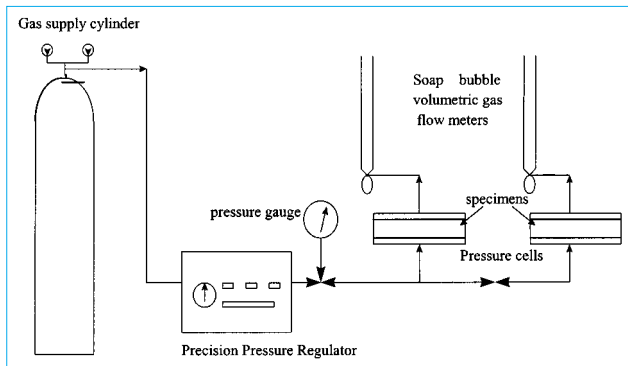


Fig. 1 – Layout of the experimental set-up.

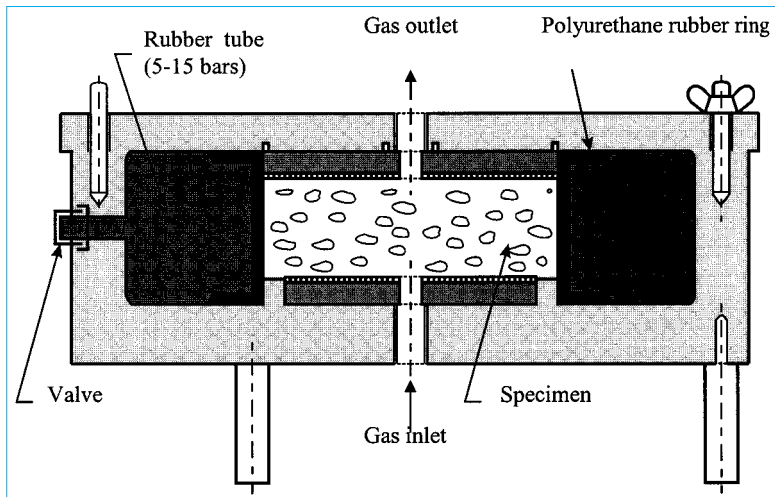


Fig. 2 – Permeameter cell [1].

4. TEST SPECIMEN

4.1 Size and shape of test specimens

The test specimens for the measurement of gas permeability shall be discs with a thickness of $50 \text{ mm} \pm 1 \text{ mm}$ and a diameter of $150 \text{ mm} \pm 1 \text{ mm}$. A minimum of three test specimens are required to characterize a concrete.

The test specimens are cast in molds of steel or polymer of sufficient rigidity and appropriate size to assure the required dimensions and circular shape of the concrete disc. Pouring and compaction of the concrete shall comply with national regulations until approval of EN 206.

4.2 Initial conservation and demolding

During the first 24 h after pouring of the fresh concrete, the test specimens are kept under wet burlap and plastic sheet at an ambient temperature of $20^\circ\text{C} \pm 2^\circ\text{C}$. Then, the test specimens are demolded and cured as specified for the particular investigation. For a comparison of different concretes, the same curing procedure must be applied.

4.3 Preconditioning

After completion of the specified curing regime, the specimens are preconditioned according to the draft standard “Preconditioning of concrete test specimens for the measurement of gas permeability and capillary absorption”.

5. TEST PROCEDURE

(1) Measure the diameter of the test specimen in 4 positions (two perpendicular diameters in both top and bottom faces) with a precision of 0.1 mm. The diameter D is the mean value of the four readings. The thickness L of the test specimen is determined in four positions equally distributed along the perimeter.

(2) Place the test specimen in the cell and assemble the apparatus.

(3) Build up a minimum lateral pressure of 7 bar (0.70 MPa) on the rubber tube.

(4) Select 3 pressure stages: start with 1.5 bar (0.15 MPa) and increase to 2.0 (0.20 MPa) and then 3.0 bar (0.30 MPa) absolute gas pressure. Correct the input pressure of gas if necessary within 10 minutes.

(5) Wait for 30 minutes before measuring the first flow.

(6) Measure the flow at each pressure stage until it becomes constant, as follows:

(6a) Moisten the capillary of the soap bubble flow meter 1 minute before creating the bubble for measurement.

(6b) Always start the time measurement when the bubble is at the lowest marking of the calibrated tube.

(6c) Select the measuring volume by choosing the appropriate soap bubble flow meter such that the time reading is more than 20 seconds.

(6d) Take provisional readings of the flow rate. If the difference between successive readings within 5 to 15 minutes is less than 3%, take at least 2 readings in quick succession and determine the flow rate Q_i (passed volume V_i at pressure stage i divided by average time reading of the previous two readings t_i): $Q_i = V_i/t_i$ (m^3/s) for the given pressure stage. If this condition is not reached within 3 hours (no constant flow is attained, e.g. very low-permeability concretes), take the previous value of the flow rate.

(7) Increase the pressure to the next pressure level and repeat the procedure with steps (6a) through (6d).

Ensure that there are no leaks during the tests: the coefficient K_i should decrease when the pressure increases. If this is not the case, check the test set-up for possible leaks and repeat the measurements.

6. CALCULATION OF THE PERMEABILITY COEFFICIENT

For each specimen, evaluate the average flow rate Q_i at each pressure stage and calculate the coefficient K_i according to equation (1). Determine the mean coefficient K from the three values of K_i . The test result is the average of the three specimens.

$$K_i = \frac{2P_a Q_i L \mu}{A(P_i^2 - P_a^2)} \quad (1)$$

7. TEST REPORT

All available information on the concrete mix and curing conditions are to be given.

Test report on Rilem-Cembureau standard test of gas permeability of concrete

Concrete reference:

Unambiguous identification of the test specimen:

Date of the test:

Diameter and thickness of the specimen:

Mix proportions: (optional)

Curing (method, duration):

Other information:

Any deviation from standard test method

Absolute gas pressure [MPa]	0.15	0.20	0.30	Mean value K (m ²)
sample 1				
sample 2				
sample 3				

REFERENCE

- [1] Kollek, J. J., 'The determination of permeability of concrete by Cembureau Method. A recommendation', *Mater. Struct.* **22** (1989) 225-230.

C. DETERMINATION OF THE CAPILLARY ABSORPTION OF WATER OF HARDENED CONCRETE

1. SCOPE

This draft standard describes the laboratory method for the experimental determination of the water take-up of hardened concrete by capillary absorption on separately cast concrete specimens.

The method is applicable to ordinary concrete grades for structural applications as well as for similar cement-based materials used in construction.

2. TEST SPECIMENS

2.1 Size and shape of test specimens

The preferred shape of the test specimens is a circular disc with a diameter of 150 mm and a thickness of 50 mm. Rectangular specimens may be used if necessary and the minimum test area of such specimens shall be 17,500 mm².

A minimum of three specimens shall be used for each test.

2.2 Manufacturing of separately cast specimens

Separately cast specimens shall be manufactured in molds made of steel or polymer of sufficient rigidity and appropriate size. Pouring and compaction of the concrete shall comply with national regulations on the production of test specimens until approval of EN 206.

No form oil or releasing agents shall be used on the bottom side of the mold when casting the specimens. If steel molds are used, a separation of the hardened concrete from the mold is provided by covering the bottom of the mold with polyethylene sheets or films.

During the first 24 hours after pouring, the specimens are kept under wet burlap and plastic sheet at an ambient temperature of 20 +/- 2°C. Then, the specimens are demolded and cured as specified. For a comparison of different concretes, the same curing procedures must be applied.

3. PRECONDITIONING

After completion of the specified curing regime, the specimens are preconditioned according to the draft standard “Preconditioning of concrete test specimens for the measurement of gas permeability and capillary absorption of water”.

4. TEST METHOD

4.1 Preparation of the test specimens

In order to avoid a moisture exchange of the test specimens with the ambient air during the absorption experiment, the free surfaces shall be sealed against the penetration of water vapor. If a lateral sealing of the circumferential surfaces of the test specimens is not available from the preconditioning, these surfaces may be sealed by self-adhesive tape, epoxy adhesive paint or paraffin.

The top surface of the specimens shall be covered with an impermeable but flexible plastic hood to avoid pore pressure from building up.

4.2 Test procedure

The capillary absorption test is carried out with the following steps:

- The test specimens and the water reservoir are in equilibrium with an ambient temperature of $20 \pm 1^\circ\text{C}$.
- The dimensions of the test specimens, in particular those describing the test area, are measured to an accuracy of 0.1 mm.
- The weight of the prepared specimen m_0 is measured immediately before testing to an accuracy of 0.1 g.
- The molded bottom side of the specimen is immersed in water (tap water) up to a maximum depth of 3 millimeters. The water level is kept constant during the duration of the test.
- The uptake of water by capillary absorption is measured through the weight of the specimens $m(t)$ at time intervals of 10 minutes, 1 h, 4 h and 24 hours of contact with water.
- Before weighing, the surface in contact with water is wiped with a moist sponge or non-absorbing cloth in order to remove free water films, but the concrete surface must remain glossy.

Depending on the purpose of the test, the duration of the suction period may be extended beyond 24 hours,

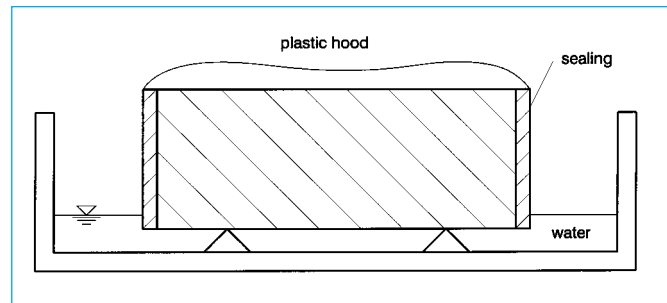


Fig. 1 – Experimental set-up for the capillary absorption test.

but must be completed when the rising water front reaches the top surface.

5. CALCULATION AND PRESENTATION OF THE RESULTS

5.1 Evaluation of results

The water absorption of each test specimen $w(t) = m(t) - m_0$ is recorded and presented for each of the specified time intervals. Together with the absorption data, the area of the tested surface is given for each specimen. The absorption of water per unit area of the test surface [g/m^2] is calculated for the specified suction periods.

A further evaluation of the absorption data, e.g. the calculation of absorption rates, may be specified depending on the purpose of the test. For tests conducted according to this standard, no \sqrt{t} - relation for the absorption of water is expected.

5.2 Test report

The test report shall include all available information on the characteristics of the tested concrete and in particular:

- date of test and age of concrete;
- identification of the test specimens;
- description of concrete, type of cement, mix proportions, aggregate grading;
- curing conditions and duration;
- dimensions of the specimens;
- test results: the mass of water absorption [g] and the water absorption per unit area of the test surface [g/m^2] for the respective suction periods.