XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Study of Preconditioning Procedures for Absorption and Permeability of Concrete

J.P. Castro-Gomes [1]
D. Wang [2]
L. Pereira de Oliveira [3]
R.M. Ferreira [4]

ABSTRACT

The permeability and ability for capillary absorption of concrete are usually served as criteria for assessing the long-term performance (durability) of concrete. In order to know the long-term performance (durability) of concrete, the permeability or capillary absorption test is usually required. However, a long term preconditioning procedure prescribed in RILEM TC 116-PCD is unavoidable if one wants to carry out the permeability or capillary absorption tests. An attempt is made in this paper to address the possibility of simplifying the RILEM preconditioning procedure. The RILEM preconditioning method and a simplified preconditioning procedure were carried out on several sets of specimens which were cut from the same concrete slab. Thereafter, capillary absorption and gas permeability tests were carried out on these same specimens. Results of these two tests were compared between RILEM procedure and the simplified procedure and the results indicate that the two procedures provided similar results and as thus comparable to one another.

KEYWORDS

Capillary absorption, Gas permeability, RILEM preconditioning, Concrete durability.

[1] C-MADE Centre of Materials and Building Technologies, Department of Civil Engineering and Architecture, University of Beira Interior (UBI), Covilhã, PORTUGAL, castro.gomes@ubi.pt
[2] Department of Civil and Environmental Engineering, University of Macau, Macau SAR, China, astetndong@gmail.com
[3] C-MADE Centre of Materials and Building Technologies, Department of Civil Engineering and Architecture, University of Beira Interior (UBI), Covilhã, PORTUGAL, luiz.oliveira@ubi.pt
[4] University of Minho, Department of Civil Engineering, Campus de Azurém, 4800-058 Guimarães, Portugal, Phone +351 253 510 200/494, Fax +351 253 510 217, rmf@civil.uminho.pt

1 INTRODUCTION

According to the procedure given in RILEM TC 116-PCD, before carrying out gas permeability and capillary absorption tests, concrete specimens should first reach an intermediate average moisture concentration; this can be achieved by placing it in an environment of 75±2% RH and 20±1ºC, so that a uniform distribution of the evaporable water in the test specimens can be formed. The preconditioning procedure itself consists of a pre-drying step and a subsequent moisture redistribution phase and may take up to 35 days. Thus, it consists of a longer term conditioning period and offers a relatively complex preconditioning procedure. This however is unavoidable if a uniform moisture distribution in the concrete specimen is sought, as is specified prior to undertaking concrete absorption and gas permeability tests. [RILEM 1983].

An attempt is made in this paper to address the possibility of simplifying the RILEM preconditioning procedure. In this study, the RILEM TC 116-PCD and a simplified preconditioning procedure were carried out on several groups of concrete specimens cut from concrete slabs, of C20/25 compressive strength class, having aged 1 and 6 months. Capillary absorption and gas permeability tests were then carried out on these specimens [LNEC 1993], [LNEC 1993a], [Pereira et al. 2009]. Results of the capillary absorption and gas permeability carried out on groups of samples preconditioned according to the RILEM procedure and the simplified procedure were compared to determine if any differences were evident in the results when using either preconditioning method.

2 RILEM PRECONDITIONING PROCEDURE

2.1 Total Evaporable Water Content

According to the method given in RILEM TC 116-PCD, a specimen of each group should first be dried in an oven at 105ºC until the weight loss between two 24-hour intervals is less than 0.5g. The evaporable water content is then obtained as follows:

$$W_e = m_0 - m_d \tag{1}$$

Where W_e is the total evaporable water content [g], m_0 is the mass of specimen before the drying process [g], m_d is the mass of specimen after oven drying [g]. Then the evaporable moisture concentration w_e is calculated by:

$$w_e = W_e / m_d \tag{2}$$

2.2 Intermediate Equilibrium Moisture Concentration

After the specimen had been dried according to 2.1, it was then placed in a chamber (desiccator) and conditioned at of 75±2% relative humidity (RH) and 20±1ºC, until moisture equilibrium in the specimen was reached. The 75±2% RH condition was produced by a saturated solution of sodium chloride (NaCl) with excess solid salt in the solution. Equilibrium moisture conditions in the concrete was assumed when the difference between weights of specimens at two 24-hour intervals was less than 0.1g. The intermediate equilibrium water content at 75±2% RH, $W_{e,75}$ is given by:

$$W_{e,75} = m_{e,75} - m_d \tag{3}$$

Where $W_{e,75}$ is the mass of concrete at equilibrium with 75±2% RH [g],and m_d is the dry mass of concrete [g]. The intermediate equilibrium moisture concentration $w_{e,75}$ is calculated by:

$$w_{e,75} = W_{e,75} / m_d \tag{4}$$

to accelerate the drying and moisture absorption process and thus to hasten the procedure for determining the equilibrium moisture concentration of the specimen, the specimen was crushed into smaller pieces (with particle size less than 5 mm) [RILEM 1983].

2.3 Weight Loss for Each to-be-Tested Specimen During Pre-Drying

After obtaining w_e and $w_{e,75}$, one can then calculate the necessary weight loss for each specimen to be tested by:

$$\Delta m = \left(\frac{w_e - w_{e,75}}{1 + w_e} \right) m_0 \tag{5}$$

where m_0 is the mass of each specimen to be tested [g].

Attention should be paid to ensure that the small crushed pieces of specimen and the specimens to be tested should come from the same concrete slab, so one can assume that every specimen has the same initial water content. As well, during the process of determining the total evaporable water content of the specimen (2.1) and the intermediate equilibrium moisture concentration (2.2), the specimens to be tested should be sealed so that the same water content before pre-drying can be assured.

2.4 Pre-drying for Specimens to be Tested

All the specimens to be tested must be dried under a temperature of 50ºC in a ventilated oven until the difference between observed mass loss and the calculated mass loss (from 2.3) is less than 5%:

$$\frac{\Delta m_{obs} - \Delta m_{cal}}{\Delta m_{cal}} < 5\% \tag{6}$$

where Δm_{obs} is the observed mass loss during the drying process for specimens to be tested, and Δm_{cal} is the calculated mass loss to reach 75±2% RH in the specimens.

2.5 Moisture Redistribution

After the pre-drying phase, the evaporable water in the test specimen was the same amount as that in an environment of 75±2% RH, but the moisture content was not considered evenly distributed in the specimens. To achieve an even redistribution of moisture in the specimens to be tested, the specimens were sealed and then put in an oven at 50ºC for two weeks. Following this two week period, and after the specimens had cooled to room temperature, the gas permeability or capillary absorption test were carried out on the preconditioned specimens.

3. SIMPLIFIED PROCEDURE FOR ABSORPTION TEST

The RILEM procedure may provide an accurate moisture content which is the same as moisture under the environment of 75±2% RH in the specimens (actually, it is really hard to assure the specimens are really sealed during moisture redistribution period, mass loss can always be observed during moisture redistribution). However, the time to complete this process can be really long. For instance, cutting the specimens and natural drying for specimens can take 2 days. Then determining the intermediate equilibrium moisture concentration can take 4 or 5 days. Pre-drying for the specimens to be tested can take 3 or 4 days. Moisture redistribution will take two weeks. So totally, the conditioning for specimens needs 3 to 4 weeks or so. And, as obviously, long time of conditioning can reduce the

efficiency of research studies. Thus, several simplified procedures were applied in this study. Then the results of capillary absorption and gas permeability tests were compared to evaluate the possibility to use the simplified procedures as alternative to RILEM procedure.

3.1 Comparison Between Samples Preconditioned According to RILEM Procedure and Samples Without any Preconditioning.

Before carrying out the simplified procedures, a comparison between the samples preconditioned according to RILEM procedure and the samples without any preconditioning were made. The purpose of this comparison was to see whether there was an obvious difference in results if no preconditioning was carried out. Tests were carried out on concretes that had been aged for 1 month and 6 months, respectively. Results of capillary absorption tests, for a group of six specimens, are shown in Figures 1 and 2. From the information given in these two figures, it can be observed that the specimens which had been preconditioned have a higher capillary absorption than those without any conditioning. As well, concrete aged for 1 month has higher capillary absorption than concrete aged6 months. However, in the RILEM procedure, during the moisture redistribution period, an amount of 15 g and 11 g moisture loss were observed for the concrete aged 1 month and 6 months, respectively. So the absorption results may be affected by this loss of water.

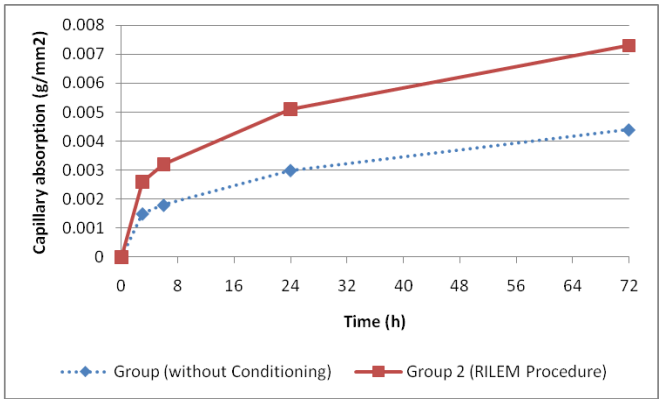

Figure 1. Capillary absorption test comparison between 1 month concrete with conditioning and without conditioning

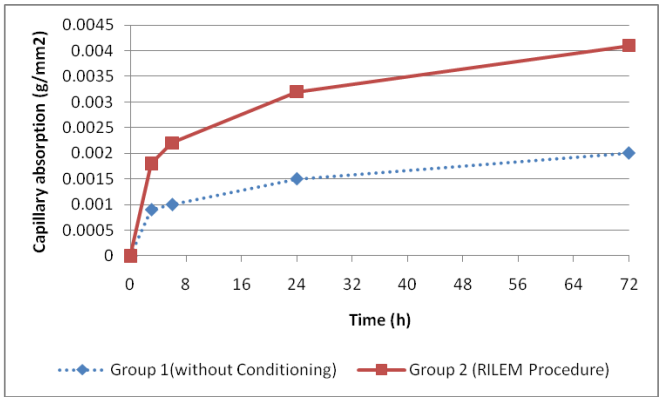

Figure 2. Capillary absorption test comparison between 6 months concrete with conditioning and without conditioning

3.2 Comparison Between RILEM Procedure and Simplified Procedure

Because too much moisture was lost during completing the procedures in section 3.1, a test was redone on the same specimens that had aged 6 months. This test was carried out after one month from those tested in 3.1. The results are shown in 3.2.1.

3.2.1 Simplified Procedure 1

After the specimens were placed in the laboratory for one month, the specimens that were not conditioned in 3.1 were put in a sealed box with 75±2% relative humidity for two weeks. And for the specimens that were pre-conditioned by RILEM procedure, they were immersed in water for half an hour and then dried until the mass reaches to the calculated pre-drying mass. And then they were sealed and put into oven with 50ºC, moisture redistribution for two weeks. Results of capillary absorption tests on these two groups of specimens are shown as in Figure 3. From this figure, one can see the capillary absorption for two groups are similar to each other, and the group with RILEM procedure has slightly higher absorption ability. However, the specimens pre-conditioned according to simplified procedure had been espoused in laboratory for one month. This is quite a long time. So new specimens were made and new tests were carried out on 6 months aging concrete as in 3.2.2 and 3.2.3.

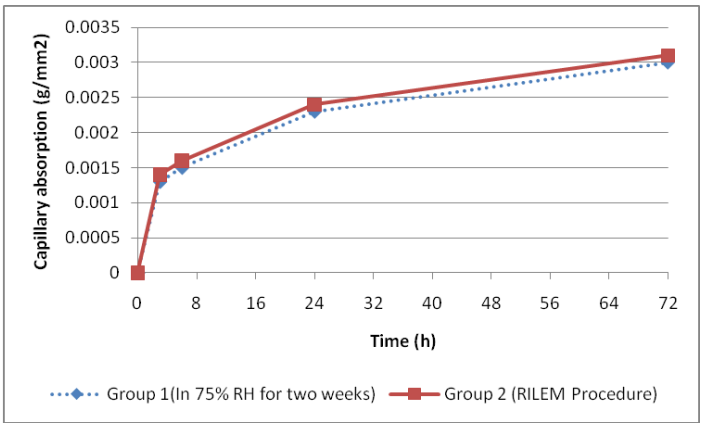

Figure 3. Capillary absorption test comparison between 6 month concrete for group 1: natural dried in laboratory for one month and then put in sealed 75%HR box for two weeks. Group 2:RILEM Procedure

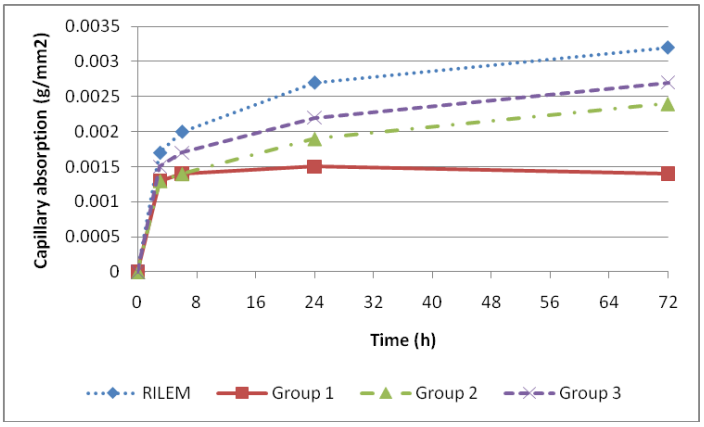

Figure 4. Capillary absorption test comparison between 6 month concrete for RILEM: conditioning according to RILEM procedure. Group 1: natural drying two days, 24 hours oven drying, 1 week 75% RH box, open space absorption test. Group 2: natural drying two days, 24 hours oven drying, 1 week 75% RH box. Group 3: 24 hours oven drying after cutting from concrete slab, 1 week 75% RH box.

3.2.2 Simplified Procedure 2

In this simplified procedure, specimens were naturally dried for 2 days after cutting from the concrete slab. Then they were put in a 50ºC ventilated oven drying for 24 hours. Then they were put in a sealed box with 75% RH for one week. Absorption test was carried out in an open space and in a sealed box, respectively. Specimens in the test carried out in an open space were denoted by group 1, and

specimens in the test carried out in a sealed box were denoted by group 2. In this study, all the absorption tests were carried out in a sealed box except for group 1 in this part.

3.2.3 Simplified Procedure 3

This procedure is similar to 3.2.2, except that the specimens were directly dried in the oven after cutting. That is, specimens were put in a 50ºC ventilated oven drying for 24 hours after cutting from the concrete slab, when it was totally wet. Then they were put in a sealed box with 75% RH for one week. Then absorption test was carried out. Specimens treated by this procedure were denoted by group 3. Capillary test results of these three groups and their comparison to RILEM procedure are shown in Figure 4.

Form Figure 4, we can see the capillary absorption ability of group 1 increases in the first 24 hours, then it decrease from 24 hours to 72 hours. Attention should be paid that the absorption test of group 1 was carried out in an open space (the laboratory) which has a RH about 50%. The mass of sample decreases from 24 hours to 72 hours might be due to the moisture that absorbed is slower than the moisture evaporate from the specimens. Considering the relative humidity in each laboratory is different, carrying out the absorption test in the sealed box is preferred.

Results of group 2 and group 3 have similar pattern to the result of RILEM procedure. But the specimens pre-conditioned according to RILEM procedure still have higher absorption ability. And group 3, in which specimens were put into oven immediately after cutting, has higher absorption ability than group 2, in which samples had been naturally dried for two days. This may due to the capillary effect in the void of concrete, if there is water in the surface of concrete, when it is dried in the oven, the evaporated water in the surface can form a negative pressure so that the inner surface water is attracted to the outer surface. Then much more water is evaporated, and higher absorption ability can be expected.

3.3 Summary

The absorption test should be carried out in a sealed box rather than in an open space because the relative humidity in each place can be different, and this variable environment can change the results obtained from the absorption test. The simplified procedure can provide similar results to RILEM procedure. However, a difference still exists. If the simplified procedure is to be used, the following one is suggested: the samples should be placed in a ventilated oven at 50ºC for 24 hours immediately after cutting the specimen from the slab (or immersed in water for half an hour if the samples were cast). The specimens should then be placed in a sealed box with 75% RH for one week. The absorption test can then be carried out in a sealed box. The absorption results with samples conditioned by this procedure can be smaller than the specimens conditioned by RILEM procedure. However, a coefficient of 1.18 can be multiplied so that the results by simplified procedure can match the results by RILEM procedure. However, further study for the value of the coefficient is still needed.

4. SIMPLIFIED PROCEDURE FOR GAS PERMEABILITY TEST

After comparing the absorption test results derived from specimens tested using the simplified procedure and the RILEM procedure, a similar comparative study was carried out for the gas permeability test.

Specimens for the gas permeability test were cut from a concrete slab that had been aged for 6 months. A column of concrete of 5 cm diameter was first cut and thereafter three samples of 4cm height were cut from this column. Hence, each sample had dimensions of 5 cm diameter by 4 cm high. The gas permeability of six groups of samples prepared in this manner was then tested and a comparison was made amongst the results obtained for the different groups. For each of the six groups

of specimens, three samples were located, respectively, in the upper, the middle, and the lower part of the concrete slab. After one day in natural drying conditions, the 6 groups of specimens were further conditioned as follows:

Table 1. Simplified conditioning procedure for gas permeability test of different specimen groups.

Specimen set	Designation*	Conditioning method	
		Drying	Moisture redistribution
Group 1	1T, 1M and 1B	RILEM procedure	RILEM procedure
Group 2	2T, 2M and 2B	24 hours in 50ºC ventilated oven	sealed container for one week at 75% RH and 25ºC
Group 3	3T, 3M and 3B	24 hours in 50ºC ventilated oven	sealed container for 2 weeks at 75% RH and 25ºC
Group 4	4T, 4M and 4B	24 hours in 50ºC ventilated oven	sealed container for 3 weeks at 75% RH and 25ºC
Group 5	5T, 5M and 5B	No oven drying	sealed container for one week at 75% RH and 25ºC
Group 6	6T, 6M and 6B	No oven drying	sealed container for 2 weeks at 75% RH and 25ºC

*T; M; B denote top, middle, and lower samples respectively

Each specimen was tested under an absolute pressure of 2.4 bars, and the time for a bubble traveling 10 cm in a graduated pipette was recorded [Pereira et al. 2009]. The permeability of the specimen was calculated by the following equation:

$$K = \frac{4.04vL*10^{-5}}{A(P_1 - 1)} \tag{7}$$

where υ is the flow, which can be read from the pipette [m^3/s], L is the specimen height [m], A is the cross section area of the specimen [m^2], p_1 is the test pressure [Pa].

The results of the 6 groups of specimens are shown below in Table 2. From Figure 5, one can see that there is a greater difference between the groups without oven drying (Group 5 and Group 6) and the RILEM procedure than the groups with 24 hours of oven drying. As well, for the groups that had been dried in an oven for 24 hours, given that the time for redistribution of moisture increases, the higher the expected permeability of the specimens. It can be seen from a comparison of results from group 2 to group 4, that the permeability of the specimens gets closer to that of the specimens in group 1, the group 1 specimens having been conditioned according to the RILEM TC 116-PCD procedure. In this instance, one can use the simplified procedure, as was demonstrated for group 4, to replace the RILEM procedure when testing the permeability of concrete samples. However, a coefficient of 1.08 is nonetheless needed to calibrate the results thus making the results from the different procedures comparable.

Table 2. Permeability results for each specimen [m^2].

Group / No. / Sample location	1	2	3	4	5	6
T	1.06×10^{-17}	3.20×10^{-18}	5.52×10^{-18}	6.07×10^{-18}	1.89×10^{-18}	1.90×10^{-18}
M	8.76×10^{-18}	3.25×10^{-18}	6.31×10^{-18}	5.73×10^{-18}	3.82×10^{-18}	2.61×10^{-18}
B	5.73×10^{-18}	3.48×10^{-18}	5.47×10^{-18}	1.14×10^{-18}	3.20×10^{-18}	2.76×10^{-18}
Average	8.36×10^{-18}	3.31×10^{-18}	5.77×10^{-18}	7.73×10^{-18}	2.97×10^{-18}	2.42×10^{-18}

From Table 1, one can see that permeability is related to the conditioning procedure and the location of the samples. However, the average permeability of each group can still be made to permit a comparison amongst the different conditioning methods and how these procedures would affect the permeability results. Hence the average permeability of each group was also calculated; results are shown in Figure 5.

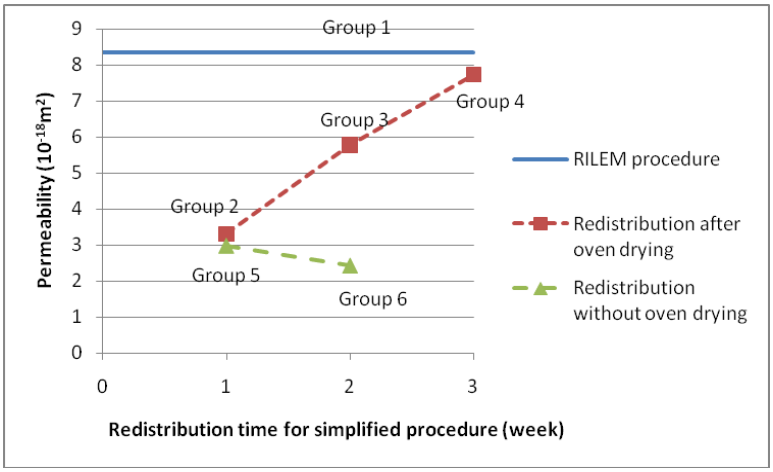

Figure 5. Permeability results for group 1: RILEM procedure. Group 2: Drying in oven for 24 hours, 1 week redistribution in 75% RH. Group 3: Drying in oven for 24 hours, 2 weeks redistribution in 75% RH. Group 4: Drying in oven for 24 hours, 3 weeks redistribution in 75% RH. Group 5: 1week redistribution in 75% RH without oven drying. Group 6: 2 weeks redistribution in 75% RH without oven drying.

5 CONCLUSIONS

In the study described in this paper, simplified procedures were sought for the pre-conditioning of specimens prior to undertaking standard concrete absorption and gas permeability tests. The samples for the simplified procedure and which had been dried in a ventilated 50ºC oven, and thereafter placed in a sealed box having 75% RH, showed similar values for concrete absorption and gas permeability to those specimens which had been conditioned according to procedure given in RILEM TC 116-PCD. For the absorption test, if the conditioning time is limited, one can condition the specimens according to the simplified procedure, which only takes two weeks, and then multiply the results by a coefficient, as provided in this study, to match the RILEM results. For the permeability test, one can condition the specimens as follows: drying in a ventilated 50ºC oven for 24 hours, then moisture redistribution in a sealed box having 75% RH for three weeks. Results of specimens conditioned by these respective procedures are comparable to results obtained using RILEM procedure.

REFERENCES

RILEM 1999, *RILEM TC 116-PCD, Permeability of Concrete as a Criterion of its Durability*, Materials and Structures/Materiaux et Constructions, Vol. 32, April, pp 174-179.

LNEC 1993, *E392, Concrete: Determination of the permeability to oxygen*, LNEC specification, Portuguese National Laboratory of Civil Engineering. Lisbon.

LNEC 1993a, *E393, Concrete: Determination of the absorption of water through capillarity*, LNEC Specification, Portuguese National Laboratory of Civil Engineering. Lisbon.

Pereira, C.N.G. & Oliveira, L.A.P. & Castro-Gomes, J.P. 2009, *Influence of natural coarse aggregates size, mineralogy and water content on the permeability of structural concrete*, Construction and Building Materials, Volume 23, Issue 2, February, Pages 602-608.