

# DETERMINATION OF THE QUALITY OF THE SURFACE LAYER OF CONCRETE USING THE TPT METHOD AND SPECIFICATION OF THE IMPACT OF HUMIDITY ON THE VALUE OF THE AIR PERMEABILITY COEFFICIENT

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*The paper deals with the quality/durability of concrete cover layers and presents results of the experimental works. The work of the team focuses on one of the methods that specify the permeability - and therefore the quality - of the concrete structure cover layers, the TPT (Torrent Permeability Tester) method. The experiments deal especially with the one of the main problems concerned with the air permeability measurement namely with the question - how to take into account the actual humidity of the measured surface during the measurement evaluation. The main aim of performed experiments was to suggest the conversion relation in order to convert the results obtained by the measurement of the permeability using TPT equipment on the material surface with the current humidity into the results determined for the same material with the referential humidity of 3 %. The characteristics of pore structure were not taken into account during the data evaluation.*

## INTRODUCTION

In recent years, concrete quality/durability has been one of the most frequently discussed themes and has been the object of many research studies and projects. The main problem in this field is a non-uniform interpretation of the term “concrete quality/durability” and the absence of a comprehensive collection of the testing methods and procedures for the uniform assessment and prediction of concrete durability which can be applied in the laboratory as well as in-situ. Currently, a lot of non-destructive and destructive testing methods are recommended and used for the description and determination of the actual state of the inner structure of concrete as well as its cover layers. Nevertheless, some of them may be used only for laboratory measurement and have no equivalent for in-situ measurement. Likewise, there is no uniform system for classification of concrete durability or quality in the world. The durability of concrete and its other characteristics depend mostly on the quality of a covercrete (covercrete = cover concrete). The covercrete is a layer of concrete up to a depth of 20-50 mm that comes into greatest contact with external forces

influencing the structure of concrete. In order to understand and cope with the true and expected durability performance of concrete structures, the deterioration mechanism must be known. In fact, this problem concerns the exact knowledge and understanding of the transport mechanism of liquids and gaseous substances into and within concrete structures.

The permeability of materials is defined by several properties that characterize penetration of water and gases as well as thermal and electric conductivity. The permeability of concrete depends especially on the porosity of the cement matrix structure and has undoubtedly a significant impact on the quality and durability of concrete. The porosity of concrete (or rather of cement stone) is determined by [1]:

- the amount of water that is not needed for hydration of concrete (water – cement ratio  $> 0.23$ ),
- air pores caused by an imperfect compaction of fresh concrete,
- aeration of concrete using aerating additives,
- cracks wider than  $10^{-4}$  m arising during the setting of concrete.

The part of concrete structures that is subjected to the greatest impact of external forces is the surface. The TPT (Torrent Permeability Tester) method enables - with help of long-term comparative measurement - a specification of five qualitative categories of concrete (its surface layer), i.e. from very good to very bad. This method can be used with the vacuum system for measuring the air permeability (determined by the  $k_T$  permeability coefficient) of the surface layer of concrete. The categories of quality of the covercrete specified with the help of the (air) permeability coefficient are shown in Tab. 1 [2].

Table 1. Evaluation of the concrete cover with the help of the permeability coefficient.

Quality of the concrete cover	Index	$k_T$ ( $\times 10^{-6} \text{ m}^2$ )
Very bad	5	>10
Bad	4	1-10
Medium	3	0.1-1
Good	2	0.01-0.1
Very good	1	<0.01

Using the TPT method, we can obtain data that significantly contribute to the evaluation of the quality of the covercrete; however, the testing is so far listed only in the [3] Swiss norm. Implementation of this method for more extensive evaluation of existing constructions is currently being considered. It is therefore necessary to point out that especially the field of evaluation of test results and of determination of the impact of humidity of the surface layer of the studied concrete is not entirely complete.

#### The TPT method

The TORRENT instrument for permeability testing (see Figure 1) is a measuring device suitable for non-destructive specification of air permeability of the sur-

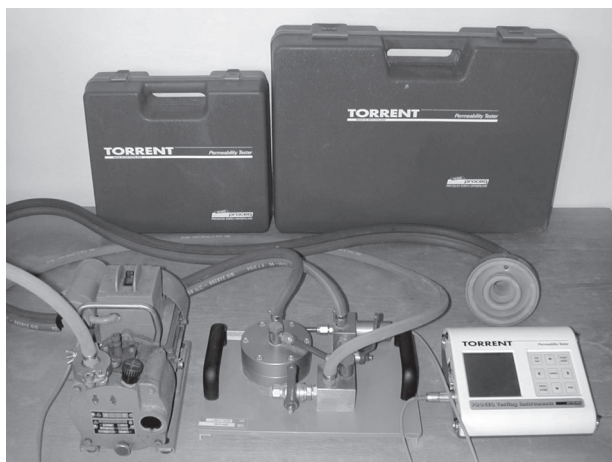


Figure 1. The Torrent instrument.

face layer of concrete. The instrument works together with a vacuum pump and can be used for measuring on site as well as in laboratory.

The essential features of the measuring system that form the basis of the TORRENT (TPT) measuring method are a two-chamber vacuum cell (see Figure 3) and a pressure recorder that ensure air flow into the inner chamber situated vertically to the surface. The measuring method is based on the possibility to calculate the permeability coefficient  $k_T$  on the basis of the given theoretical model. A diagram of the measuring device is shown in Figure 2.

The measurement limits (see Tab. 1) were determined on the basis of extensive permeability testing that was carried out by the author of the TPT device and his team of co-workers. As far as dry concrete is concerned, the results of his tests corresponded well with other laboratory methods, such as oxygen permeability, absorptive capacity of capillary water, chloride permeability and other [2, 4].

According to the authors of the method, the humidity of concrete is the main factor influencing the extent of air permeability. In order to compensate for the humidity, they measured the electric resistance of concrete  $\rho$  using the so-called Wenner probe and compiled a monogram defining the dependence of the extent of the coefficient  $k_T$  on the electric resistance  $\rho$ . The monogram can be used, as the authors claim, for determination of the qualitative category of the cover of humid concrete (Figure 4).

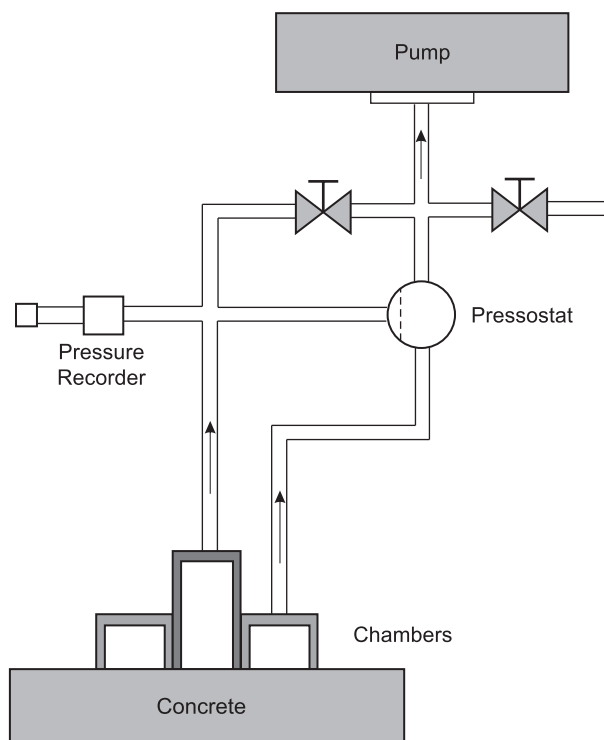


Figure 2. A diagram of the Torrent instrument.

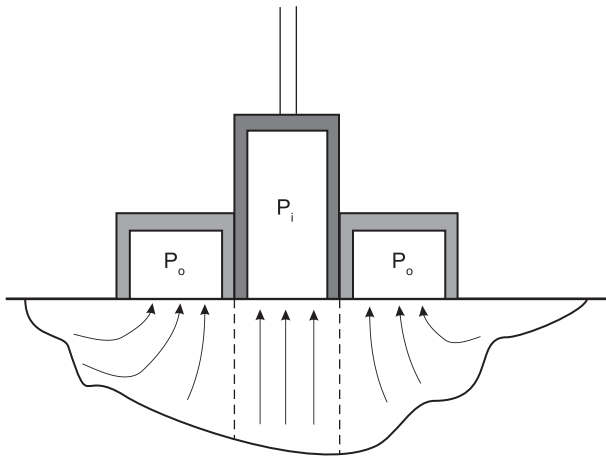


Figure 3. Vacuum chambers of the Torrent instrument.

The TPT measuring device enables, in comparison with other similar devices, a relatively simple manipulation, does not require complicated adjustments of the measured areas on the structure, and the length of the testing is defined by the quality of the tested concrete. The measuring itself does not take longer than 12 min. on one measuring area. This fact enables performing a great amount of measurements and obtaining extensive results necessary for evaluation of the current state of the surface layer of concrete [4]. The TPT method is also described in [5] and [6].

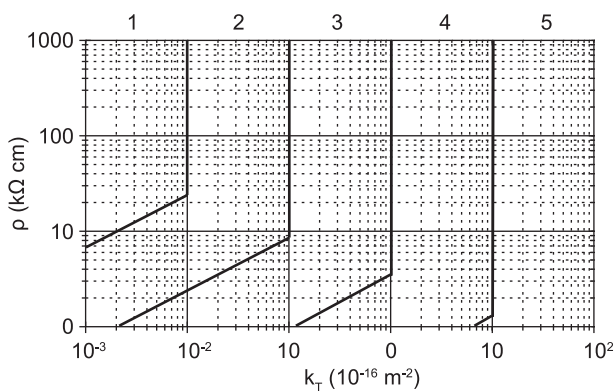


Figure 4. The monogram for determination of the qualitative category of concrete in relation to the current humidity.

### EXPERIMENTAL

Requirements concerning the shape, size, adjustment and treatment of tested specimens

Since it is possible to do tests using the TPT method not only directly on existing structures but in laboratory conditions as well, we will now discuss the requirements related to tested specimens.

During the production, it is necessary to pay great attention to the storage, or rather to the compaction of concrete. It is essential to inhibit the segregation of individual ingredients of the mixture and at the same time thoroughly remove all the redundant air. The upper surface of the specimen that is intended for testing must be even and smooth. If a layer of cement milk, containing a great number of air pores, gathers on the upper surface of the specimen, the surface is not much acceptable for testing and must be smoothed by fine abrasion; otherwise the results may differ considerably from reality.

After removal of the mould, the surfaces for measuring air permeability should include as few caverns and pores as possible. A surface of the specimen containing caverns or a net of air pores is not very adequate for measuring. The coarseness of the measured surface will influence the original value of pressure which creates the vacuum. Different values of the pressure creating the vacuum does not necessarily lead to influencing the final results of the measuring. If the surface of the tested specimen displays considerable unevenness, it is necessary to regulate it by grinding. The surface of the specimen must not show any traces of the presence of micro cracks.

The dimensions of the specimens must meet the requirements stated by the authors of the measurement, i.e. the distance between the outer part of the measured surface and the outer diameter of the cell should be minimally 20 mm. In laboratories of the Institute of Building Testing FCE BUT, cubes with 150 mm edge length were used for this type of measurement. The requirements given by the producer were formally met; however, as became later evident, this type of specimens does not seem to be very acceptable. One of the reasons was the need of a too high accuracy when stoking the vacuum pump to keep the prescribed distance from the edge of the specimen. Another reason was the fact that the distance of only 20 mm between the vacuum pump and the edge of the specimen seemed to be insufficient in relation to the material as such - to its porous structure, to be specific - and it could be deduced that there can appear pressure losses through lateral sides of the specimen. This theory was checked by a simultaneous measurement of permeability on cubes with 150 mm edge length and on tiles with dimensions 300×300×80 mm. And with this experiment it was confirmed - far lower values of the air permeability coefficient  $k_T$  were obtained by measuring the tiles than the cubes. Another advantage of the tiles (regarding their lower thickness) was the possibility of a more precise determination of the current mass humidity with the help of surface probes for humidity measurement. If the process of the air permeability coefficient is observed in time, it is adequate to carry out the measurement always at the same place. Time interval between particular measurements performed at the same place is at least 30 min.

An important step in the specimen's preparation is the selection of a suitable storing place after removal from the mould, because this factor is closely connected with the rate of drying, i.e. with the current mass humidity of the specimen. In the producer's instructions, it is stated that the tested surfaces must not be wet. Therefore there are two options how to prepare the specimens. First, we can store them in laboratory conditions in air or covered with foil so that the specimen can dry freely, or we can "pre-dry" a specimen that was stored in a humid place or in water to the required humidity value of the covercrete. In case the humidity of the covercrete is high, the results of measuring at the same place are usually of great variability. It is also recommended that the age of concrete at the time of measuring should be at least 28 days, otherwise the standard process of ageing (or hydration) of the cement composite could be disturbed.

The impact of humidity on the air permeability coefficient  $k_T$

The measurement of  $k_T$  was carried out on specimens of ordinary structural concrete of the C20/25 class with dimensions  $300 \times 300 \times 80 \text{ mm}^3$ . The specimens were removed from the moulds the day after concreting and stored in a humid place with relative humidity of 95% and temperature of  $21^\circ\text{C}$ . After 28 days, they were removed and stored in water for 48 hours. Before the first testing, they were left for 24 hours in laboratory environs with relative humidity of circa 48% and temperature of  $23^\circ\text{C}$ . The aim of this was to simulate various levels of humidity and to observe changes in the coefficient  $k_T$ .

The current humidity of the specimens was measured with a surface probe - the KAKASO capacitive humidity meter, eight times on every specimen. The value gained by this measurement is, however, not the mass humidity proper and it is thus necessary to measure simultaneously the weight of the samples in the current state of measuring and after drying into steady weight and then convert it. For the conversion, it was necessary to create a calibration curve that differs slightly for each material.

For the shape of the calibration curve, the following fractional rational function was chosen:

$$w = \frac{p_1 k_s + p_2}{k_s + q_1} \quad (1)$$

where  $w$  is mass humidity [%],  $k_s$  is the value of the KAKASO capacitive humidity meter [-] and  $p_1 = 6,518$ ,  $p_2 = -86,63$  and  $q_1 = 4,954$  are regression coefficients. The process of dependence and measured values are shown in Figure 5.

The test specimens were measured during their gradual drying in laboratory environs and then after drying in a drying room for different time spans at the temperature of  $50^\circ\text{C}$  and  $105^\circ\text{C}$  in order to observe the

behaviour of the air permeability coefficient  $k_T$ . After each phase of drying, the current weight was measured; the KAKASO indicator and the coefficient  $k_T$  were specified. All in all, 153 measurements were carried out.

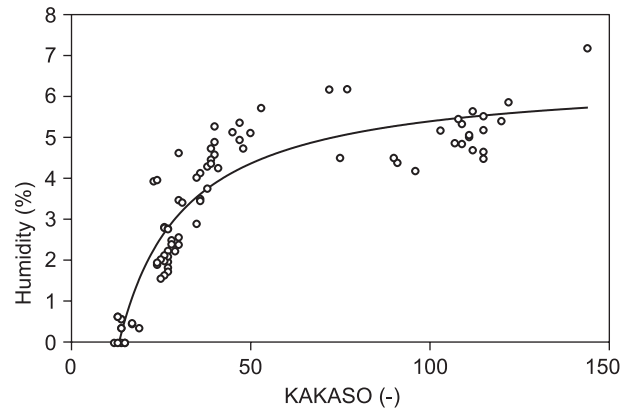


Figure 5. The dependence of mass humidity and the value of the KAKASO capacitive humidity meter.

RESULTS AND DISCUSSION

The final values of  $k_T$  related to the current mass humidity are stated in Figure 6. To make it more lucid, a logarithmic scale was set on the y axis. An exponential shape was chosen for the regression model, considering mostly the character of the measured data. The smallest squares method was used for suggestion of the following optimal dependency:

$$k_T = \beta \cdot e^{\alpha w} \quad (2)$$

where  $w$  is the mass humidity of the examined surface (%) and  $\beta = 5.255$ ,  $\alpha = -0.8623$  are regression coefficients. Because of the logarithmic scale, the exponential process in Figure 6 is transformed into a straight line. It is evident that the dependency of  $k_T$  on the current humidity of the studied concrete is very strong.

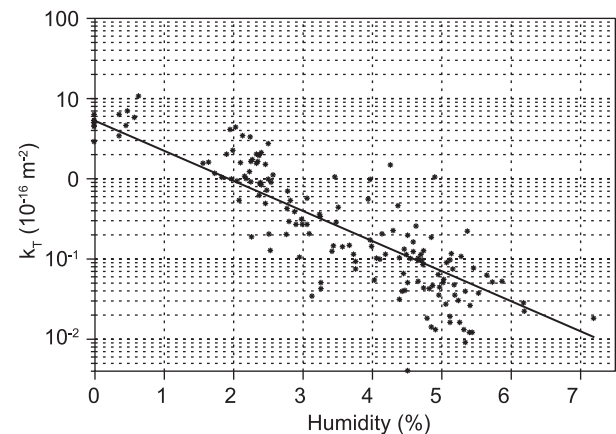


Figure 6. The dependency of  $k_T$  on mass humidity.



### A proposal of correction of $k_T$ with respect to the current humidity

When assessing the quality of the surface layer of concrete in a structure, it is essential to enable making comparisons either between various materials or between different states of a material during a time span. As has been claimed, the coefficient  $k_T$  is strongly dependent on the current humidity of the surface layer [7]. Therefore it is useless to measure the  $k_T$  without taking into account the current humidity, since it is not possible to make comparisons or classification of the quality of the surface layer (see Table 1). For these reasons, it is logical to convert  $k_T$  to a referential value of humidity.

With respect to the common state of structures in practice, the mass humidity of 3% was selected as the referential humidity. Let us indicate the value of the air permeability coefficient with mass humidity of the material being 3% as  $k_{T,3}$  and the value with current humidity  $w$  as  $k_{T,w}$ . The basic converting relation is as follows:

$$\alpha = \frac{\ln k_{T,w} - \ln k_{T,3}}{w - 3} \quad (3)$$

where  $\alpha$  is the linear function coefficient  $\ln k_T = \alpha \cdot w + \beta$ . Let us call this coefficient that defines the inclination of the linear dependency (see Figure 6) the correcting humidity coefficient. The value of this coefficient can differ, especially due to the dependency on the composition and characteristics of the studied material (concrete). Long-term comparison tests of ordinary and lightweight concrete have shown that the composition influences mainly the coefficient  $\beta$  (that determines the shift of the straight line). The coefficient  $\alpha$  (that defines the inclination of the line), however, does not differ considerably due to the influence of the composition of concrete. For these reasons, we can assume the value of the correcting humidity coefficient to be  $\alpha = -0,862$ , determined by the regression model as the recommended value for specifying the air permeability coefficient with referential mass humidity of 3%.

Through balancing the equation (3), we get the relation

$$\ln k_{T,3} = \alpha(3 - w) + \ln k_{T,w} \quad (4)$$

and after delogarithmic calculation, we arrive at:

$$k_{T,3} = k_{T,w} \cdot e^{\alpha(3-w)} \quad (5)$$

The last of the above stated relations can be used for determination of the value of the air permeability coefficient with referential humidity of 3% that has been mentioned before.

## CONCLUSIONS

The TPT (Torrent Permeability Tester) method is a relatively new and prospective method that enables a very quick and simple evaluation of the quality of the

surface layer of concrete that has crucial impact on the durability of concrete structures.

The results obtained by measurements using this method also show a strong dependency on the current humidity of the studied surface layer that must be therefore simultaneously observed. The procedures for determining the value of the coefficient  $k_T$  with the humidity of the material being 3% that were published in this article seem to be applicable not only for scientific purposes, but for practical ones as well. The regression model the authors used - and therefore the value of the correcting humidity coefficient as well - is influenced by the measured data and thus by the character of the material. We must consequently state that these values are not universally valid, but only for the specific studied material. Nevertheless, one can assume that the values will not differ significantly with different materials.

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## References

1. Pytlík P.: *Technologie betonu*, 1<sup>st</sup> ed., VUT v Brně. Brno 1997.
2. Torrent R. J. in: *Materials and Structures*, 25 (1992).
3. SN 505 262/1 Construction en béton - Spécifications complémentaires.
4. Adámek J., Juránková V., Juránek P.: *Materiály pro stavbu*, 8 (2004).
5. Neves R., Vinagre Santos J. in: RILEM Symposium on On Site Assessment of Concrete, Masonry and Timber Structures - SACoMaTiS 2008, p. 299-307, Varenna - Lake Como 2008.
6. Imamoto K., Shimozawa K., Nagayama M., Yamasaki J., Nimura S. 2008. in: RILEM Symposium on On Site Assessment of Concrete, Masonry and Timber Structures - SACoMaTiS 2008, p. 169-177, Varenna - Lake Como 2008.
7. Romer M.: *Materials and Structures* 38, 279 (2005).
8. Andrade C., Sagraera J. L., Martínez I., García M., Zuloaga P. in: *Transactions of the 17<sup>th</sup> International Conference on Structural Mechanics in Reactor Technology (SMiRT 17)*, Prague 2003.
9. Śliwiński J., Tracz T. in: *Materiály Konferencji Dni betonu - tradycja i nowoczesność*, p. 327-341, Ed. Stowarzyszenie Producentów Cementu i Wapna, Polski Cement, Szczyrk 2002.