EAN 2012
50th annual coference on experimental stress analysis

Permeability of Concrete Surface Layer

Pavel Reiterman[1], Martin Keppert[2], Ondřej Holčapek[3], Zlata Kadlecová[4] &

Karel Kolář [5]

Abstract: More widespread use of fair-face concrete in building structures leads to more intensive examination of its behavior and material parameters. The article presents the results of an experimental program focused on the characteristics and properties of the surface layer properties in relation to the overall durability and longterm resistance to aggressive agents. Permeability was selected as the main parameter determining and describing the properties of the surface layer, while predicting the durability. Permeability was conducted on three tests methods using different test media. For GWT and ISAT permeability was determined for water while for TPT permeability was determined for air. System of testing is completed with the values of sorption coefficients, mechanical properties of surface layer and resistance to chemical de-icing agents.

Keywords: Durability; Surface Layer; Permeability

1. Introduction

The origin and character of the concrete surface layer is given by the technology of production of concrete elements; during vibration compaction is going on initiation and rising of air bubbles upward. This eliminates air content in concrete, but also concentration of fine particles takes place close the walls of the formwork. Coarse aggregate – due to its geometry – can´t get its entire plane to formwork or to the corners [1]. Hence the concrete surface exhibits completely different properties compared to bulk – so called wall effect. The characteristic properties of the surface layer is low content of coarse aggregates and an increased amount of cement stone which consists of fine fractions of aggregate and cement hydration products. A very important feature is especially high content of pores in comparison with the inner layer. Such a surface layer having a thickness of 20-50 mm has a very different, usually worse properties than the surrounding material. Therefore attention is drawn

[1] *Ing. Pavel Reiterman, Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague; Thákurova 7,166 07 Prague, Czech Republic; pavel.reiterman@fsv.cvut.cz*

[2] *Ing. Martin Keppert, Ph.D. Department of Material Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague; Thákurova 7, 166 07 Prague, Czech Republic; martin.keppert@fsv.cvut.cz*

[3] *Ing. Ondřej Holčapek, Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7; 166 07 Prague, Czech republic; ondrej.holcapek@fsv.cvut.cz*

[4] *Ing. Zlata Kadlecová, Institute of Building Testing, Faculty of Civil Engineering, Brno University of Technology, Veveří 95; 602 00, Brno, Czech republic; kadlecova.z@fce.vutbr.cz*

[5] *Doc. Ing. Karel Kolář, CSc., Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7; 166 07 Prague, Czech Republic; karel.kolar@fsv.cvut.cz*

to quality of concrete surface layer. Each void and crack decreases a steel covering concrete layer and thus accelerates the process of its corrosion which is associated with visual degradation of the building.

Environment induces several physico-chemical processes in concrete which completely change its properties. Changes that are noticeable to human eye and reduce the aesthetic parameters of the material are important for the classification of visual elements [2]. The material alterations – accompanied in some cases with visual changes – occur mostly due to interaction of environment components with concrete. The intensity of these processes depends on the chemical and physical conditions, such as concentration of acting media, temperature, pressure, humidity, etc. The causes of degradation processes can be divided into the following groups:

- physical action (temperature and moisture changes, freezing action, solar or UV radiation of another origin, leaching),
- chemical influences (action of corrosion media, e.g. acid rains, carbonation, expansion processes),
- physico-chemical influences (impact of water, de-icing salts, corrosion under tension).

All the mentioned degradation processes are closely related to the quality of the surface layer and the pore system of concrete. Since the coating layer is the most exposed and thus the most polluted site of structure, there is an even distribution of tension across the section. Stresses are concentrated at the weakest point along the cracks and voids. There are mostly tensile stresses that exceed the material tensile strength and cause cracking which is becoming the reason of visual problems. Such a disruption creates a new access for aggressive media, which contribute to the gradual degradation of the material. It is an extensive and complex chemico-physical process and therefore it is very difficult to separate the individual simultaneous degradation processes from each other. Penetration of aggressive gaseous or liquid substances from the environment depends on the condition and character of pore system. Permeability of concrete surface layer is affected by many aspects - choice of used components, composition of fresh concrete mixture, formwork, the method of concrete compaction and its curing during setting and hardening [3].

Influence of surface structure lies in the fact that the appearance of the facade elements - in particular its brightness - will vary depending on the surface roughness and degree of hydration. In other words, when one performs a color treatment to a perfectly smooth surface and to a rough surface, the rough surface will appear darker, especially when the color will be deeper. This is due to higher absorption of radiation on the structured surface. Danger lies in structural surfaces treated by a shade, which was chosen according to color card, which is usually smooth. Contractor monitors the concrete shade preparation usually on the smooth surface; it may therefore happen that shade of structure is properly delivered and applied, but later the object appears darker.

Differences in surface color and other color defects are a usual problem in the case of requirement a uniform shade across the entire surface area. This inconvenience can´t be removed or controlled by precast production, because the production of large amounts of elements is indeed possible to frontload and prevent complications with different production batches of individual components, but the elements are always produced under different climatic conditions. It has been long generally known that when the concreting is performed at lower temperatures the surfaces reach a much richer and brighter tone due to slower hydration and subsequent finer crystalline structure of hydration products. Susceptibility to defects in the visual elements can be relatively easy to suppress by using of a separation device or by structuring of concrete surface. Probably the oldest and simplest way to improve the surface quality is good curing of concrete but this method is in practice often associated with considerable problems [4]. Today - thanks to the quality of raw materials and admixtures - excellent results are achieved in the visible concrete.

When one designs a concrete structure with respect to its durability it is necessary to distinguish the transport of gaseous and liquid media. The following chapters present the experimental methods for assessing the quality of the surface layer in terms of its transport parameters.

2. Experimental methods

2.1. Torrent Permeability Tester (TPT)

The apparatus works by creating a vacuum in the concrete and measuring the flow of air from the surface layer of concrete over the bi-chamber cell which is accompanied by reducing the value of vacuum. From the measured time and changes in air pressure flowing into the middle chamber is calculated permeability coefficient k_T for air expressed in 10^{-12} m^2. Calculation of the air flow through the concrete pore structure is performed by the Haagen - Poiseuill's equation (1).

$$Q = \frac{\pi}{2\eta} \cdot \frac{\Delta p}{\Delta l} \cdot \int_0^r (r^2 - y^2) \cdot y \cdot dy = \boldsymbol{\frac{\pi r^4}{8\eta} \cdot \frac{\Delta p}{\Delta l}} \qquad \textbf{(1)}$$

The entire process of calculating the permeability coefficient k_T and depth of vacuum penetration takes place automatically by the device. Quality class of concrete surface layer is determined by using *Tab. 1*.

Table 1. Evaluation of durability of concrete surface layer

Surface layer quality	Index	k_T 10^{-16} m^2
very bad	5	> 10
bad	4	1,0 - 10
medium	3	0,1 – 1,0
good	2	0,01 – 0,1
very good	1	< 0,01

2.2. Germann Water permeation Test (GWT)

Apparatus for determination of surface layer permeability works by measuring the pressure of water flow velocity through the surface layer in time. Coefficient of concrete permeability is calculated according to Darcy's law. It is than converted to the intrinsic permeability coefficient k_i [m^2]. Its value depends on the difference between input and output flow pressure, dynamic viscosity of liquid, its density and gravitational acceleration [5]. According to German standard DIN 1045 concrete is considered as durable when its intrinsic surface layer permeability is smaller than k_i $1*10^{-16}$ m^2.

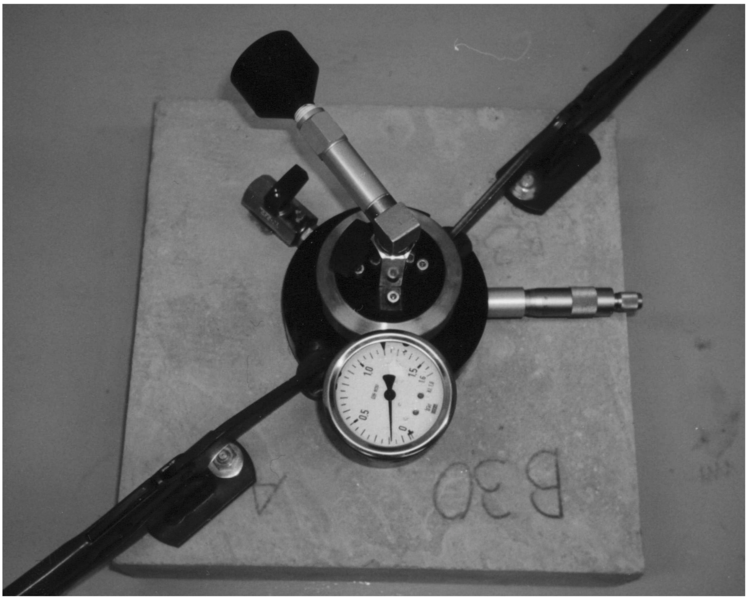

Fig. 1. Germann Water permeation Test

2.*3. Initial Surface Absorption Test (ISAT)*

ISAT method uses water as measuring medium too, but it can express very well the initial surface water absorption. The test consists of the measurement of water flow into the test specimen through a known surface area and results are expressed in ml m^{-2} s^{-1}. Levitt derived the following mathematical formula (2), which captures the essence of the tests:

$$p = a \cdot t^{-n} \tag{2}$$

Where: *p…initial surface absorbtion*
t…time

a…constant
n…parametr of values 0,3 to 0,7depending on the degree of coming out mechanism

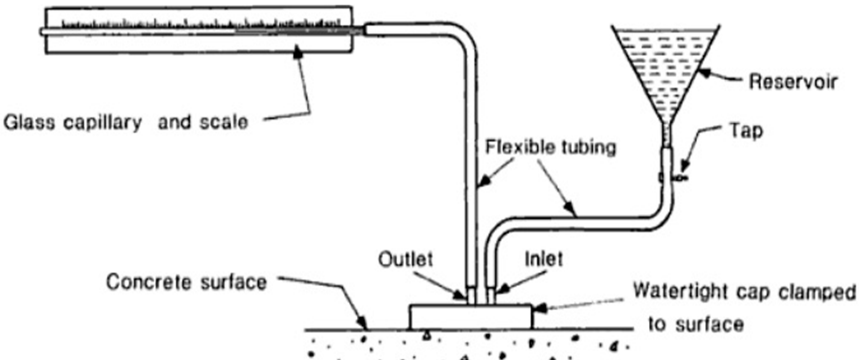

Fig. 2. ISAT scheme

2.4. *High pressure permeameter*

Hydraulic conductivity was measured by means of high pressure permeameter made by CNE Technology. The design is based on work [11]. The cylindrical sample, placed in Hassler cell, is saturated by water; during the experiment is water flowing through and pairs pressure – flow rate are recorded. The method is based on definition equation (3) where Q is flow rate [$m^3 \cdot s^{-1}$], Δp is pressure diference across the sample, l and d its length and diameter and ρ is liquid density; slope of dependence of Q on Δp is the searched hydraulic conductivity. Equation (3) assumes the validity of Darcy's law. This method is standardized America [12].

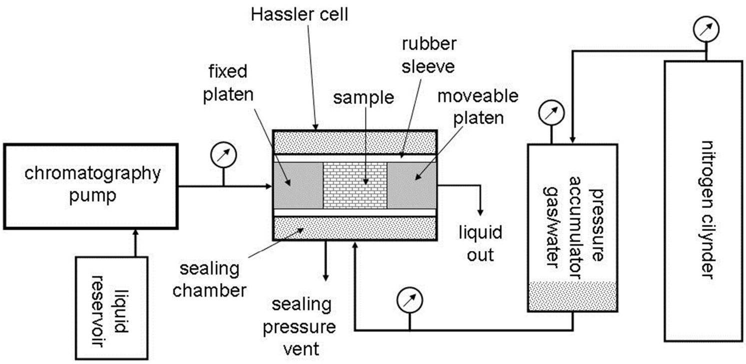

Fig. 3. Scheme of device for measuring hydraulic conductivity

$$k = \frac{Q}{\Delta p} \cdot \frac{1}{\frac{\pi}{4} \cdot d^2} \cdot \rho \cdot g \quad \textbf{(3)}$$

3. Comparison of experimental results

Table 4. Results of measurement by TPT and GWT

Mix.	TPT				GWT	
	Moisture of surface	Permeability coefficient k_T*10^{-16}	Vacuum penetration depth	Surface layer quality	Intrinsic permeability coefficient k_i	Is concrete durable?
	[%]	[m^2]	[mm]	[1-5]	[m^2]	[ano/ne]
I	2.8	0.090	20.0	2 - good	$1.606E^{-15}$	NO
II	2.5	0.434	33.3	3 - medium	$1.777E^{-15}$	NO
III	4.0	0.021	8.7	2 - good	$2.272E^{-15}$	NO
IV	3.2	0.015	4.0	2 - good	$2.277E^{-15}$	NO

Note: by DIN 1045 concrete is durable when $k_i < 1.0*10^{-16}$ m^2

Table 5. Results of measurement by ISAT, Schmidt hammer and pull-off test

Mix	ISAT							Schmidt	Pull-off test
	Surface humidity	5 s	30 s	60 s	10 min	30 min	60 min		
	[%]	[ml/m^2/s]						[MPa]	[MPa]
I	2.6	1.08	0.98	0.91	0.27	0.16	0.12	39	3.1
II	2.4	1.56	1.46	1.32	0.23	0.15	0.11	34	2.2
III	4.0	0.24	0.16	0.13	0.09	0.05	0.03	39	3.2
IV	3.2	0.36	0.28	0.27	0.17	0.12	0.07	38	2.9

Table 6. Results of hydraulic conductivity measurement

Mix	k
	m/s
I	$0.8E^{-11}$
II	$1.2E^{-11}$
III	$1.2E^{-11}$
IV	$1.2E^{-11}$

By above described method was measured hydraulic conductivity of four fair-face concrete *Tab. 6.* Given that the hydraulic conductivity was low, the experiment was close to limit the applicability of this method, using a higher sealing pressure occurred due to cracking of the samples exceeded the transverse tensile strength. Was measured the pressure gradient at a flow rate 0.02 $ml.min^{-1}$ and these values were calculated according to the hydraulic conductivity (3) (Table 6). Measured, relatively low values of order 10^{-11} m.s^{-1} (corresponding permeability 10^{-18} m^2) meet the requirements for "durable concrete" classification according to RILEM [14]. These values, given this specific movements on the border of applicability of the method can´t be taken as absolutely physically correct.

The subject of discussion might be whether the used method, or even hydraulic conductivity as a parameter are suitable for estimating durability of concrete. The test does not describe the influence of mixture composition on the durability, which would certainly be desirable output from the experiments.

4. Conclusion

Action of aggressive media concentrated in the external environment is to develop a wide range of corrosion mechanisms. Most buildings are protected from the effects of adverse conditions by other types of structures. In case of the fair-face concrete, however, this protective layer is formed by the material itself. Due to the fact that concrete degradation processes are going on a long - term, and aggressive substances act at low concentrations, it is very difficult to describe such effects and to quantify the resulting degradation phenomenon under test in the laboratory. Durability depends not only on the quality of the surface layer, but also on the nature of the pore system that is truly defining parameter because it affects the rate at which aggressive substances, gaseous or liquid, penetrate from the external environment into the internal structure of concrete, and thus the rate of degradation of the material and its durability. Very important is the limitation of water and moisture transport of having a role in reinforcement protecting against corrosion.

Many leading experts agree on the importance of monitoring the "skin" of concrete as the most loaded part of construction due to environment, so for the evaluation of the quality of the surface layer was included mainly measurements predicting the durability of concrete. To compare all provided tests, surface must have the same humidity. In addition to high-pressure permeameter all introduced methods have proved suitable results for assessing the quality of surface layers. In the case of porous building materials is hydraulic conductivity one of the parameters that affect their behavior in structures; depend on it water resistance and indirectly resistance to action of frost, salts and other degradation processes, that is durability. Hydraulic conductivity, permeability and sorption are, in the case of concrete, physically defined alternative to the results of tests for water resistant test. It should be noted that the in construction practice and research, the term of permeability is used quite freely (for different tests), it is always necessary to present the results along with the method and conditions of the experiment. It is obvious that a material will have a dramatically different permeability for air, for water or chloride ionts.

Experimental measurement of permeability of the surface layer of concrete blocks showed that the air permeability coefficient k_T and surface permeability coefficient k_i are significant criteria for the evaluation of the surface concrete. Measured data indicate that the composition of concrete mixtures significantly affects the properties of a surface layer of concrete, while the results of these tests will become the basis for a correlation dependence permeability of concrete and concrete methodologies for evaluation in terms of its durability.

Acknowledgement

This research was supported by MSM **6840770031**, which is gratefully acknowledged.

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