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Permeability properties of concrete with metakaolin addition

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Abstract. Surfacing, concrete mixture composition and curing are of great importance for the concrete surface resistance. That's the reason, why many leading experts agree on the importance of monitoring the "concrete skin" as the most loaded area affected by the external environment. Many research works demonstrate that application of metakaolin improves properties of concrete as freeze-thaw resistance and resistance against de-icing salts with freeze-thaw cycles combination. A very important role in concrete performance in such severe environment is played by porous system and surface of hardened concrete. The paper introduces an experimental program focused on the monitoring of water transport in surface layer of fair-face concrete aimed at monitoring the permeability of concrete, since concrete permeability is a property uniquely affecting durability of concrete. These methods are complemented by experimental results and other traditional tests. These findings will serve to further optimization of the structure being created, thus ensuring its better aesthetic and functional characteristics.

Introduction

Fair-face concrete is very popular technical solution for modern structures, but evaluation of their quality is always very complicated. Usually are preferred only subjective methods based on the visual observation. Concrete surface layer is the most affected area of fair-face concrete structure by the impact of external environment, that´s why is necessary to ensure its long-term durability.

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 – cannot 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 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. Degradation processes are closely related to the quality of the surface layer and the pore system of concrete. Environment induces several physico-chemical processes in concrete which can 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. 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, humidity, etc.

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.

Experimental program

Permeability of porous materials is one of the principal parameter influencing their transport properties and durability. The intrinsic permeability of material K [m^2] is defined in terms of Darcy's law describing flow of a liquid through a porous material saturated by the liquid under the action of pressure gradient across the material. It is material property and thus does not depend on the kind of permeating liquid. One of possible definitions of K is given by equation (1) [1].

$$j = -K \cdot \frac{\rho_l}{\eta} \cdot \frac{\partial p}{\partial x} \quad (1)$$

$$k = \frac{Q}{\Delta p} \cdot \frac{l}{\frac{\pi}{4} \cdot d^2} \cdot \rho \cdot g$$

(2)

There j is mass flux [$kg\ m^{-2}\ s^{-1}$], ρ is density of the liquid [$kg\ m^{-3}$], η is dynamic viscosity of the liquid [Pa s] and driving force is pressure gradient through the material. Intrinsic permeability is extremely dependent on properties of porous system of hardened concrete. That is one of the reasons of very different result of experimental works.

Table 1 – Concrete composition

Mixture		A	B	C
Components		[kg/m^3]	[kg/m^3]	[kg/m^3]
Cement CEM I 42,5 R Mokrá		400	400	370
Aggregate:	sand 0-4 mm, Dobříň	930	930	930
	crushed 4-8 mm, Zbraslav	315	315	315
	crushed 8-16 mm, Zbraslav	600	600	600
Plastisizer (Sika 1035)		3	2	3
water		180	180	180
metakaolin		-	-	30

Table 2 – Chemical properties of used cement and metakaolin

Chemical properties	CEM I 42,5 R	Mefisto K 05 [% weight]
SiO_2	23.9	58.70
Al_2O_3	5.2	38.50
Fe_2O_3	2.9	0.72
TiO_2	-	0.50
MgO	3.0	0.38
CaO	58.8	0.20
K_2O	0.8	0.85
$K_2O + Na_2O$	1.1	0.9
Loss of ignition	2.9	1.67
Specific surface	3.43 m^2/g	13.06 m^2/g

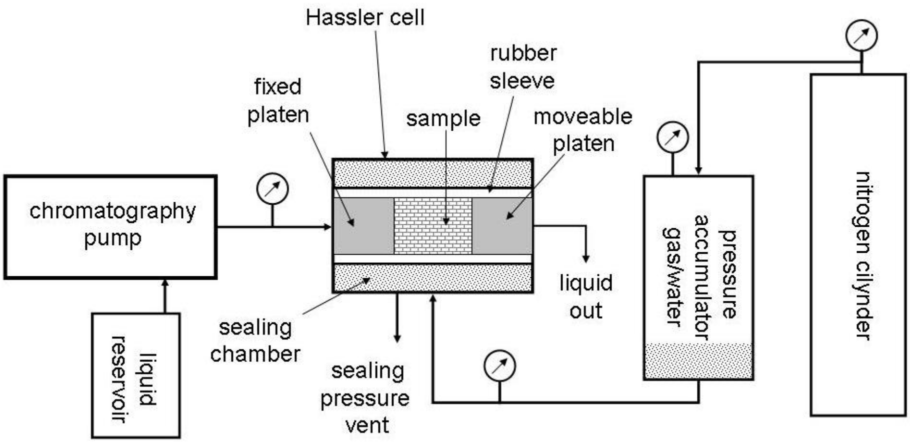

Fig. 1 – High-pressure permeameter scheme

Hydraulic conductivity was measured by means of high pressure permeameter made by CNE Technology. The design is based on work [2]. The method is based on definition equation (2) where Q is flow rate [m^3 s^{-1}], Δp is pressure difference 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 (2) assumes the validity of Darcy's law. This method is not standardized in Europe, but there is an American standard [3]. Altogether were measured three concrete mixtures (tab. 1), with dosage of metakaolin and different amount of plasticizer.

Pore size distribution was determined by means of mercury intrusion porosimetry (MIP). The method is based on intrusion of mercury – non wetting liquid – to pores of studied sample. The penetrated pore's diameter is inversely proportional to applied pressure (Washburn equation). The applied pressure is gradually increasing during the experiment and thus mercury penetrates narrower pores. The result of experiment is dependence of pore volume (it corresponds to measurable volume of intruded mercury) upon pore diameter (corresponds to applied pressure). The experiment was carried out by means of Pascal 140 and 440 devices (Thermo).

The water vacuum saturation method was used for the measurements of bulk density, matrix density and open porosity. Each sample was dried in a drier to remove majority of the physically bound water. After that the samples were placed into the desiccator with deaired water. During three hours air was evacuated with vacuum pump from the desiccator. The specimen was then kept under water not less than 24 hours

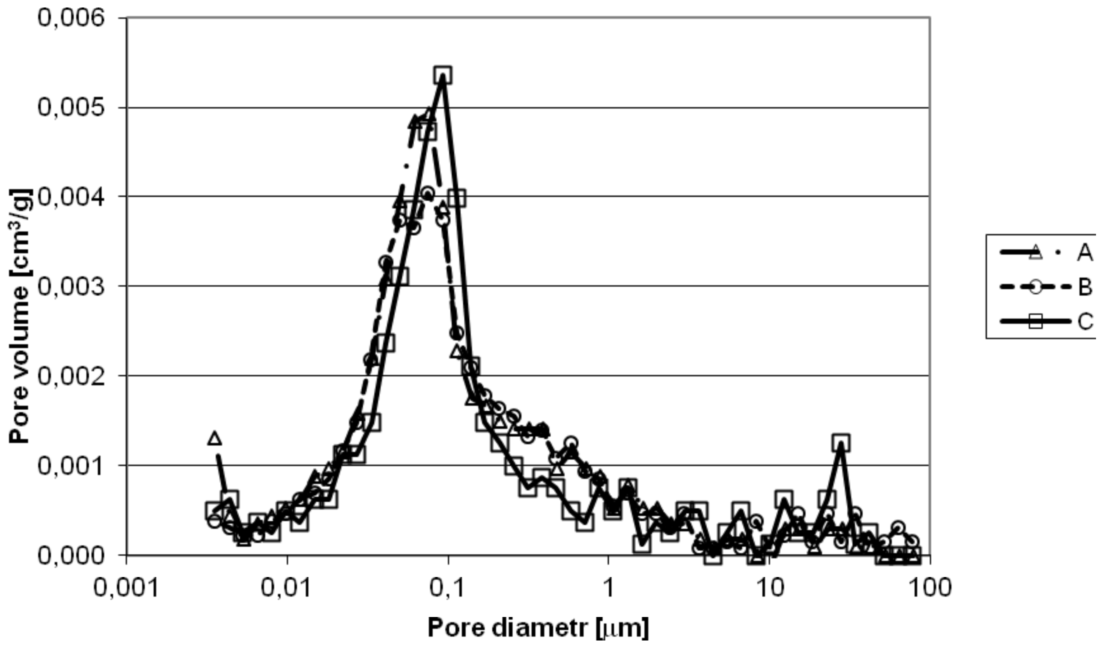

Fig. 2 – Pore distribution

From the mass of the dry sample m_d, the mass of water saturated sample m_w, and the mass of the immersed water saturated sample m_a, the volume V of the sample was determined from the equation (3).

$$V = \frac{m_w - m_d}{\rho_w} \quad (3)$$

Where ρ_l is the density of water. The open porosity ψ_0, the bulk density ρ and the matrix density ρ_{mat} were calculated according to the equations (4), (5), (6).

$$\psi_0 = \frac{m_w - m_d}{\rho_w} \quad (4)$$

$$\rho = \frac{m_d}{V} \quad (5)$$

$$\rho_{mat} = \frac{m_d}{V\left(1 - \psi_0\right)} \quad (6)$$

Table 3 – Properties of concrete mixtures

Mixture	A	B	C
Bulk density [kg/m^3]	2310	2320	2325
ρ_{mat} [kg/m^3]	2598	2600	2579

ψ_0 [-]	10.18	11.48	12.65
Compressive strength [MPa]	67.8	60.5	68.5
Hydraulic conductivity [m/s]	$1.2 \cdot 10^{-11}$	$1.2 \cdot 10^{-11}$	$1.0 \cdot 10^{-11}$
Depth of pressure water penetration [mm]	38	48	25
Equilibrium volume moisture [-]	6.2	5.8	5.7

Sufficient concrete surface resistance depends not only on the quality of the surface layer, but also on the character of the pore system. It directly affects the rate of penetration of aggressive substances from the external environment to the internal structure of the concrete and thus the degradation rate of the material. It is very important therefore to reduce transport of liquid water solutions and water vapor as a primary protection against corrosion of reinforcement. Determination of depth of penetration was performed according standard ČSN EN 12390-8; water has a pressure of 0.5 MPa for 72 hours. Gravimetric amount of absorbed pressure water during testing and its evolution is displayed on fig.3.

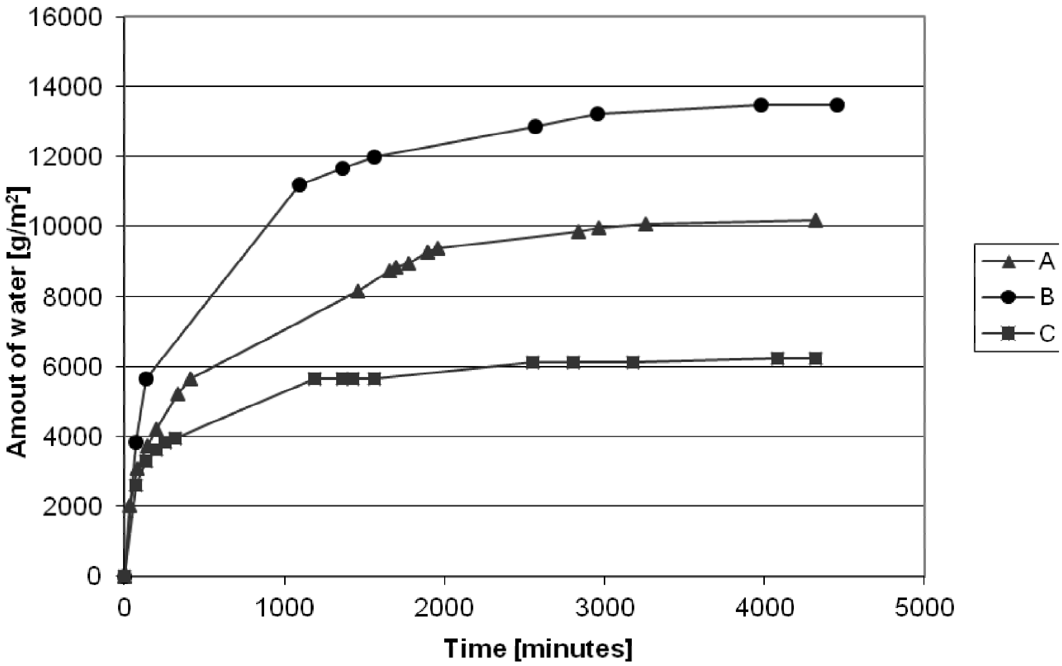

Fig. 3 – Evolution of absorbed pressure water

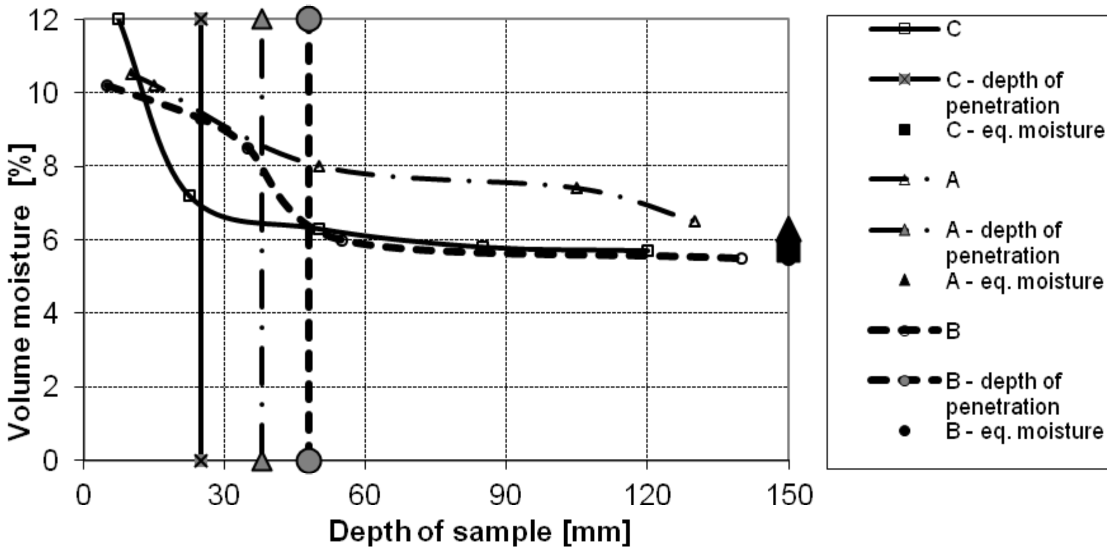

Fig. 4 – Moisture profiles

Conclusion

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. 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.

In connection with the introduction of the new standard system came into issues of concrete durability on importance. Action of aggressive media concentrated in the external environment is to develop a wide range of corrosion mechanisms (CRD C 163-92:),(RILEM). 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. In the case of porous building materials is intrinsic permeability 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.

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References

[1] Cerny, R., Rovnanikova, P.: Transport processes in concrete. London: Spon press 2002.

[2] Green, K. M., Hoff, W. D., Caqrter, M. A., Wilson, M. A., Hyatt, J. P.: A high pressure permeameter for the measurement of liquid conductivity of porous construction materials. Review of Scientific Instruments, 1999, Vol. 70, pp. 3397 – 3401.

[3] Rilem TC 116-PCD: Permeability of concrete as a criterion of its durability. Materials and Structures, 1999, Vol. 32, pp. 174-179.

[4] Mualem, Y. A.: New model for predicting the hydraulic conductivity of unsaturated soils. Water Resources Research, Vol. 12, 1976, pp. 513-522.