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Influence of moisture content of samples on the depth of penetration of water under pressure

R Figmig and M Kovac

Department of Material Engineering, Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Kosice, Vysokoskolska 4, 042 00 Kosice, Slovakia

Abstract. The article deals with the impact of samples moisture content on the results of the depth penetration of water under pressure according to EN 12390-8, considering the fact, that technical standard does not prescribe definite condition of the samples prior testing. To obtain results of the water penetration depth, samples from eight different batches (strength classes from C 12/15 to C 55/67) were prepared. The experiment simulated two boundary conditions: saturated samples were tested immediately after taking from the water. This procedure of samples treatment was marked as the reference (REF). The second one: oven dried samples were tested after cooling to room temperature. This procedure of samples treatment was marked as the comparative (COMP). The results showed an increased tendency in the penetration depth when the samples were oven dried compared to the reference method. There is also discussed the substance, aim and relevance of the technical standards in connection with practical use.

1. Introduction

Durability is one of the essential concrete properties [1]. Basic durability parameter determined on the hardened concrete is watertightness that defines the resistance of concrete against penetration of water [2]. Watertightness is in the close relationship with the permeability of concrete and plays important role in the durability of concrete in sense, that prevent the concrete structure from penetration groundwater under pressure, that may contain chemical compounds, causing its deterioration [3-4].

At present, the penetration test according to EN standard [5] is required to declare the watertightness of concrete. For this parameter, an achievement the depth of penetration of water under pressure must be lower or equal to 50 mm of the highest measured result from the set of testing samples. Watertightness is an obligatory parameter of environmental exposure classes XF2, XF3, XF4, XA1, XA2 and XA3 in the Slovak Republic [6]. More strictly requirements are defined in the Czech Republic, where the obligatory depth of water penetration limits are 50 mm for classes XC3, XC4, XD1, XD2, XF1, XA1, 35mm for XF2 and XA2 and 20mm for XD3, XF3, XF4 and XA3 [7].

Based on mentioned above, it can be declared, that unified and definite complex testing procedure for the determination of a depth of penetration of water under pressure as classification criteria of watertightness should be included in the harmonized technical standard. It ensures precision (reproductivity, repeatability) and comparability of measuring. According to the authors' opinion, the technical standard should prescribe methods of testing concrete (but not only), that simulate the real behavior of concrete in the environment. From the authors' experience, some technical standards determine procedures and requirements, which are not relative to industrial practice. As examples can be noted optimal grain curves of aggregate according to STN EN 206+A1 [8], which do not take into account the aggregate properties as a source, type, grain shape etc. [9]; water/binder ratio requirements (criticized e.g. by prof. Hela on the Concrete 2016 conference, Oct. 2016, Štrbské Pleso, Slovakia; also [10]); or procedure determination of water needed for standard consistency of cement paste, test by EN 196- 3 [11], which determines the temperature of testing cement at 20°C, what is temperature, which is rarely obtained when delivered from cement plant, what subsequently caused increased water need.

Another example of uncertainty is the standard EN 12390-8 which does not prescribe the conditions of samples prior the testing exactly. The common practice in performing the test is, testing the samples taken out of the water 24 hours before the test. However, because not exact standard description, there is the risk that non-uniform state of samples will affect the results of depth of penetration. In the following experiment, the influence of moisture content of the samples on the results of the depth of penetration of water under pressure is demonstrated. The purpose of the experiment is to point out the differences in the results regarding the extreme values of specimens' saturation.

2. Materials and methods

For the experiment, 8 samplings (divided into the 1st and 2nd sampling performed in the different interval) from the random and independent batches of various concrete strength classes of standard cement concrete were performed. The sampling covered various strength classes of concrete to obtain various results in the depth of water penetration. Concrete samples were divided in 4 groups regarding the strength class. Concretes being in the 1st and 2nd group were intended as common ready-mixed concretes (strength class from C 12/15 to C 25/30). Concretes being in the 3rd and 4th group were intended as watertight precast concrete (strength class from C 35/45 to C 55/67). Considering the purpose of the experiment, it is not necessary to give the particular mix design. The samples (cubes 150 x 150 x 150 mm) were taken from 1.0 m^3, respectively 1.5 m^3 batch of concrete. For each strength class 6 samples were taken in the 1st and also in the 2nd sampling. For each of 2 testing methods, 3 samples from each concrete batch were tested. Sampling, preparation, and curing were performed according to EN technical standards as standard procedures. Boundary conditions of samples moisture content were intended as fully saturated and oven dried on the other hand.

First set of samples (of minimal age 28 days) was tested right after samples were taken from the water. This procedure was marked as reference method (REF). This method is currently almost the same compared with the usual one in laboratory praxis. Usual praxis resides in taking samples from the water 1 day before the water penetration test. Second set of samples was tested in the oven dried conditions. Samples were dried at 105 °C ± 5 °C until constant mass of samples was achieved. This procedure was marked as comparative (COMP). Comparative procedure of samples treatment represents an opposite state of the samples moistness state compared with the reference one.

The depth of penetration of water under pressure as such was performed according to standard EN 12390-8 [5] (the water under a pressure of 500 ± 50 kPa was applied for 72 ± 2 h). No deviations were observed during performing the water penetration tests.

3. Results

In this chapter, the results of determining the depth of penetration of water under pressure are given. In Table 1 and Figure 1, results of samples from 1st sampling are given and in Table 2 and Figure 2 results of samples from 2nd sampling are given. In both, 1st and also 2nd sampling the decreasing tendency in depth of water penetration along with increasing strength class of concrete was achieved what is in accordance with theoretical assumption. All samples from 1st sampling treated by REF procedure complied the requirement for water tightness and so, achieved the lower depth of water penetration than 50 mm.

Samples from 1st sampling treated by COMP procedure achieved multiple higher depth of water penetration compared with the samples treated by REF procedure. Only samples from 3rd group complied the requirement for water tightness and so, achieved the lower depth of water penetration than 50 mm. Using comparative testing method (COMP), multiple increments of the depth of water penetration was observed in all tested samples. The same behavior was observed during testing the samples from 2nd sampling. In this case, all samples (excluded 1st group) treated by REF procedure complied the requirement for water tightness. If more strict requirements were considered according to [7], none of tested concrete samples did comply requirements for water tightness of concrete. Samples from 2nd sampling treated by COMP procedure also achieved multiply higher depth of water penetration compared with the samples treated by REF procedure.

Differences between selected testing methods are very high and they point out the importance of uniform standard procedure and sample preparation. Significant differences in the results of determination the depth of water penetration under pressure are illustrated also in Figure 3.

Table 1. Results of determining the depth of penetration of water under a pressure of samples from 1st sampling.

Testing method	1st sampling C 12/15	C 25/30	C 40/50	C 55/67
	25	8	3	5
REF [mm]	25	10	5	8
	45	12	10	9
	75	20	0	15
COMP [mm]	82	35	30	54
	85	95	35	60

Table 2. Results of determining the depth of penetration of water under a pressure of samples from 2nd sampling.

Testing method	2nd sampling C 16/20	C 25/30	C 35/45	C 55/67
	35	40	22	10
REF [mm]	48	41	23	14
	53	42	39	21
	114	65	64	52
COMP [mm]	118	84	95	54
	123	95	106	55

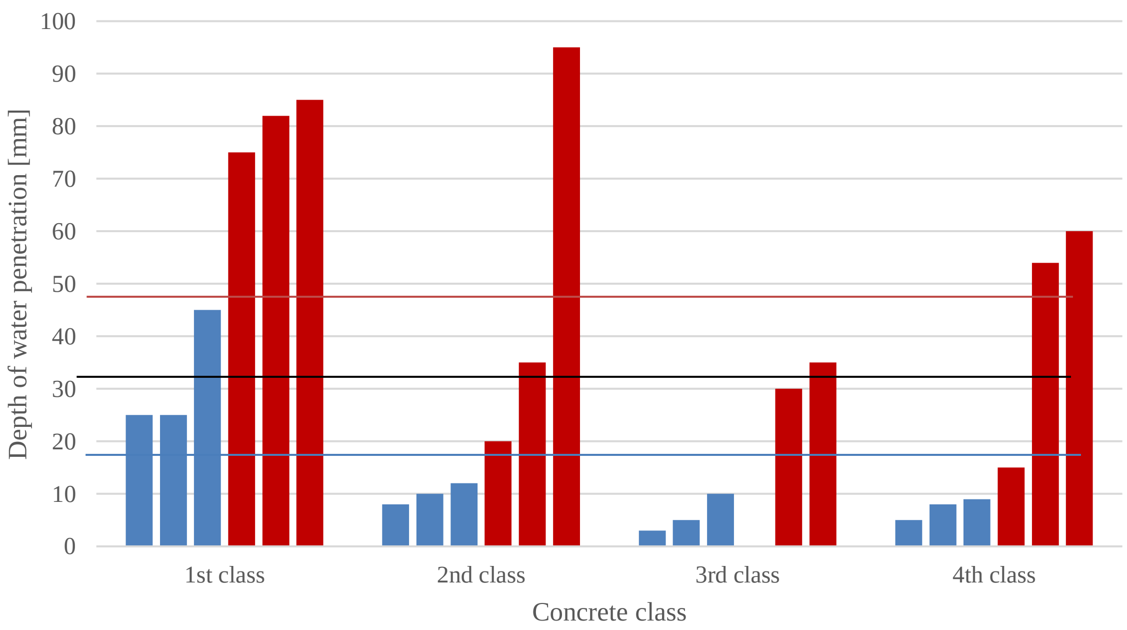

Figure 1. Depth of penetration of water; 1st sampling, Blue: REF, Red: COMP, Limits for maximal depth of water penetration according to [7].

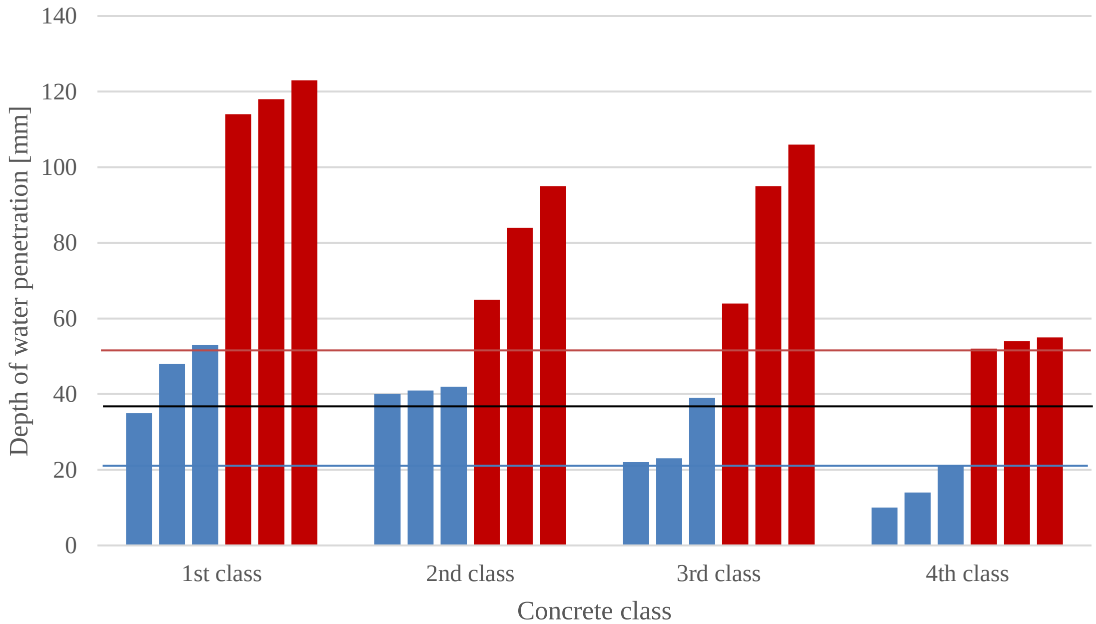

Figure 2. Depth of penetration of water; 2st sampling, Blue: REF, Red: COMP, Limits for maximal depth of water penetration according to [7].

Figure 3. Splitted samples after water penetration test, red line marks the maximum depth of water penetration, samples treated by COMP procedure are on the left, and samples treated by REF procedure are on the right.

4. Conclusion

Based on the results, it can be deduced, that the moisture content of sample has a crucial impact on the result of a watertightness test. Results obtained by testing samples treated by REF procedure are several times lower than that of obtained by samples treated by COMP procedure. In the case, when this parameter is demanding, moisture content has an impact on results in the sense of meeting or failing to meet the standard requirements. The query is, which of the state, saturated or dried, simulates the real concrete condition and environment the best. The saturated state is different considering various pore-capillary systems in connection with different concrete mix designs. Absolutely dryness will rarely be reached in real condition. Based on the authors´ experience and also in according to [12], oven-drying causes change in concrete micro-structure (micro-cracking, particular heat material degradation) what leads to higher permeability. The solution of described issue may lay in measuring the real casting concrete moisture condition in particular environment. Then the specimens should be prepared (cured) in relation to those results.

In authors' opinion it would be more suitable to express the results by maximal value of depth of water penetration (covering extreme value of a set of samples) and also by average value of depth of water penetration (covering particular samples deviation, which can be caused by unequal specimens making).

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References
[1] Neville A M 1995 *Properties of Concrete* (London: Longman) p 482-497
[2] Schlumpf J, Bicher B and Schwoon O 2012 *Sika Concrete Handbook* (Zürich: Sika Services AG) p 126-129
[3] Zhang H 2011 *Building Materials in Civil Engineering* (Sawstone: Woodhead Publishing) p 113
[4] Zongjin L 2011 *Advanced Concrete Technology* (Hoboken: John Wiley & Sons) p 217-221
[5] EN 12390-8: 2011 *Testing hardened concrete* Part 8: Depth of penetration of water under pressure
[6] STN EN 206/NA: 2015 *Concrete. Specification, performance, production and conformity*
[7] ČSN P 73 2404: 2016 *Concrete - Specification, performance, production and conformity - Additional information*
[8] STN EN 206+A1: 2017 *Concrete. Specification, performance, production and conformity*
[9] Figmig R, Kováč M and Sicakova A 2017 *The influence of grain aggregate on the consistency of freshness concrete* (Bratislava: SAVT) p 35-44 (in Slovak)
[10] Wasserman R, Katz A and Bentur A 2009 *Mater. Struct.* **42** 973-982
[11] EN 196-3: 2017 *Methods of testing cement - Part 3: Determination of setting times and soundness*
[12] Hager I 2013 *Bull. Pol. Ac.: Tech.* **61** 1-10