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Estimation of Durability of Fiber Concretes With Concrete Recyclate Based on Different Interpretation of Capillarity and Absorptivity Values

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Abstract: The estimation of the durability of fiber concretes is very important information for a wider use of concretes in the building industry. It is obvious that the durability of concrete is directly related to the spatial arrangement of its pore structure. The specified values of absorptivity and capillarity of concrete may very well characterize their vulnerability to future damage with frost and chemicals. The physical nature of tests for the determination of absorptivity and capillarity of concrete, however, is different in both methods, and this difference should be included in the final interpretation of the test results to obtain an objective estimation of the durability of tested concretes.

Key words: fiber concrete, pore structure, absorptivity, capillarity, estimation of durability

1. Introduction

Using fibers in a cement-bonded system is the best way to avoid crack growth. Cracks can occur due to tensile stress, which is caused by plastic shrinkage, drying shrinkage or autogenous shrinkage. At the same time, other properties can be improved, such as flexural and impact strength or abrasion resistance. Fiber-reinforced concrete is a modern building material with sufficiently proven mechanical and deformation properties. Long polymer fibers purposefully improve the mechanical properties of the concrete composite. However, the presence of fibers in a concrete composite can also have its negative aspects [1]. Scattered fibers are able to improve the low tensile strength of concrete, but at the cost of potentially exceeding the critical shear stress of the fiber-cement paste contact. According to some authors, poor adhesion of the fibers to the cement matrix, exceeding the shear stress or corrosion can lead to an increase in the permeability and, as a result, to a decrease in the durability of the cement composite. Some experts, on the other hand, believe that the addition of long and short fibers to the concrete will increase its durability by preventing the formation of microcracks at all stages of concrete curing. However, it should be noted here that due to the different moduli of elasticity of the polymer and steel fibers, additional tensile microcracks may occur when the concrete shrinks in the rigid wire fiber framework. The durability of concrete [2, 3] is determined mainly by its susceptibility to mass transport in the heterogeneous porous media [4], i.e., also the transport of water and aqueous solutions [5] caused by chemical potential gradient, temperature and pressure potentials, or external force field [6, 7]. It will certainly be beneficial to compare two basic physical and material characteristics of the pore system of concrete — laboratory-determined absorptivity and capillarity [8], for fresh concrete after one month of curing, and then for the same concrete damaged by

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carbonation, i.e., stored for another 8 months in a simulated environment of concentrated 98% CO_2.

2. Materials and Methods

The research study is focused on evaluating the possibility of an alternative use of physically different but principally simple methods of determining the absorptivity and determining the capillarity to estimate the durability of fiber concrete from natural dense aggregates and polymer and steel fibers. In one formulation, the coarse fraction of dense aggregate is substituted by the recycled concrete fraction of 0–16 mm from the Dufonev company. The values of absorptivity of the tested concretes are compared with the corresponding values of capillarity, namely at the stage of one month of curing in a wet storage and after the following 8 months of exposure in a concentrated environment of 98% CO_2.

2.1 Formulations of Concrete

Eight concrete formulations were used to produce 16 beam samples (1st formulation — reference — with dense aggregate marked "O", 2nd formulation — dense aggregate with 0.15% PP fibers marked "HV", 3rd formulation — dense aggregate with 0.5% PP fibers marked "H", 4th formulation — dense aggregate with 1% PP fibers marked "B", 5th formulation — recycled concrete 0–16 mm with 1% PP fibers marked "C", 6th formulation — dense aggregate with 0.15% steel fibers marked "DA", 7th formulation — dense aggregate with 0.5% steel fibers marked "DC" and 8th formulation — dense aggregate with 1% steel fibers marked "DB"), see Table 1. The type of cement used was CEM II/B-S 32.5R. The concretes were prepared from natural extracted dense aggregate of fraction 0–4 mm from Bratčice, natural extracted dense aggregate of fraction 4–8 mm from Tovačov and natural crushed dense aggregate of fraction 8–16 mm from Olbramovice. When preparing the concrete from concrete recyclate, the coarse fraction of natural aggregate 8–16 Olbramovice was substituted by raw concrete recyclate by Dufonev s.r.o. of fraction 0–16 mm. All eight formulations were plasticized using CHRYSOPLAST 760 plasticizer. Polymer fibers used were of the FORTA FERRO type (virgin polypropylene–PP), length 50 mm, and steel fibers of the Dramix type, length 60 mm. Each absorptivity and capillarity test was made on two pairs of beam samples with dimensions of 100×80×300 mm from the same formulation.

Table 1 Formulations of Concrete (Mass Is Given in kg for the Mixture of 1 m^3 of Fresh Concrete).

Marking of concrete	Mass of cement m_c	Aggregate			Water/Cement ratio (in mass proportion)	Plasticizer	PP + Steel Fibers
		0–4 mm	4–8 mm	8–16 mm			
	[kg]	[kg]	[kg]	[kg]	-	[%] of m_c	[kg]
O	490	890	100	745	0.34	1	0
HV	490	890	100	745	0.35	1	1.37 (0.15%) PP
H	490	890	100	745	0.36	1	4.6 (0.5%) PP
B	490	890	100	745	0.36	1	9.1 (1%) PP
C (recyclate)	490	890	100	633 (recyclate)	0.43	1	9.1 (1%) PP
DA	490	890	100	745	0.36	1	11.7 (0.15%) steel
DC	490	890	100	745	0.37	1	39.1 (0.5%) steel
DB	490	890	100	745	0.38	1	78.0 (1%) steel

2.2 Determination of Absorptivity of Concrete

Concrete beams with dimensions of 100×80×300 mm are first weighed and then placed in an oven at 105°C for 72 hours. After removal and cooling to room temperature, they are weighed again (m_d). The beams are placed horizontally in a pot and flooded with water 2 cm above the top surface (Fig. 1). After another 72 hours, the beams are removed, surface dried and weighed. Next, the beams are placed back into a pot of boiling water for another 4 hours. After boiling, the samples are allowed to cool to ambient temperature. The samples are then surface dried and their weight (mass) is determined. Absorptivity is the ability of a porous material to absorb liquid. It is determined in [%] as the ratio of the weight of water absorbed by the test sample to the weight of the dried sample (absolute mass absorptivity).

The calculation of absorptivity is performed according to the procedure described in Czech national standard ČSN 73 1316 "Determination of moisture content, absorptivity and capillarity of concrete" [8] or according to ČSN 72 2603 "Testing of brick products. Determination of mass, volume mass and absorptivity" [9]. The resulting water absorptivity γ in [%] is expressed by the relation:

$$\gamma = (m_a - m_d) / m_d \ [\%]$$

where

γ: water absorptivity in [%],

m_a: mass of the sample after absorptivity test [kg],

m_d: weight of dried sample [kg].

The method used to determine the absorptivity by "boiling" is a long-tested combination of the method of determining the absorptivity of concrete by long-term immersion in water at room temperature (soaking of test samples is completed if the weight change during the last time interval is less than the prescribed weighing accuracy — often the test lasts three weeks) [8] and the method for determining the boiling absorptivity of brick products [9].

2.3 Determination of Capillarity of Concrete

Concrete beams with dimensions of 100×80×300 mm are dried to a constant weight before the test. Each sample is weighed. Samples are then placed vertically in a flat container with water so that they are immersed to a height of 10 mm (Fig. 2). The water level is always

Fig. 1 Determination of absorptivity of concrete.

Fig. 2 Determination of capillarity of concrete.

kept at the same height. Changes in the weight of the test samples, or current rise heights are monitored at intervals of 1 h, 3 h, 5 h, 8 h, 24 h, 2 days, 3 days, or 7, 14, 28 days. After each control weighing, the continuous size of capillarity γ_r in [%] can be determined according to the relationship given in the previous paragraph 2.2, resp. in ČSN 73 1316 [8] or in ČSN 72 2603 [9]. For the subsequent comparison of the absorptive and capillary properties of the tested concretes, the most important is the absolute mass capillarity calculated from the highest increase in capillary mass of sample.

3. Results and Discussion

Both tests for the determination of absorptivity and capillarity were performed always on two pairs of samples in two stages, after 1 month of concrete curing in a wet storage and after another 8 months of exposure of the identical concrete samples in an aggressive environment of 98% CO_2. It should be noted here that samples of formulation H and DC were not temporarily included for absorptivity and capillarity tests after eight months of exposure in 98% CO_2 due to the limited size of the carbonation chamber. By comparing the pairs of graphs in Figs. 3-4 and in Figs. 5-6, it is clear that the percentage absorptivity of concretes is 4-10 times higher than the percentage capillarity of the corresponding concrete, even after carbonation (approximately the end of the 1st carbonation stage).

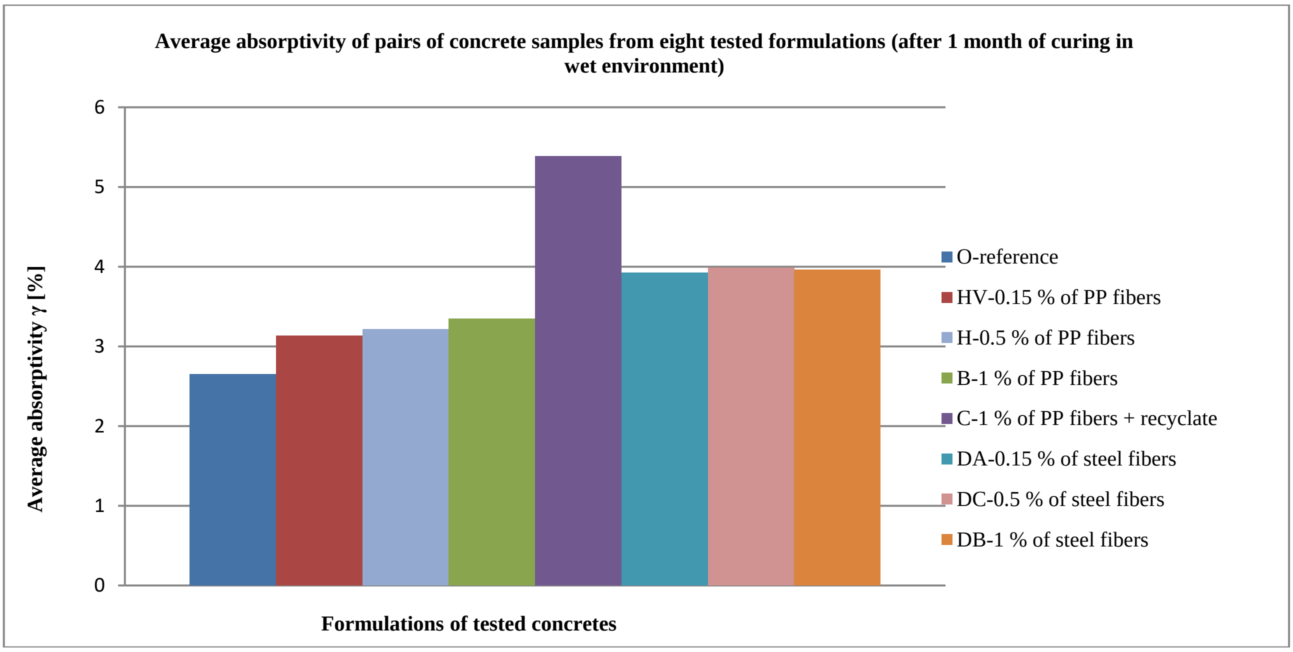

Fig. 3 Average absorptivity of tested concrete samples after one month of curing in wet environment.

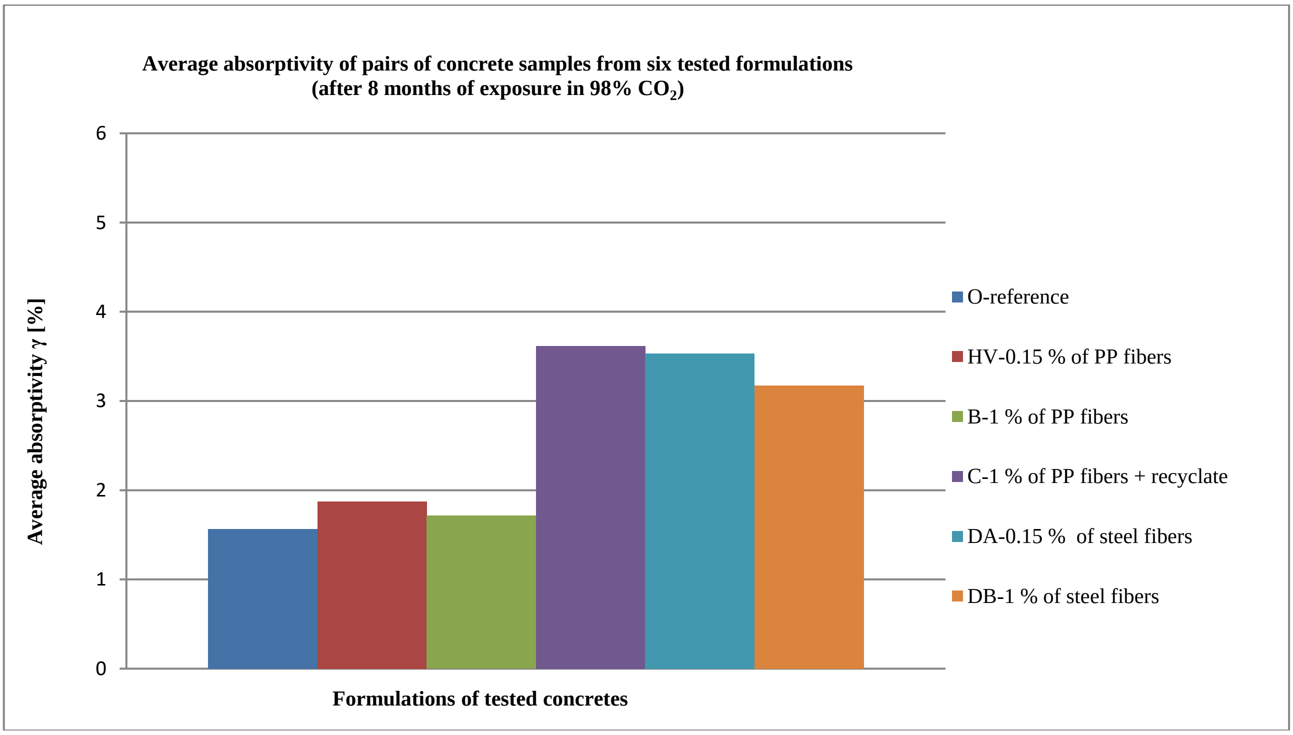

Fig. 4 Average absorptivity of tested concrete samples after 8 months of exposure in aggressive environment of 98% CO.

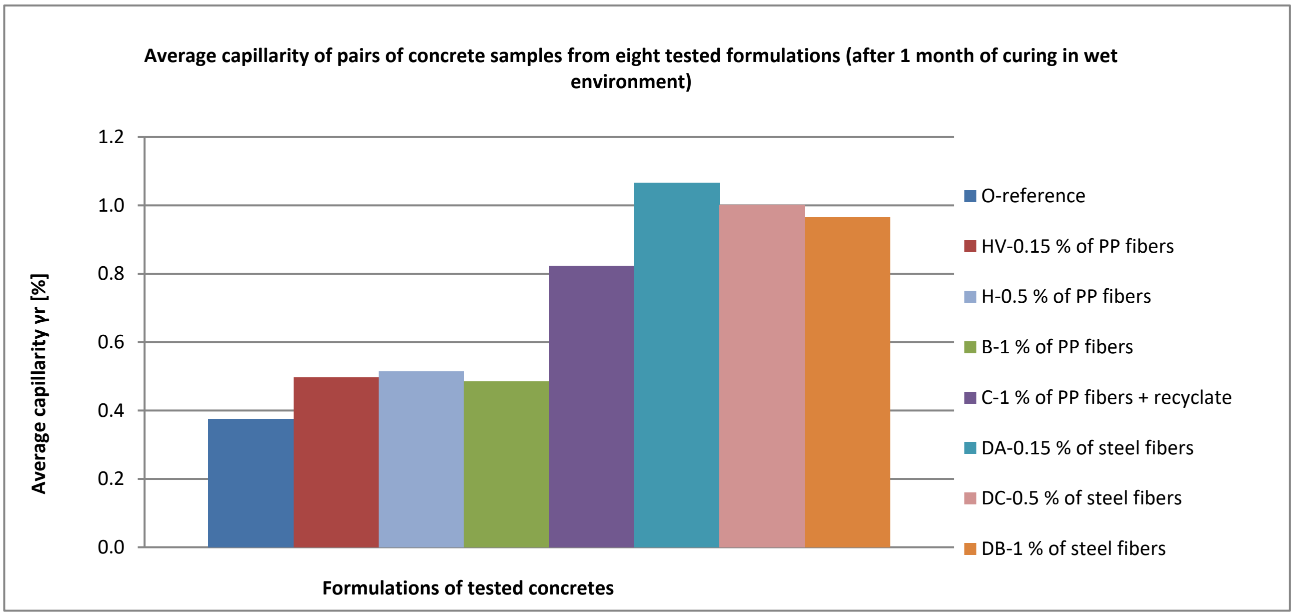

Fig. 5 Average capillarity of tested concrete samples after one month of curing in wet environment.

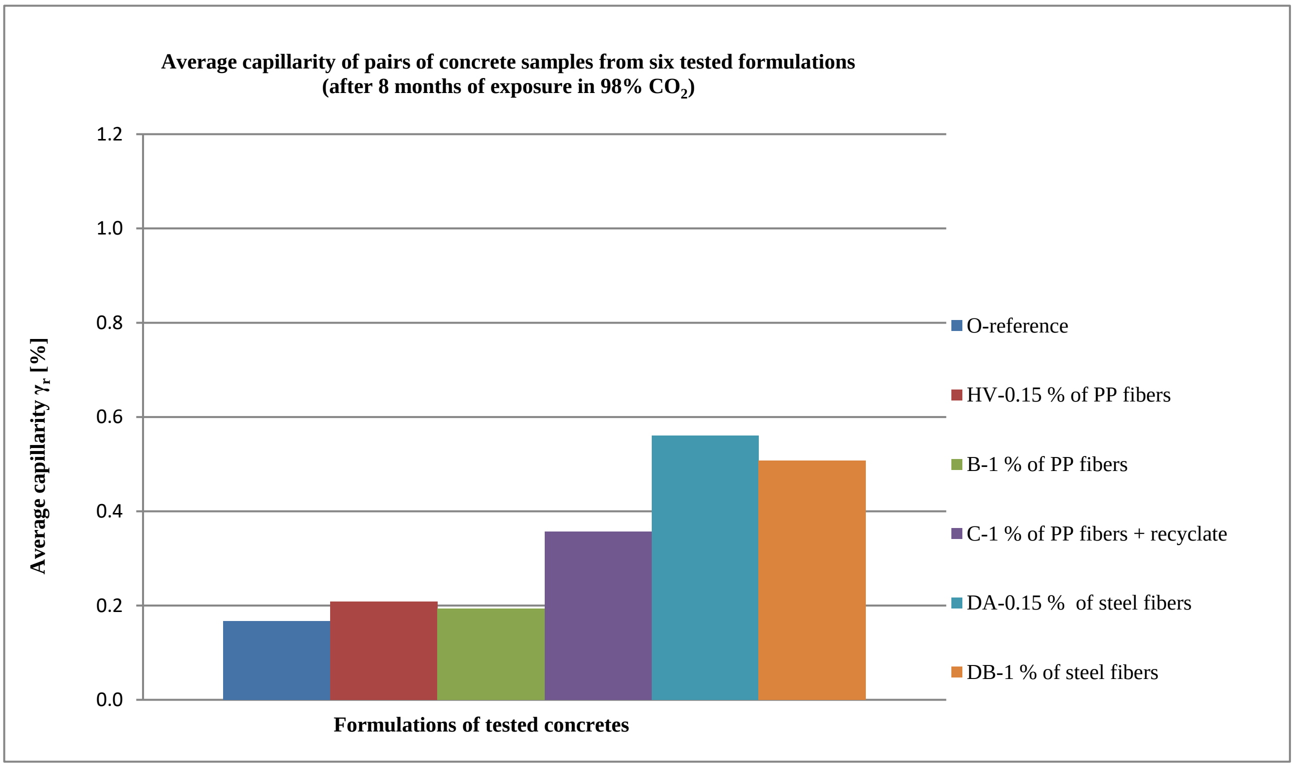

Fig. 6 Average capillarity of tested concrete samples after 8 months of exposure in aggressive environment of 98% CO_2.

The reason is the different physical nature of the penetration of liquid into the tested concrete in both methods. The highest absorptivity was measured for concrete with dense aggregate substituted by recycled concrete before and after carbonation. This high water absorption is primarily due to the significant porosity (10%) of the raw recycled concrete used. Concretes with steel wires show a slightly higher absorptivity compared to concretes with polymer fibers, except for concrete with recycled concrete. The highest capillarity was measured in concretes with steel wires (fibers), again before and after carbonation. The capillarity of concrete with recycled concrete and polymer fibers is slightly deteriorated compared to similar concretes with dense aggregates, but it is not as pronounced as in concretes with steel wires. During the process of hydration of concrete with steel wires, in the cooling phase, the cement paste shrinks, and it is torn off from the solid skeleton of the wires with the final effect of the formation of new capillaries, intensifying the capillarity process.

4. Conclusion

Methods for determining the absorptivity and capillarity of concrete samples according to ČSN 73 1316 [8] and ČSN 72 2603 [9] are completely undemanding as far as technical equipment is concerned, but they require the determination of weight at regular time intervals for a total time of one month. In the case of determining the absorptivity, the concrete samples are immersed below the water surface, and water is pushed into its pores and cracks by the constant overpressure of the water column in the given place of the standing concrete sample. Here, according to V. Pumpr & J. Mandelík (2016) [10], it can be concluded that the flow of water through the pore is directly proportional to the fourth power of the pore diameter resp. a cube of the crack width. In the case of determining the capillarity, water is drawn by capillary forces against the force of the gravitational field into a vertical capillary, and according to Ref. [11], it can be concluded that the height of water elevation through the capillary is inversely proportional to the square of the capillary diameter. Simply put, the larger the diameter of the capillary, the lower the height to which the water rises by capillary elevation, so it is possible to assume a lower suction capacity of concrete. The physical nature of both the tests, i.e., the method for determination of absorptivity and the method for determination of capillarity, is considerably different and for this reason the results of both methods cannot be clearly interchanged. The method for determination of absorptivity seems to be suitable for an estimation of the durability of concretes exposed to pressurized water for a long time, and the method for determination of capillarity seems to be suitable for an estimation of the durability of concretes partially submerged or exposed to the effects of the weather.

According to Instruction F of the European Commission from 2002, the durability of building materials can be defined as the interval during which the monitored properties remain within the limits under loading.

In the case of porous silicates, it can be assumed that their long-term durability will be significantly affected by the amount, size and interconnection of the pores. If we use the results of the specified capillarity to predict the durability of concrete, then the following can be stated: for concretes with dense aggregate substituted by recycled concrete and 1% PP fibers we can assume a slightly worse durability compared to concretes with natural dense aggregate and PP fibers, but slightly better durability in comparison with concretes with dense aggregate and steel wires. If we evaluate the durability of concrete from the results of the determined absorptivity, we can assume approximately the same durability of concrete with the substitution of dense aggregate by recycled concrete and PP fibers as that of concrete with dense aggregate and steel wires.

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