

# Permeation and diffusion tests for estimation of durability of fibreconcretes with dense aggregate and recycled concrete

**M Stehlik, J Knapova and V Hermankova**

Department of Building Testing, Faculty of Civil Engineering, Brno University of Technology, Veveri 95, Brno, Czech Republic

**Abstract.** Mechanical and deformational properties of concrete are markedly improved by the addition of long structural fibres. This addition, however, not always improves the durability of concrete. One important factor for an estimation of concrete durability is to assess the permeation and diffusion characteristics of the surface layer. The research was performed by means of the TORRENT permeability method and the method for determination of the non-steady-state migration coefficient of chlorides in concrete – NORDTEST. The addition of long polypropylene fibres contributes to increasing the permeability of the surface layer for air and chloride solution, but not too significantly. The higher permeability was determined in concrete with concrete recycle and polypropylene fibres. The measured results by both used methods are partially comparable and can be used for raw estimation of durability of concretes. The higher values of permeability indicate the expected lower durability of tested concretes.

## 1. Introduction

According to the Guidance Paper F to the European Construction Products Directive of December 2004, the durability of concrete can be defined as the ability of a product to maintain its required performance over a given or long time, under the influence of foreseeable actions. An important indicator in this respect is the surface layer of concrete constituting a “gateway” for various harmful substances [1,2]. The research of durability is mainly concerned with the study of the physico-mechanical and chemical damage to concrete.

Fibre concretes are modern building materials with the sufficiently proven mechanical and deformation properties. Long polymer fibres purposefully improve the mechanical properties of the concrete composite. However, the presence of fibres in the concrete composite can also have a negative impact [3]. The diffused fibres are able to improve the low tensile strength of concrete, however, at the cost of exceeding the critical shear stress of the fibre-cement contact. Poor adhesion of fibres to the cement matrix, the exceeding of the shear stress, or corrosion can lead, according to some authors, to an increase in permeability and subsequently to a decrease in the durability of the cement composite. On the other hand, however, some experts believe that the addition of long and short fibres to concrete increases its durability on the grounds of preventing the occurrence of microcracks at all stages of concrete curing [4]. If we accept the fact that the durability of concrete is considerably determined by the permeability of its surface layers [5], it seems to be reasonable to determine the permeability of the surface of the tested concretes by one of the modern non-destructive methods, e.g. TORRENT for air and NORDTEST for a solution of chlorides in water.



## 2. Experimental part

Focus is given to the determination of the durability properties of fibre concretes made from natural dense aggregate and polymer fibres, and alternatively, in one formula, from the concrete recyclate with a fraction of 0-16 mm by Dufonev, substituting the coarse fraction of the dense aggregate.

From among the surface permeability tests [6,7], the TORRENT test [8] was chosen (permeability of the surface layer for air). This test was carried out on the concrete tiles of 300x300x80 mm. For each formula, 6 measurements were taken. Another method used in the tests was the NORDTEST method for a determination of the coefficient of the non-steady-state migration of chlorides in concrete. This test was carried out on the segments separated from the core samples. Each segment had a diameter of 100 mm and a height of 50 mm. For each formula, the measurements were taken on two separate segments.

### 2.1 Formulas of concrete

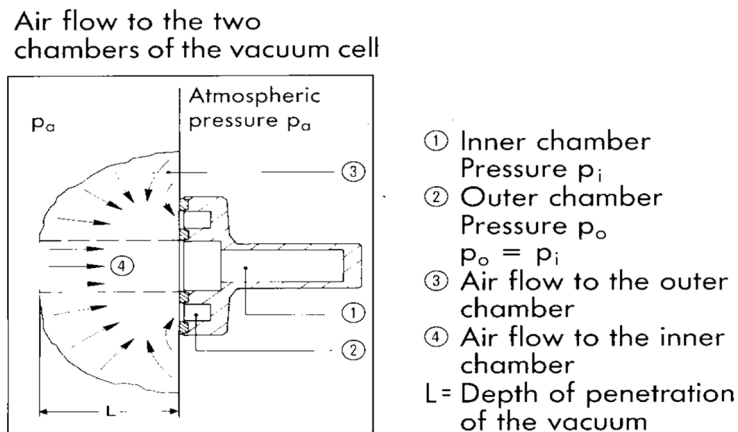
We made a total of 12 tiles (300x80x300 mm) according to 4 concrete formulas (the 1st formula – reference, with dense aggregate, „O“, the 2nd formula – dense aggregate with 1% of PP fibres, „B“, the 3rd formula – dense aggregate with 0.15% of PP fibres, „HV“, and the 4th formula – concrete recyclate of 0-16 mm with 1% of PP fibres, „C“), see table 1. The type of cement used was CEM II/B-S 32.5R. The concretes were prepared from the natural extracted dense aggregate with a fraction of 0 – 4 mm from the Bratčice sand pit, the natural extracted dense aggregate with a fraction of 4 – 8 mm from Tovačov, and the natural crushed dense aggregate with a fraction of 8 – 16 mm from Olbramovice. The concrete made from concrete recyclate was prepared by substituting the coarse fraction of the natural aggregate of 8-16 mm with the raw concrete recyclate with a fraction of 0-16 mm by Dufonev s.r.o. All the four formulas were plastified by means of the CHRYSOPLAST 760 plasticizer, and the type of long construction polymer fibres used was FORTA FERRO with a length of  $l = 50$  mm and aspect ratio of  $l/d = 110$ .

**Table 1.** Formulas of concrete.

Labelling of concrete	Amount of cement	Aggregate			Water-cement ratio	Plastisizer	PP fibres
		0-4 mm	4-8 mm	8-16 mm			
	[kg/m <sup>3</sup> ]	[kg/m <sup>3</sup> ]	[kg/m <sup>3</sup> ]	[kg/m <sup>3</sup> ]	-	[%] of $m_c$	[kg/m <sup>3</sup> ]
O	490	890	100	745	0,34	1	0
B	490	890	100	745	0,36	1	9,1 (1%)
HV	490	890	100	745	0,35	1	1,37 (0,15%)
C (recyclate)	490	890	100	633 (recyclate)	0,43	1	9,1 (1%)

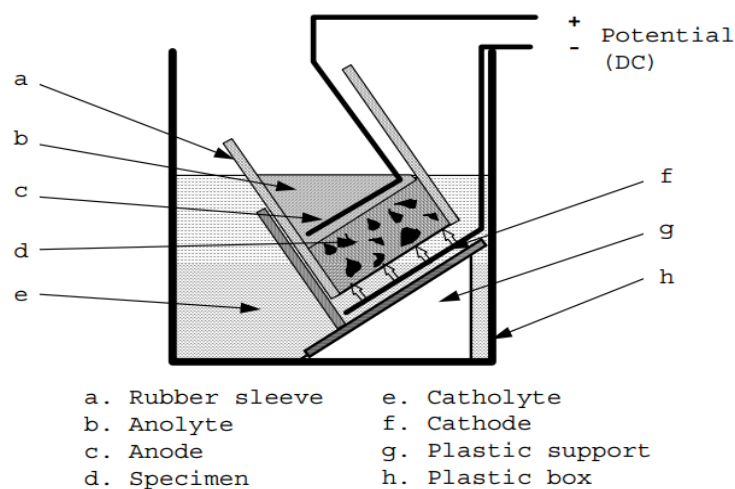
### 2.2 Principles of TORRENT and NORDTEST testing methods

The TORRENT testing method is suitable for determining the air permeability of the surface layer of concrete and it can be used both on the test specimens, and on the construction site. The principle of determining the air permeability consists in creating vacuum on the surface layer of concrete and in measuring the penetration of air through the concrete to the measuring device during the specified period of time. A cross-section of the TORRENT apparatus can be seen in figure 1.



**Figure 1.** Cross-section scheme of the TORRENT device.

In the direction of the specimen axis by the testing method NORDTEST, an external electrical potential is applied which forces the outer chloride ions to pass inside the specimen. When the specified test time interval expires, the specimen is split axially, and the freshly split surfaces are covered with silver nitrate  $\text{AgNO}_3$ . In the areas of penetration, it reacts into the white silver chloride  $\text{AgCl}$ , according to which it is easy to recognize and measure the depth of penetration. The migration coefficient is subsequently determined from this measured depth. The position of the specimen in the apparatus is shown in figure 2.



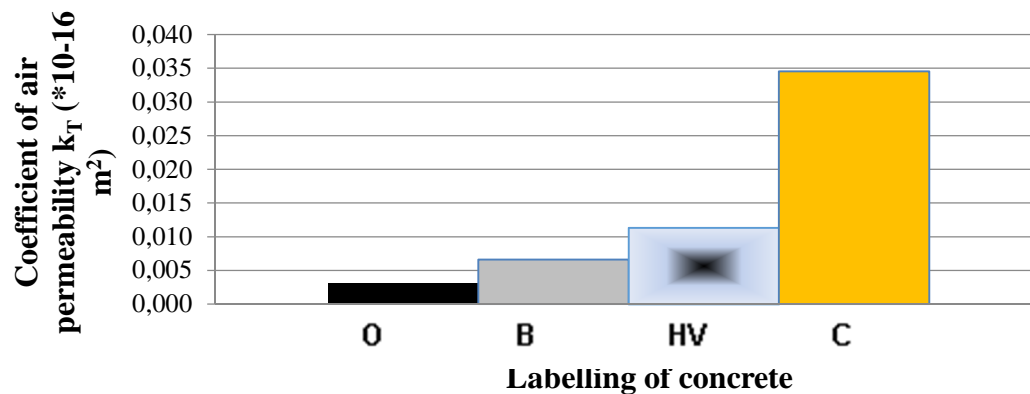
**Figure 2.** Cross-section scheme of the NORDTEST device.

### 3. Results and discussion

Both permeability tests were carried out after 1 month of the concrete specimens' curing in a humid environment and the subsequent drying to the 3% moisture content. Table 2 and table 3 give the values of the determined coefficients of permeability and of the migration of chlorides using both methods.

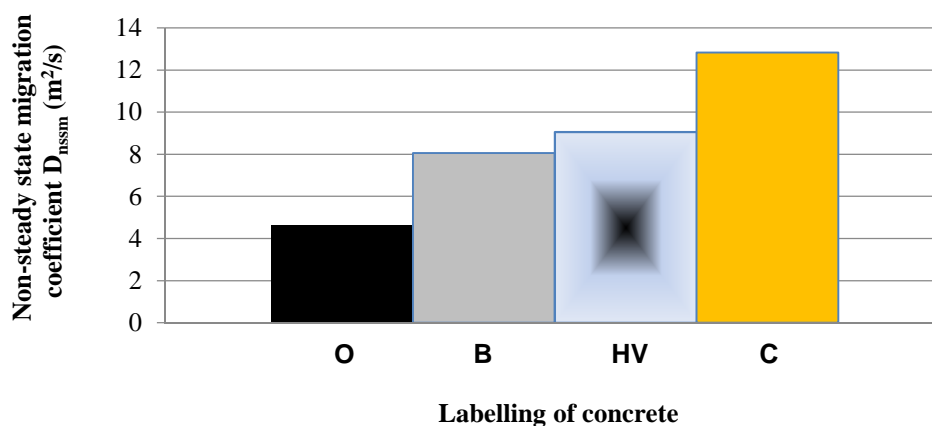
**Table 2.** Coefficients of air permeability of concretes  $k_T$  from the TORRENT method.

Labelling of concrete	Current moisture content $w$ average [%]	Correction of value $k_T$ for $w=3\%$		Depth of vacuum intrusion $L$ average [mm]	Quality of concrete layer for $w=3\%$ average
		average [ $\cdot 10^{-16} \text{ m}^2$ ]	[%]		
O (concrete with dense aggregate without fibres)	2,92	0,003	100	4,1	Very good
B (concrete with dense aggregate + 1 % PP fibres)	3,25	0,007	233,3	4,2	Very good
HV (concrete with dense aggregate + 0,15 % PP fibres)	3,42	0,011	366,6	4,5	Good
C (concrete with concrete recycle + 1% PP fibres)	3,68	0,035	1166,6	6,3	Good

**Air permeability of concrete (TORRENT method)****Figure 3.** Dependence of coefficients of air permeability  $k_T$  on types of concrete.

**Table 3.** Measured non-steady state chloride migration coefficients by the NORDTEST method.

Labelling of concrete	Initial current	Applied voltage	Chloride penetration height	Non-steady state chloride migration coefficient	
	I30v	U	X <sub>d</sub> (individually)	D <sub>nssm</sub> (individually)	D <sub>nssm</sub> (average)
	[mA]	[V]	[mm]	[m <sup>2</sup> /s]	[m <sup>2</sup> /s]
O1	45	30	10,929	4,815	4,625
O2	45	30	10,141	4,434	
B1	50	30	17,714	8,137	8,067
B2	50	30	17,429	7,997	
HV1	40	35	22,107	8,843	9,064
HV2	60	25	16,931	9,286	
C1	65	25	23,285	13,095	12,838
C2	60	25	22,431	12,581	

**Migration of chlorides (NORDTEST method)****Figure 4.** Dependence of non-steady state migration coefficient of chlorides  $D_{nssm}$  on types of concrete.

It is apparent from both charts that polymer fibres slightly increase the permeability of concrete for air and for chlorides, namely, inversely to their amount. It is possible to observe a close correlation dependence between the results of both the TORRENT and NORDTEST methods. The permeability coefficients of the concretes made from concrete recycle determined by both the methods are the highest, which is caused by the higher porosity of the concrete recycle compared to the dense aggregate. The overall permeability is probably also worsened by a combination of the concrete recycle and PP fibres. The higher permeability is characteristic of the concretes with 0.15% of fibres in comparison to the concretes with 1% of fibres. This effect is caused by an insufficient amount of fibres in the concrete volume which do not effectively suppress the occurrence of microcracks during the stages of hydration and subsequently shrinkage of concrete.

#### 4. Conclusion

Durability of concrete is from great amount a function of physical-mechanical properties of concrete layer. In this article the results of two basic methods for concrete layer testing were described. The coefficients of permeability and chloride migration determined by means of the TORRENT and NORDTEST methods are relatively closely correlationally dependent and can be used separately or in combination for a quick informative estimate of the durability properties of fibre concretes made from dense aggregate as well as from concrete recyclate. Generally, the higher value of permeability of concrete decreases its durability, or in other words, its expected life time.

If we compare the permeability and diffusion properties of the surface layer of concrete with fibres with that without fibres, it is possible to say that fibres contribute to increasing the permeability of the surface layer for air and chloride solutions, but the increase is not too marked, and according to the tables, the concretes fall under the same class. The higher permeability, especially for the gaseous medium, was determined in the concrete made from the concrete recyclate with fibres, probably due to the higher porosity of the concrete recyclate compared to the dense aggregate. In the case of the migration of chlorides, this difference is not very important.

In conclusion it is possible to say that the concrete made from concrete recyclate shows slightly worse permeability results in terms of the formulas tested, and we can expect its lower durability, but this concrete can definitely be used even in demanding structures with a low aggressiveness of the environment of class X and XC.

#### Acknowledgement

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