Scuola universitaria professionale della Svizzera italiana
Dipartimento ambiente costruzioni e design
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SUPSI

Report RAP 10906 01 **Dossier No. 10906**

SUBJECT

DETERMINING THE RADON IMPERMEABILITY OF:

CONCRETE FOR DRYTECH® WHITE TANK SYSTEMS
DRYFLEX ELASTIC FOAM RESIN
DRYSET FORMWORK PLUGGING SYSTEMS

CLIENT

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INDICE

1 INTRODUCTION

On 12 March 2018 Drytech SA Impermeabilizzazioni, Bedano, asked the SUPSI Institute for Materials and Constructions (IMC) to determine experimentally the radon impermeability of the components of the Drytech® tank system, which consists of Drytech® waterproof concrete, DRYflex elastic foam resin and DRYset formwork plugging systems.

The objective of the commission was to verify that, in addition to the Drytech waterproof concrete, which, as specified in “Radon: Praxishandbuch Bau” (Radon: Praxishandbuch Bau, 1st edition, January 2018, Faktor Verlag, Zurich; page 19), if classified as impermeability class 1 in accordance with SIA 272 regulations should be considered ex ante as an effective barrier against radon penetration for thicknesses greater than or equal to 25 cm, the other components of the Drytech® tank system were also impermeable to this gas.

The tests referred to in this report were conducted in the period between 01.10.2018 and 31.05.2019, using a diffusion chamber specifically designed by IMC, on samples prepared by Drytech SA. In the absence of standardized methods, the radon transportation properties of the Drytech® tank system components were determined using a procedure developed and validated by IMC.

The results presented in this report refer exclusively to the samples tested.

2 RADON IMPERMEABILITY CALCULATION METHOD

The diffusion chamber utilised for the experiments consists of two cells (see photograph 1, Attachment A1): a *source cell*, whose internal air is enriched with radon by way of a specific source (flow-through radon source model RN-1025; manufacturer: Pylon Electronics Inc., Ottawa, Canada), and a *collector cell*, which collects the radon that crosses through the sample positioned between the two cells. Each of the two cells is connected to an instrument measuring the radon activity concentration (radon and thoron measurement system model RTM 2200; manufacturer: SARAD GmbH, Dresden, Germany).

The radon activity concentration values in the two cells are those measured in the stationary state, which is typically reached 7 – 10 days after the start of the test. These values are then used to calculate the diffusion length R and the diffusion coefficient D of this gas. In the source cell the activity concentration equilibrium value is typically C_{SC} = 100,000 Bq/m^3. In the collector cell the C_{RC} equilibrium value varies in accordance with the permeability of the sample being tested, but is directly proportional to the exhalation rate E of the radon from the surface of the sample facing it. The proportionality constant was calculated while the diffusion chamber calibration measurements were being taken.

The method used to calculate the length of the radon diffusion coefficient is based on the hypothesis that the diffusive process is described by Fick’s law. The partial differential equation for the radon activity concentration inside the sample corresponding to this hypothesis, appropriately assigned a term that makes it possible to consider the radon decay, was solved for the stationary state, assuming third type boundary conditions (Robin conditions). Based on the solution obtained, the formula was derived for the radon exhalation rate from the surface of the sample facing the collector cell. The outcome is an equation that is non-solvable algebraically for the transportation properties (R or D) in which, in the case of homogeneous samples, like the concrete samples for instance, the thickness of sample d, the exhalation rate E of the radon toward the collector cell and the activity concentration equilibrium values C_{SC} and C_{RC} appear as calculation parameters.

For homogeneous materials, and as generally accepted in the scientific community, the radon impermeability criterion is satisfied when the thickness of the construction element exceeds, by a factor of at least 3, the length of the radon diffusion in the material from which this construction element is made (see “Radon: Praxis-Handbuch Bau”, 1st edition, January 2018, Faktor Verlag, Zurich; page 32).

3 RESULTS

3.1 CONCRETE FOR DRYTECH® WHITE TANK SYSTEMS

Tests were conducted on the concrete, made with CEM IV/A-V 32.5N cement, that is used for Drytech® white tank systems. A total number of 3 samples were tested (ID: 182551, 182590 e 182591) made from two different mixtures at the HOLCIM SA production plant in Manno. Table 1 below shows the specifications and the characteristics of the fresh concrete used to make the samples subjected to testing.

Table 1

Sample	SN EN 206:2013 concrete specification	MV [kg/m^3]	F [mm]	a_{eff}/c [-]	LP [%]	Docket no.
182551	C30/37, XC3, D_{max} 32, Cl 0.10, S4/F4	2’394	610	0.49	0.9	4730080694
182590	C25/30, XC3, D_{max} 32, Cl 0.10, S4/F4	2’372	540	0.52	0.6	4730081216
182591						

Legenda:

MV bulk density

F flow spread

a_{eff}/c effective water/cement ratio

LP entrapped air content

The diffusion test involved cylindrical samples with diameter Ø = 150 mm and nominal thickness d = 60 mm, sealed laterally by applying an epoxy resin of appropriate thickness, in order to induce a unidimensional radon flow and avoid dispersions (see photograph 2).

The results of the diffusion tests are shown in table 2 below.

Table 2

Sample	Age [days]	E [10^{-3} x Bq/s·m^2]	D [10^{-9} x m^2/s]	R [mm]	3·R [mm]
182551	56	2.58	2.80	36.5	109.5
182590	56	2.65	2.82	36.7	110.1
182591	127	1.16	1.65	28.0	84.0

Legend:

E radon exhalation rate

D radon diffusion coefficient

R radon diffusion length

The results show that the two concretes tested are typified by a radon diffusion coefficient lower than or equal to 2.82 x 10^{-9} m^2/s, and by a diffusion length lower than or equal to 36.7 mm at an age of approximately 60 days, and 28.0 mm at an age of 127 days.

The two concretes tested should therefore be considered as impermeable to radon for thicknesses greater than approximately 110 mm.

3.2 DRYFLEX ELASTIC FOAM RESIN

The DRYflex elastic foam resin sample was made by Drytech SA by pouring it, in the liquid state, into a mould with internal diameter Ø = 150 mm and depth $d_{DRYflex}$ = 3.5 mm (see photograph 3). After its polymerisation reaction, the resin sample was positioned between two cement mortar discs made in the laboratory, and whose radon transportation properties had been determined previously (D = 37.6 x 10^{-9} m^2/s; R = 133.8 mm). The thickness of each disc was d_{mortar} = 29 mm (see photograph 4).

The three-layer system was subsequently sealed on the lateral surface in order to induce a unidimensional radon flow and avoid dispersion. The multi-layer configuration was adopted in order to be able to block the resin in the diffusion chamber without damaging it: in fact, the mechanical characteristics of the resin do not allow it to sustain concentrated forces without being damaged.

In order to calculate the diffusion coefficient and length of the radon, in this case a system of three partial differential equations (one equation for each component of the system) for the radon activity concentration inside the sample had to be solved. The boundary conditions were the same as those adopted for the concrete samples (Robin conditions), and continuity conditions were set for the radon concentration in correspondence to the two contact surfaces between the components of the system. In this case as well, the outcome was an equation that is non-solvable algebraically for the transportation properties of the resin (R or D), where, in addition to those cited above (see chapter 3.1), the parameters also include the thickness and the radon diffusion coefficient of the two mortar discs between which the resin was inserted.

The results of the diffusion test are shown in Table 3 below.

Table 3

Sample	Age [days]	E [10^{-3} x Bq/s·m^2]	D [10^{-9} x m^2/s]	R [mm]	3·R [mm]
DRYflex resin	7	6.9	0.35	13.0	39.0

Legend:

E	radon exhalation rate
D	radon diffusion coefficient
R	radon diffusion length

The results show that, with a diffusion coefficient value of 0.35 x 10^{-9} m^2/s, the resin is typified by a radon permeability level that is **lower** than that of the concrete into which it has been injected. DRYflex resin should be considered as impermeable to radon for thicknesses greater than 39.0 mm.

3.3 DRYSET FORMWORK PLUGGING SYSTEMS

Tests were conducted on three different types of systems for plugging the formwork spacer holes in reinforced concrete structures. These systems were realized in a cylindrical concrete sample, pierced axially, with thickness d = 100 mm and diameter Ø = 150 mm. The specifications of the concrete used to make the samples is SN EN 206:2013 C30/37, XC3, D_{max} 32, Cl 0.10, S4/F4. The concrete was made with a CEM IV/A-V 32.5N cement at HOLCIM SA production plant in Manno (production docket No. 47300840484). When fresh, it has the following characteristics: bulk density : 2'375 kg/m^3, flow spread: 600 mm, effective water/cement ratio: 0.56, entrapped air content: 1.3%.

The three types of plugging systems tested are described in Table 4 below, and are depicted in photographs 5, 6 and 7.

Table 4

System	Description
Type 1	Hole diameter Ø = 25 mm, RIVESTOP elastic expansion plug model D24 x 50 PS
Type 2	Hole diameter Ø = 20 mm, double rubber plug (total length: 2 x 21 mm), DRYpox resin and tape on the extrados (surface area 11 cm x 11 cm)
Type 3	Hole diameter Ø = 20 mm, double rubber plug (total length: 2 x 21 mm)

The samples were installed in the diffusion chamber in such a way as to ensure that the surface corresponding to the extrados was exposed to the source cell. In the collector cell, the increase in radon activity concentration was monitored until equilibrium value was reached. This was used to calculate the equivalent radon exhalation rate. The radon proofing of the formwork plugging systems were evaluated by means of a comparison with the exhalation rate measured on a monolithic concrete sample of equal thickness (the concrete was the same as that used to make the three plugging systems).

The test results are shown in Table 5 below.

Table 5

System	$C_{SC,eq}$ **[Bq/m³]**	**E [10^{-3} x Bq/s·m²]**
Type 1	97'936	0.74
Type 2	118'879	0.75
Type 3	101'663	0.98
Concrete	100'049	0.83
Legend: $C_{SC,eq}$ equilibrium value of the radon activity concentration in the source cell E radon exhalation rate		

The results demonstrate that for types 1 and 2 systems, the equivalent exhalation rate is **lower** than the rate measured for the monolithic concrete. **These systems should therefore be considered as impermeable to radon**.

Type 3 system, on the other hand, proved to be slightly permeable to radon. In this case, the equivalent exhalation rate is greater than the rate recorded for the monolithic concrete.

4 CONCLUSIONS

The results of the radon permeability tests conducted on the concrete used for Drytech® white tank systems, on DRYflex elastic foam resin and on the formwork plugging systems made by Drytech SA allow the following conclusions to be drawn:

- the two Drytech® white tank concretes tested at 60 days were marked by a radon diffusion coefficient lower than or equal to 2.82 x 10^{-9} m^2/s, and by a diffusion length shorter than or equal to 36.7 mm; **they should be considered as impermeable to radon for thicknesses greater than 110 mm**;

- at 7 days, the DRYflex resin was marked by a radon diffusion coefficient of 0.35 x 10^{-9} m^2/s; its radon permeability is **lower** than that of the concrete for the Drytech® white tank systems into which it is injected; it should be considered as impermeable to radon for thicknesses greater than 39.0 mm.

- the type 1 and type 2 DRYset formwork plugging systems (for a detailed typology description, refer to Table 4, Chapter 3.3), should be considered as **impermeable** to radon. The type 3 system, on the other hand, should be considered as slightly permeable.

Based on the results obtained for the components of the Drytech® white tank system that were tested, **it is reasonable to expect that,** in underground rooms delimited by 25 cm-thick perimeter walls made using this system, provided this system is free of defects, and considering an air exchange rate in compliance with current legislation, neither the radon reference level of 300 Bq/m^3 specified by the Ordinance on Radioprotection (ORaP) of 26 April 2017 (status 1st February 2019) for rooms regularly occupied by people for some hours a day, nor the reference value of 100 (- 300) Bq/m^3 specified by the World Health Organisation and by the Minergie-Eco label, **have not been exceeded**.

ATTACHMENT A1 PHOTOGRAPHIC DOCUMENTATION

Photograph 1

Diffusion chamber, together with the two devices used to measure the radon activity concentration in the source and collector cells.

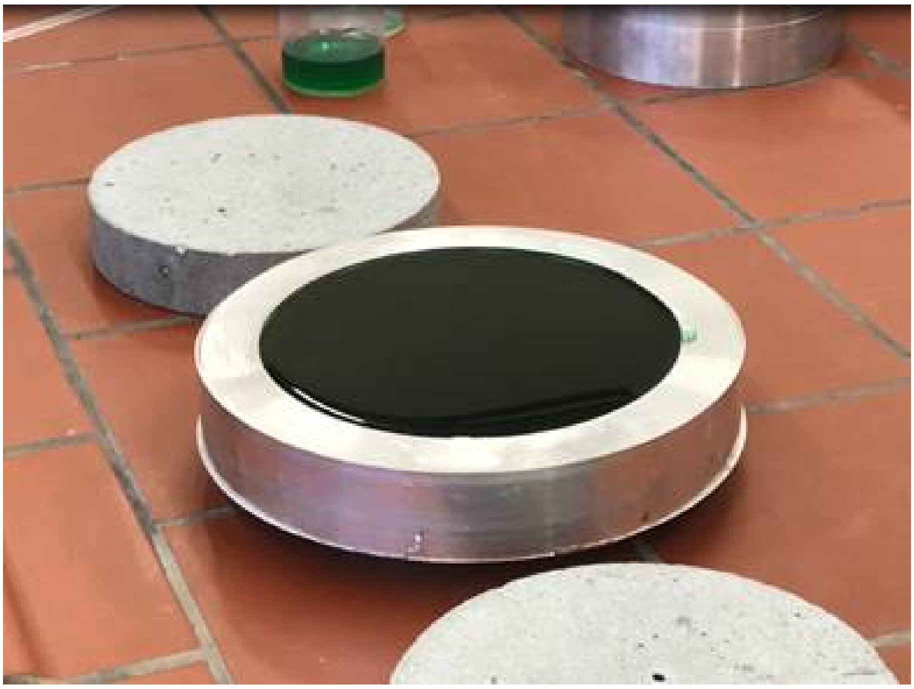
Photograph 2

Concrete sample (diameter Ø = 150 mm; nominal thickness d = 60 mm; sealed laterally).

ATTACHMENT A1 CONTINUED

Photograph 3

Mould with the still-liquid DRYflex resin and the two mortar disks between which the resin is placed.



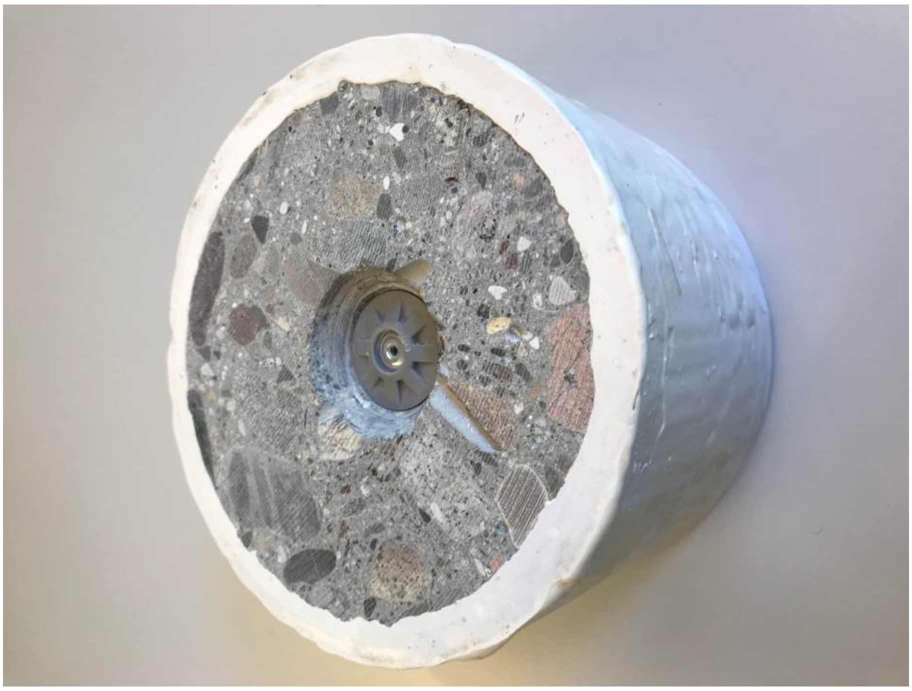
Photograph 4

Full sample used to measure the radon transportation properties of the DRYflex resin (before the lateral sealant is applied).

ATTACHMENT A1 CONTINUED

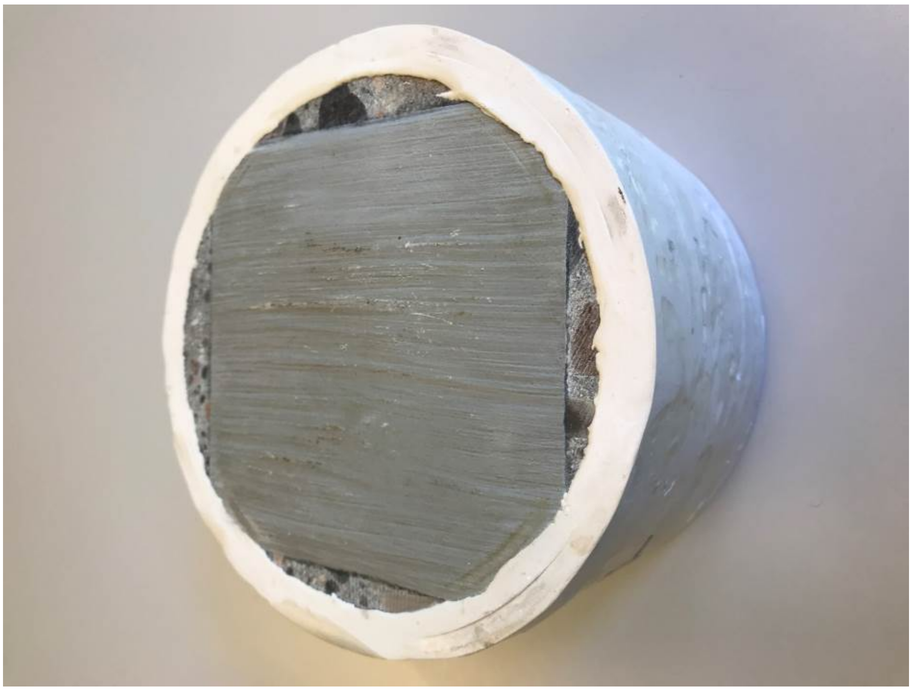
Photograph 5

Formwork plug - type 1.



Photograph 6

Formwork plug - type 2.



ATTACHMENT A1 **CONTINUED**

Photograph 7

Formwork plug - type 3.