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COMPARATIVE STUDY OF DIFFERENT TYPES OF WATERPROOFING SCREEDS WITH A FOCUS ON RADON PERMEABILITY AFTER THE FREEZE-THAW EXPOSURE

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Abstract. This study aims to verify and independently compare the functionality of waterproofing screeds against the effect of radon with the influence of freezing cycles. The effect of freezing cycles on the sealing ability against radon was investigated on polymer, silicate (mineral), and bituminous screeds. The measured values correspond to commonly used insulation materials, confirming the correctness of the measurement and evaluation methodology. Waterproofing screeds are shown to be suitable materials for substructure applications. Unlike waterproofing made from strips such as bitumen membrane or PVC membrane, they do not contain joints and can thus offer a more reliable solution. The measured values show minimal differences between the tested waterproofing screeds after freeze-thaw exposure. Especially in the case of silicate (mineral) screed and polymer screed, the effect is negligible. The greatest effect of freeze-thaw cycles on the ability to seal against radon was observed for bitumen screeds.

Keywords: Waterproofing screeds, radon, freezing cycles, sealing ability, insulation materials, substructure.

1. Introduction

Radon is a ubiquitous natural radioactive gas. It is formed by the gradual transformation of uranium, which is present in varying amounts in all materials in the Earth's crust. Radon itself is converted into other radioactive elements (isotopes of polonium, lead and bismuth), which are trapped in the respiratory tract and irradiated when inhaled [1]. Scientific studies have provided clear evidence of a link between radon exposure in building interiors and lung cancer. This risk is already present at the relatively low levels of radon commonly found in residential buildings [1, 2].

Waterproof materials provide basic protection for buildings against moisture, groundwater and radon from the soil. These are most commonly polymer and asphalt strips or waterproofing membranes. The loss of their impermeable properties due to premature deterioration may cause a complete loss of protection of the building from radon ingress from the subsoil [3]. Degrading agents such as soil bacteria, radon, high temperature and high humidity and possibly combinations of these factors have already been investigated [3] and the results of the experiments published.

In the previous research, the effectiveness of the screeds against water has been addressed. Since waterproofing materials are designed not only as waterproofing but also as insulation against radon penetration into the interior of a building, the logical next step is to verify their functionality and reliability. In the research, the ability of the screed to insulate against radon and the ability to withstand freezing cycles are analysed and tested.

2. Materials and Methods

A total of 24 supporting base plates were created. Cement-bonded lightweight material with product name "Fermacel Powerpanel H_2O" was chosen as a permeable but at the same time strong base material. It is a cement-bonded lightweight concrete panel with a sandwich structure and double-sided reinforcement under cover layers with alkali-resistant fiberglass fabric (5 mm×5 mm). The plate is produced in a thickness of 12.5 mm. The test plates were 325 mm×135 mm.

Waterproofing screeds, which were used in all previous experiments (polymeric, silicate and bituminous), were applied to the created support plates (Figure 1). To perform the calculation, reference specimen was also created without applied waterproofing screed.

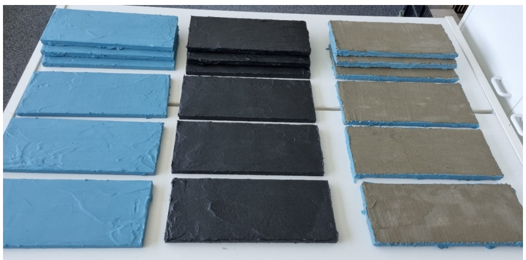


Figure 1. Specimen set with applied waterproofing screeds.

The prepared specimens were then placed in a freezing chamber. The method of stressing by freezing cycles is identical to that described in chapter 5.1.3 of the thesis (the test specimens were immersed surface with a surface treatment in water at (+20 ± 3 °C) for

6 hours. The specimens were then removed and stored in a freezing chamber at a temperature of (-20 ± 2 °C) for 18 hours). A total of 30 freeze cycles were performed in this way. After 30 cycles, the specimens are left to dry at an air temperature of (+20 ± 3 °C) and a relative humidity of (55 ± 10 %) for at least 14 days.

During the cycling time in the freezing chamber, a device was prepared to measure the radon diffusion coefficient D [$m^2\,s^{-1}$]. The device used was designed and maintained by the Department of Architectural Engineering of the Faculty of Civil Engineering CTU.

It is a measuring device consisting of three receiving chambers above the specimen and one radon source chamber below the specimen (Figure 2, Figure 3). In the lower chamber (below the specimen) the radon source is common to all 3 specimens. The specimen placed between the two chambers shall be sealed perfectly. a permanently flexible acrylic sealant shall be used for sealing.

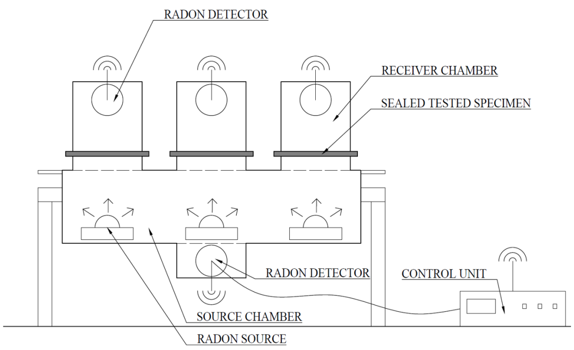


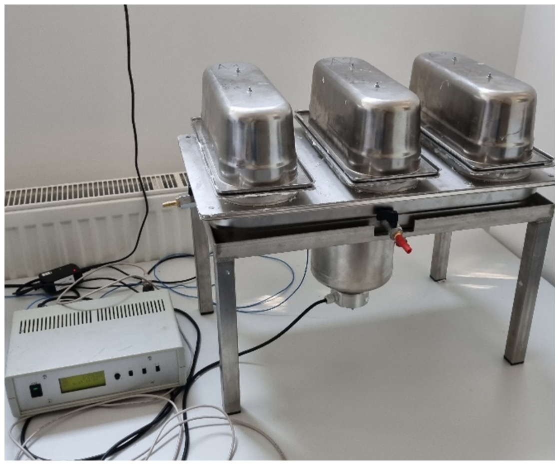
Figure 2. Measuring device with one source chamber and three receiving chambers.

The radon concentration in the upper and lower chambers is continuously measured by TESLA radon detectors. These detectors are located inside each upper chamber (the principle is based on detecting Po using a PIN photodiode). In total, there are 3 upper chambers in the measuring device and one detector in each chamber. To measure the concentration below the specimen, one detector common to all three specimens is placed in the lower chamber. The data from the detectors are transmitted wirelessly to a control unit located outside the measuring device. The area of a single specimen was $2.93\times10^{-2}\,m^2$. The volume of the source chamber was $13.9\times10^{-3}\,m^3$, and the volume of the receiver container was $2.7\times10^{-3}\,m^3$.

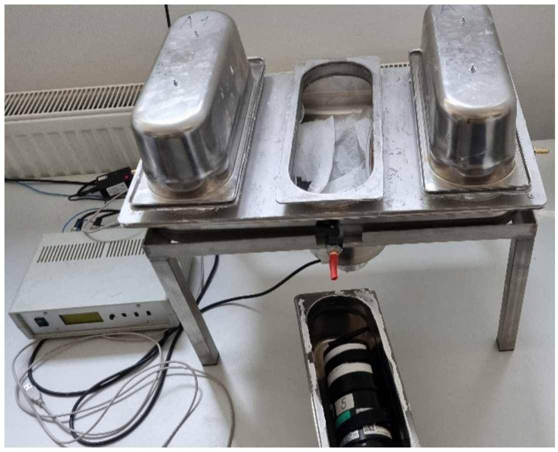
The specimens were sequentially loaded into the device and sealed (Figure 4, Figure 5). After specimen sealing, the increase in radon concentration in the upper and lower chambers is monitored until steady state.

For the selected waterproofing screeds, a time interval of 14 days was found to be appropriate. During which time the increase in concentration in the upper chamber was stabilized.

Crushed concrete made of slag with a high content of radium (1 000–4 000 $Bq\,kg^{-1}$) and sand that had been



(A). Used measuring device.



(B). Used measuring device.

Figure 3. Measuring devices used for experiments.

Figure 4. Measuring device with inserted and sealed specimens.

Figure 5. The sealed specimens.

used as a filter in a water treatment plant were used as a natural radon source. The radon diffusion coefficient D [$m^2\,s^{-1}$] was determined according to method a of ISO/TS 11665-13 from the known time-dependent curves of the radon concentrations measured on both sides of the tested specimen.

A total of 7 sets with three specimens in the measuring device were carried out.

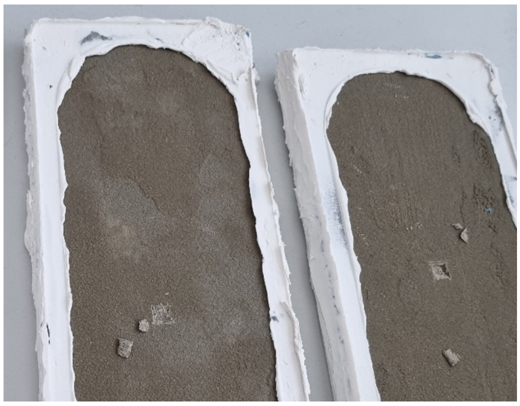
- Set 1 = 3× reference specimen without waterproofing screed,
- set 2 = 3× specimen with polymer waterproofing screed,
- set 3 = 3× specimen with bitumen waterproofing screed,
- set 4 = 3× specimen with silicate waterproofing screed,
- set 5 = 3× specimen with polymer waterproofing screed after 30 freeze thaw cycles,
- set 6 = 3× specimen with bitumen waterproofing screed after 30 freeze thaw cycles,
- set 7 = 3× specimen with silicate waterproofing screed after 30 freeze thaw cycles.

The measurements were taken between the autumn of 2022 and the spring of 2023. After the measurements were taken, the specimens were removed (Figure 6) from the measuring device and the thickness of the applied waterproofing screed was measured for each specimen separately (Figure 7).

Figure 6. Specimens removed from the measuring device, sealant visible around the perimeter.

(a).

(b).



(c).

Figure 7. Measuring the thickness of the applied waterproofing screed.

3. Results and discussion

Since the measurements were made under non-stationary conditions, the calculation is based on the numerical solution for the non-stationary differential equation of radon diffusion. a very detailed description [4] has been published, where the mathematical procedure and method of calculation is described.

In the numerical evaluation of the radon diffusion coefficient using the IterRn software [5], the process relies on time-dependent radon concentration values measured in both the source and receiver containers. The calculation involves iteratively solving equations, starting with an initial estimation of the radon diffusion coefficient range (lower and upper limits) and a defined iteration step (typically 1/10 to 1/20 of the range).

Simplified description of the procedure:

Initialization

- The estimated range of the radon diffusion coefficient and the iteration step were set.

Type of the waterproofing screed	Layer thickness [mm] Number of radon detector S1	S2	S3	Average layer thickness [mm]
Silicate (mineral) screed (reference)	2.73	2.87	3.38	2.99
Silicate (mineral) screed (30 freezing cycles)	3.18	2.85	2.96	3.00
Polymer screeds (reference)	1.77	1.84	1.28	1.63
Polymer screeds (30 freezing cycles)	1.69	1.81	1.73	1.74
Bituminous screeds (reference)	1.73	1.87	1.64	1.73
Bituminous screeds (30 freezing cycles)	1.71	1.91	1.99	1.87

TABLE 1. Measured values for each specimen.

Type of the screeds	Radon diffusion coefficient [$m^2 h^{-1}$]		Standard deviation [$m^2 h^{-1}$]	
	0 freezing cycle	30 freezing cycle	0 freezing cycle	30 freezing cycle
Polymer screeds	4.65×10^{-12}	3.73×10^{-12}	3.7×10^{-13}	8.2×10^{-13}
Bituminous screeds	4.90×10^{-12}	3.20×10^{-11}	4.0×10^{-13}	5.6×10^{-12}
Silicate (mineral) screed	4.15×10^{-12}	4.05×10^{-12}	9.1×10^{-14}	9.2×10^{-14}

TABLE 2. Radon diffusion coefficient values and their standard deviations for different types of waterproofing screeds before and after freeze-thaw exposure.

- The transient diffusion of radon through the radon barrier is calculated with the initial radon diffusion coefficient set to the lower limit.

Comparison

- The calculated time-dependent radon concentration results in the receiver container are compared with the measured data.
- Differences between the calculated and measured data sets are recorded.

Iterative Process

- The procedure was repeated with a progressively increasing radon diffusion coefficient in each step.
- The iteration continued until the upper limit of the radon diffusion coefficient range was reached.

Optimization

- The final radon diffusion coefficient was determined by minimizing variations between calculated and measured data, considering metrics such as average difference or sum of deviations.

Efficiency

- The entire iteration process is designed to be computationally efficient and typically took no more than 30 minutes on a standard contemporary computer.

IterRn software (sw.) was developed at CTU for the Microsoft Windows environment. IterRn shares similarities with TransRn software [5]. Contains standard MS Windows procedures and dialogs for creating, saving, reading and editing data files. The input values derived from the measurements were imported from a text record that was stored in a plain text file with the values separated by periods. Measured values for each specimen are shown in Table 1.

The resulting radon diffusion coefficient D [$m^2 s^{-1}$] values were determined as the arithmetic radon diffusion coefficient.

In some measurements, the measuring detector was damaged. This is the reason for the missing measured values (detector labelled S3). Unfortunately, this was only discovered during the evaluation of the measured data.

3.1. Comparison of all tested waterproofing screeds

The mean values of the radon diffusion coefficient D [$m^2 s^{-1}$] are shown in Table 2. These values were calculated from three or two specimens.

In general, it can be said that the effect of 30 freezing cycles on the resulting values is very low, but visible on the values.

The change in the diffusion coefficient was the lowest in the case of silicate (mineral) waterproofing screeds, at the same time with the highest measurement accuracy, see standard deviation. The measured mean value is 4.15×10^{-12} $m^2 s^{-1}$ in the case of the reference specimen and 4.05×10^{-12} $m^2 s^{-1}$ after 30 freezing cycles. It is evident from the measurements that the effect of 30 freezing cycles on the radon sealing ability of the silicate screed is negligible.

A polymer screeds also achieved very similar results. Here we can observe a small change in the radon diffusion coefficient. From the reference value of 4.65×10^{-12} $m^2 s^{-1}$, the value increased to 3.73×10^{-12} $m^2 s^{-1}$. In general, the lower the value of the radon diffusion coefficient, the tighter the material.

In the case of bitumen screeds, the greatest increase in radon diffusion coefficient D [$m^2 s^{-1}$] can be observed. The value measured for the reference sample is 4.9×10^{-12} $m^2 s^{-1}$ and after 30 cycles

$3.2\times10^{-11}\,\mathrm{m^2\,s^{-1}}$. There was a change of decimal order.

The measured values correspond to commonly used insulation materials, which confirm measurements, for example on bitumen membrane ($5.93\times10^{-12}\,\mathrm{m^2\,s^{-1}}$) or PVC membrane ($1.98\times10^{-11}\,\mathrm{m^2\,s^{-1}}$) carried out on the samples exposed to radon at high level [6]. It can therefore be said that the measurement and evaluation were carried out correctly. Waterproofing screeds are thus a suitable material for use in substructures. The optimal value of the radon diffusion coefficient D can be found within the range of 5×10^{-12} to $1\times10^{-11}\,\mathrm{m^2\,s^{-1}}$. All three screeds meet this condition even after freezing cycles [7]. Unlike waterproofing made from strips such as bitumen membrane or PVC membrane, they do not contain joints and can thus be a more reliable solution. The measured values show minimal differences between the tested waterproofing screeds.

The results presented here should be considered as preliminary results, more extensive research with a larger number of freezing cycles is necessary to clarify the effect of freezing cycles on the insulating abilities of the tested waterproofing screeds. Such research is very time-consuming not only during the preparation of the specimens themselves in the freezing chamber, but also during the actual measurement of the radon diffusion coefficient D $[\mathrm{m^2\,s^{-1}}]$ and the subsequent evaluation of the measured data.

4. Conclusion

The effect of freezing cycles on the sealing ability against radon was investigated on the aforementioned screeds.

- The measured values correspond to commonly used insulation materials, and it can therefore be said that the measurement and evaluation were carried out correctly.
- Waterproofing screeds are thus a suitable material for use in substructures. Unlike waterproofing made from strips such as bitumen membrane or PVC membrane, they do not contain joints and can thus be a more reliable solution.
- The measured values show minimal differences between the tested waterproofing screeds. Especially in the case of silicate (mineral) screed and polymer screed, the effect is negligible. The greatest effect of antifreezes on the ability to seal against radon was observed for bitumen screeds.

5. Acknowledgment

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