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Case Study

Long-term water absorption tests for frost insulation materials taking into account frost attack

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ABSTRACT

Water absorption of several different frost insulation materials was tested for four years. The test took into account both immersion and frost attack to materials. On the basis of the research the water absorption on XPS specimens is significantly minor compared to EPS specimens that were studied. The most significant result was that freezing of test specimens did not affect on water absorption of XPS specimens but had a major effect on water absorption of EPS specimens. With frozen EPS specimen the absorption continued increasing even after 48 months of immersion. Presumably the reason for such a behaviour is that the pore structure of EPS is not able to resist the tension caused by freezing water and therefore cracks are formed. Thus, more water absorbs inside the EPS through the cracks and it causes cracking deeper in the specimen which is why absorption increases after every freezing period.

1. Introduction

In Nordic countries there is a need for an external frost protection in buildings and all kind of foundations as well as roads and railways in the areas where the soil is frost susceptible. The thickness of frost insulation material depends on the cold content of the year. The maturity used in calculations in Finland varies between 35,000 Kh (south coastal area) and 65,000 Kh (northern Lapland) (Finnish Meteorological Institute, 2013). Typical thickness of frost insulation is, respectively, 100–150 mm, see Fig. 1. Incomplete or incorrectly installed frost insulation can cause damage not only to the foundations of the building but also the walls, ceiling or roof structures. The frost insulation plans, quality of the products and installation of frost insulation must be paid special attention. It is crucial that frost susceptible soil will stay always unfrozen.

Thermal insulation materials used for frost protection are typically expanded polystyrene (EPS) or extrusion-compressed polystyrene (XPS). Both EPS and XPS products have several different purposes of use and therefore different grades. The grade of thermal insulation depends on the needed load bearing capacity of thermal insulation.

1.1. Water absorption of thermal insulation

Water absorption into pore structure of material will increase thermal conductivity because of relatively high thermal conductivity of water. Water absorption of thermal insulation will decrease thermal resistance of material remarkably.

Frost insulation material is installed into moisture soil and it will be exposed to gravitational water caused by rain as well as melting snow and ice. Therefore the frost insulation material must be tight and have closed-sell structure. Formally

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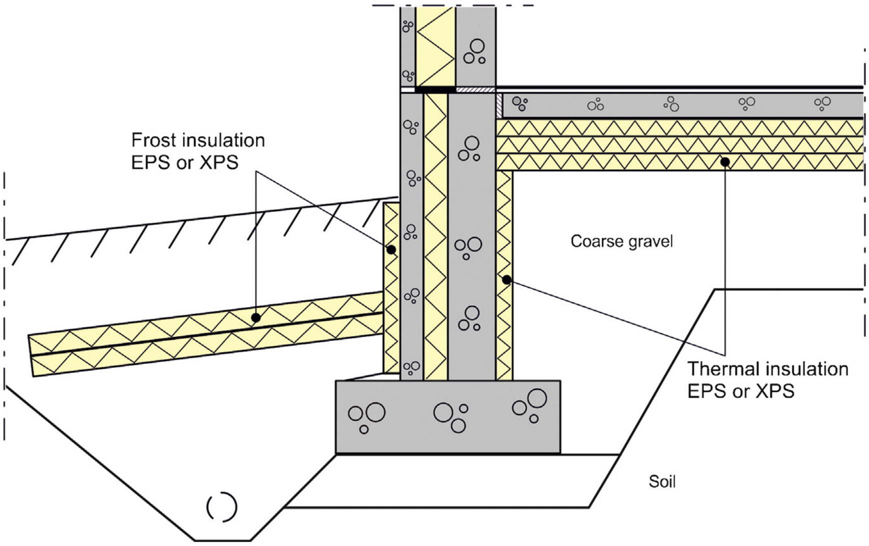

Fig. 1. Section of typical foundation of building and frost insulation.

approved the frost insulation material must fulfil all the required functional properties including the long-term water immersion test (28 days). According to EN 12087 limits for moisture content of the frost insulation material is 2% by volume.

1.2. Frost attack

The aim of frost insulation is to keep frost susceptible soil unfrozen during winter time. In heated buildings heat flow thorough floor keeps foundations unfrozen if frost insulation is enough. Frost insulation material itself is exposed to gravitational water and frost attack. To ensure long service life of frost insulation material it is important that insulation material is not frost susceptible.

1.3. Objective

Research objective was to study water absorption of several frost insulation materials in long-term tests (4 years) taking into account also frost attack to the test specimens.

2. Research material

2.1. Methods

Test procedure was carried out applying standard EN 12087 method 2A; long-term water absorption by total immersion. The test was modified to represent circumstances where frost insulation material is exposed to very high moisture stress.

Fig. 2. Immersed test specimen during the test.

Table 1
Measured weight classes of test materials.

Test material	Weight class	Test material	Weight class
EPS A	app. 22 kg/m^3	XPS 1	app. 34 kg/m^3
EPS B	app. 23 kg/m^3	XPS 2	app. 40 kg/m^3
EPS C	app. 33 kg/m^3	XPS 3	app. 44 kg/m^3
EPS D	app. 42 kg/m^3		

2.1.1. Immersion

Test specimens were immersed vertically in the tank. Water level was 10–20 mm over specimen, see Fig. 2. Temperature of water was 18–22 °C during tests.

2.1.2. Weighing of specimens

Weighing of specimens was carried out before immersion and after every 60 days. The free water on the specimen surface was clothed out before weighting. Weighing was made with balance, which allows the determination of the mass of a test specimen to 0.01 g. Before the test the specimens were weighed as dry and after 10 s immersion to estimate the amount of surface water which does not dry when clothed. The remainder was subtracted from all measurements after the immersion.

2.1.3. Freeze–thaw

The effect of freezing in water absorption in frost insulation material was studied by freezing half of specimen during weighting. The specimens were frozen to −18 °C in the air for 24 h. Thawing took place by immersing the specimens again in the tank.

2.2. Specimens

Tested thermal insulation materials were expanded polystyrene (EPS) and extrusion-compressed polystyrene (XPS). All the test materials were cut into four rectangular prisms, where width and length was identical at 200 mm and thickness, according to plate thickness, was usually 50 mm (variation 40–70 mm depending on the product). Product D made an exception. The size of one specimen was 150 mm × 150 mm because of lack of test material. Measured weight classes of test materials are given in Table 1.

Half of the specimens were cut by a circular saw (marked with CS) and half by a knife (marked with K) with thin blade. Both are typical cutting methods in situ, but knife with thin blade gives smoother surface and, therefore, there is less free water in those surfaces.

XPS 1 specimens had three different manufacturing times where the oldest specimens were a 1.5-year-old and one a year old and the newest a month old. XPS 2 specimens were manufactured in six months and XPS 3 in a year before the test. The ages of EPS products were not known.

Table 2
Water absorption after different immersion times of XPS specimen.

Specimen	Manufact. time before test	Cutting method (K = knife, CS = circular saw)	Immersion time			
			Freezing (+ = yes)	2 months [vol.%]	24 months [vol.%]	48 months [vol.%]
XPS 1A	1 month	K	+	0.40	0.69	0.73
	1 month	K		0.40	0.69	0.68
	1 month	CS	+	0.43	0.90	0.85
	1 month	CS		0.51	0.79	0.76
XPS 1B	12 months	K	+	0.14	0.32	0.29
	12 months	K		0.13	0.30	0.25
	12 months	CS	+	0.18	0.36	0.36
	12 months	CS		0.18	0.35	0.35
XPS 1C	18 months	K	+	0.17	0.26	0.31
	18 months	K		0.14	0.25	0.25
	18 months	CS	+	0.16	0.43	0.53
	18 months	CS		0.20	0.34	0.28
XPS 2	6 months	CS	+	0.23	0.48	0.44
	6 months	CS		0.21	0.33	0.33
XPS 3	12 months	K	+	0.19	0.41	0.51
	12 months	K		0.19	0.36	0.36
	12 months	CS	+	0.25	0.68	0.57
	12 months	CS		0.23	0.38	0.44

Table 3
Water absorption after different immersion times EPS specimen.

Specimen	Cutting method (K = knife, CS = circular saw)	Immersion time			
		Freezing (+ = yes)	2 months [vol.%]	24 months [vol.%]	48 months [vol.%]
EPS A	K	+	2.51	4.25	5.24
	K		2.61	3.02	2.97
	CS	+	2.14	4.17	5.47
	CS		2.08	2.67	2.62
EPS B	K	+	2.37	4.33	5.23
	K		2.16	2.35	2.52
	CS	+	2.50	4.56	5.59
	CS		1.92	2.61	2.43
EPS C	K	+	2.13	4.17	4.60
	K		2.72	3.22	3.26
	CS	+	2.38	4.43	5.14
	CS		2.83	3.17	3.06
EPS D	CS	+	0.87	4.60	6.46
	CS	+	1.23	4.43	6.28

3. Results and discussion

3.1. Total water absorption into frost insulation materials

The results are shown in Tables 2 and 3.

The total water absorption with XPS-specimens differed between 0.25 and 0.90% by volume. In all cases the absorption decelerated significantly already after two months and reached the highest water content in most cases after 26 months. The total amount was highly affected by the age of the material. The oldest specimens did not absorb as much water as the recently manufactured ones as can be seen in Fig. 3.

EPS-specimens which were not exposed to freezing reached the maximum absorption in most cases within 24 months from the beginning. The maximum values differed between 2.52 and 3.26% by volume depending on the weight class. With the specimens which were not frozen the total absorption varied between 4.60 and 6.46% by volume, see Fig. 3.

3.2. Immersion time

The XPS-specimens absorbed 29–71% of their total absorption during the first two months. The huge scatter is caused by very small absorption and accuracy of the measurement.

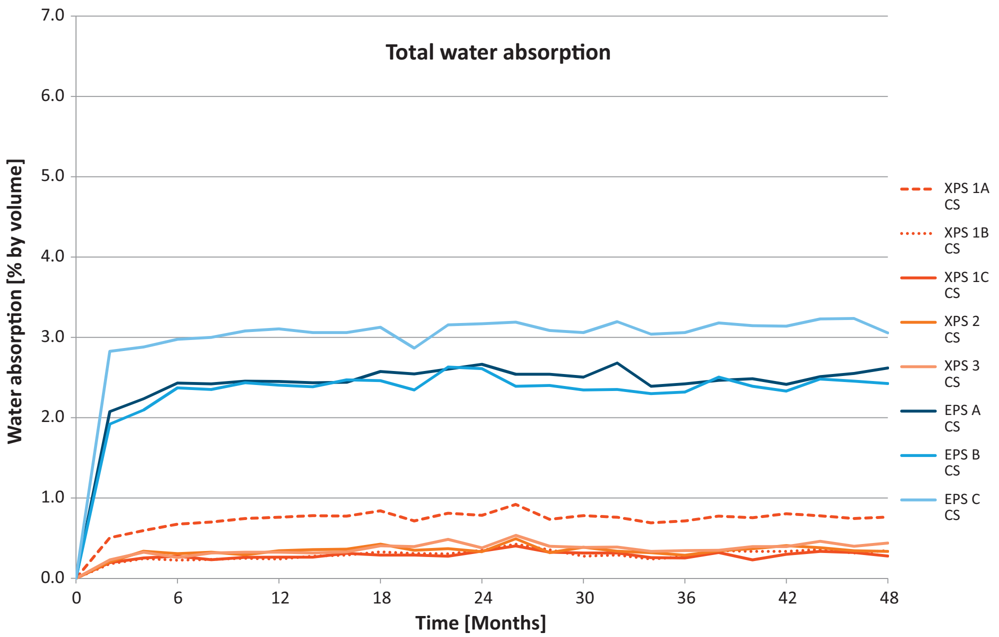

Fig. 3. Total water absorption of some of the specimens. The date after XPS specimens is the manufacturing date and CS means cutting with circular saw.

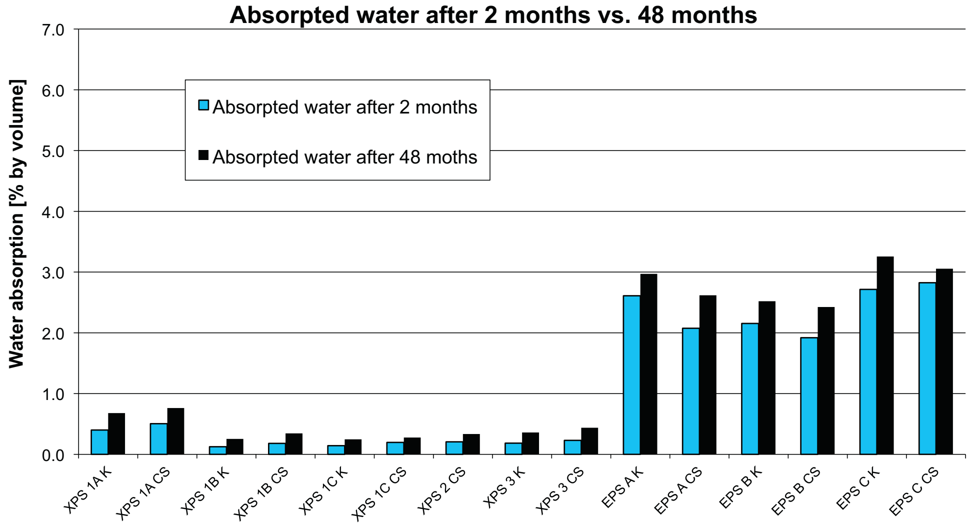

Fig. 4. The water absorption after 2 months compared to total absorption.

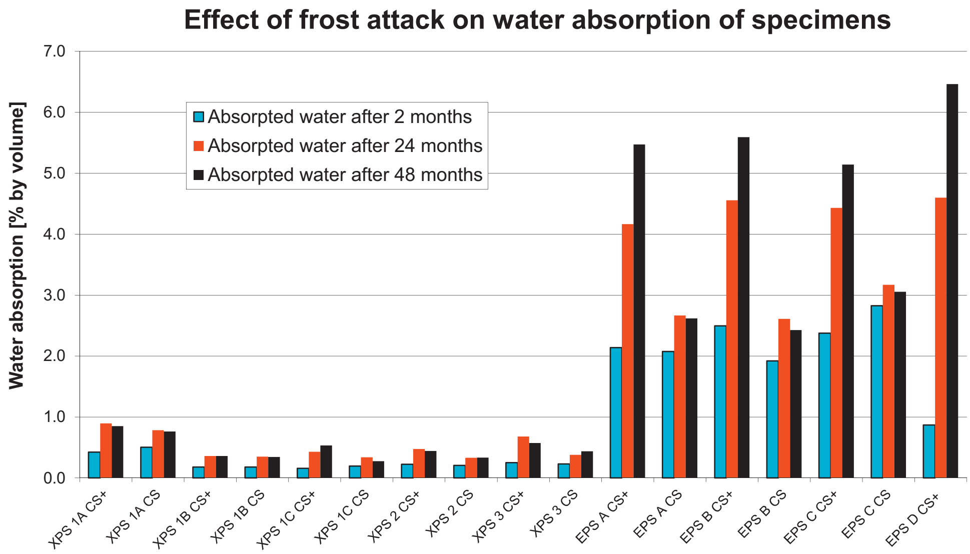

Fig. 5. Effect of frost attack on water absorption of all frozen specimens.

The unfrozen EPS specimens gained already 74–92% of the total absorption during the first 2 months. The specimens which had been frozen during the weightings acted totally different compared to the others. They continued absorbing slowly even after 48 months of immersion as can be seen in Section 3.3.

3.3. Frost attack

The specimens which were exposed to freezing before weighing composed of two classes depending on the material. With XPS-materials the specimens did not absorb water significantly differently compared to specimens without freezing, see Fig. 5. The EPS-specimens, instead, absorbed significantly more water when they were exposed to freezing and they also continued slowly absorbing water still when the test was finished after 48 months, see Fig. 6.

Freezing of wet EPS-specimens broke slightly the material's structure and, therefore made continuous water absorption possible leading approximately two times higher total water absorption in the end of test. The effect of freezing on water absorption into EPS was linear in the test and any stabilising was not detected during the test, as can be noticed from Fig. 6.

3.4. Effect of cutting

Half of the specimens were cut by a circular saw and half by a knife with thin blade. Both are typical cutting methods in situ, but knife with thin blade gives a smoother surface and, therefore, there is less free water in those surfaces.

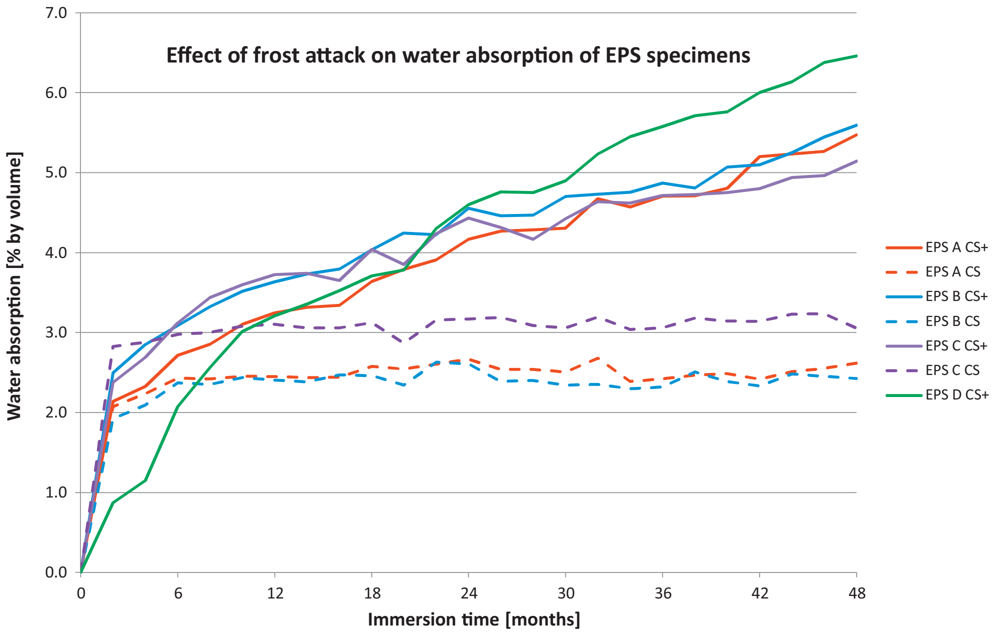

Fig. 6. Effect of frost attack on water absorption of EPS specimens.

Both in XPS and EPS specimens cutting, circular saw vs. knife have only minor effect on water absorption, as can be seen in Fig. 4. Specimens cut by circular saw have more rough edge which can hold some more surface water.

4. Conclusions

On the basis of the research the water absorption on XPS specimens is significantly minor compared to EPS specimens that were studied. The most significant result was that freezing of test specimens did not affect on water absorption of XPS specimens but had a major effect on water absorption of EPS specimens. With frozen EPS specimen the absorption continued increasing even after 48 months of immersion. Presumably the reason for such behaviour is that the pore structure of EPS is not able to resist the tension caused by freezing water and therefore cracks are formed. Thus, more water gets absorbed inside the EPS through the cracks and it causes cracking deeper in the specimen which is why absorption increases after every freezing period.

The individual issue affecting on water absorption of XPS specimens the most was the manufacturing time. The oldest specimens (18 months from manufacturing) did absorb less than half compared to a month old specimens. The result indicates that ageing time is important not only because of shrinkage of material but also for water absorption.

The specimens were exposed to much higher moisture stress during the tests than frost insulation plates exposed in normal structures. Experimental arrangement will correspond to a situation, where frost insulation will stay permanently under groundwater or perched water table e.g. when subsurface drainage has lost its ability to function. For this reason it is not possible to draw a conclusion for eligibility of tested materials for typical frost insulation. On the other hand, the target service life for frost insulation is long, generally 50 years at least, and the condition of frost insulation is not possible to find out without excavation and laboratory tests. This is the reason why short time test of frost insulation materials should be exposed to harsh circumstances.

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