

## **Long-term Performance of Extruded Polystyrene Thermal Insulation Products**

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### **ABSTRACT**

One of the essential requirements of the European Construction Products Directive (CPD) is the durability of products. This is closely linked to the sustainability of buildings and their energy consumption. Hence thermal insulation products have to provide evidence that they are durable over their service life.

The paper presents ways how to address this complex issue using the example of factory made extruded polystyrene foam XPS according to the harmonized European standard EN 13164.

XPS insulation is applied in numerous constructions which are subjected to different combined loadings, such as combined mechanical, moisture and heat impact.

In particular the hygrothermal and mechanical durability of XPS products were investigated. Both laboratory results and practical results will be presented in order to show the correlation between short-time durability tests and practical performance of products.

The application of insulation products under sustained load is another topic which will be addressed in the paper. The durability of insulation products against mechanical degradation when subjected to long-term loading is characterized by its creep performance (EN 13164 Annex ZA). The method according EN 1606 and the results of creep performance measurements for XPS products will be presented and discussed.

### **KEYWORDS**

Thermal insulation, Extruded polystyrene foam, Creep, Moisture

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## 1 INTRODUCTION

One of the essential requirements of the European Construction Products Directive (CPD) is the durability of products. Durability is defined as *the ability of a product to maintain its required performance over a given or long time, under the influence of foreseeable actions, subject to normal maintenance* [ EC 2004].

To attest its conformity with the CPD, a product put on the market must carry CE marking. CE marking attests that the product complies with the applicable technical specification (hENs, ETAs). In addition, it is compulsory for the manufacturer to declare the performance of the product for the mandated characteristics which are required by the technical specifications[CEPMC 2005].

The concept of durability related to CE marking means the permanence of the mandated characteristics of a product, linked to one or more of the 6 essential requirements. This permanence is dependent on the evolution in time, or ageing, of one or several performances of the characteristics and implies resistance to deterioration during exposure to normally foreseeable external or specific agents[EC 2004].

**Table 1.** Illustrative assumed working life (design working life) of works and construction products [EOTA 1999].

Assumed working life of works (years)		Working life of construction products to be assumed in ETAG's, ETAs, hENs (years)		
Category	Years	Category		
		Repairable or easily replaceable	Repairable or replaceable with some more efforts	Lifelong <sup>2)</sup>
Short	10	10 <sup>1)</sup>	10	10
Medium	25	10 <sup>1)</sup>	25	25
Normal	50	10 <sup>1)</sup>	25	50
long	100	10 <sup>1)</sup>	25	100

<sup>1)</sup> in exceptional and justified cases ; e.g. for certain repair products a working life of 3 to 6 years may be envisaged (when agreed by EOTA TB or CEN respectively)

<sup>2)</sup> When not repairable or replaceable “easily” or “with some more efforts”

Thermal insulating products are repairable or replaceable “with some more efforts” in many cases. There are exceptional applications, e.g. foundation insulation where the product must be assumed at least in category “Normal” which means 50 years of working life according to Table 1.

## 2 ASSESSMENT OF DURABILITY OF INSULATING PRODUCTS

The assessment of durability of thermal insulating products is possible by:

- Laboratory short-term test methods
- Laboratory ageing test methods
- Testing products in application under natural climatic conditions.

### 2.1 Laboratory Test Methods

In the following two mandated characteristics which are specified in the European product standards will be addressed:

- durability of thermal resistance against weathering, degradation and freeze-thaw

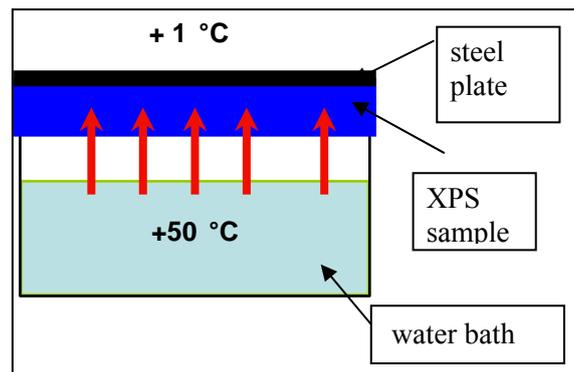
- durability of compressive strength against ageing and degradation.

### **2.1.1 Durability of Thermal Resistance against Weathering, Degradation and Freeze-Thaw**

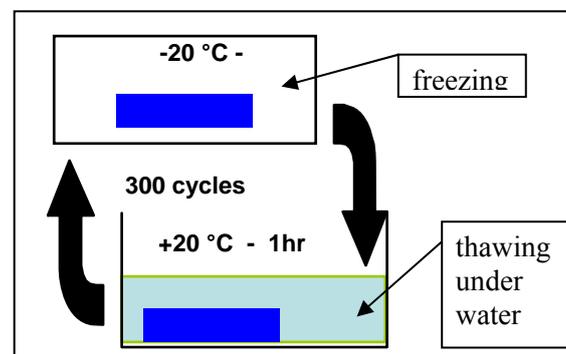
One of the most important tests for extruded polystyrene is the freeze-thaw test. It comprises two separate tests. The test for water absorption by diffusion [EN 12088] and the test for water absorption after freezing and thawing cycles [EN12091].

The test is mandatory for applications like Inverted Roofs and any insulation below ground level; e.g. perimeter insulation and insulation of road- and railways [EN 14934].

The Figures 1 and 2 show schematically the test build-up and the boundary conditions of the diffusion and freeze-thaw test.



**Figure 1.** Diffusion test (schematically), 28 days.



**Figure 2.** Freeze-thaw test (schematically), 28 days.

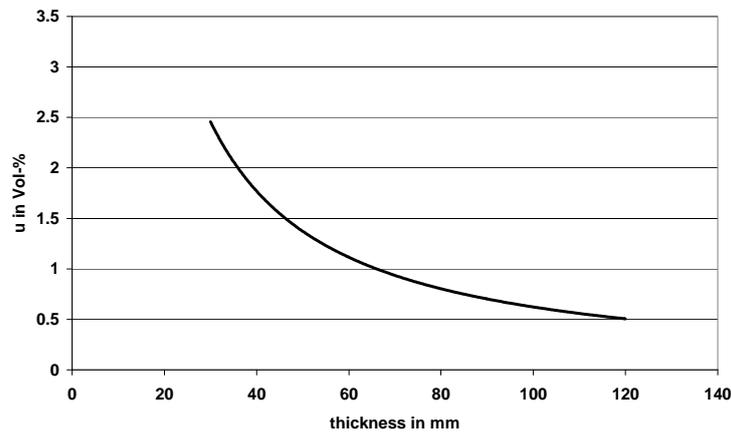
After a 28 days diffusion test the samples are used for the freeze-thaw test. The boundary conditions are more severe than climatic conditions in most of the European countries. But the results are in good agreement with practical long-term results. Thus the test conditions are simulating short-term the performance of the product under climatic conditions.

The requirements for both water absorption by diffusion and after freeze-thaw cycling are listed in Tables 2 and 3.

**Table 2.** Levels of water absorption by diffusion in relation to nominal thickness  $d_N$  according to EN 13164 [EN13164] for extruded polystyrene.

level	Requirement [ m <sup>3</sup> /m <sup>3</sup> (Vol-%)]		
	$d_N = 50\text{mm}$	$d_N = 100\text{mm}$	$d_N = 200\text{mm}$
WD(V)5	$\leq 5$	$\leq 3$	$\leq 1,5$
WD(V)3	$\leq 3$	$\leq 1,5$	$\leq 0,5$

The actual values from test results of various notified bodies in Europe are shown in Figure 3.



**Figure 3.** Water absorption by diffusion, typical values for XPS products (Roofmate).

The values in Figure 3 lead to a declaration WD(V)3 according to EN 13164. It can be assumed that such a product is durable against water impact.

**Table 3.** Levels of resistance against freeze-thaw cycling, water absorption after freeze-thaw cycling for extruded polystyrene according to EN 13164.

level	Requirement [ m <sup>3</sup> /m <sup>3</sup> (Vol-%)]
FT 1	$\leq 2$
FT 2	$\leq 1$

After freeze-thaw cycling the reduction of compressive strength shall not exceed 10% of the initial value before the freeze-thaw test. This requirement ensures that the material structure of the foam has not been deteriorated during the freezing and thawing processes.

Actual values from tests performed by European notified bodies, show nearly no reduction of compressive strength for XPS products such as Styrofoam.

### **2.1.2 Durability of Compressive Strength**

There are applications where it is not possible or not affordable to repair or replace insulating products. In particular when products are applied under foundations or within other structural parts of a building. In such a case the products must comply with the category “NORMAL” specified in Table 1. Normal means a lifetime of at least 50 years.

Extruded Polystyrene Foam has been successfully used for many years under road-and railway constructions as well as under load-bearing concrete slabs, such as foundations or industrial floors. It is necessary to know the stress-strain behavior (compressive creep) of XPS under sustained load. The assessment of thermal insulating products shall follow the European test standard EN 1606 [EN1606].

The standard comprises the measurement method and a calculation method to predict the long-term creep according to the FINDLEY approach [Merkel 2004].

This method describes the viscoelastic behavior of cellular plastic foam.

$$X_t = X_0 + m \cdot t^b \tag{1}$$

where:

$X_0$  : initial deformation 60s after the load has been applied

$m, b$  : material parameters (FINDLEY parameters)

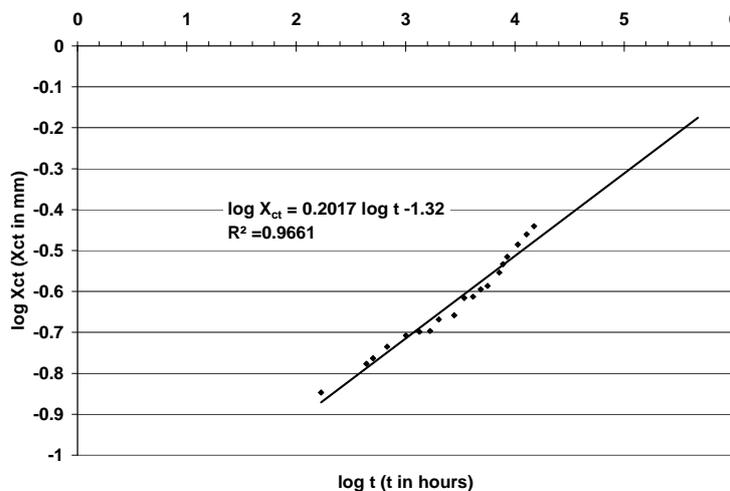
The equation (1) is known as Findley equation. The second term describes the visco-elastic part of the deformation. The material parameter  $m$  and  $b$  are stress dependent.

Equation (1) can also be expressed in a linear form by introducing logarithmic terms:

$$\log (X_t - X_0) = \log m + b \cdot \log t \tag{2}$$

The parameters  $m$  and  $n$  can be obtained from a linear regression curve, which is calculated using the measured values starting 168 hours after initial measurement. From equation (2) it follows the parameter  $b$  as the slope of the curve and  $\log m$  the intercept of the ordinate.

Figure 4 shows a typical linear regression curve for XPS from which  $m$  and  $b$  can be determined. The details of this procedure are described in EN 1606. An extrapolation 30 times the testing time is permitted when  $R^2 \geq 0.9$ .

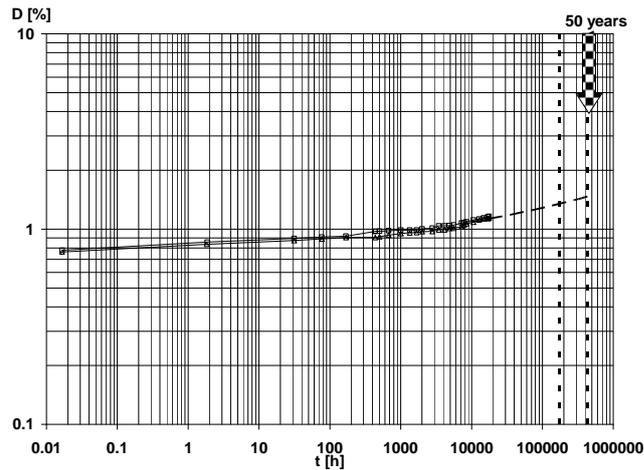


**Figure 4.** Typical regression curve for XPS to determine the FINDLEY parameter  $m$  and  $b$  (Dow Building Solutions).

Taking the given example, the FINDLEY parameters are determined to be:  $b = 0.2017$  and  $m = 0.048$ . For building applications such as thermal insulation of foundations a total reduction of  $\leq 2\%$  of the initial thickness and an extrapolation time of 50 years are generally required.

Conclusively, thermal insulating products have to be tested for 608 days at a stress level which will finally result in deformations less than 2%.

Figure 5 shows a creep curve for an XPS product according EN 1606.



**Figure 5.** Creep deformation of an XPS product under constant load of 270 kPa (Graph: Dow Building Solutions).

It is obvious that after a short period of initial response to the load applied the remaining creep part of the deformation is pretty small. The dashed perpendicular lines on the right side of the figure are at 20 years and 50 years. Between 20 years and 50 years of service the creep deformation is practically negligible.

The foam remains structural stable during the entire test-period. This means extruded polystyrene foam is highly durable against sustained mechanical loads.

## 2.2 Long-term Performance Under end-use Conditions - Examples

### 2.2.1 Civil Engineering Application

The performance of XPS frost insulation layers in roadway application in Siberia were studied over a time period of 20 years [Polukhina et. al. 2003].

The insulation layer was located about 50cm to 65cm below ground level. The climatic conditions were characterized by typical continental climatic conditions with temperature variations of about 90K between summer and winter. The results which characterize the durability of XPS products applied in this project are listed in Table 4.

**Table 4.** Results of long-term performance of XPS in roadway application [Polukhina et. al. 2003].

property	1983	1995	2003
Compressive strength [N/mm <sup>2</sup> ]	0,40	0,48	0,52
Thermal conductivity at 20°C, dry sample [W/(mK)]	0,028	0,0286	0,0295
Thermal conductivity at 20°C, wet sample [W/(mK)]	-	0,0301	0,0309

The XPS product investigated showed no deterioration under very severe climatic and complex soil and hydrological conditions over 20 years of service. The increase in thermal conductivity due to moisture impact is less than 5%. The time dependent change in thermal conductivity due to cell gas exchange is about 5%. This is well below the increase predicted at 10% according to previous German standards.

### 2.2.2 Building Application

The application of XPS outside of the water-proofing layer requires high mechanical and moisture resistance. In such applications the insulation product is exposed to a combined impact of heat, moisture and mechanical loads. Hence, the long-term performance of XPS is of topical interest.

XPS products have been tested after 5 to 22 years of service in different roofing applications and in perimeter insulation below groundwater level.



**Figure 6.** Sampling of XPS boards from a green roof (Photo: Dow Building Solutions).

The results are summarized in Table 5.

**Table 5.** Results of long-term performance of XPS in Inverted Roof (IR) and Perimeter application (Dow Building Solutions).

construction	service-life [years]	thickness [mm]	compr.strength [ kPa]	$\lambda_{10}$ measured [W/(mK)] <sup>1)</sup>	$\lambda_{\text{design}}$ [W/(mK)] <sup>2)</sup>
gravel ballasted IR	8	140	not measured	0,036	0,038
gravel ballasted IR	22	80	359	0,029	0,033
Roof garden IR	22	60	459	0,029	0,033
Perimeter below ground-water level	5	60	357	0,031	0,035

<sup>1)</sup> unconditioned sample as taken from the building

<sup>2)</sup> design values according National regulations in Austria, Germany and Switzerland



**Figure7.** Cross section of XPS insulation board after more than 20 years of service in an Inverted Roof outside of the water-proofing layer (Photo: Dow Building Solutions).

The sample shown in Figure 7 was taken from the roof and cut in half to investigate whether the foam structure has been deteriorated over the life-time. No change in cell structure could be detected. This explains why the properties of the foam are practically unchanged.

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