Analysis of Distribution of Properties of Expanded Polystyrene in Production and Their Changes in Exploitation Conditions

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The paper presents the properties of expanded polystyrene slabs manufactured by different manufacturers. The research on the effect of moisture impact on the value of thermal conductivity coefficient of expanded polystyrene products has been carried out too. The limits for application of results of research have been determined, taking into account the distribution of properties of different expanded polystyrene products produced by different manufacturers. The research results show that the thermal conductivity coefficient of EPS conditioned in 80 % relative air humidity environment rises by approximately 0.001 W/(m·K), and for EPS conditioned in 97 % relative air humidity conditions – by 0.002 W/(m·K), in comparison with the average declared values of the thermal conductivity coefficient.

Keywords: expanded polystyrene slabs, density, water vapor sorption, thermal conductivity coefficient.

1. INTRODUCTION

Expanded polystyrene slabs (EPS) are effective thermal insulation products used for insulation of buildings. Expanded polystyrene is a firm, porous material, made by fusing the granules of expanded polystyrene or of one of it's copolymers, that have closed pores filled with air. Such structure is determined for the low thermal conductivity and moisture content of the material. Both properties are interrelated: as the moisture content of the material increase, go up the thermal conductivity coefficient.

All manufacturers of expanded polystyrene slabs declare the thermal conductivity coefficient values of their products, using the results of measurements carried out in standard conditions of temperature and humidity [1]. These values are used to evaluate the thermal properties of products that are on the market. However, the design value of the thermal conductivity coefficient of the thermal insulation material, used to calculate the heat transmittance coefficient of buildings' enclosures, is calculated by adding to the declared value the corrections of thermal conductivity coefficient due to the material's moisture retention in the construction. The value of these corrections depends on the position of the thermal insulation materials in the enclosure, as well as the humidity of the surrounding environment [2, 3]. A.Endriukaitytė [4] has determined that the relative air humidity next to the “cold” side of the thermal insulation layer is slightly over 80 % only in the case of ventilated constructions. In the case of different construction solutions, the thermal insulation material is exposed to an environment, where the relative humidity of air in the cold period of the year increases up to 100 % or presses against an another layer, on which moisture condensation occurs. EPS used to insulate foundations and floors on the ground may be in direct contact with water. In [5] it was determined, that such environment humidity conditions have significant influence on the thermal conductivity coefficient of expanded polystyrene. Therefore, the purpose of this research was to evaluate the effect of moisture on the thermal conductivity coefficient of expanded polystyrene products in exploitation conditions and adjust the currently used corrections of thermal conductivity coefficient of expanded polystyrene products due to moisture absorption in enclosures. That would enable expanded polystyrene to be used more efficiently for the insulation of buildings' enclosures.

2. METHODOLOGY AND OBJECTIVES

For the research different expanded polystyrene products made of Lithuanian companies (“Prokma”, “Ukmergės gelžbetonis”, “Šilputa”, “Kauno šilas”, “Baltijos polistirenas”) were used. In order to identify the differences of properties of expanded polystyrene slabs supplied to the market by different manufacturers, in the first stage of experiment the density of the products before the conditioning of the samples and after storing the samples in a ventilated environment with the relative air humidity of 50 % and temperature of 22 °C. The results were statistically evaluated. Afterwards, the water vapour sorption according to the requirements of LST EN ISO 12571 [6], in the cases of 50 %, 80 % and 97 % relative air humidity of the environment and the temperature of 20 °C, and the long-term water absorption according to LST EN 12087 [7] were determined.

In the next stage, measurements of the thermal conductivity coefficient of expanded polystyrene products stored in humid conditions were performed [8]. Using these results as a basis, the corrections of the thermal conductivity coefficient of expanded polystyrene products to evaluate the influence of moisture were calculated.

3. EXPERIMENTAL

3.1. Properties of the expanded polystyrene slabs

The first task of the research was to determine the distribution intervals of the density of products of all EPS

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classes by every manufacturer that has presented samples for the research before the conditioning of the samples and after storing them in standard conditions [1]. While the density of the product is not directly related to the thermal and moisture properties of expanded polystyrene, the range of the change of this parameter provide general information about the stability [9] of the products' properties. After statistical evaluation the results of this research stage, the density change intervals of slabs of every EPS class were defined, with a 0.95 probability. The range of EPS density change are presented in Fig. 1.

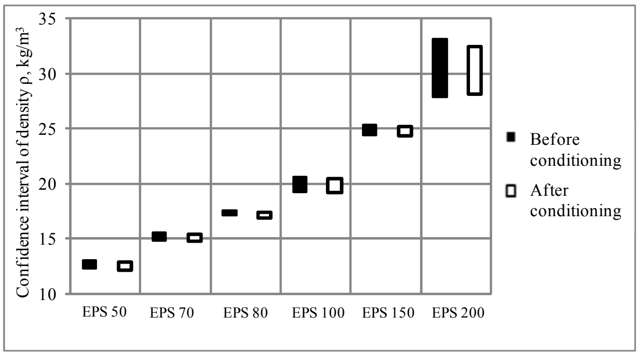

Fig. 1. EPS density reliability interval, kg/m^3

In order to evaluate the statistical significance of the density averages of EPS slabs before and after the conditioning, the Student's statistics was applied. It was determined that the density averages of EPS slabs before and after the conditioning are statistically not different.

After statistical evaluation the density diversity of slabs of the same products' class of different manufacturers, a low significance of dependence of the density of products on the manufacturer was determined. It was concluded that the samples presented for testing by various manufacturers are essentially similar in their structure.

In the following stage of research, the ability of EPS products to absorb moisture in a humid environment was examined, i. e. their long term water absorption was determined. Humid air environment conditions most often form in wall and roof constructions, where expanded polystyrene slabs of classes EPS 50 and EPS 80 are used. Tests of water vapour sorption of slabs of these classes were carried out, in 50 %, 80 % and 97 % relative environment air humidity conditions. The choice of such testing conditions is sufficient to determine what is the moisture content of EPS during the process of measuring the thermal conductivity coefficient (50 %), in the case of average humidity values of air on the outside during the heating season (80 %) [10 – 13] and conditions close to water vapour condensation (97 %). The results of measurements of water vapour sorption by expanded polystyrene of classes EPS 50 and EPS 80 are presented in Figs. 2 and 3.

As can be seen from the results, as the relative humidity of the environment changes from 50 % to 80 %, the change of moisture content of the tested EPS slabs is not significant. However, as the relative air humidity of the environment increases up to 100 %, there is a rise in the moisture content of the EPS. The moisture content value is dependent on the density of EPS slabs: the lower the density is, the higher is the moisture content. Such dependency has been noticed by other scientists as well [11 – 13].

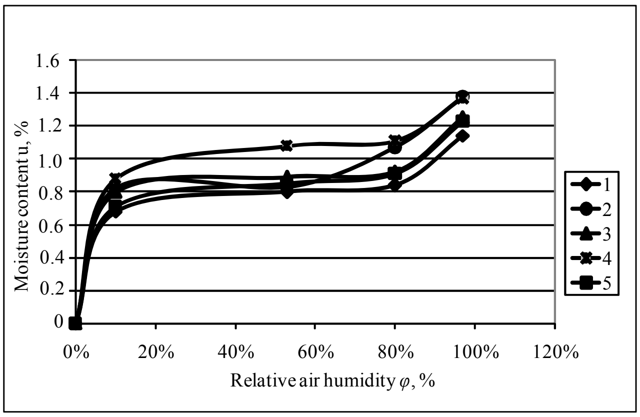

Fig. 2. The sorption curves of expanded polystyrene class EPS 50. 1 – 5 – sorption curves of products from different manufacturers'

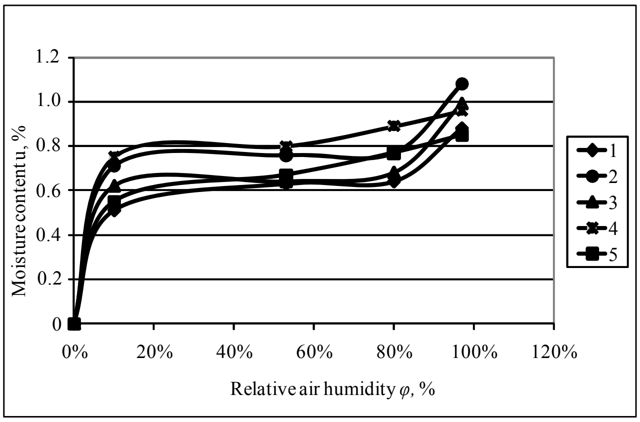

Fig. 3. The sorption curves of expanded polystyrene class EPS 80. 1–5 – sorption curves of products from different manufacturers'

Afterwards, the water absorption of EPS slabs was determined. While expanded polystyrene is not intended for use in constructions where water may accumulate, condensed or external water might reach the foundations of the building, the floors on the ground or the floors in the cellars. For use in insulation of such constructions, slabs of classes EPS 100, EPS 150 or EPS 200 are recommended, with regards to the necessary resistance to mechanical load. The long-term water absorption values of EPS belonging to these classes are presented in Fig. 4.

The results show that the analyzed expanded polystyrene, even immersed in water, does not absorb a significant amount of water (on average from 2 % to 4 %). However, it is likely that the thermal conductivity of products of such expanded polystyrene will be higher than that of the dry and sorption moisture. It was also noticed, that products by different manufacturers absorb different amount of water by different manufacturers use of different primary materials for the production of EPS slabs.

The results of analyzes of the moisture properties of expanded polystyrene slabs show how the moisture of the material changes when it is exposed to different environment humidity conditions. In the following stage,

Table 1. The results of measurements of thermal conductivity coefficient of expanded polystyrene in the case of standard environment conditions (50 % relative air humidity)

Manufacturer's No.	EPS class				
	50	70	80	100	150
	Thermal conductivity coefficient λ, W/(m·K)				
1	0.0414	0.0384	0.0361	0.0347	0.0340
2	0.0426	0.0379	0.0380	0.0360	0.0336
3	0.0402	0.0371	0.0361	0.0357	0.0347
4	0.0391	0.0380	0.0383	0.0345	0.0341
5	0.0412	0.0384	0.0365	0.0367	0.0338
Average measured value	0.0409	0.0380	0.0370	0.0355	0.0340
Declared value	0.043; 0.042	0.039	0.038; 0.037	0.035; 0.036	0.034; 0.035

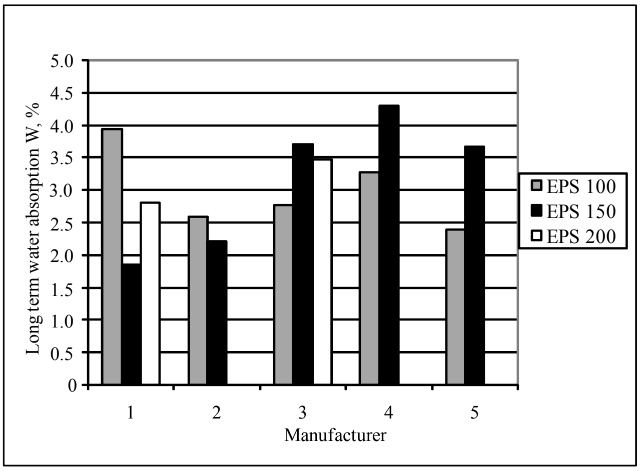

Fig. 4. The dependency of expanded polystyrene long-term water absorption on the manufacturer

the thermal conductivity coefficients of samples stored in different humidity conditions were measured.

3.2. Thermal conductivity coefficient of expanded polystyrene slabs

The thermal conductivity coefficient of expanded polystyrene slabs, measured after storing the slabs in standard conditions, was accepted as a reference value for calculating the increase of the thermal conductivity coefficient due to the influence of moisture accumulated in the products under specific conditions. These thermal conductivity coefficients are presented in Table 1.

In comparison to the values declared by the manufacturers, the measured thermal conductivity coefficient values are scarcely lower. That shows that the production of EPS is stable, the distribution of the products' thermal conductivity coefficients is low.

Following this, the thermal conductivity coefficients of samples, with moisture content equal to the determined sorption moisture content in 80 % relative air humidity environment. As such humidity conditions are only found in ventilated constructions, where class EPS 50 expanded polystyrene is most commonly used, the thermal conductivity coefficients only of products belonging to this class were measured. The results of the measurements are presented in Table 2.

Table 2. The results of measurement of the thermal conductivity coefficient of expanded polystyrene (class EPS 50) stored in 80 % relative air humidity conditions

Manufacturer's No.	Thermal conductivity coefficient λ, W/(m·K)
1	0.0439
2	0.0429
3	0.0416
4	0.0403
5	0.0436
Average value of measured coefficients	0.0425
Average value of coefficients measured in standard conditions	0.0409
Declared value	0.043; 0.042

The difference between the measured average thermal conductivity coefficient values of EPS stored in 80 % relative air humidity environment and samples stored in standard conditions is 0.0016 W/mK. This difference is even lower when the values declared by the manufacturer and the average measured values of EPS products are compared (lower by approximately 0.001 W/mK).

Therefore, using the results of performed measurements with a slight safety factor, it is possible to claim that the design value of the thermal conductivity coefficient of expanded polystyrene used in buildings' enclosures will be approximately 0.001 W/mK higher than the value of the thermal conductivity coefficient declared by manufacturers.

In the following stage of research, the thermal conductivity coefficients of samples with the moisture content equal to the sorption moisture content determined in 97 % relative air humidity environment were measured. Such humidity conditions are found in unventilated wall and roof constructions, where expanded polystyrene of class EPS 70 and higher is used. The measured thermal conductivity coefficient values of the products are presented

Table 3. The results of measurements of thermal conductivity coefficient λ, W/(m·K) of expanded polystyrene stored in 97 % relative air humidity conditions

Manufacturer's No.	EPS class			
	70	80	100	150
	Thermal conductivity coefficient λ, W/(m·K)			
1	0.0391	0.0366	0.0352	0.0350
2	0.0396	0.0383	0.0370	0.0356
3	0.0392	0.0379	0.0361	0.0351
4	0.0385	0.0384	0.0354	0.0347
5	0.0392	0.0376	0.0365	0.0347
Average measured value	0.0391	0.0378	0.0360	0.0350
The average coefficient value measured in standard conditions	0.0380	0.0370	0.0355	0.0340
Declared value	0.039	0.038; 0.037	0.035; 0.036	0.034; 0.035

in Table 3. The difference of the values of the thermal conductivity coefficients of moisture accumulated in 97 % relative air humidity environment and of samples stored in standard conditions is 0.0016 W/mK. However, water condensation is possible in these constructions or close to EPS, therefore the EPS may become more moist contacting with such surfaces. As can be seen from the results of determination of water absorption (Table 4), when contacting with moist materials, expanded polystyrene absorbs a higher amount of moisture, therefore it's thermal conductivity coefficient increases. Summing up the results of the measurement of the thermal conductivity coefficient of samples stored in 97 % relative air humidity environment and samples stored in water, it is possible to claim that the design value of the thermal conductivity coefficient of expanded polystyrene used in unventilated buildings' enclosures is approximately 0.002 W/mK higher than the thermal conductivity coefficient value of this material as declared by the manufacturers.

Table 4. The results of determination of the thermal conductivity coefficient of expanded polystyrene stored in water for 28 days

Manufac-turer's No.	EPS class			
	100		150	
	W, %	λ, W/(m·K)	*W*, %	λ, W/(m·K)
1	3.90	0.0414	1.90	0.0373
2	2.60	0.0371	2.23	0.0371
3	2.78	0.0400	3.68	0.0396
4	3.34	0.0412	4.32	0.0403
5	2.40	0.0397	3.74	0.0408
Average measured value		0.0399		0.0390
Declared value		0.035; 0.036		0.034; 0.035

When expanded polystyrene slabs are used for insulation of floors on the ground, floors in the basement and foundations, they come in contact with moist ground. Water that gets absorbed into the ground during rain and snow-melting takes long to evaporate, therefore it raises the humidity of the thermal insulation material. In order to determine the least favorable effect of moisture on the thermal conductivity of expanded polystyrene used for insulation of floors on the ground from the foundation, measurements of the thermal conductivity coefficient of expanded polystyrene stored in water for 28 days were performed, the results of which are presented in Table 4.

The analysis of these measurement results shows that the difference the average measured and declared values of the thermal conductivity coefficient is (0.005 – 0.006) W/mK. That means that in order to compensate for the increase of the thermal conductivity of expanded polystyrene used for the insulation of floors on the ground due to the effect of moisture a layer of the material thicker by approximately 15 % needs to be used. Taking into account the fact that the products of expanded polystyrene in the floors of basements and foundation may be under effect of static water pressure, the moisture content of the material may be even higher. To avoid an increase in heat losses through these enclosures due to the effect of moisture, the correction of thermal conductivity of expanded polystyrene used in basement floors and on the outer side of the foundation due to water absorption is accepted as 0.01 W/mK.

4. DISCUSSION

The principle of the effects of moisture on the thermal conductivity of thermal insulation materials is extensively investigated and detailed in scientific and technical literature [4, 5, 8, 9, 15, 16]. However, the relationship of the moisture of thermal insulation materials with the humidity conditions of the environment is constantly varying depending on the technology of production and the additives used for the production of raw materials. The manufacturers aim to supply the market with products with a moisture absorption that is as low as possible. When the moisture absorption of the material is lower, the diversity of the thermal conductivity coefficients of the materials are lower as well.

After research of humidity properties and the dependency of thermal conductivity coefficient of expanded polystyrene produced in Lithuania it was determined that the production of this thermal insulation material is stable, the humidity changes in exploitation conditions are significantly lower than those permitted, presented in the product's standard [14]. The results of the measurements of thermal conductivity of samples of exploitation humidity also show that in order to avoid the increase in heat losses through enclosures insulated with expanded polystyrene slabs due to the effect of moisture, these corrections of the thermal conductivity coefficient (Table 5, line 1) may be used. These values are approximately two times lower then presented in STR 2.01.03:2003 [17] (Table 5, line 2).

Table 5. The correction of thermal conductivity due to additional absorption of expanded polystyrene in the enclosure

No	Correction $\Delta\lambda\omega$ (W/(m·K)) due to additional absorption of expanded polystyrene in the enclosure			
	Ventilated enclosure	Unventilated enclosure	Under the rooms on the ground	On the outher side of buildings – in the ground
1	0.001	0.002	0.006	0.010
2	0.003	0.004	0.010	0.025

1 – counted value of the correction;
2 – presented value of the correction in STR 2.01.03:2003 [17].

The use of these corrections ensures the required level of thermal insulation and an economical use of thermal insulation material.

CONCLUSIONS

1. The density of a EPS product is not direct indicator of the quality of the product and its conformity to the quality requirements. Nevertheless the slight differences in density of EPS products produced by various manufacturers before and after their conditioning are an indicator of the stability of production.

2. The results of measurement of the thermal conductivity coefficient of EPS stored in standard conditions show that the difference between measured and declared values is no higher than 10 %. That means that the use of expanded polystyrene slabs for insulation of buildings' enclosures is economical.

3. The thermal conductivity coefficient of EPS stored in 80 % relative air humidity environment rises by approximately 0.001 W/mK, and that of EPS stored in 97 % relative air humidity conditions by 0.002 W/mK, in comparison with the average declared values of the thermal conductivity coefficient.

4. The differences of values of the thermal conductivity coefficients of EPS slabs stored in standard conditions and stored in water are quite similar and approximately equal to 0.006 W/mK.

5. The reduction of corrections to the thermal conductivity coefficient of expanded polystyrene based on the results of performed experiments due to the water absorption of the material in the enclosure create the conditions to use this thermal insulation material more efficiently and increases it's competitive ability in regard to other thermal insulation materials.

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