BUILDING MATERIALS AND PRODUCTS

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LABORATORY RESEARCH STRUCTURAL CHARACTERISTICS OF MOISTURE POLYSTYRENE FOAM

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Statement of the problem. Houses with solid walls and permanent formwork of expanded polystyrene are very promising for quick and cheap social housing. At the same time, this structural system developed in the Western Europe, in the domestic construction science has not been investigated. Expanded polystyrene formwork is not standardized, therefore different manufacturers supply constructional products from various expanded polystyrene structure and density. In the climate conditions of the southern Far East special attention must be paid to the work of building structures in high humidity. These circumstances made it necessary to study the humidity properties of expanded polystyrene used for wall formwork.
Results. Experimental research was conducted to identify balanced sorptional humidity of foam polysterol at the temperature of -20 °C, as at negative temperatures apart from partial pressure of water vapours, it is necessary to know the relative humidity of air at this temperature and relative humidity of air in excicators $\varphi_в$ (over water) which is equal to the ratio of the pressure to that of concentrated water vapours over water at this temperature.
Conclusions. The experimental results showed that the extruded polystyrene has the best performance in terms of humidity sorption moisture vapor permeability and water absorption. At the same time the importance of water absorption index necessitates careful waterproof outer layer of polystyrene, especially in the monsoon climate.

Keywords: permanent formwork polystyrene, humidity, water vapor permeability, water absorption.

Introduction

A technical and economic analysis of modern small-storied residential buildings conducted by the author [4] revealed advantages offered by the use of a construction system employing a non-assembly polystyrene foam wall formwork for the construction of social housing.

However, there are no guidelines regarding this kind of formwork in this country, manufacturers bring polystyrene foam construction items of different structure, density and quality. A non-assembly polystyrene foam formwork has not yet been studied in moist conditions.

1. Study of sorptional humidity at different temperatures.

Depending on the climate and external factors, relative humidity is in the range of sorptional characteristics of a material, i.e. it increases when moisture is accumulating and decreases in a dry period. The analysis of thermal conductivity of polystyrene foam in Construction Guidelines and Regulations (СниП) 23-202-2003 shows that the thermal conductivity coefficient of heat insulators in the operating conditions B is 40—80 % higher than that in dry conditions [1].

One of the methods of investigating interactions of humidity and material is to study sorption and desorption isotherm that can also be used in calculating thermodynamic mass transfer. According to the classical theory, sorptive wetting of porous construction materials is physical absorption of water vapours from humid air. A construction material is an adsorbent, water vapours are an adsorbent and the process itself is the concentration of water vapour on the pores of a construction material [3].

Sorption characteristics of construction polystyrene foam were identified at an environment temperature t_c = (20 ±2) °C using the method detailed in GOST (ГОСТ) 24816 "Cosntruction Materials. Determining Sorption Humidity". In this method samples of up to 3 mm are poured into glass weighing bottles previously dried and weighed on an analytical balance that has an accuracy of up to 0.001 g. The weighed samples were stored till they reached a constant mass at the temperature of 60 °C in a drying weighing bottle. The open boxes with material samples are placed into glass exsiccators and onto ceramic grids over the surfaces of the working solutions of sulphuric acid of different concentration to maintain the relative air humidity $\varphi_в$.

According to the standard method, sorptive humidity of materials is determined for the humidity of 40, 60, 80, 90 and 97 % and the temperature 20 °C. The author finds it important that in the calculation of heat and mass transfer through filler structures there is reliable information available on the equilibrium sorptive humidity of a heat insulator in a temperature range where these materials are used in structures.

The standard method was improved in the following way: sorption humidity of construction polystyrene foam was identified using the exsiccator method at the temperatures -20, -10.4, +1.2, +20, +35 °C. Additionally, the author considered it a good option to study equilibrium sorption humidity experimentally at the temperature -20 °C as at negative temperatures apart from partial water vapour pressure, it is necessary that the relative air humidity in exsiccators

$\varphi_л$ (over the ice) is known which is equal to the ratio of this pressure to that of concentrated water vapours over water at this temperature. Sorption humidity of materials during complete saturation ($\varphi_в = 100$ %) were not identified so that there were no wrong results. The exsiccators were tightly sealed with a lid, the samples were left to stay in the open weighing bottles. Glass weighing bottles with the material samples were occassionally weighed till they reached equilibrium moisture content between the air in the exsiccator and the tested material. A difference between the mass of the weighing bottle with the dry material and in equilibrium moisture content was used to determine the humidity of the material by the mass w, % at a corresponding relative air humidity φ, %, in the exsiccator. The results of the study of sorption humidity are presented in Table 1. A sorption isotherm of water vapours was designed using extruded polystyrene foam by Ltd. Neomir at the temperature 20 °C (Fig. 1).

The concentrations of water solutions of sulphuric acid, the relative humidity over which at the temperature +20 °C was 10, 20, 40, 60, 80 and 97 % respectively were taken from the book by A. U. Franchuk and K.F. Fokin [5] as well as papers by authors abroad [11]. Partial pressure of water vapours for the temperature -20, -10.4, +1.2, +20, +35 °C was calculated using the formula by M.Kh. Karapetyan [2] improved by European authors [11] that connect the partial pressure of water vapours p over the water solutions of sulphuric acid with the temperature:

$$\lg p = A^* - B^* T^{-1},$$

where p is partial pressure of water vapours, millimeter of water; A^* is a constant; B^* is a constant, K; T is temperature, K. The necessary constants A^* and B^* were borrowed from modern reference books [11].

Table 1

Experimental sorption humidity of polystyrene foam samples

Polystyrene foam by “Noviy isodom”							
φ, %	0	0	0	0	0	0	97
w, %	1.1	1.3	1.5	1.7	1.9	2.1	2.7
Polystyrene foam by “StroiProfiGroup”							
φ, %	40	50	60	70	80	90	97
w, %	1.0	1.2	1.4	1.6	1.8	2.0	2.5
Extruded polystyrene foam by Ltd. “Neomir”							
φ, %	40	50	60	70	80	90	97
w, %	1.4	1.45	1.5	1.55	1.6	1.7	2.0

According to [3], the dependencies of equilibrium sorption humidity of construction materials ω_p on the temperature Θ in the range of -10.4 to +35 °C can be represented as the following linear function:

$$\omega_p(\Theta) = a_\omega \Theta + b_\omega,$$

where a_ω is an angular coefficient of regression, %; a_ω is a constant regression coefficient, %; Θ is the temperature,°C.

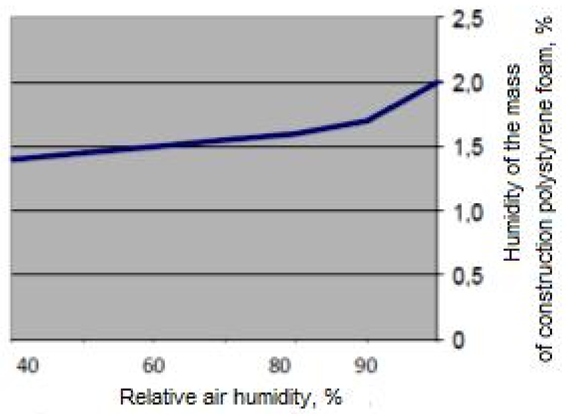

Fig. 1. Sorption isotherm of water vapours using an extruded polystyrene foam by Ltd. "Neomir" at 20 °C

The dependencies of equilibrium sorption humidity of construction polystyrene foam are in Fig. 2.

Experimental studies to determine equilibrium sorption humidity of polystyrene foam at the temperature -20 °C were also performed. A particular thing about them was that it was necessary to identify the relative air humidity in the exsiccators $\varphi_л$ (over the ice) and relative air humidity in the exsiccators $\varphi_в$ (over the water) (Table 2).

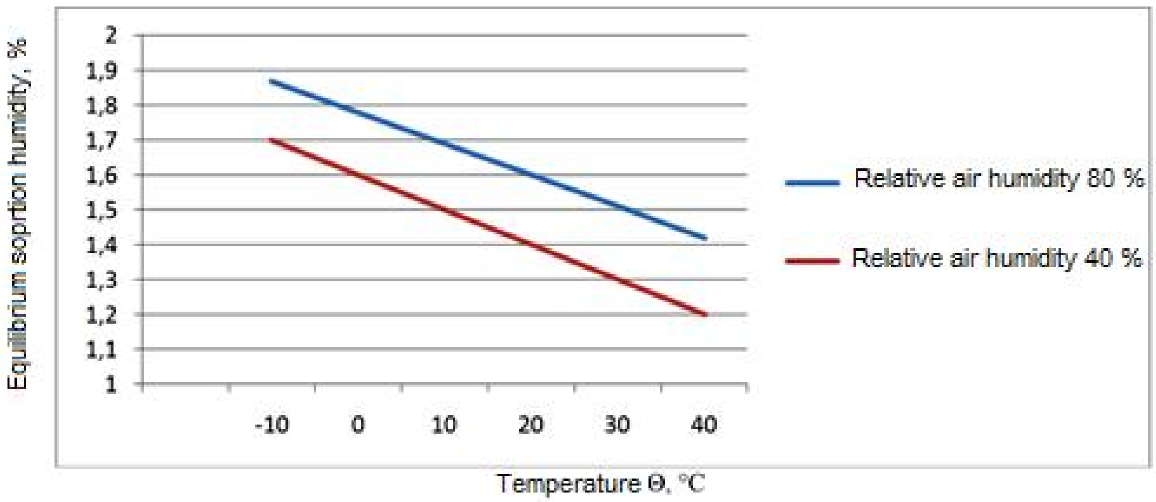

Fig. 2. Dependence of equilibrium soprtion humidity ω_p on the temperature Θ

Table 2

Equilibrium sorption humidity ω_p of extruded polystyrene foam by Ltd. "Neomir"

Density, kg/m^3	Equilibrium sorption humidity ω_p,% at a relative air humidity φ, %				
	6.1 (5.0)*	19 (16)*	48 (40)*	82 (68)*	98 (81)*
40	0.5	1.0	1.2	-	1.7

Note. *In brackets is a relative air humidity over the water.

The connection between $\varphi_л$ and $\varphi_в$ is described by an empirical equation by Ye. Washburn [3]:

$$\phi_л = \phi_в \exp\left[2,303\left(\frac{1,149\Theta}{273,15+\Theta} - 1,330\times10^{-5}\Theta^2 + 9,084\times10^{-8}\Theta^3 - 1,080\times10^{-9}\Theta^4\right)\right].$$

The comparison of the data on the equilibrium sorption humidity of the investigated materials at the temperatures -20, -10.4, +1.2, +20, +35 °C shows that the equilibrium sorption humidity at the temperature -20 °C and each investigated relative air humidity is smaller than the equilibrium sorption humidity at the temperatures -10.4, +1.2, +20 °C. Moreover, the equilibrium sorption humidity at the temperature -20 °C and relative air humidity which is 80 % smaller than the relative sorption humidity at the temperature +35 °C and relative air humidity of 80 %.

2. Water absorption

For the study samples of parallelepipeds with the size 94.8×97.2×75 mm, 119×121×75 mm and 93.3×96.3×75 mm were used that were dried until they reached a constant mass. The method involved a measurement of the amount of water absorbed by a tested sample by weighing the sample after it had been in distilled water over a specified period at the temperature (20 ±2) °C and normal pressure. The samples were put on the grid so that the water level was 2—10 cm higher and stored there from 1 to 40—42 days. The samples were occasionally weighed.

Water absorption of polystyrene foam was defined as an arithmetic mean of the results of the tests of three samples.

Weighed water absorption was calculated according to the formula

$$W = \frac{W_0 \gamma_0}{1000}, \ \%,$$

where γ_0 is the density in the dry state; W_0 is water absorption of the sample in % by the mass:

$$W_0 = \frac{m_в - m_c}{m_c} 100 \ \%.$$

The test results are in Table 3.

Table 3

Results of experimental tests to determine the density and water absorption of a construction polystyrene foam by Ltd. "Izodom"

Sizes, amount of material	Mass of the dry material, g	Density, kg/m^3	Water absorption over 24 hours during complete dipping into water			
			Mass of the sample following water absorption, g	Amount of the absorbed water, g	W, %, mass	W, %, amount
94.8×97.2×75 mm, V = 0.00069 m^3	16.01	23.2	24.87	8.86	55.3	1.7
119×121×75 mm, V = 0.00108 m^3	22.79	21.1	35.06	12.27	53.8	1.5
93.3×96.3×75 mm, V = 0.00067 m^3	14.35	21.3	23.70	9.35	65.2	1.3

The humidity of polystyrene foam taken from a heat insulating layer varied significantly and was from 3 to 11 % by the mass. This might be due to the fact that some of the water travels to polystyrene foam when cement is poured. Humidity was unevenly distributed in the heat insulating layer owing to the moisture impacting only the interior of the layer resulting in uneven drying.

Table 4 presents the water absorption of the investigated polystyrene foam for 1÷28 days.

Table 4

Water absorption of the investigated polystyrene foam samples

Polystyrene foam	Water absorption			
	1 day later		28 days later	
	$W_м$, %	W_o, %	$W_м$, %	W_o, %
Polystyrene foam "Noviy izodom"	110.1	2.6	632.3	16.8
Polystyrene foam "Izodom"	58.1	1.5	426.3	12.5
Polystyrene foam "StroiProfiGroup"	35.3	1.4	302.3	9.2
Extruded polystyrene foam "Neomir"	34.5	1.6	152.3	7.0

As apparent density decreases, water absorption increases due to the structure not being even any longer and the cells becoming larger [8], which is consistent with the experiment results. Water absorption kinetics of polystyrene foam over a specified period is in Fig. 3.

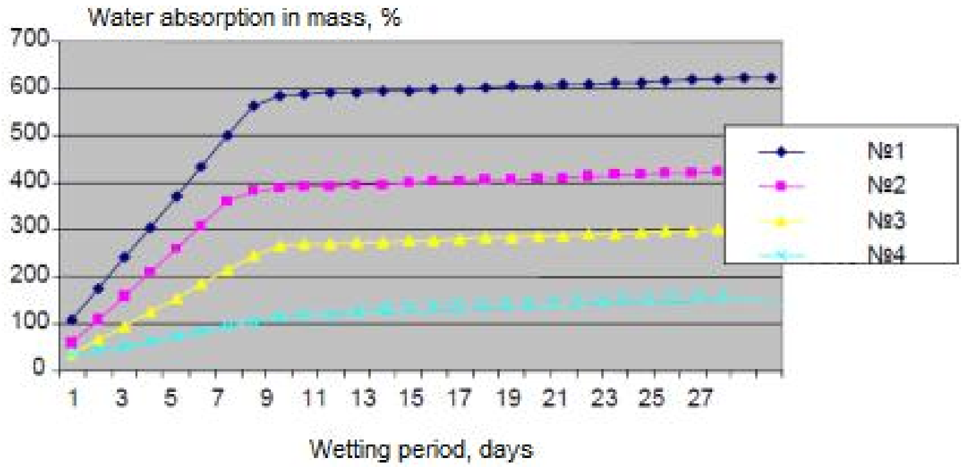

Fig. 3. Dependence of water absorption on the time of wetting of polystyrene foam:
1 is “Noviy Izodom”; 2 is “Izodom”; 3 is “StroiProfiGroup”; 4 is “Neomir”

Fig. 3 suggests that water absorption of polystyrene foam largely depends on the time of wetting. At the same time based on the research it is obvious that water absorption of polystyrene foam is sensationally high. Unlike that of the rest of the construction materials, water absorption of polystyrene foam is commonly calculated a volume percentage (not a mass percentage). This results in a lot of confusion as the acceptable wetting of up to 3 % (of the volume) for the density of 25 kg/m³ in a traditional standard is 220 % (of the mass).

Therefore researchers arguing that “polystyrene foam is quite moisture-resistant” (e.g., [6]), have it a wrong way. Conversely, the opposite theory that goes “A smallest wetting of polystyrene foam is a cause of a severe deterioration of its heat insulating properties” [7].

Comparing the results obtained in 2005 by A.Ye. Khrenov [6] (water immediately entering plastic is less than 0.25 mm per year), we argue that water absorption of polystyrene foam mostly depends on its structural features, density, manufacturing technology and water absorption period.

Polystyrene foam with isolated pores and cells has the best properties. The tests of the samples showed that complete water immersion occurs over the first ten days, then goes on and over 19 days remains around 10 % in the mass and 0.4 % in the volume. The experiment is consistent with the theory from [7]: «Originally cell samples on the surface destroyed during production are slowly filled and afterwards there is no water entering inside the material". The time of wetting also influences water absorption. According to [12], the yearly absorption of expanded polystyrene EPS increases its absorption by 2—3 times. A necessary standard fire safety also significantly improve water absorption. Fire-retardant additives in polystyrene foam stop individual granules from burning, create voids between granules according to [7, 9, 15] resulting in water absorption of self-extinguishing polystyrene foam in equal densities being 3—4 times higher than that of ordinary polystyrene foam.

Conclusions

The method of determining sorption humidity of polystyrene foam has been improved. According to the standard method, sorption humidity of materials is identified for the humidifies 40, 60, 80, 90 and 97 % and the temperature 20 °C. The standard method was improved in the following way: sorption humidity of construction polystyrene foam was identified by means of the exsiccator method at the temperatures of -20, -10.4, +1.2, +20, +35 °C.

Additionally, the author thought it necessary to conduct an experimental study to determine the equilibrium sorption humidity of polystyrene foam at the temperature -20 °C as at negative temperatures apart from partial pressure of water vapours, it is necessary that the relative air humidity in the exsiccators $\varphi_л$ (over the ice) is known which equals the ratio of the pressure to that of concentrated water vapours over ice at this temperature and the relative air humidity in the exsiccators $\varphi_в$ (over the water). According to this method, laboratory studies were performed for a temperature range from -20 to +35 °C. Water absorption for different labels of construction polystyrene foam.

The experimental results showed that extruded polystyrene foam has the best humidity characteristics in terms of sorption humidity. Water absorption being important makes it necessary that proper waterproofing of an outer layer of polystyrene foam particularly in monsoon climate. The study results also indicate that extruded polystyrene foam has worse water absorption than expanded polystyrene EPS. Therefore it was proven that extruded polystyrene foam is the best material to use in a non-assembly formwork.

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