LONG-TERM WATER ABSORPTION OF EXPANDED POLYSTYRENE BOARDS

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Received 30 Nov 2006; accepted

Abstract. The results of determining water absorption of specimens cut out from expanded polystyrene boards and having the density of 11-36 kg/m^3, which were manufactured by Lithuanian manufacturers using a non-compaction method of frothing polystyrene beads – granules, 1-3 mm in diameter, are presented. The tests were conducted in conformity with the requirements of the Standard LST EN 12087, using the method 2A. Water absorption of EPS boards subject to 7- and 28-days immersion (W_{28} is the time specified by LST EN 13163) was determined. The total time of immersion was 250 days. Based on the data obtained, some regressive equations were suggested for calculating: the prognostic value of EPS board water absorption $W_{28}^{predict.}$ based on the results obtained for W_7 and the increase of water absorption of EPS boards after 28 days of immersion.

Keywords: expanded polystyrene (EPS) boards, long-term water absorption, total immersion, predicting.

1. Introduction

The moisture content of expanded polystyrene boards used for insulation in construction usually is caused by sorption of water vapour from environmental air [1]. These products may be subjected to long-term immersion in water too (e.g. when used for foundation insulation or in other underground structures) and absorbed water content must be taken into consideration when calculating their thermal properties [2].

The data on water absorption of expanded polystyrene are scarce, while the available information mainly concerns articles of 15 and 20 kg/m^3 density [3-6]. In the previous work of the authors [7], a more detailed description of the results obtained in testing expanded polystyrene boards made by various European manufacturers for long-term water absorption was presented. The above tests were made according to methods 2A, 2B, specified by the European standard LST EN 12087 [8], while the experimental results obtained by these both methods for specimens immersed for different time length were compared. Based on the data obtained, the probable interval of increase of water absorption during time intervals up to 15 year immersion of a polystyrene board (of 12-35 kg/m^3 density) was predicted.

The present investigation concerns the experimental testing of expanded polystyrene for water absorption which was performed according to the requirements of the Standard LST EN 13163 [9]. Polystyrene boards manufactured by Lithuanian companies using a non-compaction method based on foaming polystyrene granules, 1-3 mm in diameter, which were supplied by the companies ‘STYROCHEM’ (Finland) and ‘BASF’ (Germany), were tested.

2. Testing methods

Water absorption of EPS boards was determined in percent by volume for the immersion during 7, 14 and 28 days, and, further, for the periods of 28 days in accordance with [8]. The total time of immersion was 250 days.

The specimens of the size (200x200x50) mm, cut out of the boards of 11 types (from EPS 30 to EPS 250) [9], having the density of 11-36 kg/m^3 and manufactured by various Lithuanian companies, were tested. A certain number of specimens were placed in an empty water tank and slightly pressed by a plate for total immersion. The water was poured until the top face of the specimens was 50±2 mm below the water level [8]. The total number of the test specimens was 207. Before testing, the specimens were stored for six hours at the temperature of 23±5 ºC and 50±5 % relative air humidity.

According to [9], water absorption W, vol. %, was determined by using a method 2A based on drainage. A test specimen was taken out of the water tank and placed on a mesh cage made of stainless steel and forming a chute with a slope of 45º [8]. After 10±0.5 min of drainage, the specimens were weighed. To increase the accuracy and decrease the spread in data, all procedures were performed consistently by the same researcher.

Water absorption was determined by the formula:

$$W_{\tau(2A)} = \frac{m_\tau - m_0}{V} \cdot \frac{100}{\rho_w}, \qquad (1)$$

where m_τ is the specimen mass after immersion over the period of time τ, days, kg; m_0 is the initial mass of the specimen, kg; V is the initial specimen volume, m^3; ρ_w is water density equal to 1000 kg/m^3.

3. Testing results

The values of water absorption of test specimens cut out from expanded polystyrene boards and determined according to method 2A after 28 days of immersion, W_{28}, are presented in Fig 1.

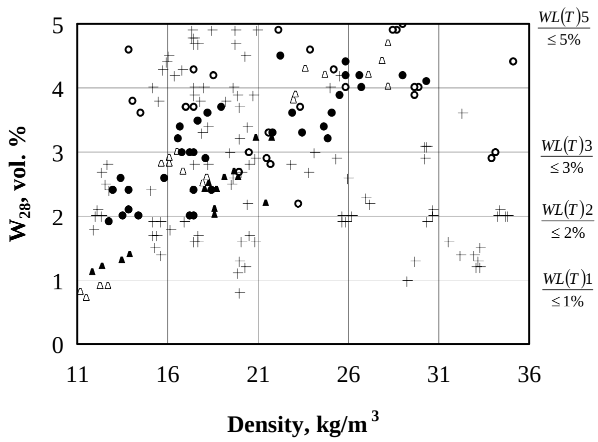

Fig 1. Experimental values of water absorption of expanded polystyrene boards. Notation: ○, Δ, +, ●, ▲ denote specimens of EPS boards supplied by various manufacturers

The boards tested for long-term water absorption satisfy the requirements of the Standard LST EN 13163, specifying the upper level $WL(T)5$, i.e. $W_{28} \leq 5$ vol. %. It should be noted, that a large part of the tested boards demonstrated water absorption lower than 3 vol. %., satisfying the upper level $WL(T)3$ or even $WL(T)2$.

It was not feasible to determine the relationship between water absorption of EPS boards and their density (because boards were obtained from various enterprises and the data on major technological parameters and size of polystyrene granules were not available). Though EPS boards manufactured by various methods have actually similar density, they have different water absorption values because of different porosity [10].

A histogram of relative frequency of W_{28}, matching the intervals of values corresponding to the curve of normal distribution (Fig 2), was constructed based on the experimental values of EPS boards presented in Fig 1.

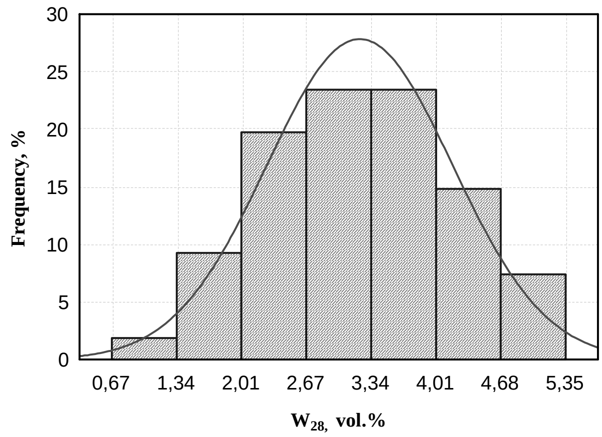

Fig 2. A histogram of empirical distribution of relative frequencies of W_{28} matching the intervals of values corresponding to the curve of normal distribution. Density of EPS boards is 15-35 kg/m^3

According to the form of histogram, a hypothesis may be put forward that the statistical distribution of water absorption value of W_{28}, vol. %. of EPS boards with the density of 15-35 kg/m^3 can be described by the law of normal distribution. A hypothesis about the agreement of statistical distribution with normal distribution was proved by applying Pearson's criterion (χ^2), when the confidence level $P = 0.95$. The calculations were made using the program STATISTICA and the section Normal of the module Nonparametric Statistics and Distribution Fitting [11]. First-type error probability proved to be equal to 0.72. It follows that a hypothesis about the normal distribution of experimental values of W_{28} can be accepted. The mean value of W_{28} is 3.2 vol. %., while the standard deviation $S_w = 1.0$ vol. %., according to the test results ($n = 162$).

A possibility of quantitative expression of water absorption W_{28} of EPS boards of seven-day immersion based on the values of W_7 was also investigated (e.g. for effective control of this parameter at manufacturing enterprises). Based on the data (Fig 3) obtained in testing, the relationship between water absorption of boards W_{28} and W_7 (vol. %.) may be approximated by the following equation [12]:

$$\overline{W}_{28} = 0.61 + 1.18 \cdot W_7 \qquad (2)$$

with the standard deviation $S_r = 0.50$ vol. %. (an absolute value of mean deviation of experimental data from the empirical regression line, constant for all its sections) determined by the formula:

$$S_r = \sqrt{\frac{\sum_{i=l}^{n} \left[W_{28(i)} - \overline{W}_{28(i)} \right]^2}{n - m}}, \qquad (3)$$

where $W_{28(i)}$ is the experimentally obtained i-th value of water absorption; $\overline{W}_{28(i)}$ is the same for empirical relationship (2); n is the number of experiments; m is the number of regression equation parameters.

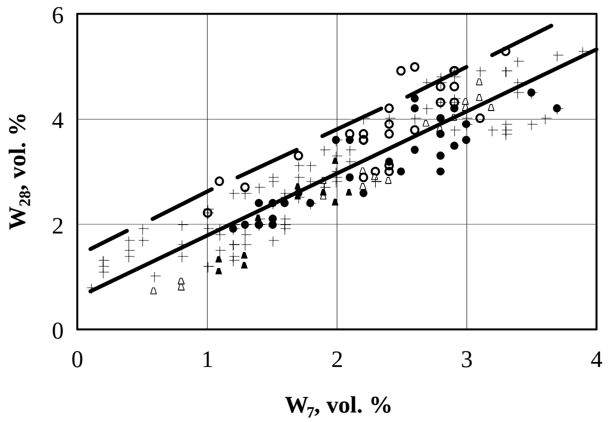

Fig 3. The empirical regression line of water absorption of EPS boards $\overline{W}_{28}$ based on the values obtained for W_7. A dotted line denotes the predicted values for $W_{28}^{predict.}$. Notation: see comments to Fig 1

Determination coefficient $r^2_{w_{28}\cdot w_7}$ is equal to 0.82, thereby showing that the variation of water absorption values of W_{28} is accounted for by the changes in the values of W_7 values (about 82 %) and by other factors (18 %). This allows the extrapolation of W_7 to $\overline{W}_{28}$ values. In this case, a confidence interval for predicting water absorption W_{28} by using the equation (2), when $n = 188$ and $t_\alpha = 1.29$ [13], is $\delta = +t_\alpha \cdot S_r = 0.64$ vol. %., with the probability being $(1-\alpha) = 0.90$. It follows that, based on the data obtained, the maximum predicted values $W_{28}^{predict.}$, depending on W_7, may be described by a regression equation (see Fig 3, a dotted line):

$$W_{28}^{predict.} = 1.25 + 1.18 \cdot W_7 \qquad (4)$$

Hence, for example, it follows from the equation (4) that the highest level $WL(T)5$ of water absorption of EPS boards $W_{28}^{predict.}$ may be expected if W_7 value is not higher than 3.1 % vol. Similarly, the upper level of $WL(T)3$ can be achieved if the value of W_7 is not higher than 1.4 % vol.

A comparison of the values $\overline{W}_{28}$ and $W_{28}^{predict.}$, obtained in testing expanded polystyrene boards by the authors of the present work, with their data provided in [7] is shown in Fig 4.

It should be noted that the values of $\overline{W}_{28}$ given in the equation (2) exceed the respective values presented

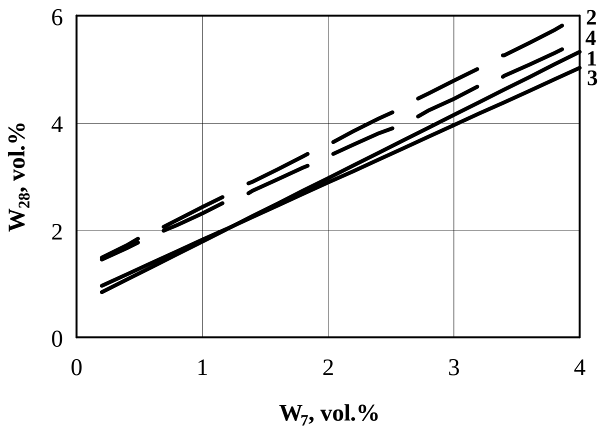

Fig 4. A comparison of empirical regression lines of the values of $\overline{W}_{28}$ and $W_{28}^{predict.}$, based on the results obtained for W_7. Lines 1, 2 are empirical regression lines for the mean values of $\overline{W}_{28}$ and the predicted $W_{28}^{predict.}$ (see eq. (2), (4)); lines 3, 4 show the same, based on [7]

in [7] by 6.5 %, while the values of $W_{28}^{predict.}$ given in the equation (4) exceed them by 8.5 % (in the considered interval $W_7 \leq 4.5$ vol. %.). Taking into account the experimental error, these results show good agreement of water absorption levels of EPS boards manufactured by European and Lithuanian manufacturers.

The kinetics of water absorption of expanded polystyrene boards having the density of 11-36 kg/m^3 and immersed for 250 days is shown in Fig 5.

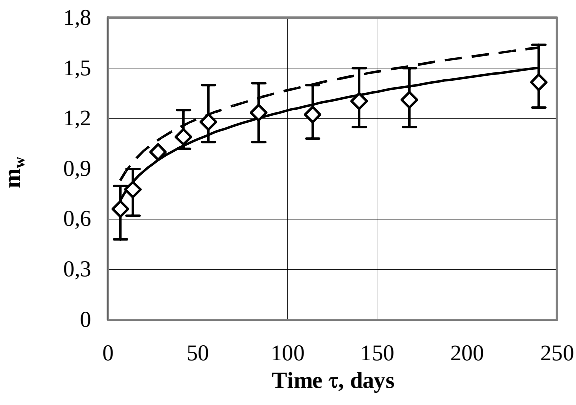

Fig 5. The empirical regression line showing the increase of water absorption of the EPS boards (with density of 11-36 kg/m^3), depending on the time of immersion. A dotted line denotes the predicted values $m_w^{predict.}$. ◊ is the mean value and the range of individual m_w values of the tested specimens of boards supplied by various manufacturers

It can be observed that water absorption of expanded polystyrene is getting slower in time. This process may be divided into two stages: the first one (28 days), when the ultimate level of water absorption is declared according to [9], and the second stage characterized by a slower rate of water absorption. Using the data obtained, the growth of water absorption of expanded polystyrene may be approximated by a relationship of the type used in [7] and based on the comparative analysis of some analytical relationships $f(\tau)$ in a regression model of the form:

$$\overline{m}_w = f(\tau) + \delta. \qquad (5)$$

Here, $f(\tau)$ means mathematical expectation, i.e. the mean value of $\overline{m}_w$ for a fixed value of the argument τ (i.e. a regression line), while δ is a random value, depending on uncontrolled random spread of values $m_{w(i)}$. It is also assumed that mathematical expectation (the mean value) $M \cdot \delta = 0$ and variance $D \cdot \delta = S_r^2 = const$ do not depend on τ.

The empirical regression equation $\overline{m}_w$, based on the fixed τ values, is of the form [11, 12]:

$$\overline{m}_w = 0.47 \cdot \tau^{0.212} \qquad (6)$$

with the standard deviation $S_r = 0.096$ and determination coefficient (a square correlation) $\eta^2_{m_w \cdot \tau} = 0.857$.

In the equation (6), $\overline{m}_w = \dfrac{W_\tau}{W_{28c}}$; W_τ is water absorption of expanded polystyrene at the moment of time τ, days, vol. %.; W_{28} is the same for the fixed time $\tau = 28$ days.

A unilateral confidence interval for predicting the increase of water absorption of expanded polystyrene according to equation (6), when $n = 706$ and $t_\alpha = 1.28$ [13], is $\delta = 1.28 \cdot 0.096 \approx 0.12$, with the confidence $(1-\alpha) = 0.90$. It follows that the maximum predicted values $m_w^{predict.}$, based on the testing data obtained depending on the time of immersion τ, days, may be expressed by the following equation (see Fig 5, a dotted line):

$$m_w^{predict.} = 0.47 \cdot \tau^{0.212} + 0.12 \qquad (7)$$

Thus, for example, the predicted growth of water absorption of expanded polystyrene after 250 days of immersion is 1.64 times that of W_{28}.

A relatively high value of determination coefficient $\eta^2_{m_w \cdot \tau} = 0.857$ in the regression equation (6) allows the above equation to be used in predicting m_w for a longer period of time. The increase of water absorption depends on various factors. However, the particular influence of each factor can hardly be determined. Therefore, the value of m_w is associated only with time. The regression equation (6) is a useful practical tool for prediction (allowing for extrapolation). Outside the range of observations, an error caused by the altered interrelationship in this case may be put within a confidence interval (the definition of which, as one of the major tasks in extrapolation, is considered separately in [7]).

Therefore, the expression given below may be used to determine water absorption of expanded polystyrene products W_τ subjected to long-term immersion τ, days:

$$W_\tau = \overline{W}_{28} \cdot m_w, \qquad (8)$$

where $\overline{W}_{28}$ is the value of water absorption for the fixed time $\tau = 28$ days, based on experimental data [9] or calculated by the regression equation (2), using the data on 7-day immersion; m_w is the increase of water absorption calculated by the regression equations (6) or (7) for $\tau \le 250$ days, according to the methods described in [7] for $\tau >> 250$ days.

4. CONCLUSIONS

The constructed histogram and density of distribution of experimental data on water absorption, as well as control of their validation by Pearson criterion (χ^2), prove that the water absorption values, W_{28}, of EPS boards with density of (15-35) kg/m^3 manufactured by a non-compaction method at Lithuanian enterprises have normal distribution. The mean value of W_{28} is 3.2 vol. %., while the standard deviation $S_w = 1.0$ vol. %., according to the test results.

A regression equation (4) is suggested for calculating the prognostic value of water absorption of EPS boards, $W_{28}^{predict.}$, based on the data obtained for W_7, which can be used for assessing the products manufactured at Lithuanian enterprises.

The prognostic m_w values, indicating the increase of water absorption of EPS boards with density (11-36) kg/m^3, compared to the value obtained for a fixed time $\tau = 28$ days, depending on the time of immersion, are expressed by a regression equation (6).

Good agreement of water absorption values obtained for expanded polystyrene boards manufactured in Lithuania and other European countries was demonstrated.

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