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Analysis of Extruded Polystyrene Short-Term Compression Dependence on Exposure Time

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Extruded polystyrene is extensively used in many applications such as thermal insulation, packaging, structural use and buoyancy. In order to an effective use of this material it is essential to know its behavior under compression. The research in this work was carried out by using extruded polystyrene boards (F200, F300, F400, F500 and F700) which were produced by Lithuanian and Finland manufacturers. The changes of extruded polystyrene ultimate compressive stress σ_{cr}, ultimate strain, initial modulus of elasticity and thickness were determined right away after production and after a certain exposure time of specimens. It was noticed significant changes in strength characteristics after 45 days. Compression tests and conditioning of specimens were conducted at 23 °C ±2 °C ambient temperature and 50 % ±5 % relative humidity. Regression dependences of ultimate compressive stress σ_{cr} and ultimate strain on exposure time (from 10 to 326 days) were presented.

Keywords: extruded polystyrene boards, ultimate compressive stress, ultimate strain and modulus of elasticity.

INTRODUCTION

Foamed products are universal and can be used in many applications such as thermal insulation, sound deadening, furniture as well as impact-absorbing material [1, 2]. For this purpose foamed polymeric products are characterized by various properties, which satisfy the relevant provisions of the use of these materials [3]. Likewise these materials are defined by satisfactory mechanical, heat saving and acoustics properties. Some of these properties may be controlled by the amount of foaming agent and the others – by the choice of the right type of foaming agent.

The usage of foaming agents in closed cell products production changes their structure, which is characterized by the nature of cells, the amount of gas in cells and their distribution. These are the main parameters, which have an influence on materials properties [4, 5].

Currently extruded polystyrene production is one of the most promising technologies of thermal insulation materials. Extrusion process enables to produce a brand new material which structure differs from the structure of ordinary expanded polystyrene.

Foaming agents are classified into two main groups: physical (CFCs – fluorocarbons; HCFCs – chloroflorocarbons; pentane, isopentane, cyclopentane; CO_2) and chemical (isocyanate and water; hydrazine, bicarbonate and other nitrogen based materials).

Scientists are searching for cheaper, less damage causing to the ozone layer and more practical material, which could be used as a foaming agent.

One of the most perspectives foaming agent is CO_2. However, this technology is fairly new; therefore, lots of experimental and modelling investigations must be done [6] because obtained results enable to explain the mechanism of structure formation and its collapse. These results can be also used in optimization of production processes, the usage of these materials in construction and etc.

Foamed materials may withstand great plastic strain under constant stress as well as before the destruction to absorb great amount of kinetic energy. Consequently, these materials are used as impact absorbers. The behaviour of these materials under quasi-static loading is characterized by their modulus of elasticity and strength of plastic collapse [7].

Gases that are closed in cells have very low strength, so the more products is foamed the lower strength it will have. Otherwise, mechanical properties are poorer when the material has lower density.

Deformation and compressive collapse character of foamed polimeric materials depends on polymer structure, compressive strength of physical and certain macrostructural elements [8, 9]. Most thermal insulating materials under compression have similar behaviour, which is characterized by three stages – elastic, plastic and densification. The greatest influence for such behavior has density and polymer material. Denser polymeric thermal insulating materials have shorter plastic zone [10]. The higher density is, the higher modulus of elasticity, plastic stress and lower strain material has [11, 12].

The aim of this work is to determine the influence of exposure time on mechanical and deformational properties under short-term compressive loading of extruded polystyrene, foamed using CO_2 gas.

STUDY METHOD AND EQUIPMENT

The investigation in this work was carried out by using extruded polystyrene boards (F200, F300, F400, F500 and F700) which were produced by Lithuanian and Finland manufacturers. Compression tests were carried out by using extruded polystyrene cubic specimens with the side size of 100 mm and thickness of 50, 80 and 100 mm

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[13, 14]. Compressive stress kinetics of extruded polystyrene is determined after 10, 45, 65, 90, 110, 180 and 326 days after production of boards.

Conventional compressive strength σ_m, initial modulus of elasticity E were determined and strain diagram was drawn for every tested extruded polystyrene specimen (Fig. 1). Compression tests were performed by using computerized testing machine H10KS (Hounsfield, England), loading speed was $(0.1 \cdot d_s \pm 25\ \%)$ mm/min (where d_s – thickness of specimen) [14], force meter accuracy ranged from 1 N to 11 N. Compression tests and conditioning of specimens were conducted at 23 °C ± 2 °C ambient temperature and 50 % ±5 % relative humidity.

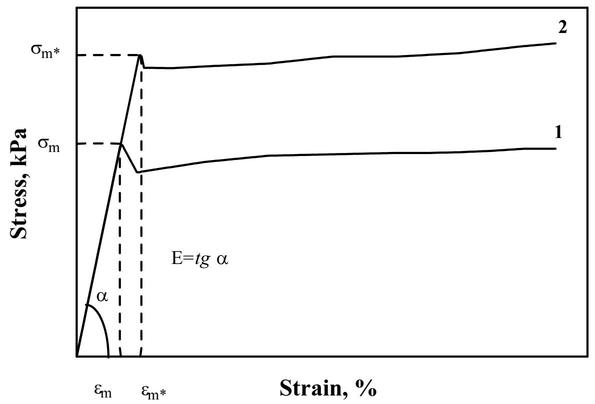


Fig. 1. Diagram of initial modulus of elasticity E and ultimate stress σ_m of extruded polystyrene under short-term compressive loading: 1 – σ_m after 10 days; 2 – σ_{m*} after 326 days

Mathematical-statistical methods were used for experimental evaluation of extruded polystyrene boards strength and deformability characteristics: regression dependences were obtained, standard deviations S_r and coefficients of determination $R^2_{y \cdot x}$ were calculated in accordance with obtained experimental data [15].

EXPERIMENTAL RESULTS AND ANALYSIS

Isotropy of cellular structure is the main requirement for structural extruded polystyrene. It mostly depends on density of the material. The density of extruded polystyrene, which was used for the experimental investigation, was in the range of $\sim(33.7 \div 39.7)$ kg/m^3. In order to maximize the efficient comparison of various physical properties of polymeric foams, it is essential to evaluate structural parameters of extruded polystyrene: porosity $(1-\rho/\rho^*)$ and relative density (ρ/ρ^*), where ρ is a density of polymeric foam, ρ^* is a comparative density of polymeric material. For the evaluation of these parameters, the comparative density was $\rho^* = 1058$ kg/m^3. Porosity of extruded polystyrene was in the range of $\sim(96.2 \div 96.8)$ % and relative density – $\sim(0.032 \div 0.038)$. Fig. 2 shows the structure of extruded polystyrene and it may be seen that the structure consists of closed cells.

The compressive strength of extruded polystyrene is essential parameter because it is usually used as structural-thermal insulating material, which must withstand compressive loadings. The compressive strength of this material depends on gestation ("hardening") conditions, exposure time and especially structure – strength is increasing in time to a certain limit. It can be said that due to these factors physical properties of extruded polystyrene variously change in time.

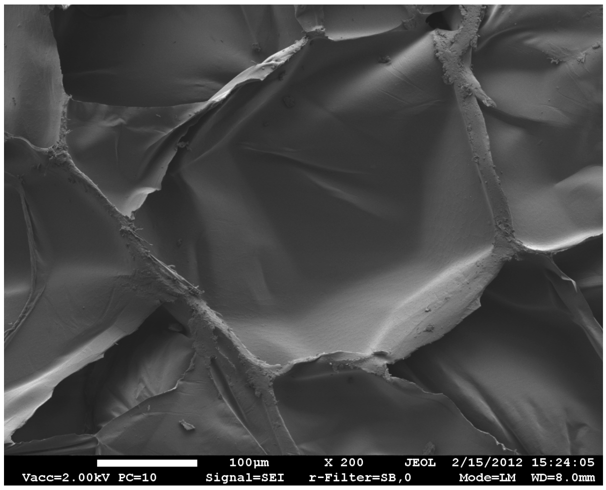
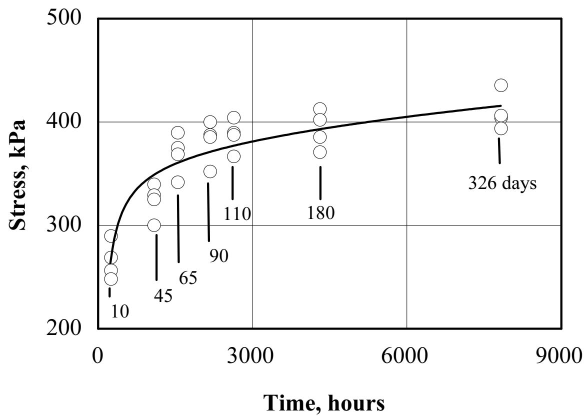
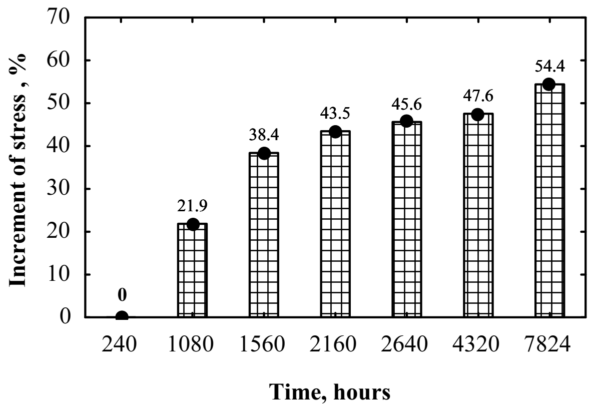


Fig. 2. SEM photo of extruded polystyrene structure



a



b

Fig. 3. Kinetics of extruded polystyrene compressive stress: a – extruded polystyrene compressive stress development in time; b – compression stress increment

Figure 3, a, presents kinetics of extruded polystyrene compressive stress σ_m increment. Analysis of experimental data has showed that extruded polystyrene relationship between compressive stress σ_m (kPa) and exposure time T (hours) may be approximated by regression equation:

$$\sigma_m = 333.8 + T^{0.489} - \frac{21401}{T} \quad (1)$$

with average standard deviation $S_r = 20.8$ kPa and coefficient of determination $R^2 = 0.839$. As shown in Figure 3, a, it can be seen an increase in compressive stress, especially in first intervals of the research. According to the requirements of standard LST EN 13164:2009 compressive stress of extruded polystyrene must be determined after 45 days of exposure, however, the results (Fig. 3, b) have shown that from 45 to 90 days of exposure of extruded polystyrene specimens the compressive stress has significantly increased. As a result, the compressive stress of this material expediently should be determined after 90 days of boards exposure. After 326 days the results of tested extruded polystyrene specimens have shown that compressive stress σ_m has increased by 54.4 % and linear increase can be seen from 90 to 326 days of specimens exposure.

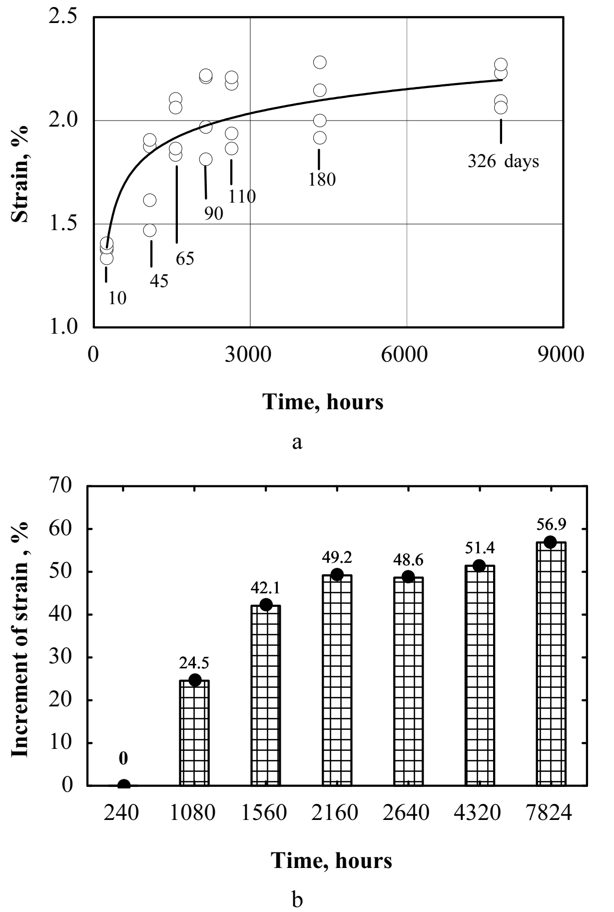


Fig. 4. Kinetics of extruded polystyrene ultimate strain ε_m: a – extruded polystyrene ultimate strain development in time; b – ultimate strain increment

Figure 4, a, shows kinetics of extruded polystyrene ultimate strain ε_m increment. Analysis of experimental data has showed that extruded polystyrene relationship between ultimate strain ε_m (%) and time T (hours) may be approximated by regression equation:

$$\varepsilon_m = 0.205 + T^{0.0774} - \frac{88.0}{T} \quad (2)$$

with average standard deviation $S_r = 0.157$ % and coefficient of determination $R^2 = 0.738$. In Figure 4, a, we can see an increase in ultimate strain, especially in first intervals of research. Results analysis (Fig. 4, b) has shown that after 90 days of exposure of specimens ultimate strain has increased by 49.2 % and after 326 days – by 56.9 %.

Measured specimens have shown that after 10 and 326 days after exposure their thickness has not changed. Specimens with the thickness of: 50 mm – by 0.42 %, 80 mm – by 0.013 % and 100 mm – by 0.28 %.

Initial modulus of elasticity of foamed polymeric materials is one of the most important index of deformability properties. Therefore, it is essential to know kinetics of initial modulus of elasticity.

Initial modulus of elasticity in diagram $\sigma - \varepsilon$ (Fig. 1) corresponds to curve tangent superimposed through the point beginning of coordinates. Practically, initial modulus of elasticity E is determined as a relation between normal stress and its corresponding relative strain.

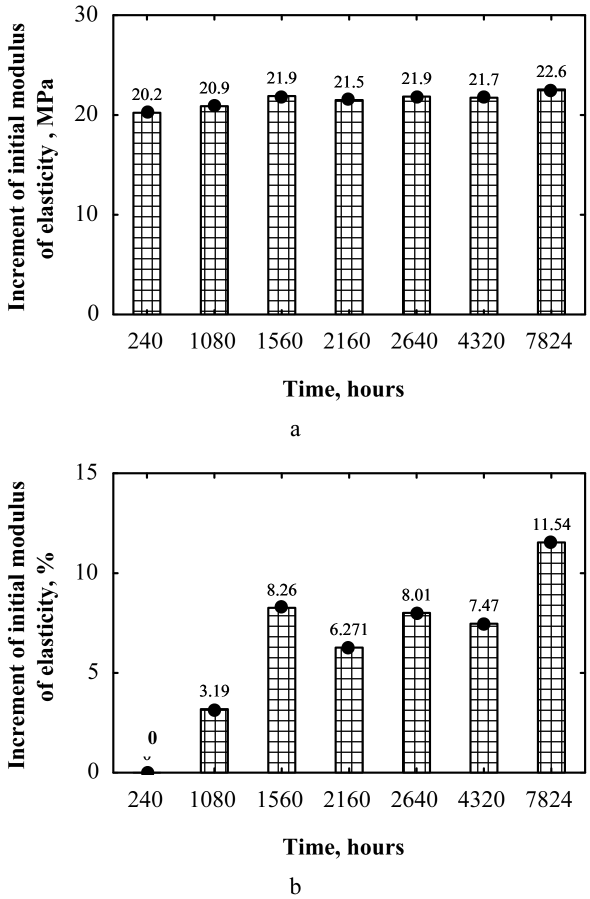


Fig. 5. Kinetics of extruded polystyrene initial modulus E of elasticity: a – kinetics of initial modulus of elasticity; b – initial modulus of elasticity increment

Figure 5 shows kinetics of extruded polystyrene initial modulus of elasticity. Results have shown that the value of initial modulus of elasticity in time changes only slightly. Initial modulus of elasticity of extruded polystyrene after 45 days has increased by 3.2 %, after 65 days – by 8.6 % and after 180 days increment is almost constant. After 326 days initial modulus of elasticity has increased by 11.5 %.

It can be stated that the value of initial modulus of elasticity changes in time only slightly. This can be explained by the constancy of curve tangent superimposed through the point beginning of coordinates (Fig. 1).

DISCUSSION

The fall of stress under low strain rate can be seen in the diagram (Fig. 1) of extruded polystyrene and this can be explained by the fact that cell nodes loose their stability, they collapse or buckle due to constrained elastic deformation and as a result sudden stress decrement appears. This phenomenon is not yet fully investigated but it is believed that stiffness loss of specimens depends on density and the structure of the material [16].

It was determined that the higher density is, the higher modulus of elasticity and plastic stress and lower strain can be seen [12]. Meanwhile, our performed experimental study has shown that extruded polystyrene initial modulus of elasticity value changes in time only slightly even the ultimate stress σ_m and corresponding strain increases.

Obtained experimental results of extruded polystyrene have shown that after 326 days of specimens exposure their thickness changes in time only sligthly. Meanwhile it was determined that dimensional stability of the most closed cell polymeric materials foamed using CO_2 as a foaming agent decreases [17, 18]. This can be explained by the fact that CO_2 from the open cell foams escapes quickly. Whereas, extruded polystyrene is produced by extrusion when closed cell structure is formed [19, 20] and surface of the product is coated by the solid crust, so the CO_2 escape from the product is a long-term process.

CONCLUSIONS

1. On the basis of experimental results the relationship between extruded polystyrene ultimate compressive stress and specimens' exposure time, which varied from 10 to 326 days, was determined. For the evaluation of this relationship regression equation was obtained (1). It was determined that increment of ultimate compressive stress after 90 days is 43.5 % and after 326 days – 54.4 %. Significant increase can be seen from 45 to 90 days of specimens exposure, therefore, the compressive stress of extruded polystyrene foamed using CO_2 as a foaming agent expediently should be determined after 90 days of boards exposure.

2. It was determined the relationship between extruded polystyrene ultimate strain and specimens exposure time which varied from 10 to 326 days. For the evaluation of this relationship regression equation was obtained (2).

3. Obtained results of extruded polystyrene initial modulus of elasticity show that the value of initial modulus of elasticity in time shanges only slightly. After summarizing the otained results after 10, 45, 65, 90, 110, 180 and 326 days, it was determined that initial modulus of elasticity has increased from 20.2 MPa to 22.6 MPa. This can be explained by the fact that extruded polystyrene initial modulus of elasticity tangent of the angle of inclination remains constant.

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