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Experimental Analysis of Structure and Deformation Mechanisms of Expanded Polystyrene (EPS) Slabs

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Durability and stability of polymeric foam products used in building application in most cases is associated with compressive strain. The mechanical characteristics of such products for the most part depend on the materials structure and density as well as on the applied load value. In this work the analysis of expanded polystyrene slabs (EPS) structure and deformations are provided. The influence of the average beads diameter on the density of EPS specimens was estimated. The analysis of the materials structure is revealed through the compressive stress-strain diagram. The analysis of EPS micro and macro structure was carried out at each point where the compressive diagram breaks. The study of the changes that take place between and inside the beads of EPS specimens, when they are under compression, revealed the mechanism EPS deformations.

Keywords: expanded polystyrene slabs (EPS), bead walls, compression, deformations, stress-strain diagram, structure, spaces between beads.

INTRODUCTION

The EPS products are widely used in many applications. Most often they are used for thermal insulation, packing, structural use and buoyancy [1]. Polymeric thermo insulating materials posses a number of valuable properties such as following: sufficient strength, low density, water absorption, resistance to watering and thermal conductivity. Moreover, these materials are easily processed; they may be molded or cut into unlimited shapes as well as recycled [2, 3]. One of the main features that characterize the material is the density of polymeric thermo insulating material. If the density of the porous material is known, thermal and strength properties of the material may be approximately predicted [4]. However, sometimes it happens vice verse: though the density of the materials is the same but the structure is different, the mechanical characteristics of the material may also differ [5].

The cellular material may be produced using most of the polymer materials, nonetheless, only some of them are used in industrial application [2]. Most widely used polymers are as follow: polyurethane, PVC, polystyrene, polypropylene, epoxy, phenol-formaldehyde, cellulose acetate, silicone, etc [6]. Expanded polystyrene slabs are widely used due to the fact that its manufacturing technology is rather simple and the production costs are rather low [7]. The EPS materials are made out of hard polymeric matrix and gaseous phase. Gaseous phase of expanded polystyrene slabs can take up as many as 98 % of its volume. In the open cell foams gas may navigate through the chanels of matrix, whereas, in the closed cell foams gas navigates only through the walls of cells by diffusion. Gas conduction through matrix is one of the factors that determine physical and mechanical characteristics of cellular plastics. In real cellular plastic both structural types may exist at the same time. The number and size of closed cells are the main structural characteristics of the cellular material because they influence the mechanical characteristics of the porous material, water absorption and thermal properties [2, 3]. The number and size of polymeric thermo insulating materials beads depend on the raw materials used and production process.

Most often expanded polystyrene slabs are manufactured by steam molding: raw polystyrene beads are expanded and then fused together in closed mold. In order to get an evenly porous structure and optimal physical-mechanical characteristics of the material, all the beads in the form must be heated equally and fast. This condition may be reached when optimal parameters of thermal heating using steam regime are set. When the pressure of steam is constant, the amount of heat conducting depends only on the time length of the process [8].

Exploitation of polymeric foam products used in building application in most cases is associated with compressive strain. The compressive strains and collapse of EPS may be revealed through stress-strain diagram [1, 6, 9 – 11]. Different mechanical states of expanded polystyrene slabs are presented in Fig. 1. In this diagram σ_A indicates the end of stress-strain approximately linear dependence. σ_B indicates the end of bending deformations process in cell walls, which causes the walls to lose stability. If σ_B is exceeded, the elements of structure are damaged, and the densification of the material starts.

The aim of this work is to evaluate the relationship between the expanded polystyrene slabs density and porous structure as well as establish mechanism of deformation and effects of compressive load on the structure.

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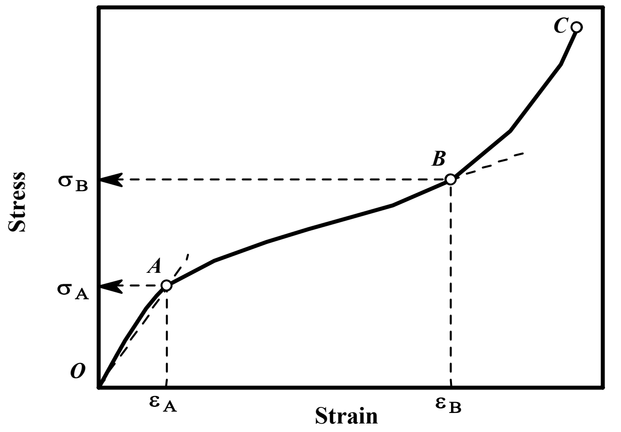


Fig. 1. The diagram of expanded polystyrene under short-term compression [9]

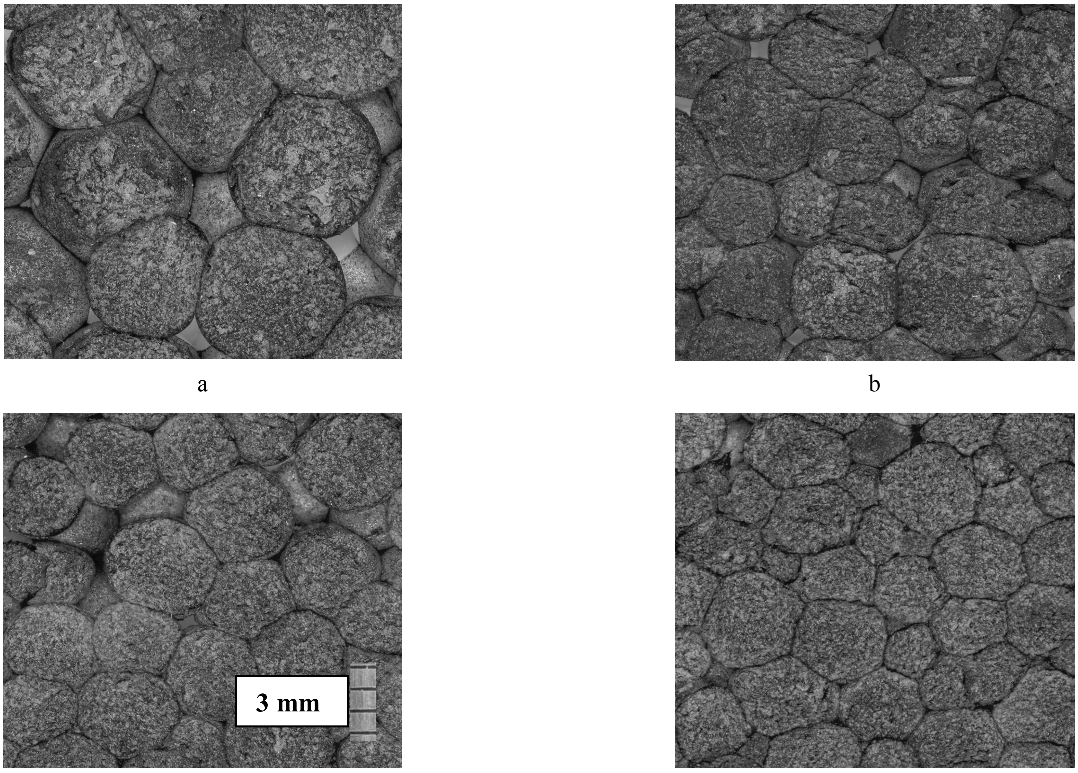
EXPERIMENTAL

In order to analyze the dependency of expanded polystyrene density on the average diameter of the beads the slabs produced in Lithuanian factories with densities of 11 kg/m^3 – 33 kg/m^3 were used. The sections were prepared using these slabs; the surface was examined using a microscope that enlarged the view 6 times. The diameter of the beads is established in the following way: at certain points of the beads the largest and the smallest diameter is measured and consequently an average diameter estimated.

In order to analyze macro (80 times enlargement) and micro (800 times enlargement) structure of expanded polystyrene when it is under compressive load, the specimens (20×20×20) mm, were prepared. Since EPS is a poor dielectric, the surface of this material was steamed up with a very thin gold layer. The steamed up specimens were put between two screwed metal blocks meant for compression of the specimens. The specimens placed into the device were put into the scanning microscope for the analysis of macro and microstructure. First analysis is carried on the specimen while it is not deformed yet; the following analyses are done each time the blocks are screwed until wanted deformation is reached. The specimen is being compressed as long as it is needed to destroy the structure.

RESULTS AND ANALYSIS

Since the density of EPS is the main parameter that characterizes most of the materials properties when it is under static load, it is important to evaluate the relationship between this parameter and the porous structure. The microstructure of the specimens, which density is different, is presented in Fig. 2. It may be noticed that the higher is the density the smaller is the diameter of the expanded polystyrene beads. Moreover, the area between the beads also narrows, and the number of them considerably increases in the same area. As it may be noticed in Fig. 2, the diameter of the specimen beads may vary. More the density of specimens increases, the greater is the difference between the diameters of the beads. During the experiment the diameters of the beads differed up to 6 times (see Fig. 2, d) when the density of the specimens was 30 kg/m^3. When the density was 12 kg/m^3, the diameters of beads differed only 2 times (Fig. 2, a). Such dispersion of the beads is due to the parameters that were chosen by the manufacturer and are closely related with the primary expansion of the beads.



a b

c d

Fig. 2. The macrostructure of EPS when density is different, kg/m^3: a – 12; b – 17; c – 23; d – 30

The EPS density dependence upon the diameter of the beads is shown in Fig. 3.

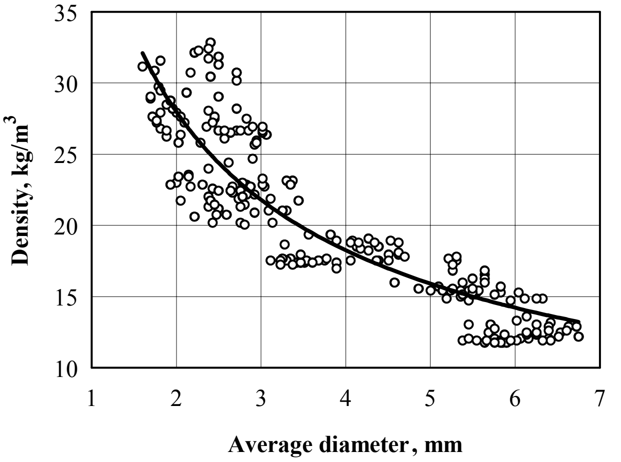


Fig. 3. The dependence of EPS density on the beads diameter

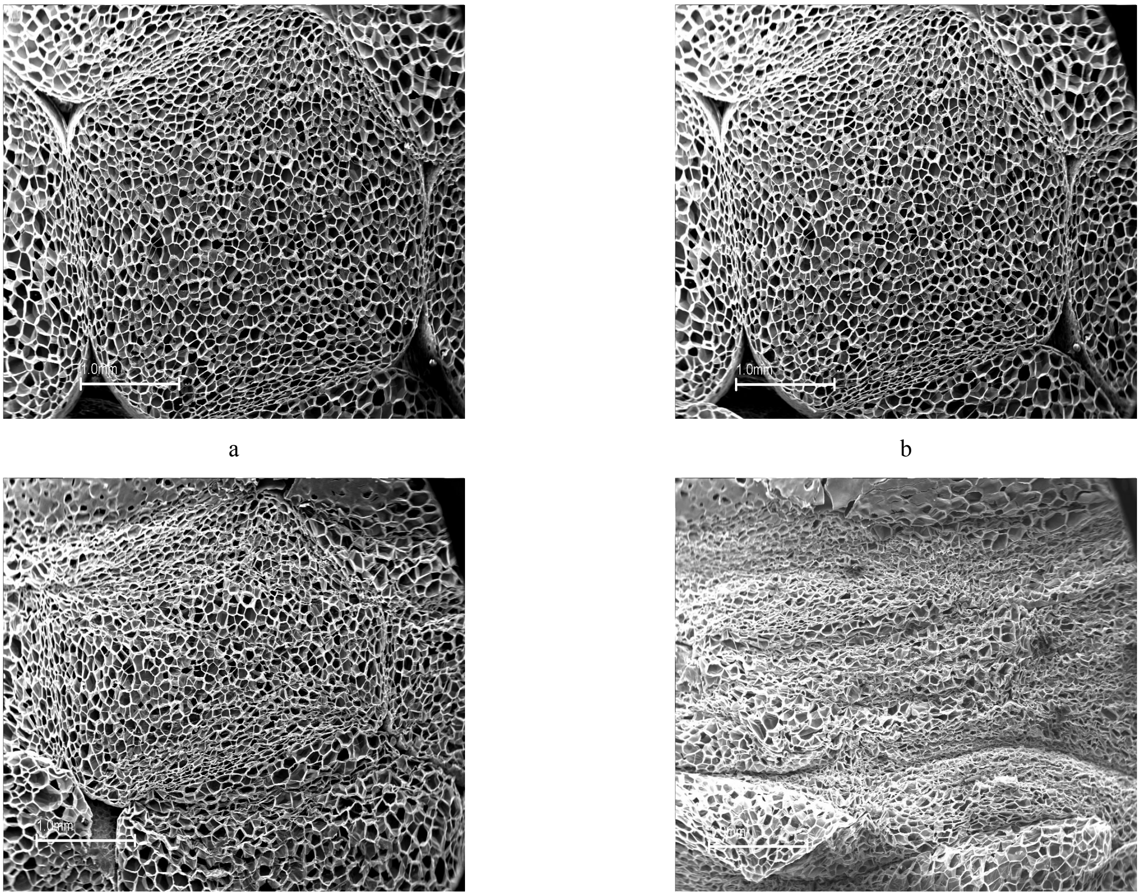
The regressive analysis of expanded polystyrene specimens microstructure showed that the dependence of EPS specimens density ρ, kg/m^3, upon average diameter of the beads $d_{\text{av.}}$, mm might be expressed by a progressive equation:

$$\rho = 42.86 \cdot d_{\text{av.}}^{-0.616}. \tag{1}$$

In the equation above the standard deviation is $S_r = 2.61$ kg/m^3 and the coefficient of correlation is $R^2 = 0.792$. This coefficient shows that the variation of density depends approximately 79.2 % on the average diameter of expanded polystyrene beads and only 20.8 % on the other factors.

The dependence is not linear. In order to explain it, the technological process of manufacturing has to be identified. In the process of EPS manufacturing the primary expansion of the beads is used. In order to manufacture the products of higher density (17 kg/m^3 – 35 kg/m^3), one stage of expansion is needed, and two stages of expansion are required when the products are of lower density (11 kg/m^3 – 17 kg/m^3). The different primary expansion of the beads may be the reason for the curved-line dependence.

The changes of EPS macrostructure that take place under different levels of compression are presented in Fig. 4. In the structure of not yet deformed specimen few interconnected beads as well as spaces between them are clearly seen (see Fig. 4, a). When the deformation is 3 % (Fig. 4, b) (this deformation is equal to σ_A – see Fig. 1), spaces between beads diminish lightly, i.e., the beads move towards free space and the structure of the beads undergoes almost no changes. A considerable diminishing of spaces between beads may be noticed in Fig. 4, c (only 1 space between beads is left out of 4 observed spaces). The beads get deformed at the places where they connect with each other.



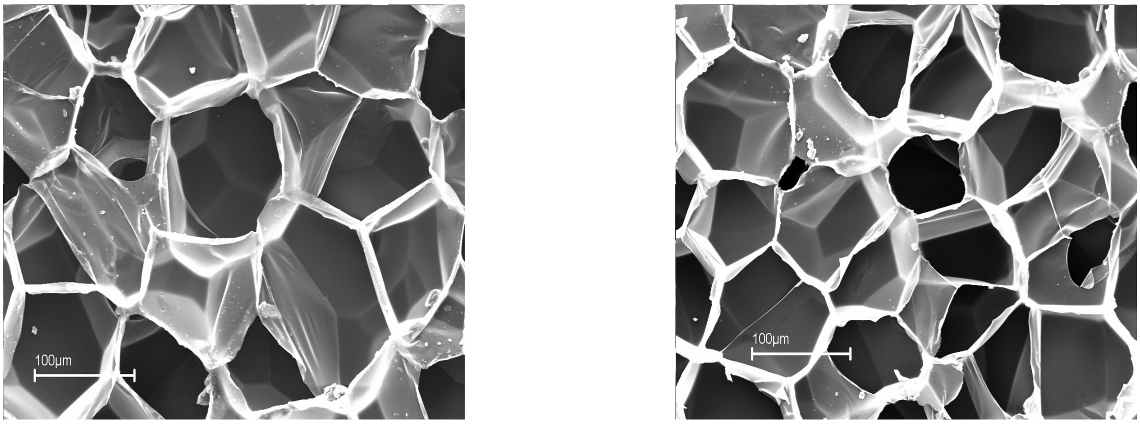
a

b

c

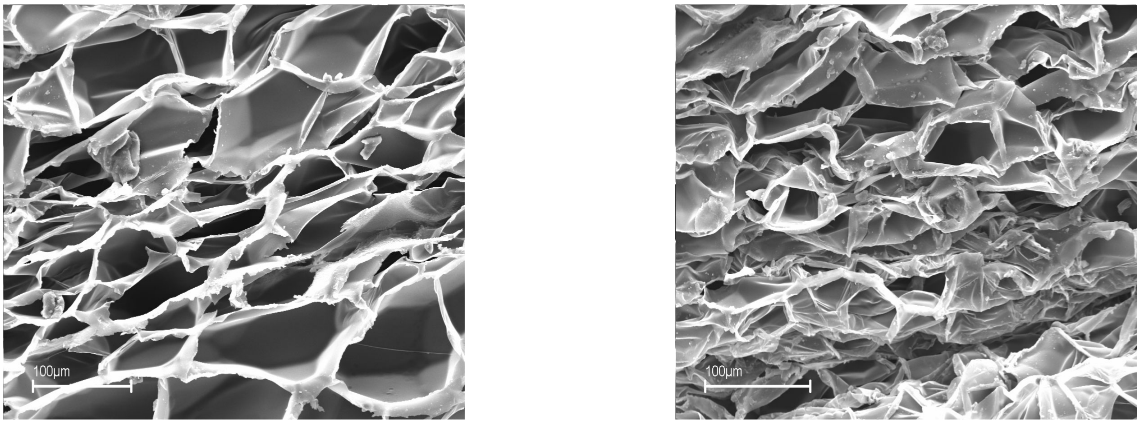
d

Fig. 4. The changes of EPS macrostructure under different levels of compression, %: a – 0; b – 3; c – 30; d – 60



a b

Fig. 5. The changes of EPS microstructure in the middle part of bead under different levels of compression, % : a – 0; b – 60



a b

Fig. 6. The changes of EPS microstructure in the places of beads connections under different levels of compression, %: a – 30; b – 60

It has to be explained why the beads get deformed only in these places. When the specimen is under compression, the beads move to different directions. It is possible that not only compression stresses but also tensile as well as shear stresses appear between the beads. According to the stress-strain diagram, when 60 % of deformation is reached (Fig. 4, d) (it equals to ε_B – Fig. 1) the beads can not move any more due to the fact that there are no more space left for movement. It means that the stresses of tensile as well as shear are over, which leads to the pure processes of compression, i.e., the beads start to densificate.

The analyses of microstructure are more complicated. The analyses of polymeric materials with closed cells are complicated for technical and structural reasons. Technically it is complicated, because: first, the cell faces scatter light, preventing optical microscopes from viewing its interior; second, the cell walls are to thin to be resolved by X-ray micro tomography [5]. Structurally it is complicated because one bead is combined of thousands cells therefore it is almost impossible to determine in which cell exactly the changes take place.

The analysis of cells microstructure in the middle part of bead is presented in Fig. 5. The undeformed specimen is presented in Fig. 5, a, and the compressed specimen up to 60 % is presented in Fig. 5, b. Basically, there are no differences between the Fig. 5, a, and Fig. 5, b. Wrinkles that could appear during formation process of the specimen or cutting it out may be noticed on certain cell walls.

The analysis of cells microstructure that was done in the places of the beads connection is presented in Fig. 6. The microstructure of the specimen that was compressed up to 30 % is presented in Fig. 6, a, and the microstructure of the specimen that was compressed up to 60 % is presented in Fig. 6, b. When the deformation reaches 60 %, all the cells are wrinkled, while when the deformations are lesser, only few cells get wrinkled. Thus, it can be stated that only gradual collapses of microstructure takes place when deformations are below 60 %.

CONCLUSIONS

1. The density of expanded polystyrene is determined by the size of beads. This dependence may be expressed by a regression equation $\rho = 42.86 \cdot d_{\text{av.}}^{-0.616}$. When the beads diameter increases 4 times, the density decreases 2.3 times.
2. At the primary stage of compression from 3 % to 30 % of relative deformation a decrease of spaces between beads occurs and progressive deformations of connected beads walls appear.
3. When the compression is below 60 % of deformation, only insignificant changes take place within the bead

middle, and the collapse process starts only within interconnected beads walls.

4. The analyses of macrostructure as compared with microstructure are more informative for the evaluation of the changes, which take place in the structure of the whole specimen.

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