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Investigation of Bending Modulus of Elasticity of Expanded Polystyrene (EPS) Slabs

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Rigidity of expanded polystyrene slabs, which is described by modulus of elasticity, in sandwich is very important in their application. When material is bent it is necessary to determine its bending modulus. Bending modulus is determined according to the force-deflection curve, by fixing loads and deflections. Results of expanded polystyrene slabs bending modulus of elasticity are presented in this article. Bending modulus of elasticity was fixed experimentally by 3 and 4 point bending methods. Possibilities of determination of bending modulus of elasticity dependence on material density or type are shown. Comparison of moduli of elasticity calculated applying 3 and 4 point bending is given also.

Keywords: expanded polystyrene (EPS) slabs, mechanical properties, bending modulus of elasticity, 3 point bending, 4 point bending.

INTRODUCTION

Polymer foams consist of solid polymer matrix and gaseous phase. They provide a unique combination of mechanical properties and low density [1]. The macrostructure of the material depends on raw material and technological production parameters. The higher is density of the material, strength and elasticity of materials is higher [2, 3].

Expanded polystyrene is the most common of such foams. Thanks to good mechanical properties it is widely used as thermal-construction material. Its mechanical properties are described by different characteristics. More often its compression strength at 10 % deformations according [4] requirements is determined. Mechanical behaviour and other properties of EPS are investigated due to the need of their various applications, investigation extends to micromechanical scale. Cell structure, foams density and environmental temperature affect mechanical properties of foams, which were extensively investigated [5]. It was determined, that density of slabs has the greatest influence on durability at compression, and loading speed and steady-state moisture content [6 – 8] have significantly lower influence It is common to determine modulus of elasticity according to bending diagrams.

Using EPS in sandwich the most important characteristic is their bending modulus. More often in building materials practice bend is tested by a method of 3 or 4 points. Thermal insulation materials usually are tested by a method of 3 points [1, 9]. It is defined by two factors: 1) the simplest test method and calculation results 2) standard requirements [10]. According to these requirements bending strength is determining using 3 point bending, however, definition of the modulus is not given.

Results of tests of bending modulus of wooden samples are presented. Comparison of moduli of elasticity and values calculated using 3 and 4 point bending tests on wooden samples are different and, therefore, recalculation is necessary [11].

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The aim of this work is to determine bending strength and modulus of elasticity of expanded polystyrene slabs using 3 and 4 point bending methods.

EXPERIMENTAL

Expanded polystyrene slabs made by Lithuanian factories were used for the experiment. Density of the slabs ranges from 11 to 34 kg/m^3, types of the products are EPS30 to EPS200. Rectangular specimens (300×150×50 mm) were made out of the slabs for both test methods. Samples from the slabs were cut by a hot wire.

H10KS press made by Hounsfield was used in the experiment. Machine used in the experiment was connected to PC. All parameters (measurements of the specimens, loading speed, etc.) were controlled and monitored by PC. Bending modulus of elasticity was calculated by computer program according to formulas set for 3 point bending:

$$E_{b3} = \frac{l_1^3 (F_2 - F_1)}{4bt^3 (a_2 - a_1)}, \quad (1)$$

where l_1 is the span between support edges, b is the width of the specimen, mm; t is the thickness of the specimen, mm, $F_2 - F_1$ is the increase of load at straight portion of the load-deflection curve, N; F_1 should amount approximately 10 % and F_2 – approximately 40 % of the highest load; $a_2 - a_1$ – is the increase of the deflection at the centre of load span, mm (corresponding $F_2 - F_1$); and for 4 point bending:

$$E_{b4} = \frac{(F/2)a(3l^2 - 4a^2)}{24 fI}, \quad (2)$$

where F is applied force, N; f is the deflection at the centre of load span, mm; I is the moment of inertia, mm^3; a is the distance from the outer support to the loading point (l/3), mm.

Bending modulus of elasticity is determined at the straight portion of the force-deflection curve by fixing loads and deflections.

The experiment took place on two supports, the distance between which is 250 mm. Surface of the specimen was sheer strained by bending die, it steadily moved down at speed of 10 mm/min. The force was applied directly to the centre of the specimen held on supports positioned at equal distances (Fig. 1).

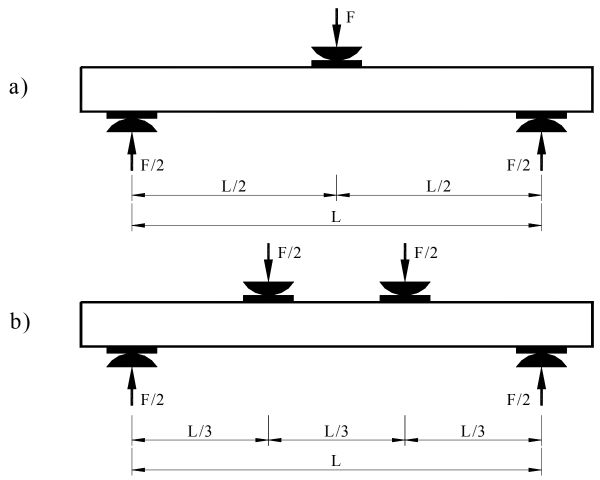


Fig. 1. Principles of the apparatus for testing of bending by 3 (a) and 4 (b) point bending methods

Diameter of the supports is 30 mm. Distribution plates with a thickness of 1 mm were used for slabs protection from crushing under steel load. Width of the distribution plates is 30 mm and their length is 5 mm greater than the width of test specimen. Shift of the bending die was measured with an accuracy of 0.01 mm; and sensor of the force enabled constant measurement of power with an accuracy of 0.5 % during the whole experiment.

RESULTS AND ANALYSIS

Specimens of different density were used in order to establish bending modulus of elasticity. It was determined that bending modulus of elasticity of expanded polystyrene slabs depends on materials density. The results of the experiment are given in Fig. 2. The figure shows that dependence of expanded polystyrene slabs bending modulus on material density is linear at application of both bending methods. The dependence may be described by the empirical equation of regression for 3 point bending:

$$E_{b3} = 0.615\rho - 3.270\,, \quad (3)$$

with coefficient of determination $R^2_{E\rho} = 0.914$, where E_3 is bending modulus of elasticity determined by 3 point bending method, MPa; ρ is the density, kg/m^3; and for 4 point bending:

$$E_{b4} = 0.699\rho - 4.000\,, \quad (4)$$

with coefficient of determination $R^2_{E\rho} = 0.928$, where E_4 is bending modulus of elasticity determined by 4 point bending method, MPa.

Data analysis shows that values of bending modulus are greater when 4 point bending method is applied. Bending modulus values for EPS slabs, with the density ranging from 11 to 44 kg/m^3, differ from 6 to 12 %. This difference is greater when density increases. Dependence of bending modulus of elasticity on density determined by 3 and 4 point bending methods is presented in Fig. 3.

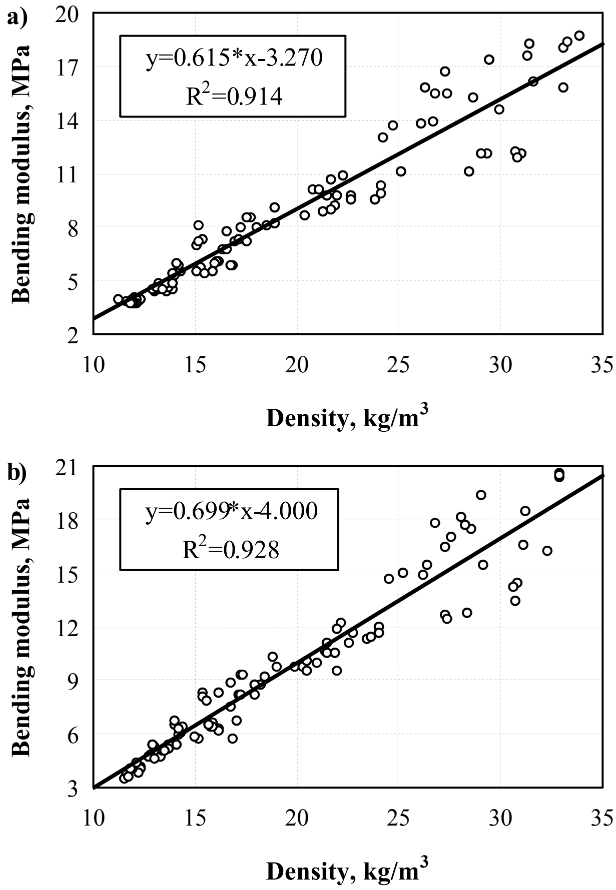


Fig. 2. The dependence of bending modulus on density set by 3 (a) and 4 (b) point bending method

The dependence is linear and may be described by an empirical equation of regression:

$$E_{b3} = 1.098 \cdot E_{b4}\,. \quad (5)$$

Now slabs are classified on their type, which is determined by compression test up to 10 % of deformation. EPS type is marked on the each slab at the factory. This time density remained as an auxiliary criterion of slabs manufacturing.

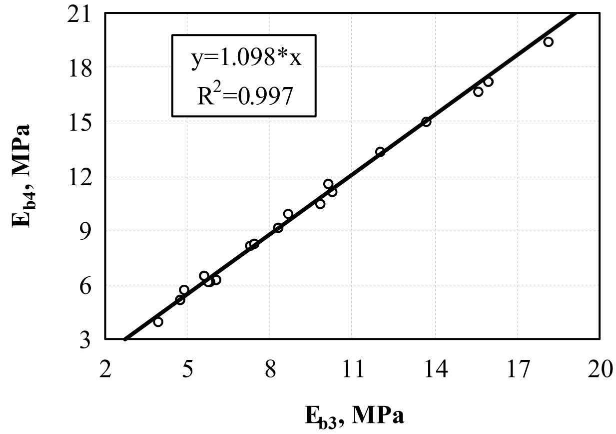
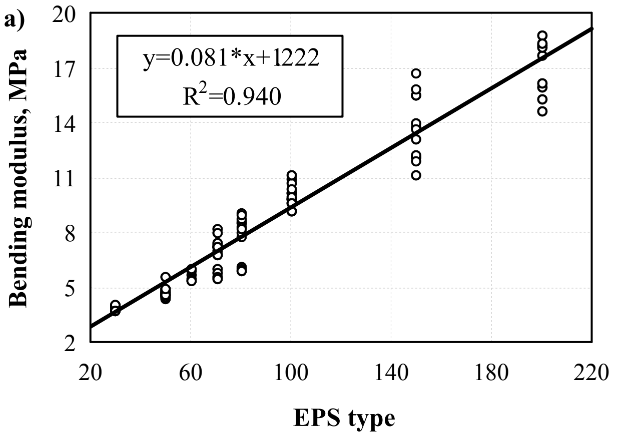


Fig. 3. The dependence of bending modulus by 3 and 4 point bending methods

Dependence of bending modulus of elasticity set by 3 and 4 point bending methods on the EPS type is determined for this purpose Fig. 4.

a)



b)

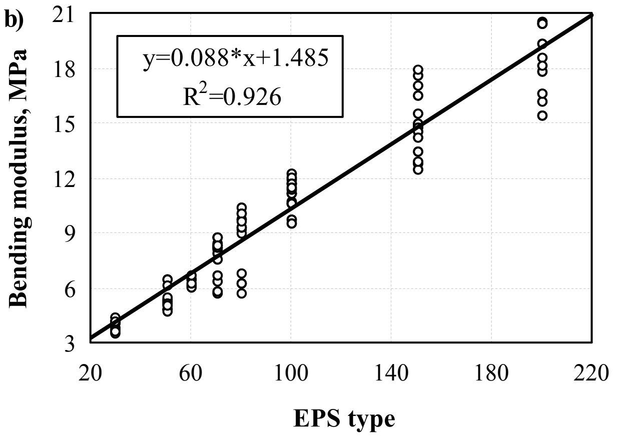


Fig. 4. The dependence of bending modulus on EPS type fixed by 3 (a) and 4 (b) point bending

These dependences can be described by empirical equations of regression for 3 point bending:

$$E_{b3} = 0.081T - 1.222, \quad (6)$$

with coefficient of determination $R_T^2 = 0.940$, where T is type of expanded polystyrene slabs, and for 4 point bending:

$$E_{b4} = 0.882T + 1.485, \quad (7)$$

with coefficient of determination $R_T^2 = 0.926$.

CONCLUSIONS

1. The article shows possibilities of determination of elasticity modulus (fixed by 3 and 4 point bending methods) of slabs according to slab density or type. Statistical analysis of the data shows that the dependences of expanded polystyrene slabs bending modulus on the material density and type are linear.
2. It was established experimentally that results differ when different test methods are applied. When 3 point bending is applied modulus is lower and it is necessary to recalculate results. The equation $E_4 = 1.098E_3$ is offered for recalculation of results.

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