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Experimental Determination of Compressive Properties for Rigid Polyurethane Foams

Emanoil Linul, Liviu Marşavina

"Politehnica" University of Timisoara, Department of Mechanics and Strength of Materials, Bd. Mihai Viteazul, No. 1, Timisoara, Romania
e-mail: linul_emanoil@yahoo.com, msvina@mec.upt.ro

Abstract

The paper presents experimental results obtained from compression test for five rigid polyurethane foams with densities of 40, 80, 120, 140 and 200 kg/m^3. One of the most significant effects of mechanical properties in compression of polyurethane foams is the density. The experimental tests were carried out on specimens in the form of cubes. The specimens were subjected to uniaxial compression with loading speed of 2 mm/min at room temperature.

Key words: *polyurethane foam, density, compression tests, Young's modulus, Yield stress.*

Introduction

Rigid polyurethane foams are used in a wide variety of engineering applications such as packaging and cushioning, and are attracting increasing attention from engineers and researchers [1]. Common to all foam materials are the following properties: of high porosity, light weight, high crushability and good deformation energy absorption capacity, [2]. Their cellular structure enables them to mitigate collision damage by dissipating impact energy over a long stroke, thus limiting the transmitted force to safe levels. The attribute of high crushability arises from the large void ratio in the material, [3].

The main use of polyurethane foams are for sandwich panels because it presents a high stiffness, they are used as cores, and that faces can use different types of materials (carbon fibre, aluminium), depending on use of panel, [1], [4]. The faces will act together to form an efficient stress couple counteracting the external bending moment. The core resists shear and stabilises the faces against buckling or wrinkling. The bond between the faces and the core must be strong enough to resist the shear and tensile stress set up between them, [5].

The compression behaviour of such foams is very important. Studies on the mechanical properties of rigid polyurethane foams are extensive and have been well documented. Many efforts were made in recent years to characterize the behaviour of different types of foams in different loading conditions. Avalle et al., [6] present an optimization procedure in order to identify the micromechanical parameters from uniaxial compression test of different types of foams. The effect of the density and filler size was also investigated in Avalle et all., [7].

For the characterization of mechanical behaviour in compression polyurethane foams having densities 40, 80, 120, 140 and 200 kg/m^3 were used in the experimental program.

Defining the properties and their experimental determination

The main compression parameters studied in this paper are:

- Young's Modulus;
- Yield Stress;
- Plateau Stress;
- Densification Strain.

Young's modulus, E [MPa] - the ratio of stress (nominal) to corresponding strain below the proportional limit of a material expressed in force per unit area based on the minimum initial cross-sectional area, [8].

Compressive yield point, σ_y [MPa] – the first point on the stress-strain diagram at which an increase in strain occurs without an increase in stress (figure 1), [8].

Plateau stress, σ_{pl} [MPa] – constant stress when strain increases, [1], [9]. For many types of rigid polyurethane foams, the plateau regime starts from the crush strain, ε_y, or crush stress, σ_y, representing the initiation of the new deformation mechanism of the cell wall or the cell wall failure, and ends at a critical strain, ε_{cd}, representing the onset of densification (figure 1), [10].

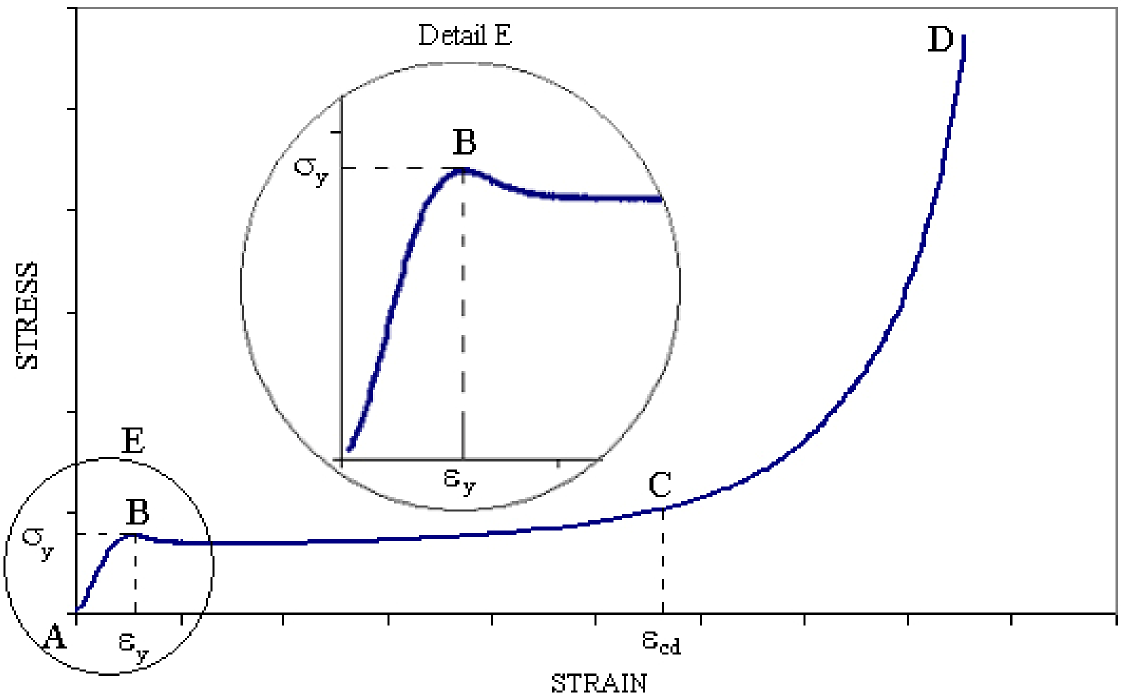


Fig.1. Stress-strain curve typical for rigid polyurethane foam

The onset strain of densification, ε_{cd} [%] is defined as the strain at which the slope of the curve in a plot of energy efficiency (η) versus strain (ε) is zero, eq. (2):

$$\eta(\varepsilon) = \frac{1}{\sigma(\varepsilon)} \cdot \int_0^{\varepsilon} \sigma(\varepsilon) \cdot d\varepsilon \tag{1}$$

$$\left. \frac{d\eta(\varepsilon)}{d\varepsilon} \right|_{\varepsilon=\varepsilon_D} = 0 \tag{2}$$

The onset strain of densification of cellular solids represents the start of the cell wall interactions, which enhance the compressive resistance of a cellular solid (figure 1), [10].

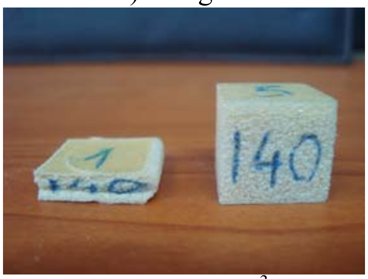
Experimental results

The specimens used in the experimental tests were in the form of cubes, [2], [7]. Shapes of used specimens are shown in figure 2, in the same figure are presents a comparison between the initial shapes of the specimen, non-deformed and deformed after the load, [4].

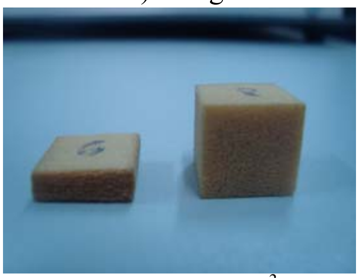
a) 40 kg/m^3

b) 80 kg/m^3

c) 120 kg/m^3



d) 140 kg/m^3



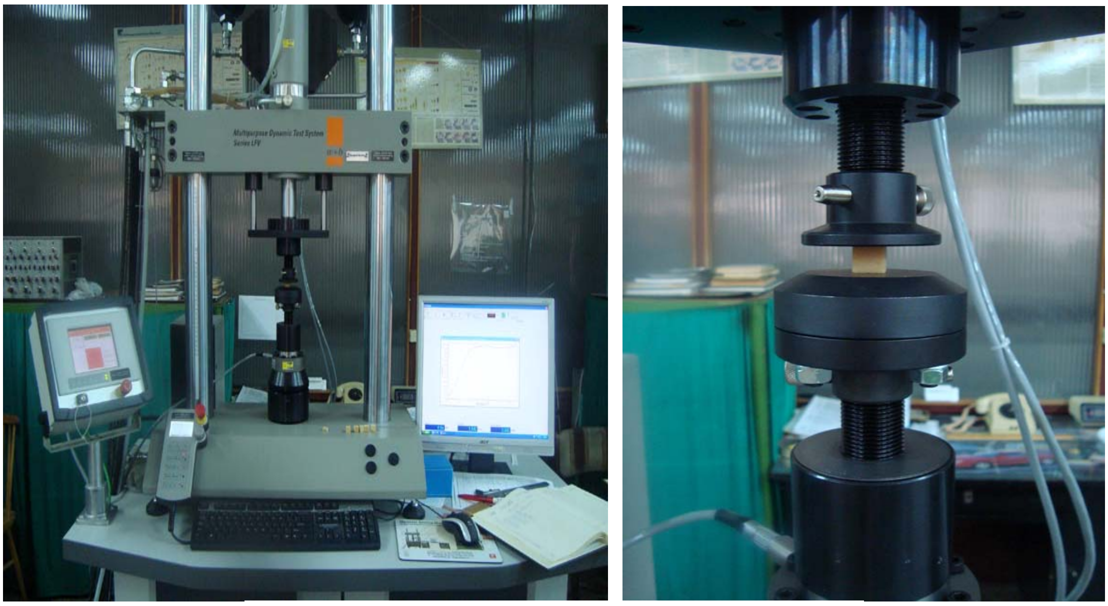
e) 200 kg/m^3

f) all densities

Fig.2. Compression specimens

Experimental tests were performed on a Walter Bay 10 kN testing machine (figure 3.a), at room temperature.

The samples were subjected to a uniaxial compressive loading at a speed of 2 mm/min. In figure 3.b is shows the positioning of the specimen. For each type of test 5 specimens were used, and the tests were performed according with ASTM D1621, 2000, [8].



a) **b)**

Fig.3. Walter Bay 10 kN testing machine

Figure 4 presents Young's modulus histogram for polyurethane foams with density of 40, 80, 120, 140 and 200 kg/m^3.

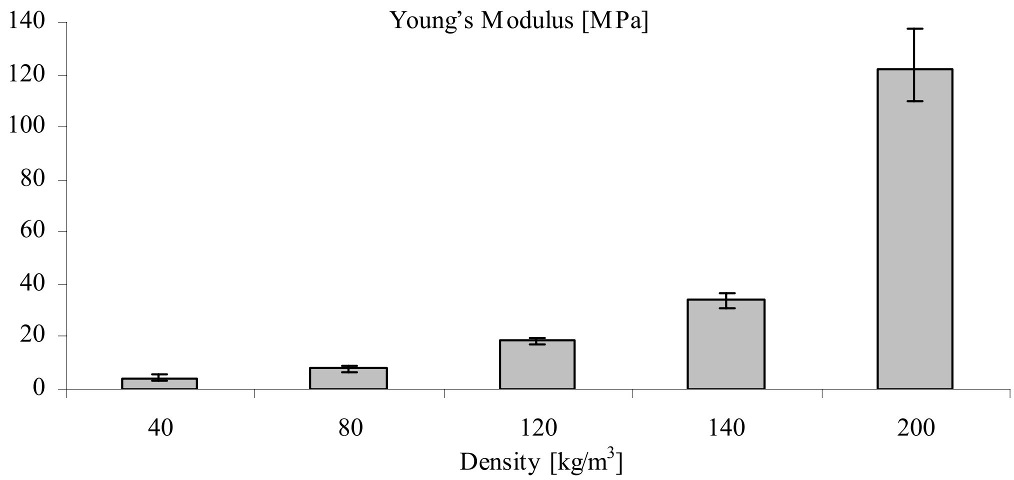


Fig. 4. Young's modulus versus density

Figure 5 presents Yield stress histogram for rigid polyurethane foams with density of 40, 80, 120, 140 and 200 kg/m^3.

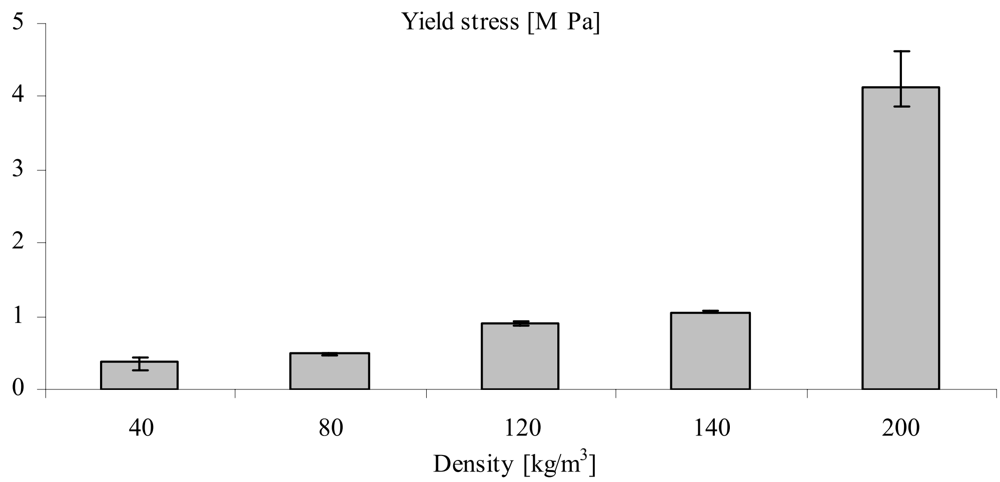


Fig. 5. Yield stress versus density

In figure 6 is shown plateau stress-density variation for rigid polyurethane foams studied.

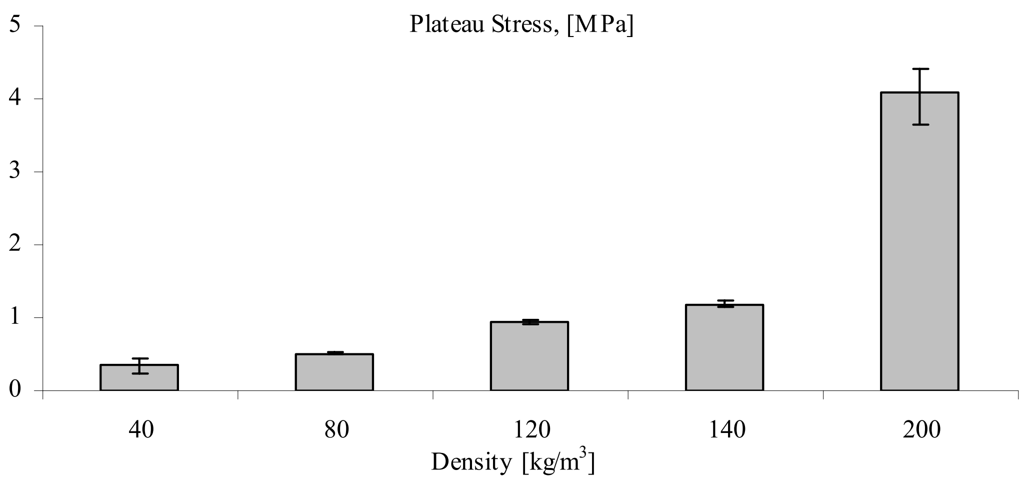


Fig. 6. Plateau stress versus density

The onset strain of densification and the densification strain correspond to different levels of interaction between cells, and therefore to different points on a compressive stress-strain curve. The cellular material is completely compacted when the strain reach a complete densification strain, causing a steep increase in the slope of the stress-strain curve, [10].

The onset strain of densification is determined according with eq. (2). Based on the experimental data the energy efficiency (according with eq. (1)) is plotted in figure 7 for rigid polyurethane foams with densities of 40, 80 and 200 kg/m^3.

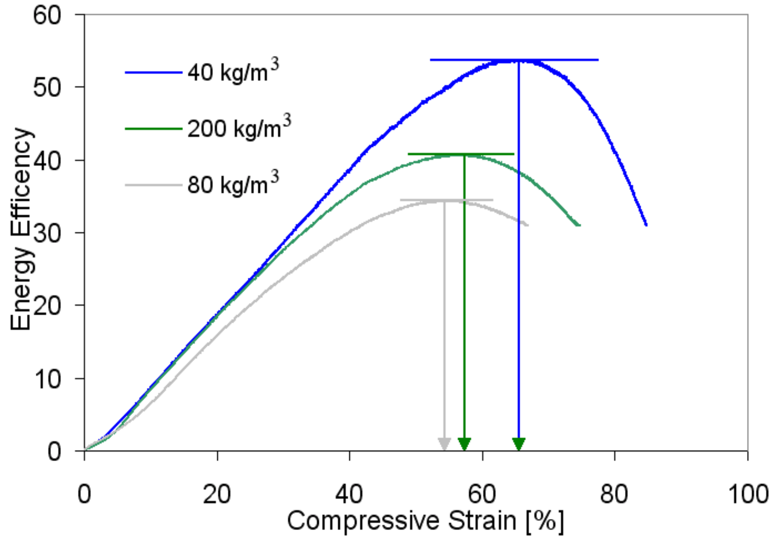


Fig. 7. Energy efficiency-Strain curves of three densities (40, 80 and 200 kg/m^3)

In figure 8 is shown densification strain-density variation for rigid polyurethane foams with density of 40, 80, 120, 140 and 200 kg/m^3.

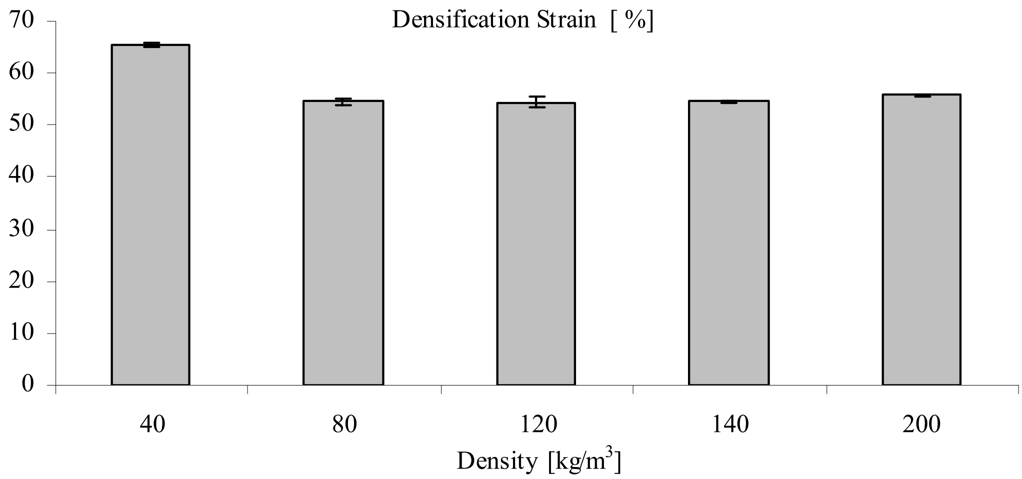


Fig. 8. Densification strain versus density

Conclusions

This paper presents an experimental study on the compression properties of rigid polyurethane foam. This study shows variation of Young's modulus, yield stress, plateau stress and densification strain according to density.

Experimental results show that Young's modulus (figure 4), yield stress (figure 5) and plateau stress (figure 6) properties increases with increasing density. The maximum value of densification strain is obtained for rigid polyurethane foam with density 40 kg/m^3, and for other densities we obtain a value approximately equal ($\varepsilon_{cd} \cong 55$ %), (figure 8).

Also, is presented the calculation of densification strain for rigid polyurethane foams (figure 7). The onset strain of densification is an important parameter in the design and modelling of cellular materials.

Acknowledgements

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References

1. Gibson, L.J., Ashby, M.F., *Cellular solids, Structure and properties, Second edition*. Published by the Press Syndicate of the University of Cambridge, (1997).
2. Marsavina, L., Sadowski, T, Constantinescu, D.M. & Negru, R. Polyurethane Foams Behaviour. Experiments versus Modeling. *Key Engineering Materials,* Vol. 399, 123-130, (2008).
3. Shim V. P. W., Yap K. Y. Modeling impact deformation of foam-plate sandwich systems. *International Journal of Impact Engineering, Vol. 19, No. 7, pp. 615-636,* (1997).
4. Linul, E., Marsavina, L. & Cernescu, A.V. The effect of loading speed, the direction of formation and density of rigid polyurethane foams subjected to compression. Acta Tehnica Napocensis. Series: Mechanical Engineering. Materials Science 53, 311-316, (2010).
5. Burman M. *Fatigue crack initiation and propagation in sandwich structures*. Academic dissertation, Stockholm, Sweden, (1998).
6. Avalle, M., Belingardi, G. & Montanini, R. Characterization of polymeric structural foams under compressive impact loading by means of energy-absorption. *International Journal of Impact Engineering* 25, 455-472, (2001).
7. Avalle, M., Belingardi, G. & Ibba, A. Mechanical models of cellular solids: Parameters identification from experimental tests. *International Journal of Impact Engineering* 34, 3-27, (2007).
8. ASTM D1621 Standard Test Method for Compressisive Properties of Rigid Cellular Plastics
9. Tu, Z.H., Shin, V.P.W. & Lim, C.T. Plastic deformation modes in rigid polyurethane foam under static loading. *International Journal of solids and Structures* 38, 9267-9279, (2001).
10. Li, Q.M., Magkiriadis, I. & Harrigan, J.J. Compressisive Strain at the Onset of Densification of Cellular Solids. *Journal of Cellular Plastics,* 42; 371, (2006).

Determinarea experimentala a proprietatilor la compresiune pentru spumele poliuretanice rigide

Rezumat

În lucrare sunt prezentate rezultatele experimentale obținute în urma încercărilor de compresiune pentru spume poliuretanice rigide având cinci densități diferite 40, 80, 120, 140 respectiv 200 kg/m^3. Unul dintre efectele cele mai semnificative asupra proprietăților mecanice la compresiune ale spumelor poliuretanice rigide este densitatea. Încercările experimentale s-au realizat pe epruvete sub formă de cuburi. Epruvetele au fost supuse unei încărcări uniaxiale la compresiune cu o viteză de încărcare de 2 mm/min la temperatura camerei.