SCIENTIFIC BULLETIN OF
THE POLITEHNICA UNIVERSITY OF TIMISOARA, ROMANIA
TRANSACTIONS ON MECHANICS
Vol. 58 (72) ISSN 1224 - 6077 Issue 1, 2015

DETERMINATIN OF ELASTIC PROPERTIES FOR RIGID POLYURETHANE FOAMS USING IMPULSE EXCITATION TECHNIQUE

Tudor VOICONI [*], Emanoil LINUL[*], Liviu MARSAVINA[*], Mihai HLUSCU[*], Dana SILAGHI-PERJU[*], Emanuel VASILEAN[*]

[*]Politehnica University of Timisoara, Faculty of Mechanical Engineering,
Department of Strength of Materials, Blvd. Mihai Viteazu No. 1, Timisoara,
tudor_2015@yahoo.com, emanoil.linul@upt.ro, liviu.marsavina@upt.ro,
mihai.hluscu@upt.ro, dana.silaghi-perju@upt.ro

Abstract. This paper presents a mechanical characterisation for polyurethane materials using Impulse Excitation Technique. The experimental test was carried at room temperature out on round discs and rectangular bars samples having densities 100, 160, 300 kg/m^3. Another issue of this paper is to determine if this foams materials shows isotropic or anisotropic behavior, for this where cut rectangular samples from three different directions. As we expected Young's Modulus, Shear Modulus and Poisson's Ratio for polyurethane foams increase with increasing density. After comparing values of the elastic properties of the three directions shows that high density polyurethane foams studied have an isotropic behavior.

Keywords: rigid polyurethane foams, elastic properties, density, Impulse Excitation Technique.

1. Introduction

Rigid polyurethane (PUR) foams are made of interconnected networks of solid struts and cell walls incorporating voids with entrapped gas. Due to the main characteristics of PUR foams (light weight, high porosity, high crushability, and good energy absorption capacity), they are widely used in a wide variety of engineering applications such as packaging and cushioning and are attracting increasing attention from engineers and researchers [1-12].

The purpose of this paper is to determine the main elastic properties for polyurethane materials using Impulse Excitation Technique in accordance with ASTM E 1876 – 01[13]. This test method measures the fundamental resonant frequency of test specimens of suitable geometry by exciting them mechanically by a singular elastic strike with an impulse tool. A vibration is induced by a small mechanical impulse. The energy is dissipated by the material into a vibration. This vibration has a frequency spectrum according to its resonant frequencies which are depending on: the elastic properties of the material, the geometry and the density [13-15]. Each frequency will damp according to the energy absorption of the material. The exact micro structural origin of damping, or internal friction or mechanical loss varies from one class of materials to the other. The vibration is detected by a transducer. The transducer produces an electrical signal which is sent to the computer, where the signal will be analyzed. The method is non-destructive and is used for material characterization [16-20]. The simplified diagram of the test apparatus is shown in Figure 1.

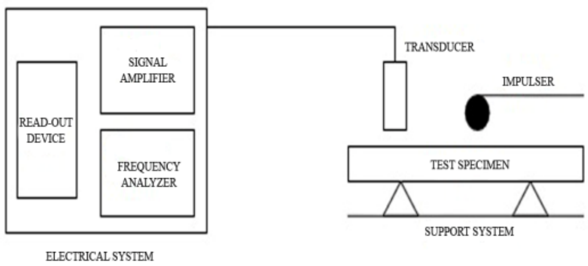


Figure 1 Diagram of the test apparatus

2. Experimental program

Round disc samples were made by turning on a CNC machine, main condition should be that the value of diameter to thickness ratio must be at least four, see Figure 2.

Figure 2 Round disc samples

In Table 1 are presented the diameter, D, and thickness, t, of round disc samples for all three densities.

Table 1 Dimensions for round disc samples

Density [kg/m^3]	D [mm]	t [mm]
100	59.26	10.17
160	59.45	10.16
300	59.81	10.1

In Figure 3 are presented rectangular bar samples used for Flexural and Torsion mode. The length, L, width, b, and thickness, t, for all three densities of rectangular bar samples are shown in Table 2.Experimental test were performed at room temperature (T = 23°). For each test were recorded at least five measurements. Another important feature for resonant frequency determination is weight, the samples was weighted on Sartorius GD 503 Class Balance.

Figure 3 Rectangular bar samples

To determine if this materials with densities of 100, 160, 300 kg/m^3 shows isotropic or anisotropic behavior, were cut rectangular samples from three different directions. Figure 4 shows the sampling mode for the three different directions. Samples were made by milling on CNC machine. In Table 3 are presented the length, L, width, b, and thickness, t, for all three densities of rectangular bar samples.

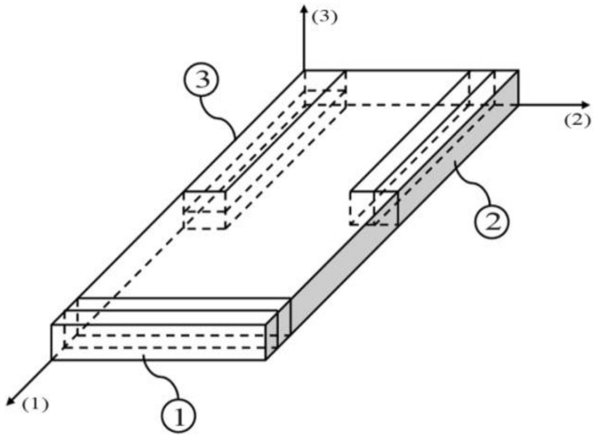


Figure 4 Sampling modes from a polyurethane plate

Table 2 Dimensions for rectangular bar samples

Density [kg/m^3]	Direction	L [mm]	b [mm]	t [mm]
100	1	84.83	35.21	9.7
	2	84.86	35.25	9.97
	3	85.01	35.22	10.02
160	1	84.9	35.16	10.04
	2	84.12	35.02	10.01
	3	83.87	34.85	10.05
300	1	81.35	34.1	10.1
	2	84.52	34.99	10.02
	3	84.91	34.91	10.11

To achieve the experiment we used the Resonant Frequency and Damping Analyzer (RFDA) which is a non-destructive testing device to determinate the resonant frequency of materials. This measuring technique consists four steps: (i) first step is the positioning the specimen on supports – the support frame is made from aluminum and nylon straps; (ii) second step is the impulse – the test specimen starts vibrating due to a small mechanical impulse and to excite the test specimen we used a steel ball 6 mm in diameter glued to the end of a flexible 100 mm long polymer rod; (iii) third step is the detection of the vibration – we used a non-contact transducer (microphone) and (iv) fourth step is to analyze the signal – after the mechanical vibration are detected by the transducer are sent to the computer all data are available for making measuring reports and further interpretations on standard PC software [16]. The testing device is shown in Figure 5.

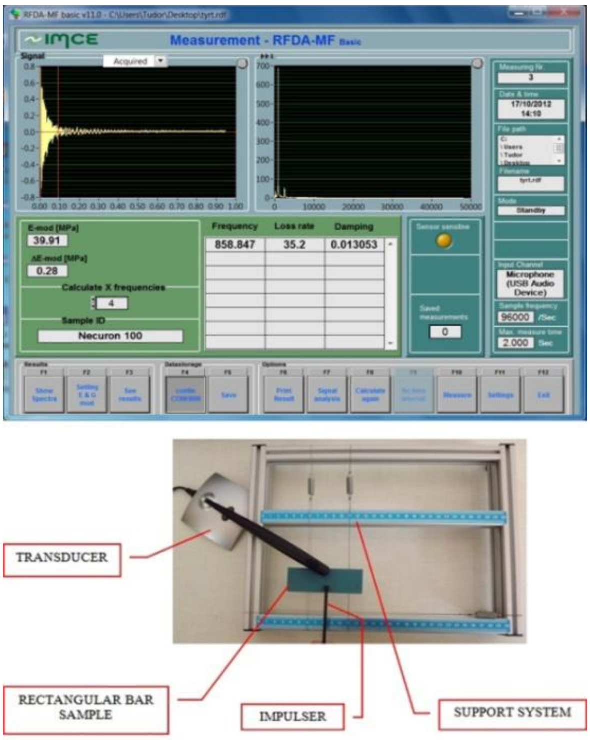


Figure 5 RFDA testing device

For Young's Modulus, Shear Modulus and Poisson's Ratio determination using round disc samples is due registering first and second natural vibration. For the first natural vibration mode, the node are located along two orthogonal diameters, offset 45° from the point where the vibration was induced. The anti-nodes are located along two orthogonal, 90° offset, diameters in the disc, with one diameter intersecting the point where the vibration was induced. For second natural vibration mode of a disc, the nodes are located in a circle concentric with the center of the disc with fractional radius of 0.681 of the disc radius. The anti-nodes are located at the center and around the circumference of the disc specimen.

For round disc, Poisson's Ratio can be determined directly from the experimental values of the first natural resonant frequency (f1) and the second natural resonant frequency (f2), the value for Poisson's Ratio is interpolated using the ratio of the second natural resonant frequency to the first natural resonant frequency (f2/f1) is correlated with the ratio of the specimen thickness to the specimen radius. For Young's Modulus of round disc samples, are calculated two E (E1 and E2) values from the two resonant frequency measurements and a final value of Young's Modulus is determined by averaging the two calculated E1 and E2. Figure 6 shows the position for round disc samples, transducer position and strike points for determination the first natural resonant frequency (f1) and the second natural resonant frequency (f2) for the two tips of materials, with low and high density, [21].

$$E_1 = \frac{[37.6991 f_1^2 D^2 m(1-\mu^2)]}{K_1^2 t^3} \tag{1}$$

$$E_2 = \frac{[37.6991 f_2^2 D^2 m(1-\mu^2)]}{K_2^2 t^3} \tag{2}$$

$$E = \frac{E_1 + E_2}{2} \tag{3}$$

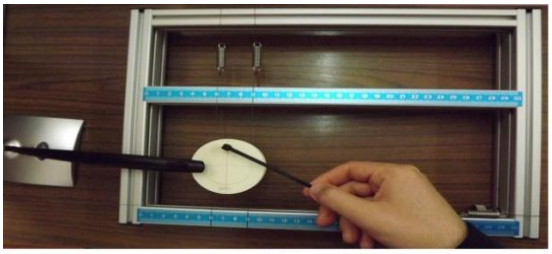
Where:
E = Young's Modulus (MPa)
E_1 = first natural calculation of Young's modulus
E_2 = second natural calculation of Young's modulus
f_1 = first natural resonant frequency of the disc (Hz)
f_2=2nd natural resonant frequency of the disc (Hz)
D = diameter of the disc (mm)
m = mass of the disc (mm)
μ = Poisson's Ratio
K_1 = first natural geometric factor
K_2 = second natural geometric factor
t = thickness of the disc (mm)
r = radius of the disc (mm)

The Shear Modulus is determined from the calculated Young's Modulus value and the Poisson's Ratio.

$$G = \frac{E}{2(1+\mu)} \tag{4}$$

Where:
G = Shear Modulus (MPa)
E = Young's Modulus (MPa)
μ = Poisson's Ratio.

For Young's Modulus and Shear Modulus determination of rectangular bar samples we used Flexural and Torsion mode. Figure 7 shows the position for rectangular bar samples, transducer position and strike points.

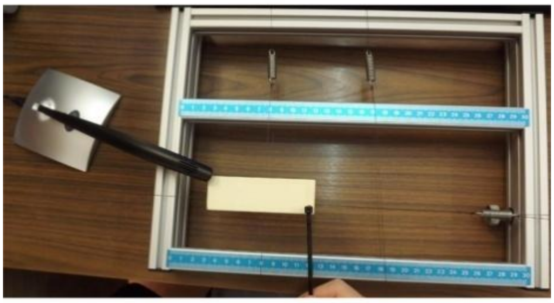


(a)

(b)

Figure 6 Round disc sample position for determination the first natural resonant frequency (a) and the second natural resonant frequency (b)

(a)

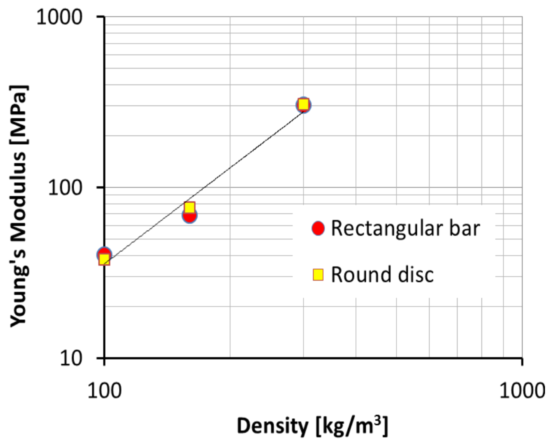


(b)

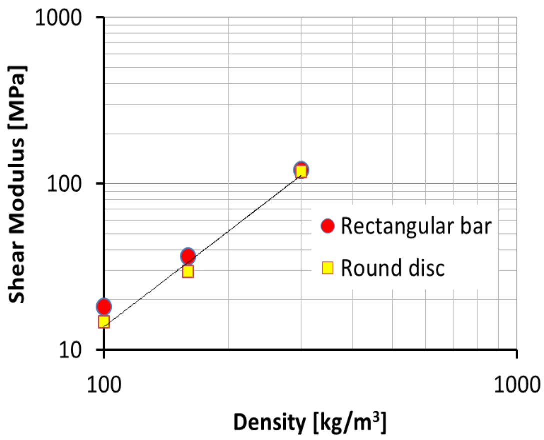
Figure 7 Rectangular bar position for Flexural mode (a) and Torsion mode (b)

3. Results and Discussions

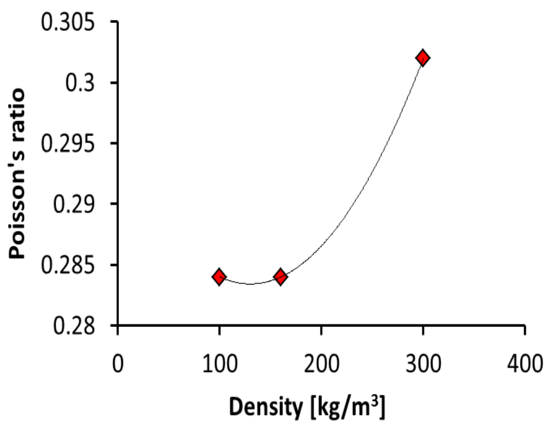
As we have presented in this article, for determination of main elastic properties of polyurethane foams we used two types of samples, round discs and rectangular bars. A comparison between results obtained using round discs and rectangular bars samples is presented in Figure 8. Figure 8 (a) shows results for Young's Modulus for all three densities used in experiment, Young's Modulus being determined on round disc and rectangular bar samples. Figure 8 (b) shows results for Shear Modulus for all three densities used in experiment, Shear Modulus being determined on round disc and rectangular bar samples. Results for Young's Modulus and Shear Modulus using rectangular bars samples are determined in Flexural and Torsion mode. Figure 8 (c) shows Poisson's Ratio results determined on round discs samples.



a) Young's Modulus



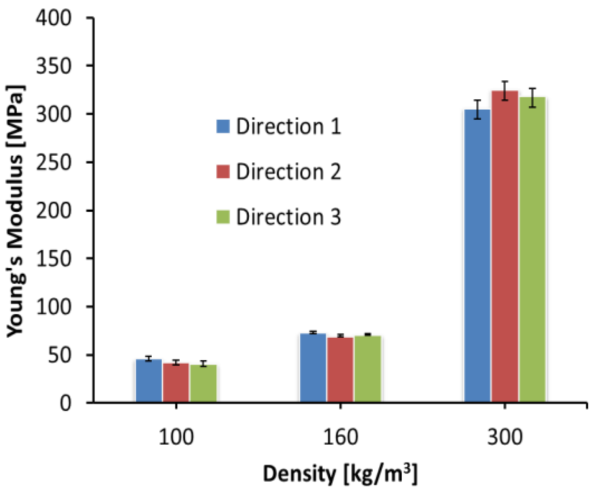
b) Shear Modulus



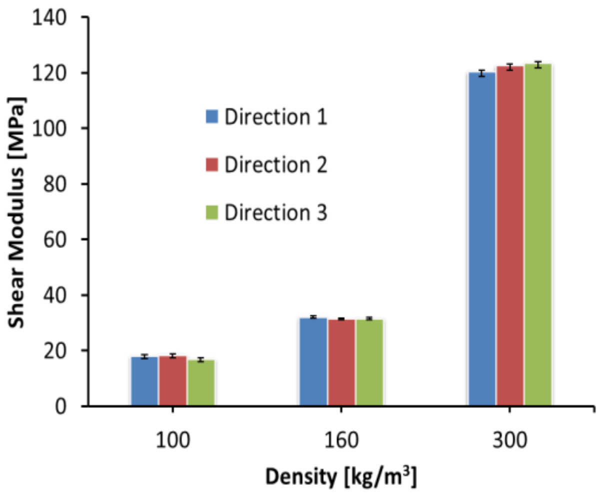
c) Poisson's Ratio

Figure 8 Elastic properties versus density

In Figure 9 (a) and (b) are presented results for Young’s Modulus and Shear Modulus for materials with density 100, 160, 300 kg/m^3 for three different directions. Comparison of the all elastic properties is based on density. Density has an important role in characterizing of cellular materials.



a) Young’s Modulus



b) Shear Modulus

Figure 9. Elastic properties versus density for three different directions

4. Conclusions

Determination of elastic properties for polyurethane foams was carried out on two types of samples, round discs and rectangular bars. To establish if this polyurethane foams shows isotropic or anisotropic behavior we cut samples from three different directions.

As we expected Young’s Modulus, Shear Modulus and Poisson’s Ratio for polyurethane foams increase with increasing density. After comparing values of the elastic properties, the three directions shows that high density polyurethane foams materials studied have an anisotropic behavior.

5. Acknowledgements

This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013 and by the CNCS-UEFISCDI Grant PN-II-ID-PCE-2011-3-0456, contract number 172/2011.

References

1. M. F., Gibson, L. J., Ashby, *Cellular Solids*, 2nd ed. Cambridge University Press. 1997.
2. L. Marsavina, D.M. Constantinescu, E. Linul, D.A. Apostol, T. Voiconi, T. Sadowski, *Refinements on fracture toughness of PUR foams*, Engineering Fracture Mechanics, 129, 54-66, 2014
3. L. Marsavina, E. Linul, T. Voiconi, T. Sadowski, *A comparison between dynamic and static fracture toughness of polyurethane foams*, Polymer Testing, 32, 673-680, 2013
4. M. Birsan, T. Sadowski, L. Marsavina, E. Linul, and D. Pietras, *Mechanical behavior of sandwich composite beams made of foams and functionally graded materials*, International Journal of Solids and Structures, 50, 519-530, 2013.
5. E. Linul and L. Marsavina, *Prediction of fracture toughness for open cell polyurethane foams by finite element micromechanical analysis*, Iranian Polymer Journal, 20(9), 736-746, 2011
6. L. Marsavina, D.M. Constantinescu, E. Linul, T. Voiconi, D.A. Apostol, T. Sadowski, *Evaluation of mixed mode fracture for PUR foams*, Procedia Materials Science, 3, 1342-1352, 2014
7. E. Linul, T. Voiconi, L. Marsavina, T. Sadowski, *Study of factors influencing the mechanical properties of polyurethane foams under dynamic compression*, Journal of Physics: Conference Series 451, 1-6, 2013
8. L. Marsavina, E. Linul, T. Voiconi, D. M. Constantinescu, D. A. Apostol, *On the crack path under mixed mode loading on PUR foams*, Fracture and Structural Integrity, 34, 444-453, 2015
9. T. Voiconi, R. Negru, E. Linul, L. Marsavina, H. Filipescu, *The notch effect on fracture of polyurethane materials*, Fracture and Structural Integrity, 30, 101-108, 2014
10. E. Linul, T. Voiconi, L. Marsavina, *Determination of mixed mode fracture toughness of PUR foams*, Structural Integrity and Life, 14(2), 87-92, 2014
11. R., Negru, L., Marsavina, T., Voiconi, E., Linul, H., Filipescu, G., Belgiu, *Application of TCD for brittle fracture of notched PUR materials*, Theor. Appl. Fract. Mech. (2015), http://dx.doi.org/10.1016/j.tafmec.2015.05.005
12. L., Marsavina, D.M., Constantinescu, E., Linul, T., Voiconi, D.A., Apostol, Shear and mode II fracture of PUR foams, Eng. Fail. Anal. (2015), http://dx.doi.org/10.1016/j.engfailanal.2015.05.021

13. ASTM E-1876-01, Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Impulse Excitation Technique of Vibration.
14. C., Bellan, J., Dhers, *Evaluation of Young modulus of CVD coatings by different techniques*. In: Thin Solid Films 469–470, p. 214–220, 2004.
15. S., Ganci, *A simple experiment on flexural vibrations and Young's modulus measurement*. In: Physics Education 44, p. 236-240, 2009.
16. L., Kiesewetter, J., Zhang, *Determination of Young's moduli of micromechanical thin films using the resonance method*. In: Sensors and Actuators A, 35, p. 153-159, 1992.
17. T., Lauwagie, H., Sol et al., *Validation of the Resonalyser method: an inverse method for material identification*. In: Proceedings of ISMA 2002 – volume II, p. 687-694.
18. H., Mukarram, V., Ramireddy, *Vibration-based Technique for Young's Modulus Determination and Permanent Deformation Assessment of Sheet Materials*. In: Master's Degree Thesis, Department of Mechanical Engineering Blekinge Institute of Technology Karlkrona Sweden, 2007.
19. H., Němcová et al., *Comparison of methods for dynamic Young's modulus determination in gypsum materials*. In: The 4th Int. Conf. of Modelling of Mechanical and Mechatronic systems, Herľany, Slovak Republic, Sept. 20-22, p. 335-338, 2011.
20. M., Radovic, E., Lara-Curzio et al., *Comparison of different experimental techniques for determination of elastic properties of solids*. In: Materials Science and Engineering A 368, p. 56–70, 2004.
21. 10. *RFDA MF basic MANUAL*, Version1.0, IMCE N.V, Genk, Belgium.

DETERMINAREA PROPRIETATILOR ELASTICE PENTRU SPUMELE POLIURETANICE RIGIDE UTILIZAND METODA EXCITATIEI PRIN IMPULS

Rezumat

Această lucrare prezintă o caracterizare mecanică pentru materiale poliuretanice utilizând Metoda Excitației prin Impuls. Programul experimental a fost realizat la temperatura camerei pe epruvete de tip disc si epruvete rectangulare având densități 100, 160, 300 kg/m^3. Un alt scop al acestei lucrări este de a determina dacă acesta materiale poliuretanice prezintă un comportament izotrop sau anizotrop, iar pentru aceasta au fost prelevate epruvete dreptunghiulare din trei direcții diferite. Așa cum ne-am așteptat modulul de elasticitate longitudinal, transversal și coeficientul lui Poisson pentru spume poliuretanice crește odată cu creșterea densității. După compararea valorilor proprietăților elastice ale celor trei direcții arată că spumele poliuretanice cu densitate mare prezinta un comportament anizotrop.

Scientific reviewers: **Nicolae FAUR[*], Politehnica University of Timisoara, Romania**
Radu NEGRU[**], Politehnica University of Timisoara, Romania