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Experimental Determination of Compressive Properties for Closed-Cell Aluminium Foams

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Abstract

This paper presents mechanical characterization of two different types of closed-cell aluminium foams under static compressive loading. The experimental tests were carried out on cylindrical specimens with skin (D = 40 mm, H = 51 ÷ 52 mm) having densities in range of 507 and 1026 kg/m^3 for AlMg1Si0.6 and between 472 and 866 kg/m^3 for AlSi10Mg0.6 foams. The compression tests were made at room temperature (T = 23°C) with constant crosshead speed of v = 10 mm/min. Experimental results show that the mechanical properties increases with increasing of density.

Key words: *aluminium foams, closed-cell, density, compression tests, and mechanical properties.*

Introduction

Metallic foams, especially those made from aluminium and its alloys, have received a significant increase of interest in the past few years. They present excellent stiffness to weight, impact energy absorption, vibration damping, noise attenuation, electromagnetic shielding at a relatively low density (300 - 900 kg/m^3).

Manufactured cellular materials such as metallic, polymer and ceramic foams offer an extremely attractive option as materials and can be engineered for a wide range of applications like filters, light-weight structures, biomedical implants, heat exchangers, sound absorbers, mechanical damping devices, electrodes, sensors and catalyst substrates [1-6].

Although relative density has long been believed to be the dominating factor determining the stiffness and strength of foams [1], other parameters, such as cell packing, cell distribution and cell shape, might influence the mechanical behavior [7–9]. Li et al. [10] studied the effect the dual cell size morphology on the mechanical properties of open cell foams.

Saadatfar et al. [3] characterize four metallic foam samples manufactured under various experimental conditions. They used X-ray tomography to study 3D structure of the foam samples. The influence of meso-inhomogeneities of the apparent density on the quasi-static and dynamical energy absorption behavior of aluminium foam was examined by Daxner et al. [11]. Kesler and Gibson [12] studied the impact of the foam shear strength size effect on the limit load of foam core sandwich beams. Mechanical effects of mass density gradients in metallic foams have been investigated experimentally by Doyoyo and Mohr [13]. Also, experimental tests of sandwich beams with open and closed-cell metallic foam cores were performed under a range of temperatures and applied stresses by Kesler et al. [14].

Cellular structures of used Aluminium Foams: AlMg1Si0.6 and AlSi10Mg0.6 are presented in Figure 1. The useful properties of these materials are a direct consequence of their cellular characteristic. It is important therefore to link the physical properties of cellular solids to their apparent density and parameters such as average cell size, cell size distribution, cell wall thickness, etc.

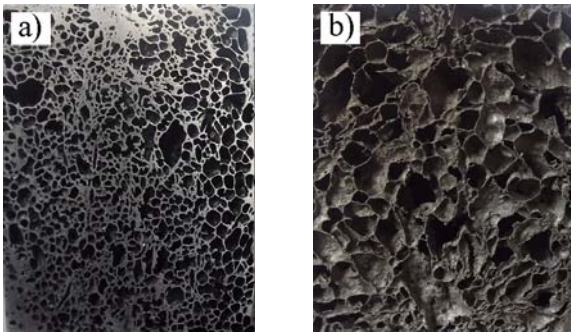

Fig. 1. Cellular structure of used Aluminium Foams: a) AlMg1Si0.6; b) AlSi10Mg0.6

Experimental Results

This work presents a mechanical characterization of two different types of closed-cell aluminium foams AlMg1Si0.6 (M8) and AlSi10Mg0.6 (S7) under static compressive loading. Experimental tests were performed using a testing machine produced by LBG Testing Equipment: A009 ELECTROMECHANICAL-COMPUTERIZED 100 kN, (figure 2a). In figure 2b is presented the positioning of the specimen.

a) b)

Fig.2. LBG 100 kN testing machine

The compression tests were performed at room temperature (T = 23°C) with constant crosshead speed of v = 10 mm/min. For each type of test 5 specimens were used, and the tests were performed according to International Standard for Compression Test of Porous and Cellular Metals.

The experimental tests were carried out on cylindrical specimens (D = 40 mm, H = 51 ÷ 52 mm) with skin having densities in range of 507 and 1026 kg/m^3 for M8 and between 472 and 866 kg/m^3 for S7. Shapes of used specimens are shown in Figure 3. Also, the same figure presents a comparison between the initial shapes of the specimen, non-deformed and deformed.

Fig.3. Compression specimens

Figure 4 presents typical stress – strain curves for different densities of AlSi10Mg0.6, indicating an increase of mechanical properties with increasing density.

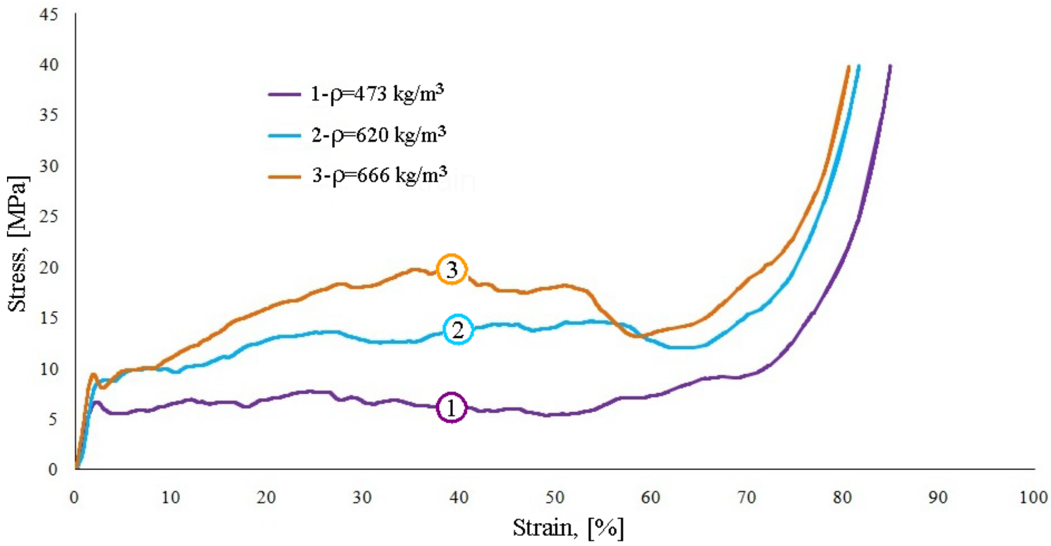

Fig.4. Stress-strain curves for AlSi10Mg0.6 foam - static compression tests

Stress-strain curves resulted from experimental tests, shows three regions: linear elastic region, plateau region with hardening and densification (figure 5) [15, 16].

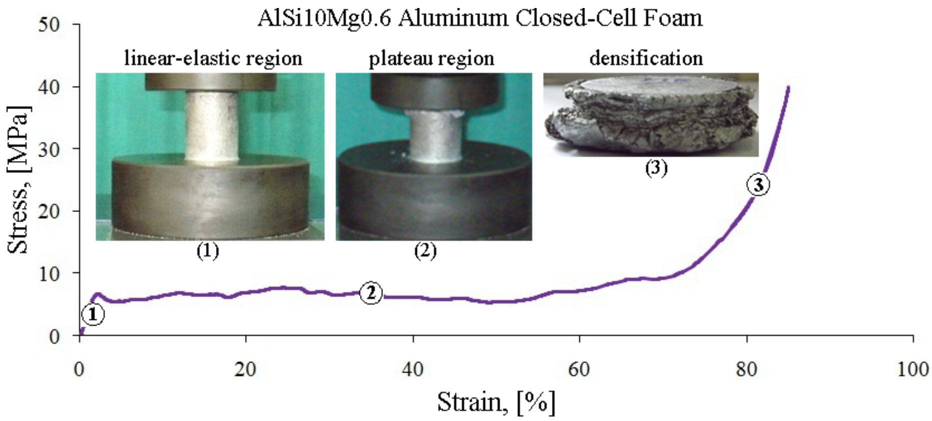

Fig. 5. Typical regions from stress-strain curve for AlSi10Mg0.6 foam

The compressive stress–strain curve of open-cell metal foams shows linear elasticity at low strains, caused by the bending of cell walls. At higher strains, plastic hinges form in the cell walls, causing the cells to collapse, which results in a long collapse plateau (increasing strain at constant stress). Finally, the foam densifies, resulting in a steep rise of the stresses. In case of closed-cell foams the above mechanisms are accompanied by cell face stretching in the elastic regime and by face yielding during collapse [17].

The mechanical characteristics of the used AlMg1Si0.6 metal foams depending on density are listed in Table 1. Table 2 presents the same properties for AlSi10Mg0.6 metal foams.

Table 1. The mechanical characteristics of AlMg1Si0.6

Sample	Density [kg/m^3]	Young Modulus [MPa]	Yield Stress [MPa]	Plateau Stress [MPa]
M8-1	645	176.7	4.9	8.3
M8-2	754	310.1	11.6	25.6
M8-3	928	754.3	16.1	37.4
M8-4	1026	1625.8	21.1	55.2

Table 2. The mechanical characteristics of for AlSi10Mg0.6

Sample	Density [kg/m^3]	Young Modulus [MPa]	Yield Stress [MPa]	Plateau Stress [MPa]
S7-1	473	447.71	6.5	6.8
S7-2	620	629.62	8.7	13.0
S7-3	666	656.23	9.2	18.2
S7-4	865	865.6	10.9	29.5

Young's Modulus histogram versus density for AlMg1Si0.6 aluminium foams are presented in Figure 6. In Figure 7 is shown Yield Stress and Plateau Stress histogram versus density for AlMg1Si0.6.

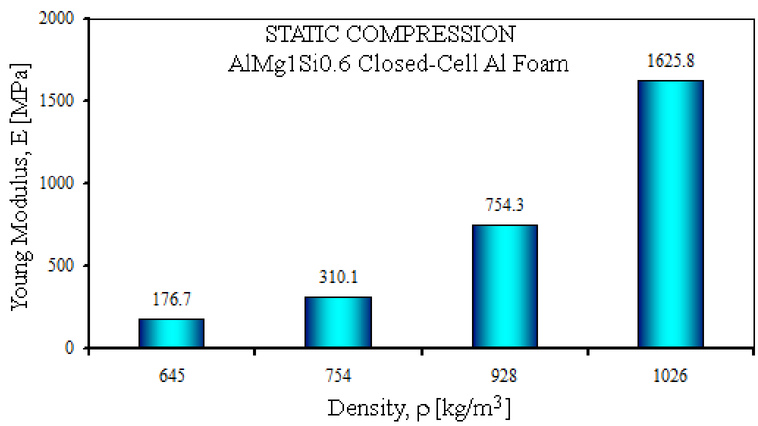

Fig.6. Young's Modulus versus density for AlMg1Si0.6.

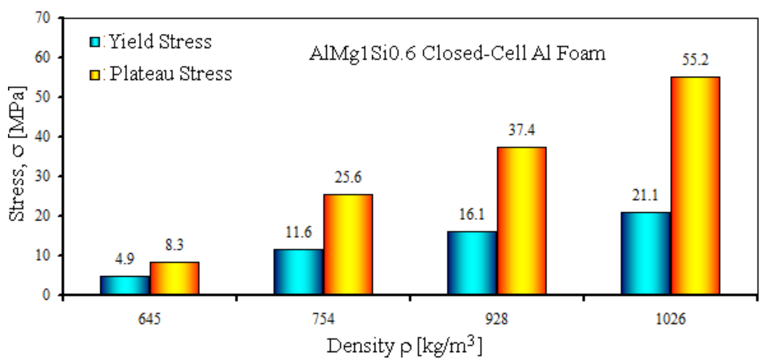

Fig.7. Yield Stress and Plateau Stress versus density for AlMg1Si0.6.

Figure 8 presents Young's Modulus histogram versus density for AlSi10Mg0.6 aluminium foams. In Figure 9 is presented Yield Stress and Plateau Stress histogram versus density for AlSi10Mg0.6.

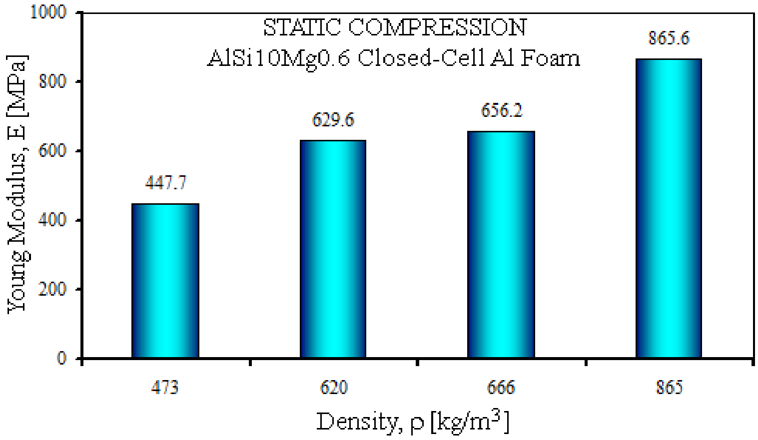

Fig.8. Young's modulus versus density for AlSi10Mg0.6

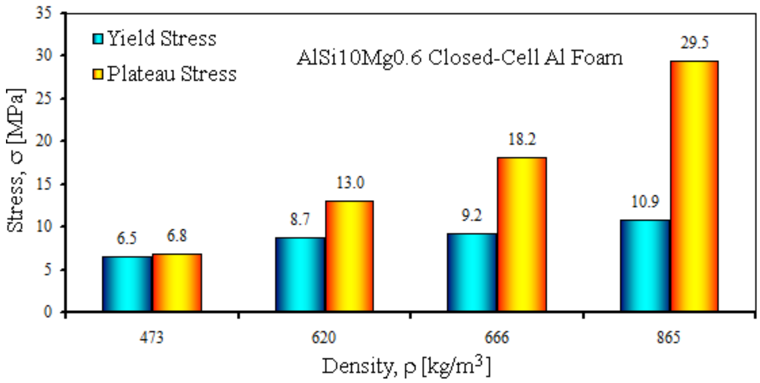

Fig.9. Yield Stress and Plateau Stress versus density for AlSi10Mg0.6

Conclusions

This paper presents an experimental study on static compression properties of closed-cell aluminium foams AlMg1Si0.6 and AlSi10Mg0.6. This study shows the influence of density on Young's modulus, yield stress and plateau stress. Experimental results show that Young's modulus (figure 6 and figure 8), yield stress and plateau stress (figure 7 and figure 9) properties increases with increasing density. It is shown that the density of foam and type of used aluminium alloy have a major role on mechanical properties in compression.

It could also be observed that the hardening increases with density and the ratio between plateau stress and yield stress increase from 1.7 for 645 kg/m^3 density to 2.62 for 1026 kg/m^3 for AlMg1Si0.6 and from 1.05 for 473 kg/m^3 density to 2.7 for 865 kg/m^3 for AlSi10Mg0.6.

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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. Song, H.W., He, Q.J., Xie, J.J. and Tobota, A. – Fracture mechanisms and size effects of brittle metallic foams: In situ compression tests inside SEM, *Composites Science and Technology*, **68**, 2008, pp. 2441–2450.
3. Saadatfar, M., Garcia-Morenob, F., Hutzler, S., Sheppard, A.P., Knackstedt, M.A., Banhart, J., Weaire, D. – Imaging of metallic foams using X-ray micro-CT, *Colloids and Surfaces A: Physicochem. Eng. Aspects*, **344**, 2009, pp. 107–112.
4. Banhart, J., Baumeister, J. – Deformation characteristics of metal foams, *J. Mater. Sci*., **33**, 1998, pp. 1431–1440.
5. Gibson, L.J., Ashby, M. – *Cellular Solids: Structure and Properties*, Cambridge University Press, 1999.
6. Ashby, M.., Evans, T., Fleck, N.A., Gibson, L.J., Hutchinson, J.W. – *Metal Foams: A Design Guide*, Elsevier Science & Technology Books, 2000.
7. Fazekas, A., Dendievel, R., Salvo, L., Brechet, Y. – Effect of microstructural topology upon the stiffness and strength of 2D cellular structures, *Int. J. of Mech Sci*., **44**, 2002, pp. 2047–2066.
8. Zheng, Z.J., Yu, J.L., Li, J.R. – Dynamic crushing of 2D cellular structures: A finite element study, *Int. J. Impact Eng.*, **32**, 2005, pp. 650–664.
9. Nieh, T.G., Higashi, K., Wadsworth, J. – Effect of cell morphology on the compressive properties of open-cell aluminum foams, *Mat. Sci. Eng.*, A283, 2000, pp. 105–110.
10. Li, J.R., Cheng, H.F., Yu, J.L., Han, F.S. – Effect of dual-size cell mix on the stiffness and strength of open-cell aluminium foams, *Mat. Sci. Eng.*, A362, 2003, pp. 240–248.
11. Daxner, T., Bohm, H.J., Rammerstorfer, F.G. – Mesoscopic simulation of inhomogeneous metallic foam with respect to energy absorption, *Comp Mat Sci*, **16**, 1999, pp. 61-69.
12. Kesler, O., Gibson, L.J. – Size effects in metallic foam core sandwich beams, *Mat. Sci. Eng. A.*, **326**, 2002, pp. 228–234.
13. Doyoyo, M, Mohr, D. – Experimental determination of the mechanical effects of mass density gradient in metallic foams under large multiaxial inelastic deformation, *Mechanics of Materials*, **38**, 2006, pp. 325–339.
14. Kesler, O., Crews, L.K., Gibson, L.J. – Creep of sandwich beams with metallic foam cores, *Mat. Sci. Eng*., A341, 2003, pp 264-272.
15. 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**, 2010, 311-316.
16. Linul, E., Marsavina, L. – Experimental determination of compressive properties for rigid polyurethane foams, *Buletinul Universității Petrol-Gaze din Ploiesti. Seria Tehnica*, Vol. LXIII, No.1, 2011, pp. 199-204.
17. Onck, P.R. – Application of a continuum constitutive model to metallic foam DEN-specimens in compression, *Int. J. Mech. Sci.*, **43**, 2001, pp. 2947-2959.

Determinarea experimentală a proprietăților la compresiune pentru spumele din aluminiu cu celule închise

Rezumat

Lucrarea prezintă o caracterizare mecanică a două tipuri diferite de spume din aluminiu cu celule închise AlMg1Si0.6 şi AlSi10Mg0.6 solicitate la compresiune statică. Testele experimentale au fost efectuate pe probe cilindrice (D = 40 mm, H = 51 ÷ 52 mm) având densitățile cuprinse între 507 si 1026 kg/m^3 *pentru M8 şi între 472 şi 866 kg/m*^{3} *pentru materialul S7. Testele de compresiune s-au realizat la temperatura ambiantă (T = 23°C) cu viteză constantă v = 10 mm/min. Rezultatele experimentale arată că proprietățile mecanice cresc odată cu creşterea densității.*