ISSN 1864-6168
UDK 62

PONOVLJIVOST ISPITIVANJA SVOJSTAVA APSORPCIJE ENERGIJE ALUMINIJSKE PJENE

REPRODUCIBILITY OF ENERGY ABSORPTION PROPERTIES OF ALUMINIUM FOAMS

Krešimir Grilec, Vedran Bojanić

Izvorni znanstveni rad

Sažetak: *Aluminijska pjena je u osnovi kompozitni materijal koji se sastoji od aluminijske osnove ili osnove od neke aluminijske legure i pora ispunjenih plinom. Ovaj rad istražuje ponovljivost rezultata ispitivanja svojstava apsorpcije energije aluminijske pjene. Uzorci aluminijske pjene proizvedeni su iz "Alulight" prekursora (AlMgSi 0.6* TiH_2*-0.4). Prekursor je stavljen u kalup i zagrijavan sve dok se plinski agens nije počeo pjeniti. Nakon toga je kalup izvađen iz peći i hlađen pri čemu je uzorak pjene poprimio oblik kalupa. Iskoristivost apsorpcije energije aluminijskih pjena procjenjena je iz rezultata tlačnog ispitivanja. Rezultati ispitivanja pokazali su da aluminijske pjene imaju dobra svojstva apsorpcije energije i da je ponovljivost rezultata relativno niska.*

Ključne riječi: *aluminijske pjene, apsorpcija kinetičke energije, kapacitet apsorpcije energije, iskoristivost apsorpcije energije, tlačno ispitivanje*

Original scientific paper

Abstract: *Aluminium foam is, principally, a composite material consisting of aluminium or aluminium alloy matrix and of pores filled up with a gas distributed throughout the matrix. This paper studies the reproducibility of aluminium foams energy absorption properties. Samples of aluminium foam were produced from an Alulight precursor (AlMgSi0.6* TiH_2*-0.4). This precursor was placed into a mould form and heated up until the agent starts to foam. Immediately thereafter the mould is taken out of the furnace and cooled off, so the aluminium foam part is frozen in shape. The ability of samples to absorb mechanical energy was estimated from the results of compression tests. Test results showed that aluminium foams have good energy absorption properties and reproducibility is relatively low.*

Key words: *aluminium foams, absorption of kinetic energy, energy absorption capacity, energy absorption efficiency, compression test*

1. INTRODUCTION

Foamed aluminium is, principally, a composite material consisting of aluminium or aluminium alloy matrix and of pores filled up with a gas distributed throughout the matrix. This unique structure possesses an unusual combination of properties, such as low thermal conductivity, high impact energy absorption capacity, very high specific toughness and good acoustic properties, especially in the case of interconnected porosity. Moreover, this exceptionally lightweight material is nonflammable, ecologically harmless and easily recyclable [2].

Although it is many years since the first patents concerning the manufacture of metallic foams appeared, the material has not been put into large-scale commercial production yet. This discouraging fact can be attributed to inadequate design of components, low reproducibility of properties, a lack of testing procedures and calculation approaches, absence of concepts for secondary treatment, as well as the production technologies being too complicated and relatively expensive [4].

Metallic foams are excellent impact energy absorber, and they can convert impact energy into deformation energy and absorb more energy than bulk metal at low stress [8].

In recent years, foamed aluminium has been frequently used in various absorbers of kinetic energy (buffers of automobiles, trains, trams) [5], figure 1.

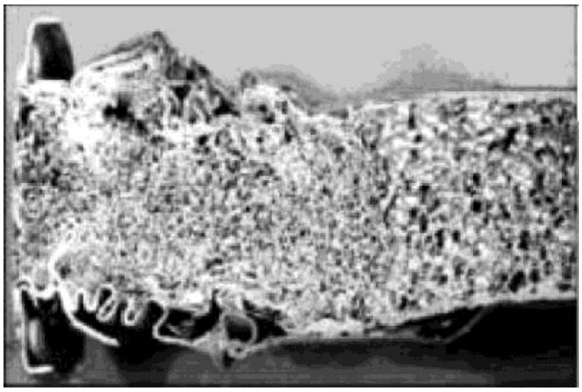

Figure. 1 - The motor carrier filed with aluminium foam after frontal impact [6]

The energy absorption capacity is defined as the energy necessary to deform a given specimen to a specific strain. So the absorption energy per unit volume for a sample, up to a strain, can be evaluated by integrating the area under the stress–strain curve, namely [7]:

$$W = \int_0^{\varepsilon_0} \sigma(\varepsilon)d\varepsilon \qquad (1)$$

W_V –absorbed energy per unit volume, J/mm^3
σ – stress, N/mm^2
ε – strain, %

Good energy absorbers have a long flat stress–strain (or load-deflection) curve like those of Figure 2.

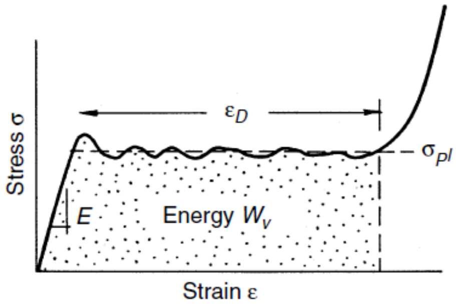

Figure 2 - Stress–strain curve for an energy absorber (σ_{pl} - plateau stress, ε_D - nominal strain) [1]

The energy absorption efficiency compares the deformation energy absorbed by a real material or component with that of an ”ideal“ energy absorber. An ”ideal“ absorber shows a rectangular march of the load-compression curve, i.e. it reaches directly the maximum admissible strain and keeps it constant during the whole deformation process. The efficiency η is defined as ratio of the actually absorbed energy after a compression strain s and the energy absorption of the ideal absorber [3]:

$$\eta = \frac{\int_0^s F(s')ds'}{F_{max}(s)s} \qquad (2)$$

where $F_{max}(s)$ is the highest force occurring up to the deformation s.

2. EXPERIMENTAL PART

For the production of Alulight foamed aluminium, Al powder is mixed with a product releasing gas at higher temperature and then compacted. This foaming agent is placed into a mold form and heated up until the agent starts to foam. Immediately thereafter the mold is taken out of the furnace and cooled off, so the aluminium foam part is frozen in shape. The outcome of this process is a closed cell aluminium foam showing a thin casting skin on the surface [9].

An electric resistance furnace with a power of 7,5 kW (situated in the Faculty of Mechanical Engineering and Naval Architecture in Zagreb, Croatia) was used for producing aluminium foam samples.

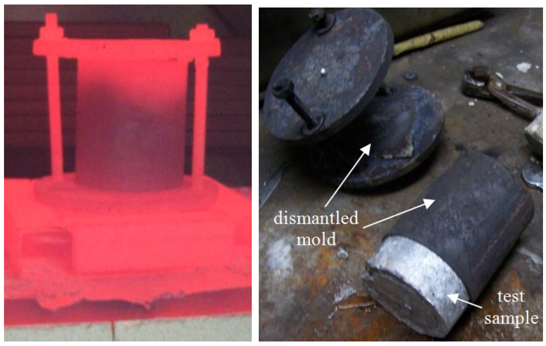

Figure 3 - The process of producing aluminium foam samples

Five samples of aluminium foams with density of foam ρ = 0,675 g/cm^3 and seven samples with density of foam ρ = 0,81 g/cm^3, with equal dimension (ϕ 84 × 100 mm), were produced from an Alulight AlMgSi 0,6 TiH_2 - 0,4 precursor. One sample from each density were cut crosswise. Figure 4 shows a cross section of aluminium foam samples.

a) ρ = 0,675 g/cm^3

b) ρ = 0,81 g/cm^3

Figure 4 - Cross section of aluminium foam samples

Compression test was carried out in the Laboratory for Mechanical Properties Testing at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb. A universal test machine, with a maximum compressive force of 400 kN was used. The feed rate was 60 mm/min which is the equivalent to strain rate of 10^{-2} s^{-1}. Figure 5 shows compression of sample.

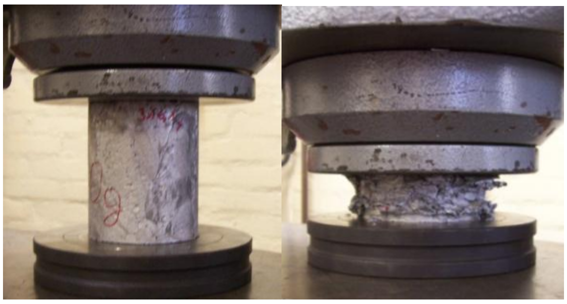

Figure 5 – Compression of aluminium foam sample

3. RESULTS AND DISCUSSION

The recorded load-displacement curves were used to calculate the compressive engineering stress-strain curves. Figure 6 and figure 7 presents approximated ”stress – strain“ diagram.

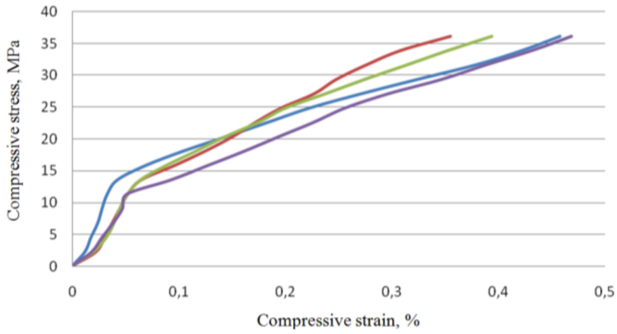

Figure 6 - Compressive engineering stress-strain diagram of four aluminium foam samples with equal dimension and density (ρ = 0,675 g/cm^3)

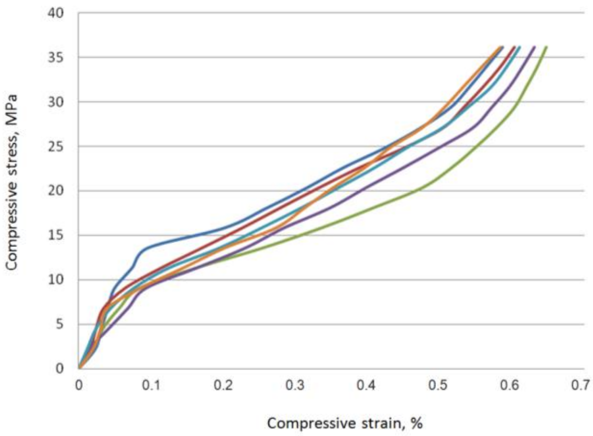

Figure 7 - Compressive engineering stress-strain diagram of six aluminium foam samples with equal dimension and density (ρ = 0,81 g/cm^3)

It can be seen that the shapes of the stress-strain curves are similar but not overlapping.

In order to determine reproducibility of aluminium foams energy absorption, the dependence of absorbed energy on the compressive force are shown in Figure 8 and Figure 9.

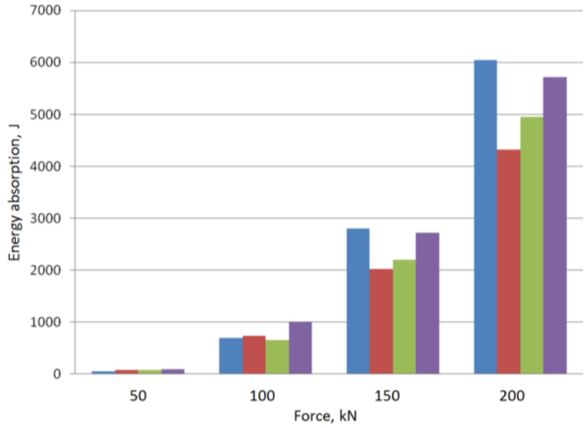

Figure 8 - Energy absorption of aluminium foams with equal dimension and density (ρ = 0,675 g/cm^3)

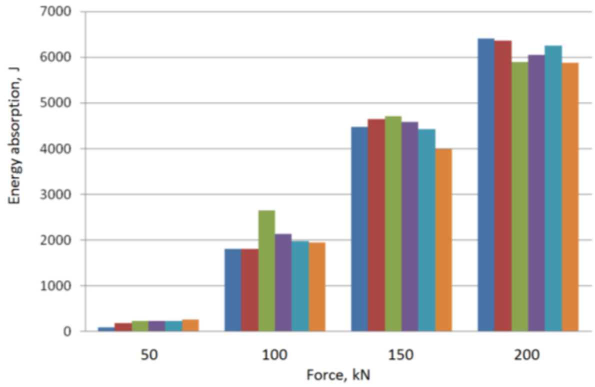

Figure 9 – Energy absorption of aluminium foams with equal dimension and density (ρ = 0,81 g/cm^3)

Standard deviations in relation with the mean values (relative standard deviation) for different forces are between 28 and 56% for density ρ = 0,675 g/cm^3 and between 4 and 28% for density ρ = 0,81 g/cm^3.

In order to determine reproducibility of aluminium foams energy absorption efficiency, the dependence of absorbed energy efficiency on the compressive force is shown in Figure 10 and figure 11.

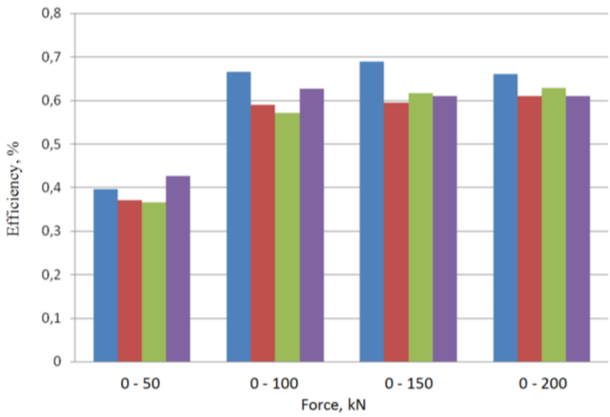

Figure 10 – Energy absorption efficiency of aluminium foams with density (ρ = 0,675 g/cm^3)

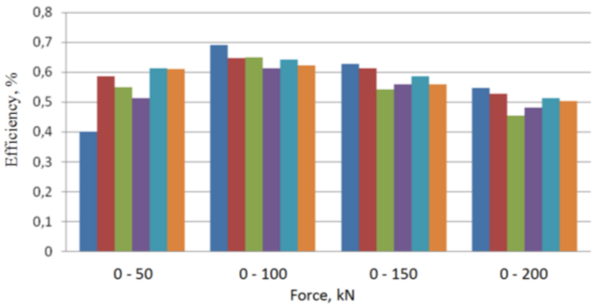

Figure 11 – Energy absorption efficiency of aluminium foams with density (ρ = 0,81 g/cm^3)

Standard deviations in relation with the mean values for different forces are between 4 and 7% for density ρ = 0,675 g/cm^3 and between 6 and 15% for density ρ = 0,81 g/cm^3.

4. CONCLUSION

Energy absorption characteristics of closed-cell aluminium foam (Alulight) were investigated through quasi-static uniaxial compression. Aluminium foams foamed by blowing agents exhibit a non-uniform cell with different sizes and shapes and with density variations within samples. Non-uniform structure and local density variations resulting in variability in energy absorption properties. Test results showed that aluminium foams have good energy absorption efficiency and reproducibility are relatively low (relative standard deviation are between 4% and 15%). Reproducibility of total energy absorption is very low (relative standard deviation are between 4% and 56%).

5. ACKNOWLEDGEMENTS

The financial support of project "Rear and side underrun protection on trucks" is gratefully acknowledged.

6. LITERATURE

[1] Ashby, M.F.; Evans, A.G.; Fleck, N.A.; Gibson, L.J.; Hutchinson J.W.; Wadley, H.N.G., (2000), *Metal Foams: A Design Guide*, Butterworth-Heinemann, Boston-Oxford-Auckland-Johannesburg -Melbourne-New Delhi

[2] Banhart, J. (2001), Manufacture, characterisation and application of cellular metals and metal foams, *Progress in Materials Science* Vol. 46, 559–632

[3] Baumeister, J., Banhart, J., Weber, M., (1997), Aluminium foams for transport industry, *Materials&Design* Vol. 18 No.4/6, 217-220

[4] Degischer, H.P., Kriszt, B., (2002) *Handbook of Cellular Metals*, Wiley-Vch Verlag GmbH, Weinheim

[5] Lebedev, V.I.; Komov, V.I.; Andreev D.A., (2003), Ability of constructions from foamed aluminium to absorb different konds of energy, *Proceedings of International Conference on Cellular Metals and Metal Foaming Technology*, Berlin, 451-455

[6] Simancik, F., (2001) Metallic foam – ultra light materials for structural applications, *Inzynieria Materialowa* Vol. 5 823-828

[7] Yi, F., Zhu, Z., Zu, F., Hu, S., Yi, P., (2001), Strain rate effects on the compressive property and the energy-absorbing capacity of aluminum alloy foams, *Materials Characterization* Vol. 47 No. 5, 417-422

[8] Zhang, C., Feng, Y., Zhang, X., (2010), Mechanical propertiesand energy absorption properties of aluminium foam-filled square tubes, *Transactions of Nonferrous Metal Society of China* Vol. 20, 1380-1386

[9] http://www.alulight.com/en/downloads/alulight_data sheets_en2006.pdf

Contact authors:

Prof.dr.sc. Krešimir Grilec
University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5
10000 Zagreb
01/6168-350
kresimir.grilec@fsb.hr

Vedran Bojanić (bivši student)
Polytechnic of Zagreb
Professional study in Mechanical Engineering
Ivana Lučića 1, 10000 Zagreb
098/1625-716
vedran.bojanic@zg.t-com.hr