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FOAMED ALUMINIUM - LIGHT STRUCTURAL AND INSULATION MATERIAL

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ABSTRACT

Foamed aluminium - an isotropic highly porous metallic material with a cellular structure has been prepared by powder metallurgical method. Its typical density lies in the range of 0,3-1 g/cm^3. The porosity is essentially spherical and closed with the average pore size between 1-8 mm depending on matrix composition and heating rate during foaming.

Foamed aluminium is very efficient in sound absorption, impact energy absorption, electromagnetic shielding and vibration damping. Mechanical and physical properties depend strongly on the foam density. Modulus of elasticity of 4-13 GPa, plastic collapse stress of 3-17 MPa, thermal conductivity of 4-15 W/mK, electric conductivity of 3-5.10^6 S.m^{-1}, have been obtained for the densities of 500-800 kg m^{-3}. The relationship between density and properties seems to obey the power-law dependence with an exponent of about 1.6.

Foamed aluminium is form-stable also at elevated temperatures, even at temperatures considerably higher than the melting point of the metal matrix.

Keywords: cellular structure, aluminium foam, sound absorption, energy absorption, structural damping, heat insulation

INTRODUCTION

"When modern man builds large load-bearing structures, he uses dense solids: steel, concrete, glass. When nature does the same, she uses cellular materials: wood, bone coral. There must be good reasons for it" [1]. Accepting this fact a considerable effort has been done to develop artificial cellular materials for industrial purposes. Different polymeric and ceramic foams have already found widespread applications as functional materials. Unfortunately, they are not suitable for constructional use because of insufficient toughness or plasticity. The necessity to overcome this lack leads to the development of various metallic foams, especially those which are based on light metals.

Foamed aluminium is, principally, a composite material consisting of aluminium or aluminium alloy matrix and of pores filled up with gas distributed throughout the matrix. This unique structure possesses 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 light weight material is inflammable, ecologically harmless and easily recyclable.

METHOD OF PRODUCING FOAMED ALUMINIUM

There are two basic preparation methods:

- mixing a foaming agent (metal hydride e.g. TiH_2) into a molten aluminium or aluminium alloy. The foaming agent decomposes at the melting temperature of aluminium, releases gas (e.g. hydrogen) and blows up the melt [2]
- heating of gas-tight precompacted mixture (preform) of aluminium or aluminium alloy powder with powdered foaming agent above the melting point of the metallic matrix; the foaming agent decomposes and expands the preform into porous cellular solid [3].

Various techniques [4] based on both principal methods have been investigated to achieve the uniform cellular structure of the foam at reasonable costs. MEPURA [5] has recently developed the cost effective method which involves a foaming up of the powder-based foamable precursor in the desired hollow mould to achieve required (also complicated) shapes. The main benefit of this method is the possibility to use the same foaming material of simple preforms (e.g. wire, balls, etc.) for different shapes to be foamed. Using this method diverse parts made from foamed aluminium (flat-, rod-, or 3D-shapes), as well as integral foams can be produced; i.e. foams connected with bulk metal sheets (e.g. sandwich structures), or hollow metallic profiles filled with the foamed aluminium.

PROPERTIES OF THE FOAMED ALUMINIUM

The ***density*** of foamed aluminium lies typically in the range of 0.4-0.8 g/cm^3. The porosity is essentially spherical and closed, although an interconnected porosity can be achieved as well. The average pore size varies between 0.5-8 mm depending on matrix composition and foaming procedure (Fig.1).

Although the properties of foamed aluminium depend also on the shape, size, and uniformity of the pores distributed throughout the matrix, they are greatly influenced by apparent density of the foam. There is a fairly close relationship between density and mechanical and physical properties. This dependence obeys the power-law function

$$K=K_0(r/r_0)^m$$

where K is the property and r is the density of foam, while K_0 and r_0 are the corresponding properties of bulk aluminium alloy. The exponent m is usually from the range of 1.5-1,7 (see Fig.2).

Fig. 1 *Foamed aluminium with different pore sizes (density 0.5 g/cm^3)*

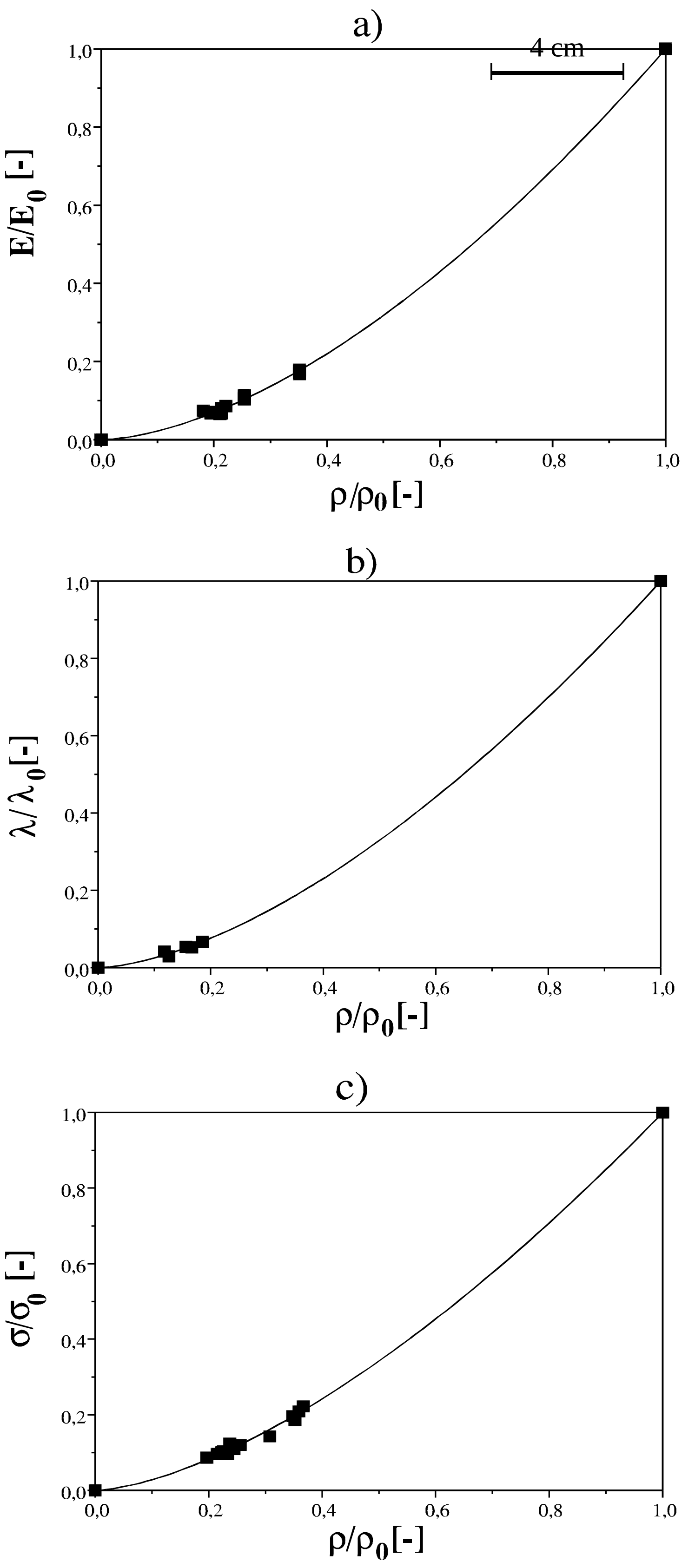

Fig.2 *Power-law dependence between density and elastic modulus (a), thermal (b) and electric (c) conductivity. The values obtained for foamed aluminium were normalised by the properties of bulk aluminium alloy.*

The *elasticity modulus* of foamed aluminium cannot be determined as usual from the slope of stress-strain curve. This is due to plastic deformations in the early stress stages. Elastic vibrational loading is therefore the more appropriate method for the measurement. Storage elasticity modulus can be calculated from the resonant frequency of longitudinal vibration of the samples. While the storage elasticity modulus of the tested samples was independent of the frequency it can be considered as a static elasticity value. Fig.2 a reveals the strong dependence of the elasticity modulus on the foam density.

Small amount of metal in given volume of aluminium foam results in significant reduction of the *thermal* and *electric conductivity* in compa-rison with bulk aluminium alloy. This reduction depends on density and alloy composition (see Fig.2b and 2c).

The compressive load-deflection curve can be divided into three different regions (see Fig.3). At low strains the material deforms elastically (cell walls bend), then a plateau of deformation at almost constant stress exists (cell walls buckle, yield or fracture) and finally there is a region of rapidly increasing stress after the cell walls crushed together. The area under the load-deflection curve up to the collapse length *l* (Fig.3) illustrates the energy needed for plastic deformation. The energy used for plastic deformation until the given maximum stress is attained in the foam is very important if the *impact energy absorption* is considered. This energy depends also strongly on the apparent density. If the density is too low the foam crushes before impact energy is sufficiently absorbed. If the density is too high the stress in the foam exceeds given critical value at low absorbed energy.

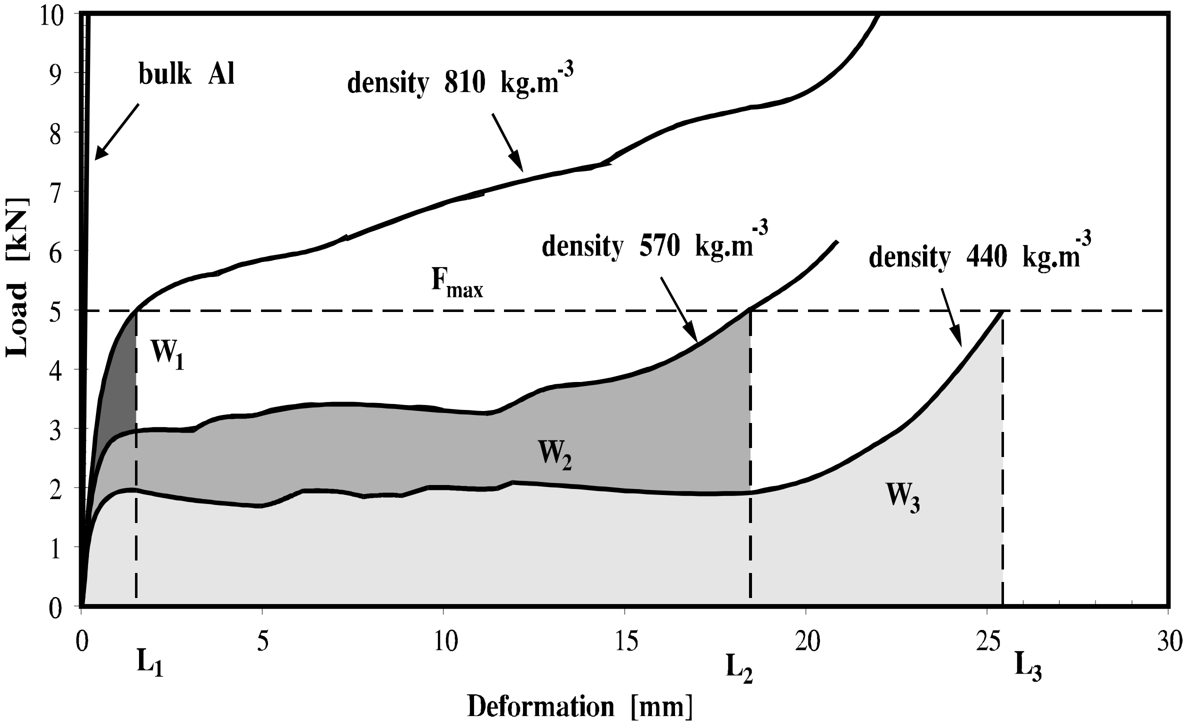

Fig.3 *Example of compressive load-deformation curves of foamed aluminium for different densities of an AlMgSi-alloy. The shaded areas illustrate the values of the energy needed for plastic deformation (Note:* $W_2>W_3>W_1$*)*

The representative *mechanical properties* of some aluminium foams with two different densities are listed in the Table 1.

Table 1 Mechanical properties of aluminium foams based on different aluminium alloys

composition	Al 99,5		AlSi12		AlMg5	6061 (T1)		6061 (T6)	
apparent density [g/cm^3]	0,57	0,85	0,54	0,84	0,80	0,54	0,81	0,53	0,80
plastic collapse stress* in compression [MPa]	3	13	7	15	8	5	15	10	17
absorbed deformation energy at the compression stress of 20 MPa [MJ/m^3]	3,8	4,8	5,5	0,6	3,8	5,0	0,7	6,0	0,3

* stress at the beginning of the plateau on the compressive stress-strain curve

Foamed aluminium maintains its shape up to high temperatures; the intensive surface oxidation produces the strong oxide skeleton (because of very high surface to volume ratio of cellular structure), which prevents the foam from collapsing even at temperatures considerably higher than the melting point of aluminium.

The contribution of foamed aluminium to the ***noise control*** can be considered from three viewpoints:

- detrimental vibrations can be suppressed by shifting the resonant frequency, which depends on the elastic modulus to density ratio of the foamed part. As this ratio can be varied, it is possible to modify the resonant frequencies within a wide range by changing the foam density.
- foamed aluminium possesses relative high ***damping capacity***, i.e. the ability to convert mechanical vibrational energy into thermal energy by internal friction. This reduces excessive noise and vibration by turning them into heat to be expelled into the surrounding area. The rate of vibrational dissipation in the material structure can be defined the by loss factor h. Loss factors of 0.001-0.004 have been experimentally (according to DIN 53 440) determined for foamed aluminium at resonance frequencies up to 10 kHz. These values are more than ten times higher than the loss factor of bulk aluminium. Loss factor of the material tested seems to have a maximum at densities around 0.65 g/cm^3.
- foamed aluminium, especially those with interconnected pores are highly efficient in ***sound absorption***: incoming sound is reflected inside the foam among the pores; the pore surfaces vibrate converting the sound into heat. A much reduced sound level is reflected back into the enclosed space. Sound absorbing material performance is defined by its absorption coefficient α (the ratio of the unreflected sound intensity at the surface to the incident sound intensity). The coefficient varies with frequency and angle of incidence. It is a function of material thickness, bulk density and pore size. Maximal sound absorption for preferred frequencies can be adjusted by the size of the air gap between foam and solid background (enlarging the air layer shifts the α-maximum toward lower frequencies). Comparison of sound absorption coefficient of open-cells foamed aluminium, bulk aluminium, glass fibre matte and PU-foam is given in Fig.4.

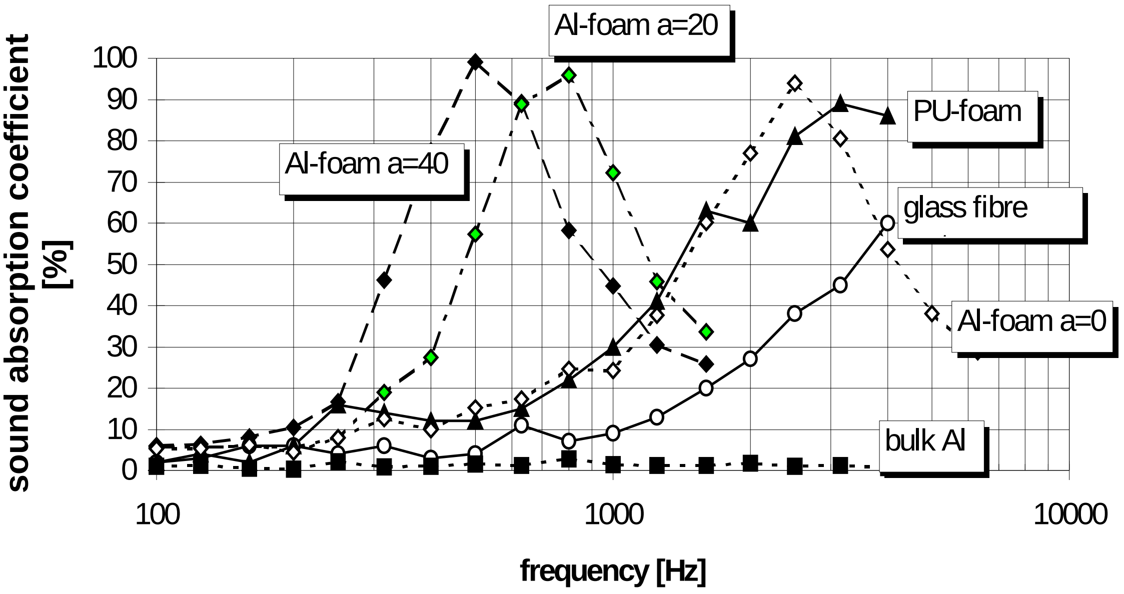

Fig.4 *Sound absorption coefficient of different foamed aluminium of 0.5 g/cm^3 with open cell structure at different "a"-depth [mm] of the air cavity between the sample and solid background compared with bulk aluminium, PU-foam and glass fibre mat.*

The foamed aluminium is ***ecologically harmless***. During the foaming process only hydrogen gas is released which burns to water immediately. The foams are able to be fully recycled and even secondary aluminium alloy powder may be used for the foam production [6].

POTENTIAL APPLICATIONS OF FOAMED ALUMINIUM

- self supporting, super light weight panels for transport and in buildings
- heat resistant, isotropic and stiff cores for doors, ceilings and wall panels
- cores for sandwich structures in marine or aircraft industries
- isotropic properties, non combustibility, form stability and simple recycling make it an alternative to wood (note: no problems from wood pests)
- as stiffening in hollow materials against buckling
- heat exchangers, filters, catalysts
- heat shields and encapsulation
- floating structures needing to withstand high temperatures and pressures e.g. floats for liquid level control in chemical processes
- car body parts to deform as protection for passengers (also from the sides)
- safety pads for lifting and conveying systems
- protective covers for high-speed rotating machines
- inflammable packaging for fragile goods
- housing for electronic devices providing electromagnetic and thermal shielding
- noise encapsulation and sound absorption under difficult conditions (high temperature, moisture, dust, flowing gas, vibrations, sterile environment)
- sound absorption in rooms where inflammability is vital (aircraft, hotels, commercial buildings, etc.)

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