ALULIGHT - HIGHLY POROUS FOAMED ALUMINIUM PANELS WITH OUTSTANDING PROPERTIES AT LOW DENSITY

František SIMANČÍK [1], Walter RAJNER [2], Jaroslav JERZ [1]

[1] Institute of Materials and Machine Mechanics
Slovak Academy of Sciences, Bratislava, Slovakia
Račianska 75, 831 02 Bratislava 3, SLOVAKIA

[2] Alulight International GmbH, Ranshofen, Austria
Lach, A - 5282 Ranshofen, AUSTRIA

Keywords:

aluminium foam, foamed panels, foam cored sandwiches, reinforced foams

Abstract

The foamed aluminium panels and sandwiches with aluminium foam core can be potentially used in automotive industry, especially for lightweight stiff body structures of vehicles. In this case very high stiffness-to-weight ratio of these panels could be beneficial. In distinction to standard sandwiches foamed panels can be shaped and manufactured at lower costs. The fracture resistance but also damage tolerance and energy absorption capacity of panels can be significantly improved by reinforcing with metallic wires or nets like concrete with only little weight increase (about 20% for 15 mm panel thickness). Usually, it is sufficient to reinforce only the tensile loaded surface of foamed panel. The liquid foam adheres to the solid material in the course of expansion, forming a diffusion bond. This type of bonding provides a certain formability of the panels and results in a significant improvement of the mechanical properties and the thermal stability in comparison with glued or brazed sandwiches. One of the attractions of this process is that the reinforced panels or sandwiches are prepared in one technological operation what significantly reduces manufacturing costs.

INTRODUCTION

The foamed aluminium panels and sandwiches manufactured using powder metallurgical (PM) technique represent new class of structural materials possessing enormous application potential in lightweight construction, mainly as an alternative to wood, plastics or various expensive sandwiches. Several of their properties are superior to those of polymeric foamed panels; they are stiffer by an order of magnitude, they are stable at elevated temperatures, they possess superior fire resistance and do not evolve toxic fumes in a fire. They can be potentially used in transport industry for lightweight stiff body structures of busses, trains, ships, cars, etc. The fracture resistance, damage tolerance and energy absorption capacity of panels can be even improved by reinforcing of their surface with steel wires or meshes without enormous increase of manufacturing costs.

PRODUCTION OF ALULIGHT PANELS

Aluminium foam produced by PM method recently developed at Institute of Materials and Machine Mechanics of the Slovak Academy of Sciences for the Austrian company MEPURA GmbH has a tradename ALULIGHT. The method (**Fig. 1**) comprises dry blending of metal powders (aluminium or its alloys) with particulate foaming agents (typically TiH_2 and ZrH_2), cold compacting and then hot extruding at about 400-480°C. The foaming agent thus becomes uniformly distributed and gas-tightly embedded in the metal matrix. The extrusion process is useful in helping to break up the oxide films on the surface of the metal powders, which facilitates consolidation. The product may be considered as a precursor material, itself not far from full density but readily convertible to a foam. This conversion is effected by simply heating the precursor to a temperature at which the alloy is liquid. The foaming agent evolves gas, thus creating a foam which is stabilised by very fine oxide particles uniformly distributed throughout the precursor after extrusion. After melting and foaming, the foamed panel is rapidly cooled to prevent collapse of the foamed structure. This technique needs special thin walled moulds withstanding temperature changes. Larger parts such as shaped panels are therefore foamed in special set-up that provides simultaneous moulding, heating and cooling. The foamed panels can be reinforced by metallic wires or nets like a concrete. In this case the reinforcing components (made of steel) are inserted in the mould together with foamable PM-precursor before foaming.

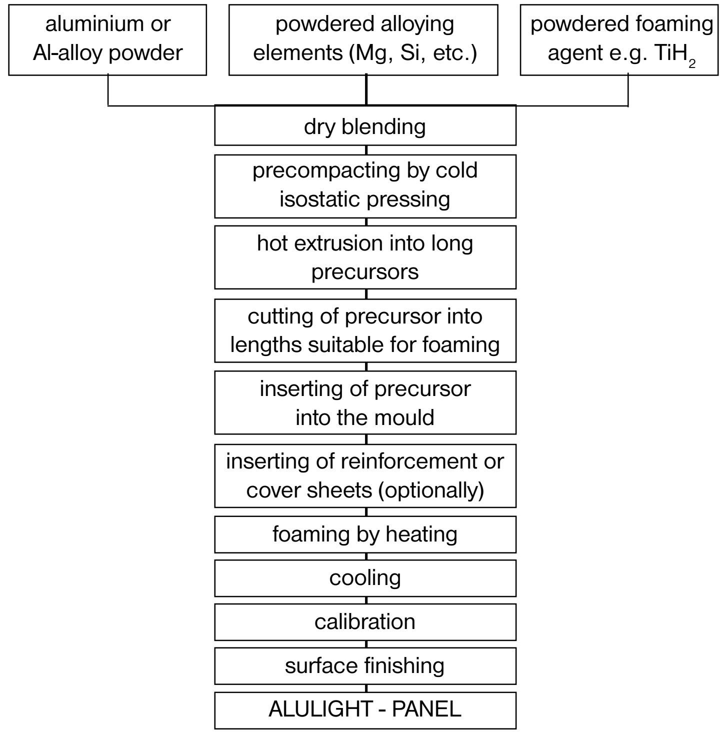

Figure 1: Typical steps of PM process for manufacturing Alulight - panels

CHARACTERIZATION OF FOAMED PANELS

The properties of panels depend on aluminium alloy used. The panels can be manufactured from different wrought or cast aluminium alloys, primarily from:

- commercially pure aluminium
- wrought aluminium alloys of 6000-Series
- cast aluminium alloys based on the AlSi12 alloy

Mechanical properties of panels can be optimized by appropriate heat treatment of the alloy after foaming.

Foamed sandwiches can also be produced with plain or shaped aluminium or steel cover sheets (**Fig. 2**) either on one or both sides if higher bending strength or specific surface quality is required. Another possibility is to reinforce foamed panel with metallic wires or nets like a concrete (**Fig. 3**). The reinforcement is always diffusion bonded to the foam structure. One of the attractions of technological process is that the reinforced panels or sandwiches are prepared during foaming in one technological operation what significantly reduces manufacturing costs.

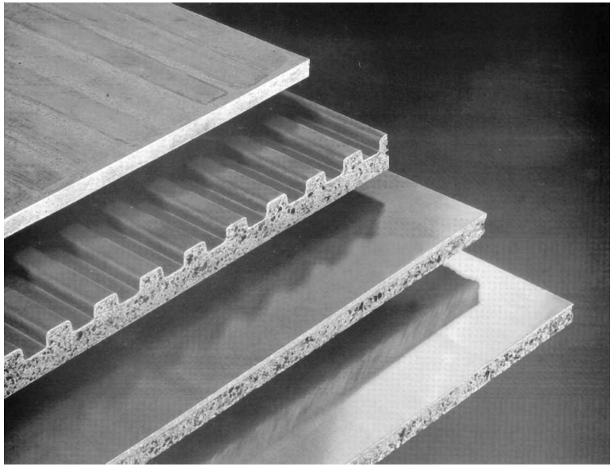

Figure 2: Al-foamed panels and sandwiches

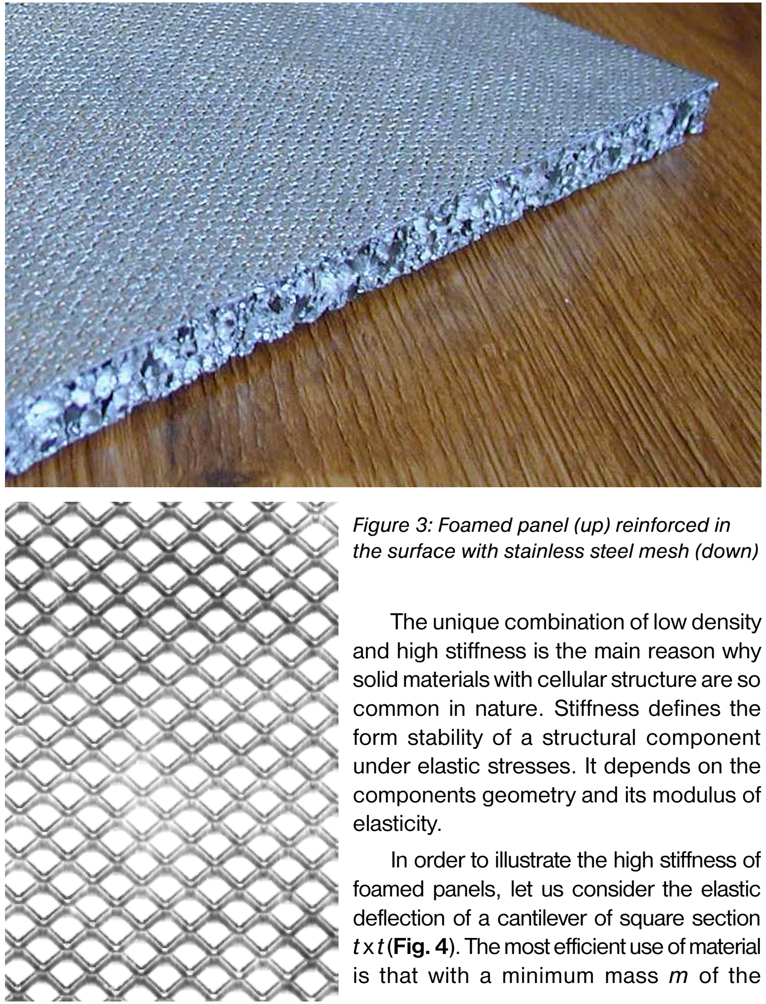

Figure 3: Foamed panel (up) reinforced in the surface with stainless steel mesh (down)

The unique combination of low density and high stiffness is the main reason why solid materials with cellular structure are so common in nature. Stiffness defines the form stability of a structural component under elastic stresses. It depends on the components geometry and its modulus of elasticity.

In order to illustrate the high stiffness of foamed panels, let us consider the elastic deflection of a cantilever of square section $t \times t$ (**Fig. 4**). The most efficient use of material is that with a minimum mass *m* of the cantilever, under the condition that a given load *F* causes a given deflection δ.

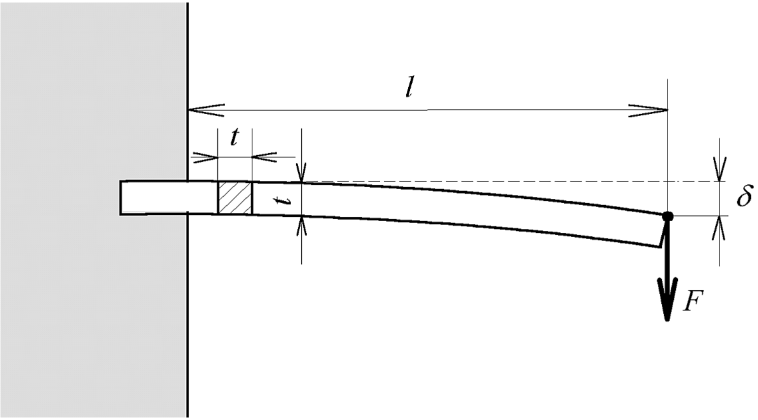

Figure 4: The elastic deflection of a cantilever of square section.

The elastic deflection δ of a cantilever is related to the modulus of elasticity of the material *E*, the load *F* and geometry of the cantilever given by the moment of inertia *J* by equation:

$$\delta = \frac{Fl^3}{3EJ} \quad (1)$$

and the mass *m* of the cantilever is given by:

$$m = lt^2 \rho \quad (2)$$

where ρ is density of the cantilever. Because the moment of inertia for a cantilever of square section $J = t^4/12$, using Eqs. (1) and (2) eliminating *t* we obtain:

$$m = \sqrt{\frac{4Fl^5}{\delta}} \cdot \sqrt{\frac{\rho^2}{E}} \quad (3)$$

The mass of the cantilever with the fixed geometry at constant F/δ ratio could be minimized by choosing a material with a maximum E/ρ^2 ratio. It can be seen from Eq. (3), that there are two ways to minimize the mass of the cantilever:

- high modulus of elasticity E of the cantilever
- low density ρ of the cantilever

Material	Density ([kg.m^{-3}]	Modulus of elasticity E [Gpa]	E/ρ^2 [GPa.kg^{-2}.m^6.10^{-5}]
steel	7800	210	0.3
aluminium alloys	2700	70	1.0
magnesium alloys	1800	45	1.4
Al-foam	500	5	2.0

Figure 5: Modulus of elasticity and density of conventional structural materials in comparison with Al-foam.

The comparison of various conventional structural materials used in automotive vehicle design at present with aluminium foam is described in **Fig. 5**.

The foamed panels can be machined as easily as wood, using conventional techniques like sawing, drilling, turning, etc. They can be nailed, screwed, bolted or joint using connection elements built in the foamed structure. The panels can also be soldered at temperatures below the melting point of base alloy. It should be noted that the very thin surface skin will be removed by machining revealing the inner pore structure.

MECHANICAL PROPERTIES OF ALULIGHT PANELS REINFORCED WITH STEEL MESH

The natural skin of aluminium foams has variable thickness and sometimes contains small holes or even cracks. This problem can be solved very effectively by reinforcing of tensile loaded surface skin with metallic or ceramic wires woven into grids with various mesh size. According to a novel foaming technique developed recently, the reinforcements are placed in the foaming mould together with foamable precursor, foam expansion moves them to the mould surface where they are infiltrated with molten cell-wall material. The main advantage of this method is the simplicity, lower manufacturing costs and the possibility to reinforce the foamed part selectively and anisotropicly according to the applied load. The stresses which usually cause the yielding or even fracture of surface skin can be overtaken by reinforcements. Thus the stiffness, strength, plasticity and damage tolerance of foamed parts can be significantly improved without excessive weight increase.

The bending stiffness of reinforced aluminium foam panels has been tested by four point bending tests. As can be seen from **Fig. 6** the bending stiffness as well as the fracture resistance of panels can be significantly improved by reinforcing with steel meshes, especially if it is placed on tensile loaded surface.

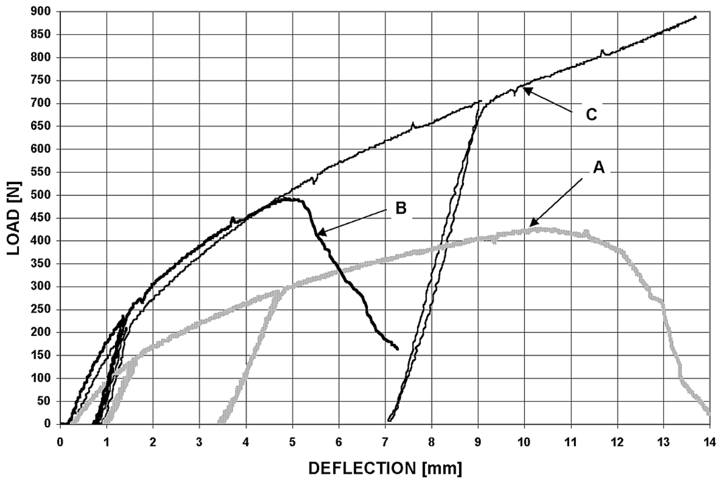

Figure 6: Four point bending test of aluminium foam panels (sample thickness 15 mm, width 50 mm, length 400 mm, cross head speed 10 mm/min, span between supports 150/300 mm)

A - without reinforcement, density 400 kg.m^{-3}

B - upper surface reinforced with steel mesh (3,4 kg.m^{-2}), apparent density 600 kg.m^{-3}

C - bottom surface reinforced with steel mesh

Improving of crash performance of Al-foam by reinforcing has been tested by impact hammer tests. Foam without reinforcement failed almost without any reduction of kinetic energy. Moreover if the reinforcement is used all kinetic energy is absorbed by the deformation of the foam without sudden fracture. In this case the reinforcing of tensile loaded side is preferable.

The main effect of reinforcements can be summarized as follows:

Reinforcements have a positive influence on:

- damage tolerance
- bending strength (especially in case that the tensile loaded surface is reinforced)
- impact energy absorption
- bending stiffness (especially in case of thin Alulight panels)
- simplicity to join the Alulight panels

Of course the use of reinforcements is accompanied also with some difficulties:

- more complicated recycling
- potential problems with corrosion resistance
- inner stresses in the structure
- slightly higher weight (20 - 30 %)

CONCLUSION

The main aim of the paper was to present an application potential of foamed aluminium panels and sandwiches with aluminium foam core in automotive industry. The extraordinary high stiffness-to-weight ratio and energy absorption capacity of panels could be beneficial. The fracture resistance and damage tolerance can be significantly improved without excessive weight increase by reinforcement with metallic wires, nets or meshes either on one or both panel surfaces. Moreover, the reinforced panels can be easily joined which open them an enormous potential for applications in automotive industry especially for lightweight body structures of future cars.

ACKNOWLEDGEMENTS

The financial support of Alulight International G.m.b.H., Ranshofen, Austria and Alulight Deutschland G.m.b.H., Aalen - Wasseralfingen, Germany is gratefully acknowledged.

REFERENCES

1. Allen, B.C.: US Patent 3 087 807, 1963.
2. Gibson, L. J. and Ashby, M. F.: Cellular Solids, Pergamon Press, Oxford, 1988.
3. Simančík, F.: In. Metal Foams and Porous Metal Structures, Ed. by J. Banhart, M.F. Ashby, N.A. Fleck, Verlag MIT Publishing, Bremen, 1999, p. 235.
4. Ashby M.F. et al.: Metal Foams and Design Guide, Cambridge Centre for Micromechanics, UK, 1998.
5. Jerz, J.: Foamed Aluminium and Aluminium Alloys Prepared by Powder Metallurgy, PhD thesis, TU Vienna, 1995.
6. Lorenzi, L. and Fuganti, A.: Aluminium foam applications for impact energy absorbing structures. SAE technical paper N. 970015.
7. Alulight - outstanding properties, product data sheet, Alulight International G.m.b.H., Ranshofen, Austria.