# PM TECHNOLOGY AND MECHANICAL PROPERTIES OF METALLIC FOAMS

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## Abstract

A new powder technological method for manufacturing lightweight materials is described. Aluminium or aluminium based alloy powder and an appropriate foaming agent are processed into a semi-finished product which can be made to expand in order to form a metallic foam of very low density. Mechanical, electrical, thermal and technological properties in general are discussed.

Keywords: metallic foam, lightweight construction, energy absorber

## 1 Introduction

In almost any range of industrial application new materials for lightweight structures are highly desired. Using foamed metals with porosity values exceeding 50% this requirement can be met.

In the past metallic foams have been prepared by adding a foaming agent to the molten metal after carefully adjusting the viscosity of the melt (Refs. 1,2). Because the gas is released instantaneously as soon as the foaming agent comes into contact with the melt this process is very difficult to control and leads to undesirable large cell sizes (Ref. 3).

A new powder metallurgical method for the preparation of metallic foams was developed (Ref. 4) which allows to produce highly porous parts with porosities up to 90%.

## 2 Preparation method

For the production of aluminium foams commercial powders of aluminium or alloys thereof are mixed with a foaming agent and subsequently compacted. As a result a semi-finished product is obtained in which the foaming agent is distributed very homogeneously within a dense, non-porous metallic matrix. This foamable material can be processed into sheets, rods, profiles etc. by conventional techniques like rolling, swaging or extrusion. Finally, foamed metal parts are obtained by merely heating up the material to the respective melting point or to a temperature above. The density of metal foams can be controlled by adjusting the content of the foaming agent and several other foaming parameters. If metal hydrides are used as foaming agents a content of less than 1% is sufficient in most cases. Due to its closed porosity aluminium foam floats upon water.

## 3 Properties of the semi-finished product

As already mentioned the compacted material can be processed into sheets for example by rolling. Even warm rolling can be employed if the decomposition temperature of the foaming agent is taken into account. In **table 1** some mechanical properties of foamable sheets of pure aluminium (99.5% purity) are compared to conventional aluminium of comparable purity and comparable heat treatment.

Some further technological features are important to note: The heating rate during the foaming process is not a critical parameter. On the other hand, when heating rates much less than 10K/min are employed and metal hydrides are used as a foaming agent there is a chance for the hydrogen to escape by means of diffusion. In this case pore formation will be reduced so that the volume increase

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| | $Al99.5+TiH_2$ | Al99.5* |
|---|---|---|
| fracture strength | 176–178 MPa | min. 140 MPa |
| yield strength | 138–148 MPa | min. 125 MPa |
| fracture strain | 6,8–11,2 % | min. 4 % |
| hardness HB | 48±2 | 45 |
| density | 2.7 $g/cm^3$ | 2.7 $g/cm^3$ |

*) according to NF A50-411, H18

Table 1: *Mechanical properties of the semi-finished product*

due to foaming will be reduced.

The use of foamable semi-finished products permits fabricating complex shaped formed parts. Arbitrarily shaped moulds can be filled with metallic foam by inserting the material into them and subsequently heating up thus making the foam expand. It was found that thin-walled moulds are particularly advantageous because these allow for a close temperature control of the expansion process.

Using appropriate heating methods it is possible to expand metallic foams selectively. This means that certain regions of the material can be kept at a high density which will facilitate the joining to other materials. In fact integral foams — as they are known from polymer foams — have also been obtained with aluminium and are characterized by a high porous core and an outer skin with higher density.

# 4 Properties of aluminium foams

The most prominent property of foamed aluminium is its low density. The density values usually are in the range between 0.5 and 1 $g/cm^3$ although even lower values down to 0.2 $g/cm^3$ can be achieved.

Mechanical testing of foams is usually done in compression. In **figure 1** the stress-strain relationships of three foams are shown. It is obvious that the strength of aluminium foams increases with increasing density. Furthermore it can be seen that foams of an aluminium alloy have a higher strength than foams of pure aluminium as it is the case for the dense conventional material, too.

Like most polymer foams highly porous me-

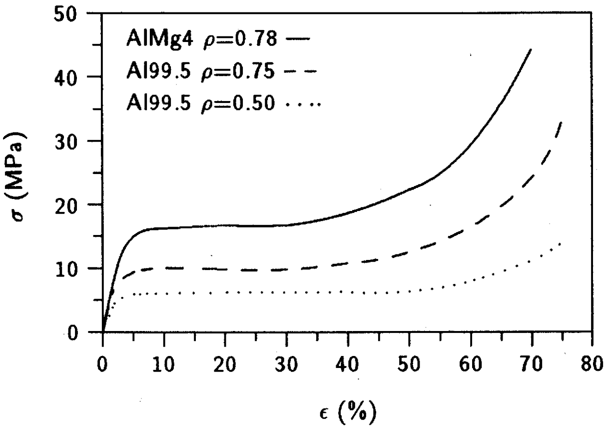


Figure 1: *Stress $\sigma$ – strain $\epsilon$ behaviour of various metallic foams*

tals have a high capacity for absorbing mechanical energy by deformation. The reason for this is the special shape of the stress-strain curve, which usually exhibits a broad plateau. Within this plateau regime work is done by deformation without a significant increase of the resulting stress. So the object to be protected does not experience inadmissibly high acceleration forces. Only after the porous structure has been densified upon compression a further increase of stress is observed.

The typical stress-strain behaviour of metallic foams is shown in **figure 2**. The shaded area below the curve represents the true amount of energy which is converted into deformation work. Contrarily, an ideal absorber would exhibit a rectangular curve shape, the area of which is defined by the maximum stress and strain values. Therefore the effectiveness of an energy absorber for a given strain value is defined as the ratio of the area below the real curve $A_{\text{real}}$ and the area of the rectangle $A_{\text{ideal}}$ for the ideal absorber:

$$\eta(\epsilon) = \frac{A_{\text{real}}(\epsilon)}{A_{\text{ideal}}(\epsilon)}$$

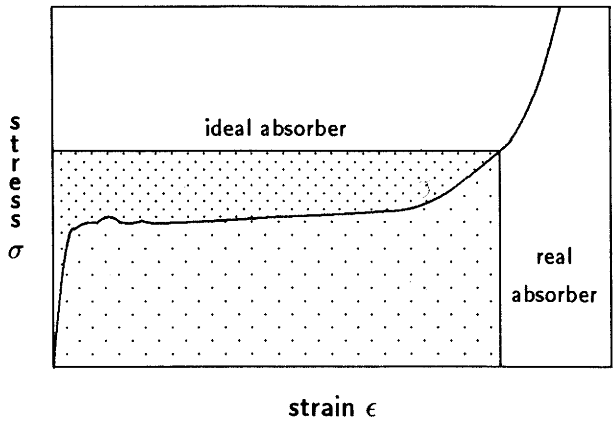


Figure 2: *The effectiveness η of an energy absober is defined as the ratio of the area below the compression curve and the area of the rectangle*

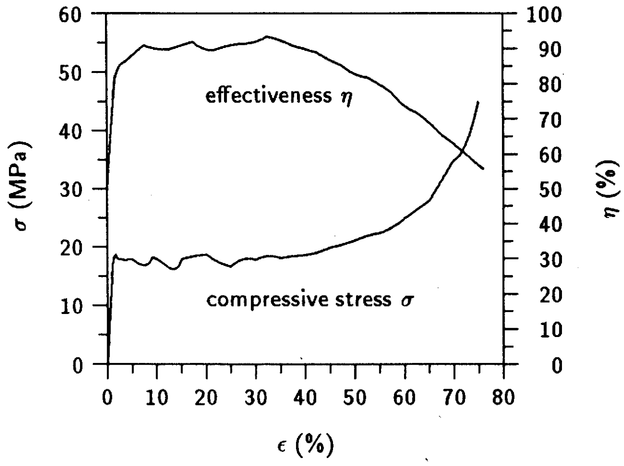


Figure 3: *Compressive stress σ and effectiveness η of an aluminium foam AlCu4Mg0.7, density 0.48 g/cm*$^3$

In **figure 3** a compression test of an aluminium foam with composition AlCu4Mg0.7 is depicted as well as the corresponding values for effectiveness. Because the actual curve approximates the rectangular shape of an ideal absorber to a high degree we observe an effectiveness of about 90% within the plateau regime. Of course, when the flow stress increases due to densification of the porous structure the effectiveness is greatly reduced.

Further properties of metallic foams are the non-combustibility and good machinability. The fact that foamed metals are fully recyclable will be of increasing importance for future applications.

A rough estimation of the thermal and electrical conductivity of metallic foams using a simple model with a cubic open pored unit cell leads to the following equation:

$$\lambda_f = \frac{1}{3}\frac{\rho_f}{\rho_s}\lambda_s$$

where $\rho_f$ and $\rho_s$ are the density of the foamed and the solid metal, respectively, and $\lambda$ is the thermal conductivity. For a closed pored model the factor 1/3 in the equation above has to be replaced by 2/3. The same relationships hold for an estimate of the electrical conductivity, because both are related by the Wiedemann-Franz law. Measured values show that a mixed model of open and closed pored structures describes the results best. Nevertheless it has to be noted that contributions due to radiation and convection within the pores are neglected in this simple model.

It is hoped that highly porous metallic foams will exhibit good damping characteristics. If this is true it will be possible to fabricate parts of low weight combined with a high capacity for damping of vibrations.

# 5 Applications of metal foams

Obviously the primary application range for metallic foams based on aluminium will be lightweight construction and energy absorption. A further potential is to be seen in fire protection as well as in insulation of thermal or vibrational energy.

By modifying the preparation technology it should be possible to obtain open pored aluminium foams, too. In this case there are several additional applications in the range of heat exchangers, filters and catalyst carriers. For this reason investigations of foamed metals also will be extended in this direction.

# References

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