Methods for the production of metallic foams

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Abstract: Metallic foams can be produced by several methods including powder metallurgy, casting and deposition techniques. The various methods are described and analysed. Obviously a powder metallurgical approach exhibits a high potential for manufacturing foamed shaped parts. This approach also can be used to produce composite materials made of conventional and foamed metals. The mechanical properties of foamed aluminium prepared by several different methods are compared. Based on the available data the dependence of mechanical properties on the apparent density is analysed. The types of dependence found are compared to the predictions of a theoretical model. From the properties of foamed metals the potential applications are derived.

1. Introduction

In almost any range of industrial applications new materials for lightweight structures are highly desired. This requirement can be met by using foamed metals with a porosity exceeding 50% and a cellular structure. From nature (e.g. woods, bones) and polymeric foams (e.g. PU-foams) it is well known that cellular materials exhibit a high stiffness combined with a very low specific weight [1]. This is also true for foamed metals so that in the past several attempts have been made to establish a production method for highly porous cellular metals.

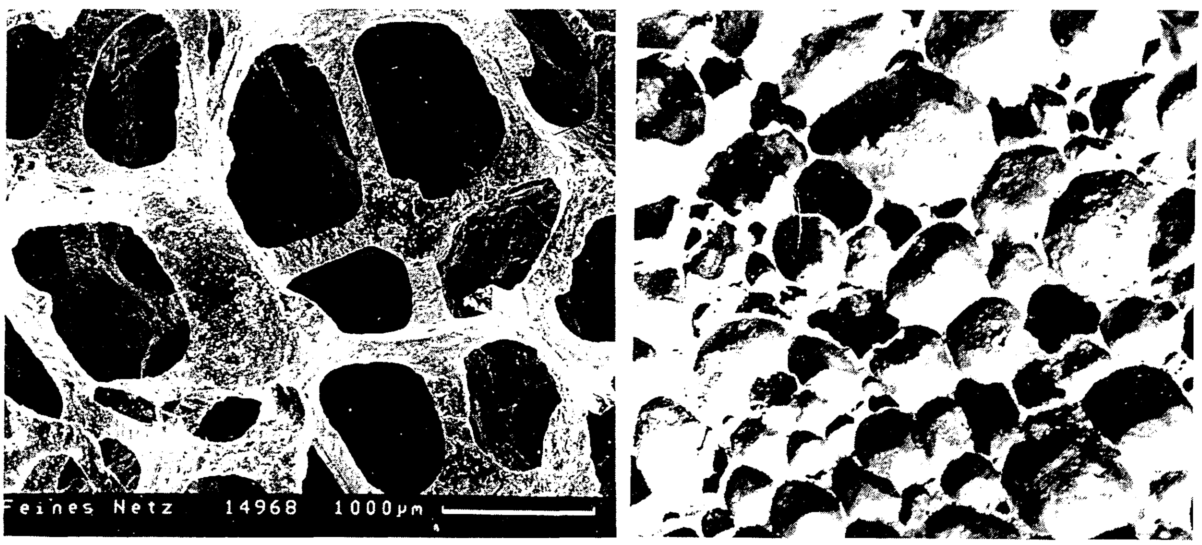
2. Manufacturing processes

The different methods for the production of foamed metals can be devided into three main categories: casting, deposition techniques and powder metallurgy.

2.1. Casting

A number of methods for the production of aluminium foams have been proposed, all of them starting from a pool of molten metal. Since a pure melt is not foamable it is necessary to modify the melt. This can be done by certain additions e.g. Ca [2], SiC [3, 4] or by stirring the melt for long times. After modification of the aluminium melt foaming of the melt is effected either by blowing gas or air into the molten metal or by introducing and distributing a gas releasing compound e.g. metal hydrides. The foaming melt is now solidified by cooling the entire foaming vessel [2] or can be drawn off from the melt

surface to solidify on a separate conveyer belt [3, 4]. The density range covered by these processes ranks between 0.05-0.54 g/cm^3 [3, 4, 12] and 0.27 g/cm^3 [2, 5].
An alternative approach comprises casting of an aluminium melt around granules of expanded clay or vermiculite, where some care has to be taken to avoid floating of the lightweight granules [6]. After solidification a composite material consisting of the vermiculite granules embedded in an aluminium matrix is obtained, the entire body having a density of about 1.4 g/cm^3 [7].
While the above mentioned processes lead to closed pore structures it is also possible to obtain aluminium foams with an open pore or skeletal structure. For this the pores of an open cell plastic foam are filled with a heat resistant material. This composite material is then heated in order to vaporise the polymeric component so that a mould having the inverse pore structure of the original plastic foam is obtained. Molten aluminium is cast into this mold and solidified. After removing of the heat resistant mould material the metallic foam has the same appearence as the original plastic foam. In this way aluminium foams with densities in the range from 0.16 to 0.32 g/cm^3 can be produced [8]. A SEM picture of this open pore skeletal foam is shown in Fig. 1a).



(a) (b)

Fig. 1a): SEM-Micrograph of the open pore skeletal foam DUOCEL [8]
Fig. 1b): Section of the closed pore aluminium foam FOAMINAL [16]

2.2. Deposition techniques

A well known method in this category comprises the metallisation of an open cell polyurethane foam. For this the precursor plastic foam is reticulated to destroy all residual membranes in the foam and subsequently coated with an electrically conductive layer by immersing it into special graphite solutions, by electroless plating or by PVD-techniques. The precoated foam can than be electroplated to the desired thickness [9]. In a final step the polyurethane substrate foam has to be removed by thermal decomposition or vaporisation. Although this method can be applied to a number of metals it is expensive and not applicable for production of aluminium foams.

2.3 Powder metallurgy

A common method for production of porous materials with an open or interconnected porosity uses sintering of loose metal powders. The powders are filled into a mould and sintered under conditions which preserve a maximum amount of porosity. Depending on size and shape of the metal powder particles relative densities in the range from 40 to 60% can be obtained. Even higher degrees of porosity can be attained by using spacing agents which are removed during or after the sintering process. For example, using fine nickel powders and methyl-cellulose as spacing agent high porosities of up to 70 to 90% can be achived [9].

Another method comprises foaming of a slurry consisting of fine aluminium powder (<400 mesh) and an organic vehicle. Foaming of the slurry is effected by whipping or by a chemical reaction. The foamed slurry is dried and subsequently cured for 2 hours at 100°C to increase the mechanical strength of the foam. Nevertheless, since a metallic bonding between individual particles cannot be achieved by this method the resulting strength of the aluminium foams is poor [10].

In 1990 a new process was developed [11]. According to this method commercially available powders of aluminium or aluminium alloys are mixed with a foaming agent by conventional means, e.g. using a tumbler mixer. In this simple manner a very homogeneous distribution of the gas releasing powder is obtained. Subsequent to mixing the powder blend is compacted to give a dense, virtually non-porous solid aluminium semi-finished product. Several compaction methods can be employed which range from uniaxial pressing over powder extrusion to roll compaction. The result of the densification step is a foamable material, which can be processed by conventional techniques like rolling, swaging or extrusion to give rods, sheets, profiles etc. of desired shape. During a final heat treatment at temperatures above the melting point this material expands into a highly porous cellular solid with a closed pore structure. For this reason it is also possible to obtain complex shaped foamed articles by filling hollow moulds with the foamable material and subsequently heating to effect foaming. The densities obtained by this method usually are in the range from 0.5 to 1.0 g/cm^3, although values down to 0.2 g/cm^3 can even be achieved. Fig. 1b) shows the closed pore structure of this material.

3. Properties of aluminium foams

Unfortunately on the properties of foamed aluminium only very few data are available and concentrate on strength values determined by compression testing. The strength of foamed metals depends on several parameters of which the apparent density is the most important. The choice of the matrix alloy, the temper condition and the morphology of the foam also have a significant influence on the mechanical strength properties. Due to the scarcity of data only the influence of the apparent density on the compressive strength could be investigated neglecting all other influencing factors.

A simple model of a foam with a cubic unit cell leads to the following expression for the strength of cellular solids [1]:

$$\sigma_f = \sigma_{ys}\left[0.3\left(\phi\frac{\rho_f}{\rho_s}\right)^{3/2} + (1-\phi)\left(\frac{\rho_f}{\rho_s}\right)\right] \quad \text{for } \rho_f < 0.3\rho_s \qquad (1)$$

where ϕ describes the contribution of the material in the cell edges and $(1-\phi)$ that of the cell faces or membranes. The index "f" denotes properties of the foamed metal, the index "s" that of the solid matrix material.

The own results and the data reported in literature are summarised in Fig. 2. A non-linear dependence of strength upon density is obvious. Quantitative analysis of all data to check the predicted power law according to (1) will not be reasonable because a) different types of alloys are used; b) some of the foams contain reinforcing particles, others do not; c) due to the different manufacturing processes different foam morphologies are obtained leading to different values for the parameter ϕ.

Nevertheless it can be seen that using the P/M method [11, 16] a wide density range can be realised. Furthermore it should be pointed out that this method offers a great variability regarding the choice of alloys and even particle reinforced foams can be produced.

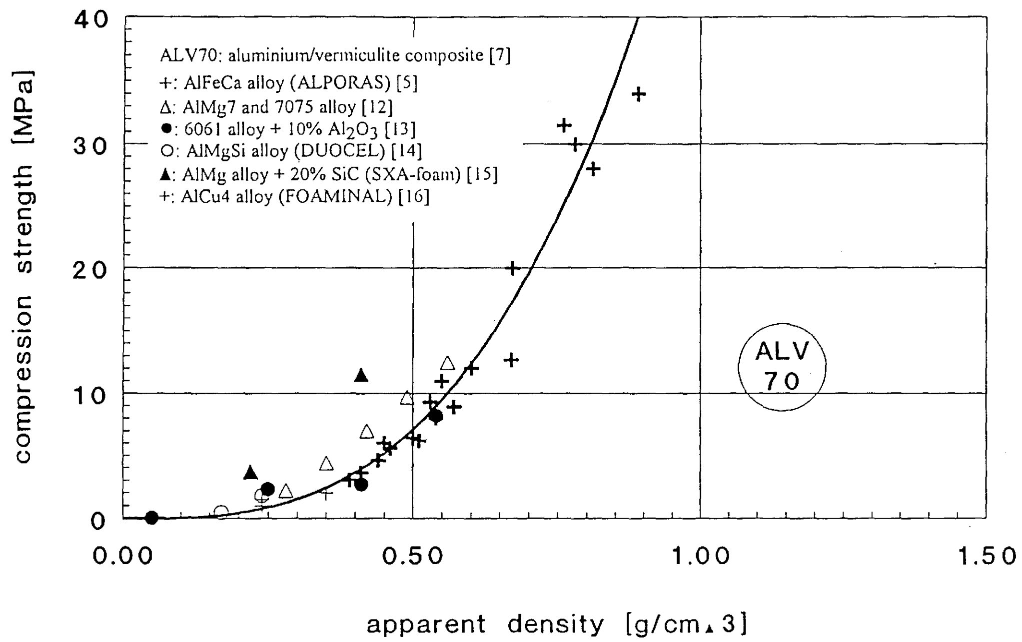


Fig. 2: Comparision of different aluminium foams and their dependence on apparent density

4. Applications of aluminium foams

An important application range for metallic foams will be energy absorption. Using suitable elements of aluminium foams it will be possible to induce a controled, programmed deformation of the crashed zone with maximum energy consumption.

Due to its low specific weight foamed aluminium will be used for lightweight constructions. As an example the replacement of honeycomb structures by foamed aluminium sheets will lead to reduced costs. A further potential is to be seen in fire protection as well as insulation of thermal or vibrational energy.

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