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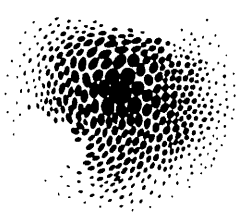

Metal foams under extreme conditions

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Abstract

A powder metallurgical process for the production of metal foams is described. Physical and mechanical properties of aluminium foams are presented with focus on the energy absorption capacity. The dependencies of foam density and material on metal foam properties are described and thereby tools for tailoring the properties of given applications discussed. The foaming process is characterised by expansion and temperature diagrams and the influence of different foaming parameters discussed.

1. Introduction

Honeycomb structures and polymeric foams are already manufactured on a large scale by man, but are subject to restrictions concerning strength, temperature durability or environmental aspects. Materials which combine the properties arising from the cellular structure and the characteristics of metals such as high strength, conductivity or recycability are highly desired. Metal foams with porosity values exceeding 50 % can meet these requirements. Initiated by this demand for new lightweight materials, methods for producing metal foams have been investigated for a long time, most of them giving rise to difficulties concerning the competitiveness for large volume markets or technical problems. The various methods for the production of foamed metals can be divided into four main categories: casting, deposition, sputter technology and powder metallurgy. Recently a powder metallurgical production method for metal foams has been developed which shows a good potential for process control and reproducibility [1-5].

2. Manufacturing of aluminium foams

Commercially available powders of aluminium or aluminium alloys are mixed with low quantities of a likewise powdered foaming agent (e.g. 0.4% TiH_2). Thus, a homogeneous distribution of the gas releasing substance in the powder mixture is prepared. Afterwards, this powder mixture is compressed to a semi-finished product of nearly vanishing porosity. Provided that correct process parameters have been chosen, the result of the compression process is a foamable semi-finished product that expands during a subsequent heat treatment at temperatures above the melting point of the corresponding alloy. This way, the material develops its highly porous structure consisting of closed cells. This implies that within the foamable semi-finished product each particle of the foaming agent must be embedded in a gas-

tight metallic matrix. Otherwise, the evolving gas could escape prior to the beginning of the expansion through existing interconnected pores and thus would no longer be effective in producing and developing pores. This manufacturing process enables a direct production of near-net-shaped foamed metal parts with closed surfaces by filling adequately shaped hollow moulds with the foamable material and then heating up both the mould and the foamable material to the required temperature. It is also possible to fill complex shaped hollow structures with metal foams in order to reinforce the existing structure. The aluminium foam is ecologically harmless and can be fully recycled [1]. This process, initially developed for aluminium foams, has also been applied to other metals (Pb, Zn, Sn).

3. Properties of metal foams

The properties of cellular materials can vary widely, depending on three sets of parameters: the properties of the matrix material of which the cells are made of, the apparent density and the morphology of the cells. Like other cellular solids, aluminium foams are characterised by a very low specific weight. Using the P/M-technological approach, density values in the range between 0.5 and 1 g/cm^3 are usually obtained, although even values down to 0.2 g/cm^3 and up to 2 g/cm^3 can be achieved.

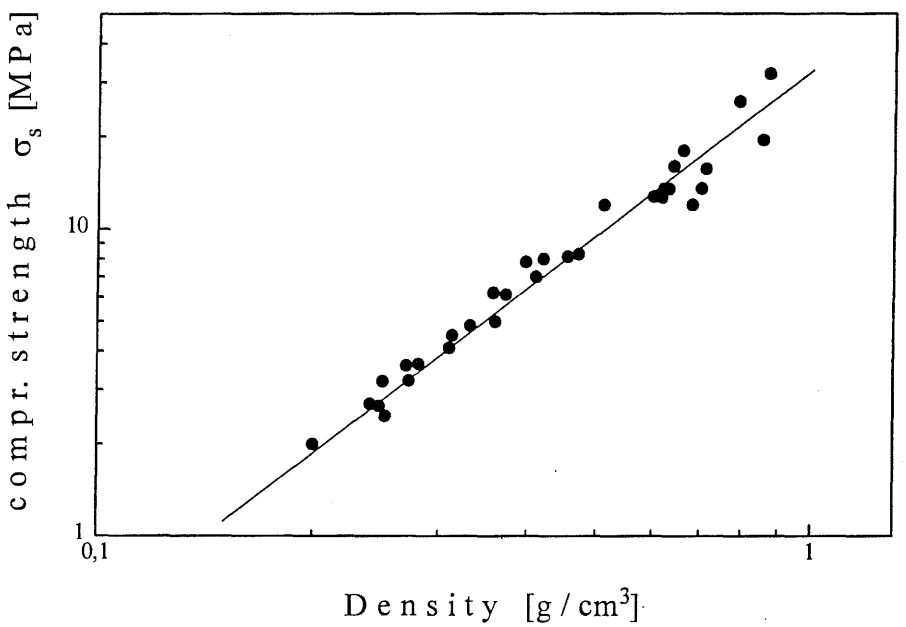

Fig. 1: Compression strength of AlSi12 foams after 20 % deformation

Significant testing of compressive yield strength, Young's-modulus, energy absorption and conductivity has been performed for foams of different density. Fig. 1 shows the data for the compression strength of AlSi12 foams plotted logarithmically vs. the foam densities. It was found that the evaluated properties obey a power law of the type

$$\varphi_f = \varphi_m \left(\frac{\rho_f}{\rho_m} \right)^n$$

Here φ_f is the foam property and φ_m the quantity of the respective base material, ρ_f is the foam density and ρ_m the density of the dense material. Examples for such power-laws have been measured for the compression strength, conductivity and Young's modulus by various authors [3-6]. The value of the exponent ranges between 1.5 an 2 which is in good agreement with values derived from theoretical models [3].

The foams exhibit a constant deformation stress during plastic deformation and this is the reason why they can absorb much more deformation energy than a piece of massive aluminium when both are loaded up to a given limited stress level. The major part of the absorbed energy is irreversibly converted into plastic deformation energy which is a further advantage of foamed aluminium. At the same stress level the dense matrix material is deformed in the regime of reversible linear-elastic stresses and releases most of the stored energy after the load has been removed. Decisive for the quality of packing protections or energy absorbers is the feature of being able to absorb energy without the maximum stress or the highest occurring acceleration exceeding an upper limit at which damages or injuries occur. The possibility of controlling the behaviour of stress and strain by an appropriate selection of matrix material, cellular geometry and relative density makes foams an ideal material for such applications. Compared to foamed organic materials, metal foams are more advantageous if, due to a small available design space, a higher deformation stress with the same or higher energy absorption is requested.

4. Foaming Process

A measuring instrument was constructed and built up which enables the in-situ measurement of foam temperature and density during the process. The expansion of an eutectic alloy is depicted in Fig. 2. As can be seen, the volume expansion takes place in four stages: first, before the melting temperature of the alloy (577 °C) is reached, the expansion is small resembling the volume increase also found for samples without foaming agent. The real expansion starts, when

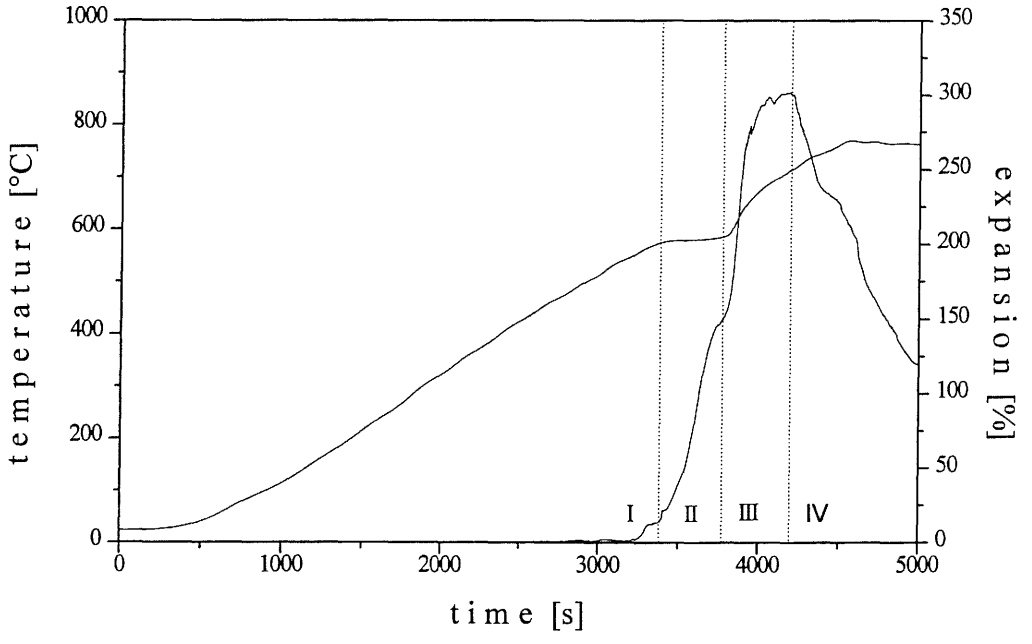

Fig. 2: Expansion characteristics of AlSi12 (heating rate 10 K/min)

the metal starts to melt and softens. The foaming agent decomposes at the same time and the released gas can inflate the pores. In this stage II the volume increases up to 2.5 times the initial volume. The expansion even accelerates as the liquidus temperature is exceeded and the now rising temperature causes a release of more and more gas (stage III). After the maximum expansion has been achieved, the foam collapses (stage IV) due to the now decreasing pressure in the cells as the foaming agent is exhausting and due to typical foam ageing processes.
The influence of different foaming parameters on porosity, homogeneity and foam stability are currently under investigation. Fig. 3 shows the expansion of AlSi12-foams with different contents of the foaming agent vs. foam temperature. Even if a first expansion is to be seen in the solid state, the real foam expansion starts with the melting of the eutectic alloy. It is only after the second stage of the expansion that higher expansion rates and earlier foam collapse are is to be found due to higher foaming agent contents.

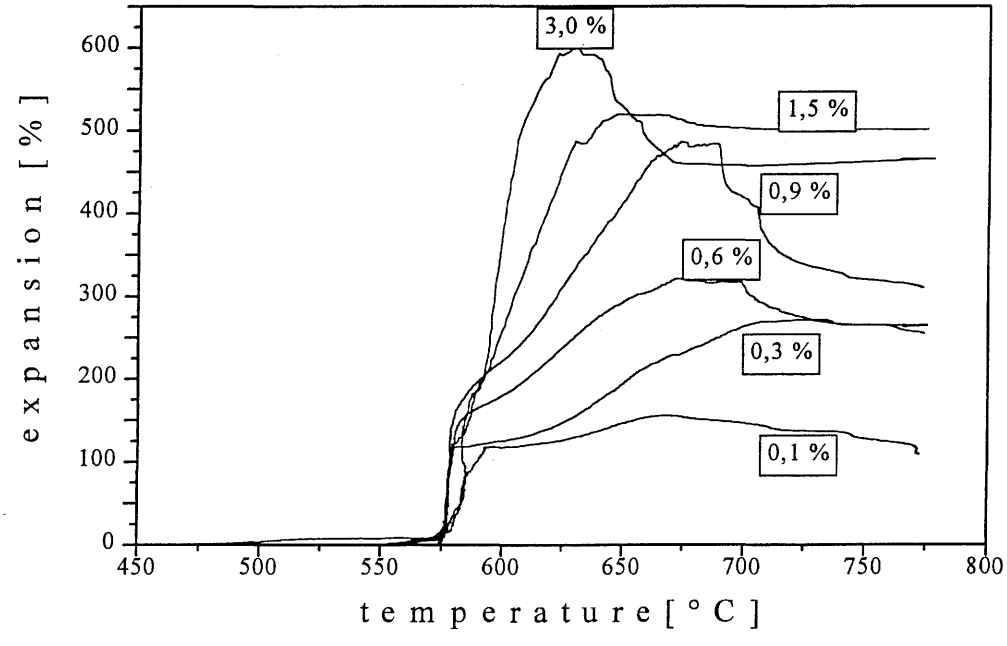

Fig. 3: Comparison of foam expansion (AlSi12) for different foam agent contents

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