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Energy absorption of foamed metals prepared by a powder metallurgical method

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Introduction

The increasing demands for safety of automobiles lead to a high vehicle weight in many cases. This is in conflict with the further demands for low fuel consumption, e.g.

For this reason materials with low specific weight and high energy absorption capability are highly desired. Foamed organic materials have a low specific weight but the amount of energy converted into deformation work is also low because of the insufficient strength of foamed plastics. On the other hand foamed metals – in particular foamed aluminium – exhibit strength values in the required order of magnitude.

Preparation method

In the past it has been shown that foamed metals can be produced by a powder metallurgical method (1,2). For the production of foamed aluminium commercial powders of aluminium or aluminium based alloys are mixed with a foaming agent and subsequently compacted. As a result a semifinished product is obtained in which the foaming agent is homogeneously distributed within a dense, virtually nonporous 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 the material to temperatures above the melting point of the matrix metal. The density of metal foams can be controlled by adjusting the content of 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.

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 Fig. 1 the compressive stress-strain curves of an aluminium foam (AlCu4 alloy, density 0.65 g/cm^3) and of a polyethylene foam (PE, density 0.12 g/cm^3) are compared. For better comparision the strength scale of the PE-foam was enlarged by a factor of 50. The initial porosity of both materials is about 75% to 80%. The curves show an approximately linear elastic regime at low stresses followed by a plastic collapse plateau, truncated by a regime of densification at high strains in which the stress rises steeply. Therefore both foams exhibit a behaviour which is typical for high porous, cellular solids (3).

Due to the special form of the compressive stress-strain curve foamed materials have a high capa-

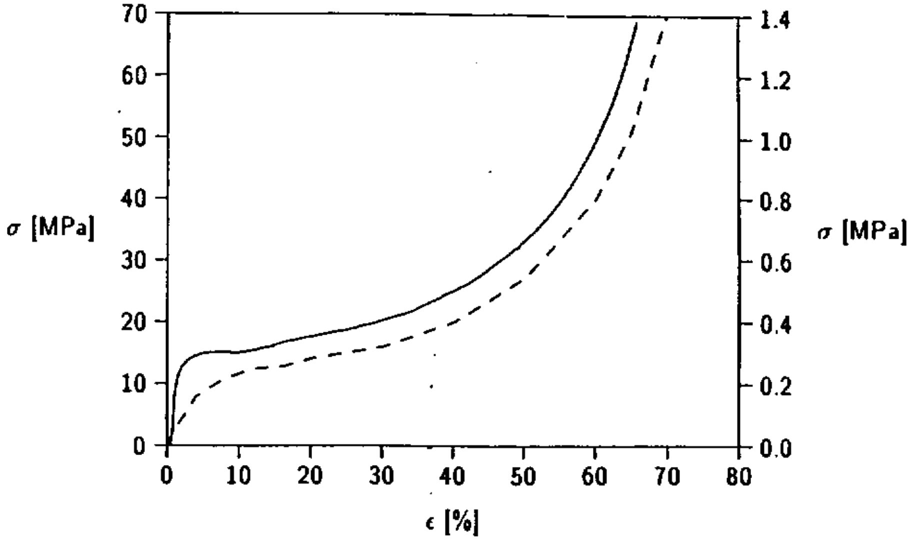

Figure 1: Stress-strain curve of an AlCu4-foam (solid line, left scale) and of a PE-foam (broken line, right scale)

bility of absorbing great amounts of energy at a relatively low strength niveau. The real absorbed energy per unit volume of an energy absorber is given by the area below the respective curve. Therefore an ideal absorber would exhibit a rectangular stress-strain curve. Obviously real absorbers just can approximate this behaviour so that it is reasonable to define the effectiveness η of an energy absorber as the ratio of the real absorbed energy to the ideally absorbed energy. This is illustrated in Fig. 2 where the stress-strain curve of a real absorber is compared to that of an ideal absorber.

In Fig. 3 a compression test of an aluminium foam with composition AlCu4Mg0.7 and a density of 0.48 g/cm^3 is depicted as well as the corresponding values for effectiveness. Because the actual

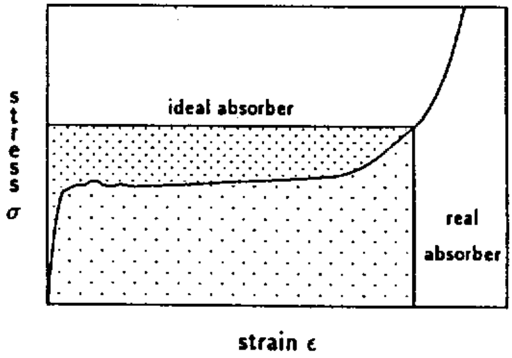

Figure 2: Comparision of real and ideal energy absorbers

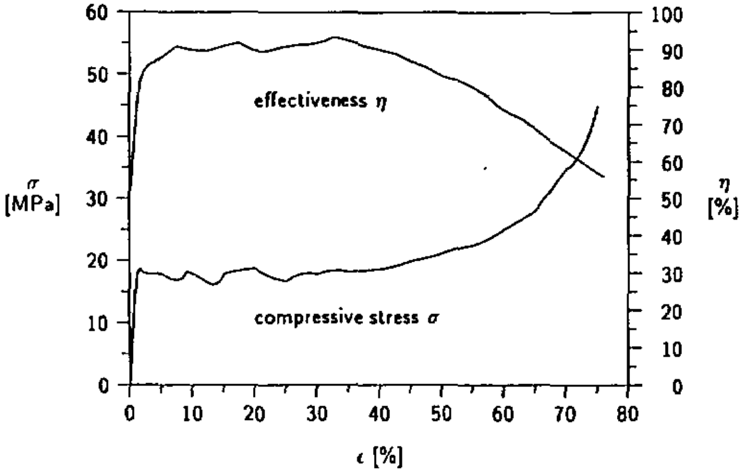

Figure 3: Stress-strain diagramm and effectiveness of an aluminium foam AlCu4Mg0.7, density 0.48 g/cm^3

curve approximates the rectangular behaviour of an ideal absorber to a high degree an effectiveness of about 90% is observed within the plateau regime. Of course, when the flow stress increases due to densification of the porous structure the effectiveness is greatly reduced. Therefore an important point for the optimum design of an energy absober is the densification strain, i.e. the strain where the stress begins to rise steeply after the plateau regime. This fact is further illustrated in Fig. 4. In order to absorb a given amount of energy W, foams with different densities can be used. Obviously for the lowest-density foam "3" the densification strain is exceeded, so that a high peak stress $(\sigma_p)_3$ is generated. On the other hand the high-density foam "1" also generates a high stress $(\sigma_p)_1$ because of its too high plateau niveau. In this case the foam denoted "2" would be the proper choice.

The strength of foamed metals depends on several parameters of which the apparent density is the most important. The choice of matrix alloy, the temper condition and the morphology of the foam also have a significant influence on mechanical strength properties. In order to investigate the correlation between apparent density and strength a number of aluminium foam specimen were produced in the density range from 0.3 to 1.2 g/cm^3. The matrix alloy was AlCu4 and the specimen were all in the same temper condition. The plastic collapse strength was determined in compression tests using a computer controlled servo-mechanical testing machine operated at a constant crosshead velocity of 2 mm/min. A difficulty appeared in determining the strength values especially for the higher-density foams because there was no well-defined transition from the linear elastic to the plateau regime. Nevertheless, using a tangent method the compressive strength of the foams could be determined with sufficient accuracy.

The measured results for the strength σ_f are shown in Fig. 5 as a function of the density. For both axes a logarithmic scale was chosen. It can be seen that in this double-log plot the strength increases approximately linear with increasing density. The slope of the straight line was found to be close to 3, thereby indicating that strength and density of aluminium foams are correlated by a

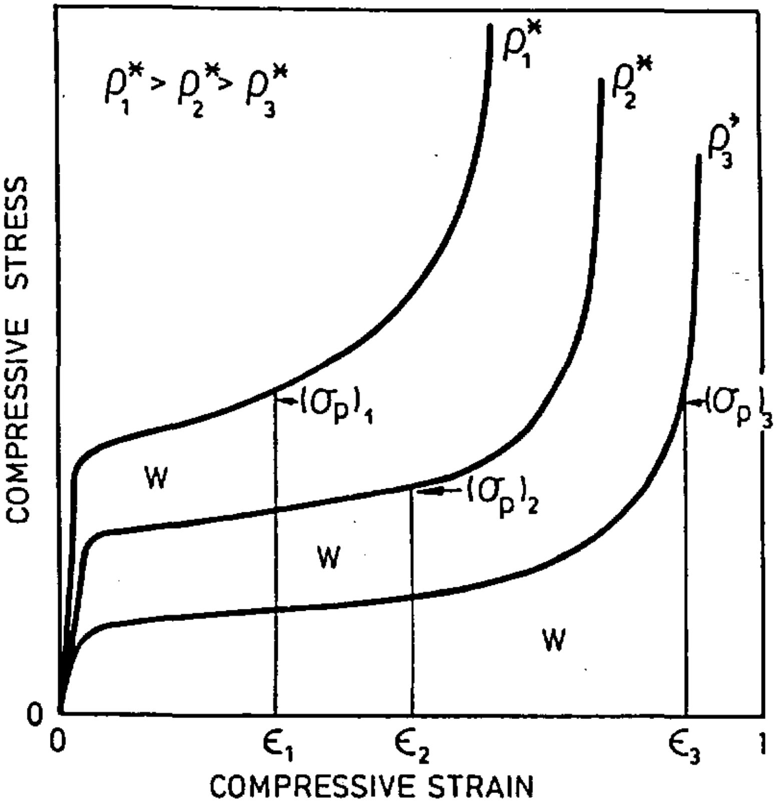

Figure 4: Comparison of three foams absorbing the same energy W

power-law type dependence.

A direct comparison of these results with other publications (4,5) is not possible because the investigated density range and the matrix metal compositions are quite different. Nevertheless it can be stated that the reported values for the plastic collapse strength agree with the results presented here within a factor of 2.

Applications of metal foams

Obviously an important application range for metallic foams will be energy absorption. Using suitable elements of aluminium foam 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 in insulation of thermal

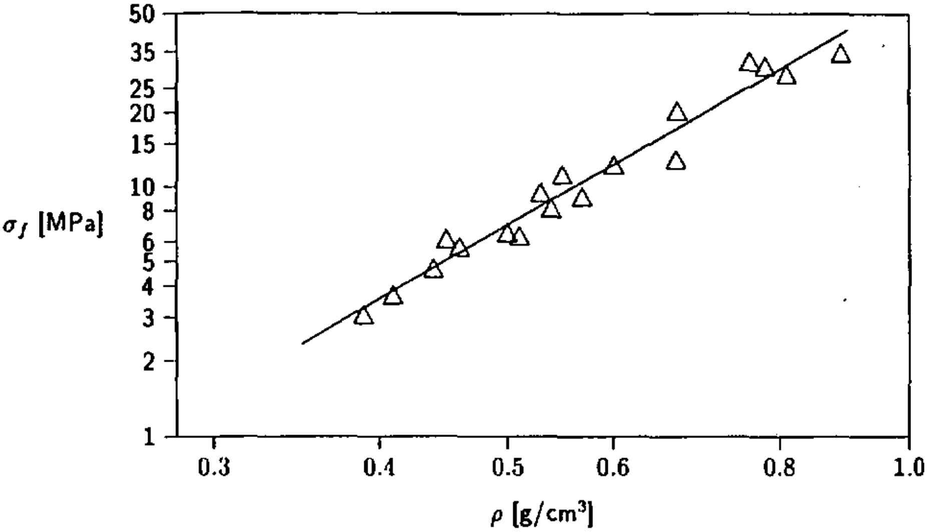

Figure 5: Plastic collapse strength of AlCu4-foams as a function of the apparent density.

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, e.g. For this reason investigations of foamed metals also will be extended in this direction.

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