

Powder Metallurgical Process for the Production of Metallic Foams

J. Banhart and P. Weigand

Fraunhofer-Institute for Applied Materials Research, Bremen, Germany

Abstract

A powder metallurgical method for the production of foamed metals with very low apparent densities is described. A possibility for characterising foaming kinetics in a specially designed foaming dilatometer is presented. Various examples for the interrelation between foaming parameters and maximum foam expansion are demonstrated. Finally, various ways for making metal foam parts are outlined.

1. Introduction

Metallic foams are now thought to be a useful and applicable material for industrial applications. Among the various available processes for making such foams [1-4] the method developed at Fraunhofer-Institute for Applied Materials Research (IFAM) in Bremen is one of the most promising ones. It has now become possible to obtain metallic foams of various metals and alloys in a fairly simple way. These foams enlarge the application range of cellular materials because of their excellent mechanical, thermal, electrical and other physical properties [5,6] as well as due to the fact that they are easier to recycle in comparison to polymeric foams. Parts of an almost arbitrary shape can be made by this foaming technique. Sandwich structures composed of a porous metallic foam core and metallic face sheets can also be produced with several options concerning material combinations and shapes.

At the moment there are three European companies that are aiming on commercialising the Fraunhofer process. The number of companies evaluating potential applications for metallic foams is large ranging from transport industries -automotive, aerospace, railway, elevators etc. - to the traditional mechanical engineering industry. An important prerequisite for a commercialisation is a further improvement of the process and the resulting material.

In the following section the foaming process is described. Then methods for characterising foaming and improving process parameters are outlined. Finally, the various possibilities for making metal foam components are discussed.

2. Process

The production process begins with the mixing of metal powders - elementary metals, alloys or powder blends - with a foaming agent, after which the mix is compacted to yield a dense, semi-finished product (Figure 1). In principle, the compaction can be done by any technique that ensures that the foaming agent is embedded into the metal matrix without any residual open porosity. Examples for such compaction methods are uniaxial compression, extrusion or powder rolling [7].

Heat treatment at temperatures near the melting point of the matrix material is the next step. During this process the foaming agent, which is homogeneously distributed within the dense metallic matrix, decomposes. The released gas forces the compacted P/M material to expand thus forming its highly porous structure.

Prior to foaming the precursor material can be processed into sheets, rods, profiles and other shapes etc. by conventional techniques like rolling, swaging or extrusion in order to improve the flow conditions during foaming inside moulds.

The density of metal foams can be controlled by adjusting the content of foaming agent and several other foaming parameters such as temperatures and heating rates. If metal hydrides are used as foaming agents, a content of less than 1% is sufficient in most cases.

Although most application ideas are based on aluminium foams, the Fraunhofer method is not restricted to this metal: tin, zinc, brass, lead, and some other metals and alloys can also be foamed by choosing appropriate foaming agents and process parameters. The most common alloys for foaming, however, are pure aluminium, 2xxx alloys and 6xxx alloys. Casting alloys, such as AlSi7 and AlSi12, are also frequently used because of their low melting point and good foaming properties, while in principle virtually any aluminium alloy can be foamed by properly adjusting the process parameters.

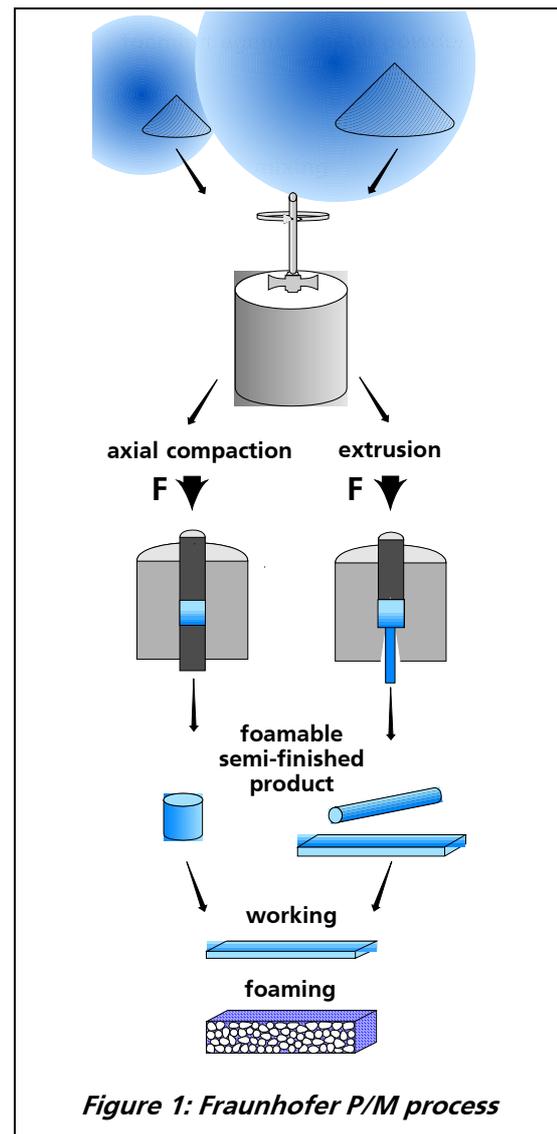


Figure 2 shows a typical cross section of an aluminium foam. One sees that the distribution of cell sizes and shapes is random which is typical for a foaming process.

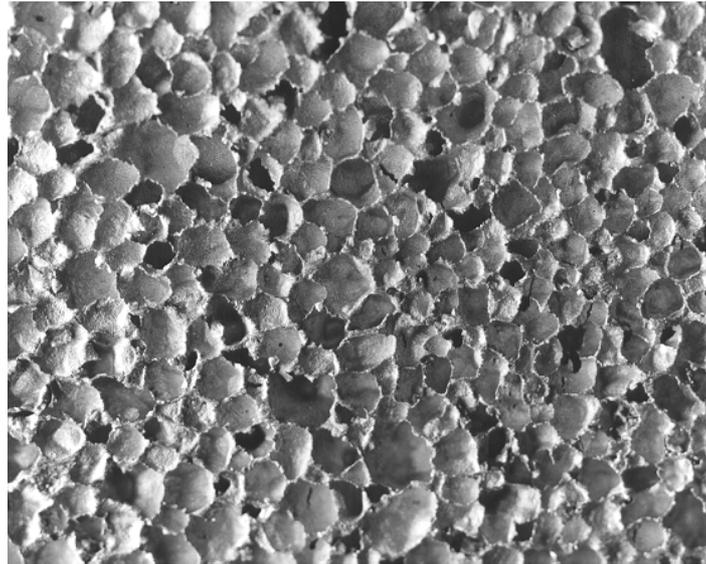


Figure 2: Optical micrograph of an aluminium foam (3:1)

2. Characterising and improving the foaming process

Foaming is a very complicated process in which a large number of parameters has to be adjusted properly. Up to the present no complete, theoretically based understanding of all details of the foaming process has been developed. However, a set of empirical rules has been worked out that allows to produce metal foam parts of a considerable quality and complexity. For sake of a further improvement of the material, however, it is important to develop tools and procedures, that allow to characterise the foaming properties of metal foams and therefore permit to improve the powder mixtures, compaction procedures, and foaming parameters.

Figure 3 lists the most important parameters that influence the Fraunhofer foaming process. The properties of the powder blend, the compaction conditions, the form of the precursor material finally used, and the actual foaming conditions all have to be chosen carefully.

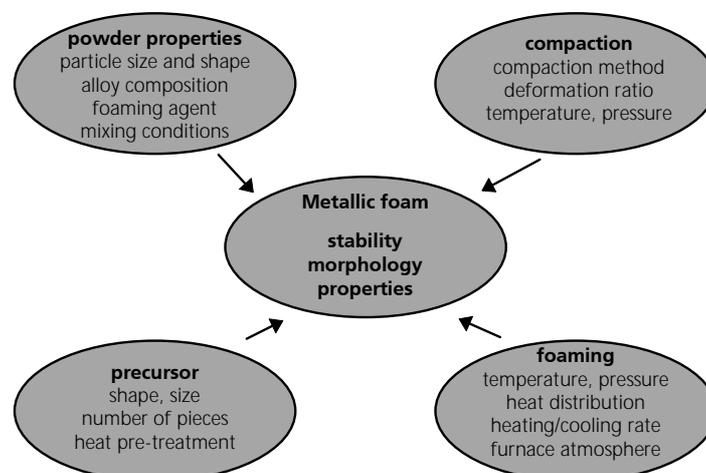


Figure 3: Factors influencing the Fraunhofer foaming process (after [8])

Standard values for all these parameters have been found by varying some parameters and inspecting the influence of the variation on the foam quality. For a more quantitative analysis of the foaming process a device as shown in Figure 4 is very helpful. Here a cylindrical sample of foamable precursor material (4) is placed into a tube of the same diameter (2). A thermocouple (3) measures the temperature of the sample. The tube with the foamable material is heated by a furnace (1) which can be placed over it at the beginning of an experiment. The foamable material starts to expand after a certain time and will move a small ceramic piston (5) which fits into the foaming tube. The position of the piston can be read out by an inductive detector (6) and recorded on a computer.

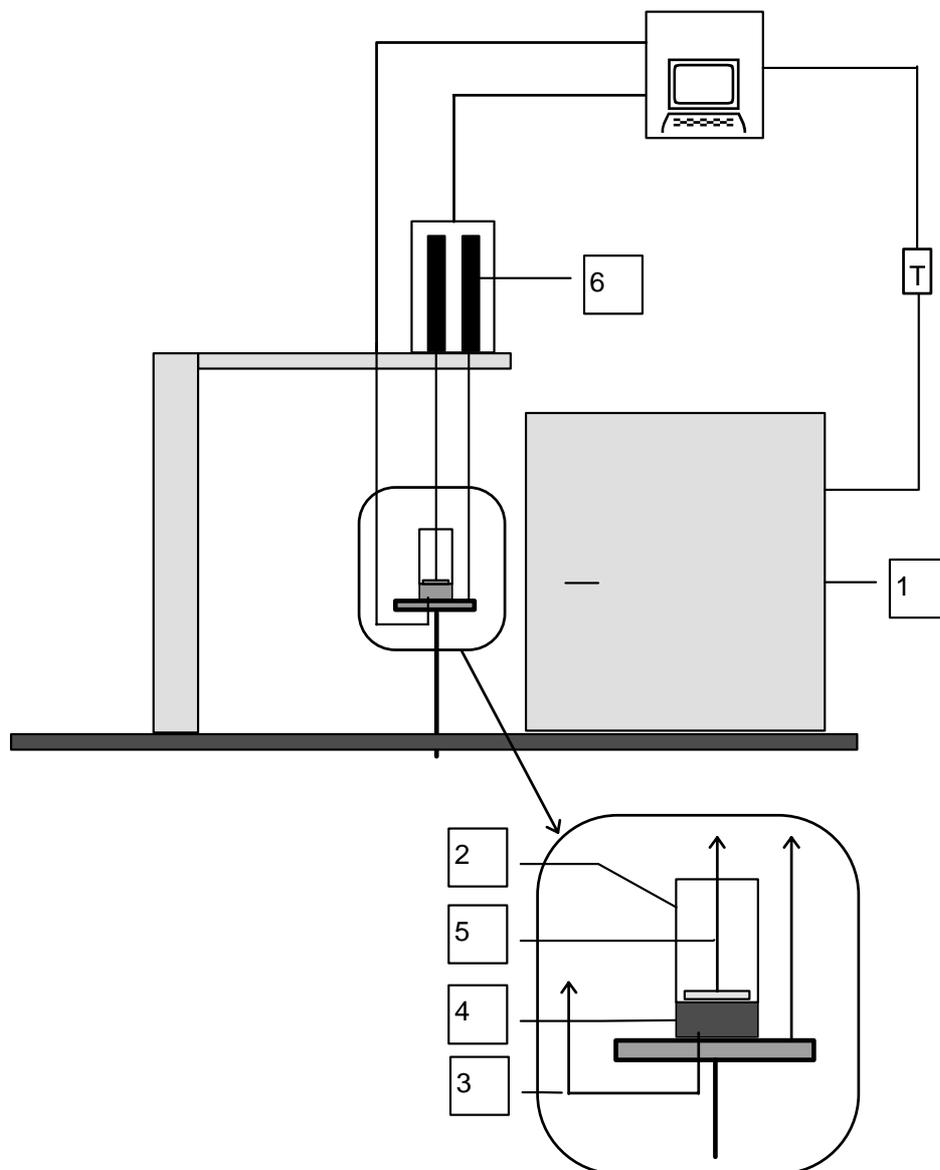


Figure 4: Device for measuring the foam expansion

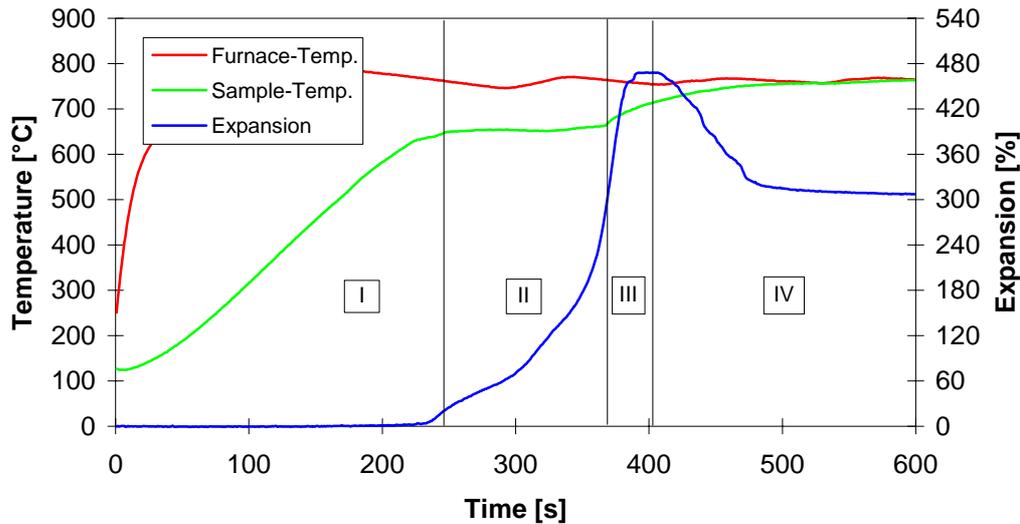


Figure 5: Expansion diagram for an aluminium foam

The result of a measurement will be a graph of volume and temperature versus time as shown in Figure 5. At the beginning of the experiment the preheated furnace is placed around the tube causing an immediate rise of temperature within the experimental zone. The sample temperature itself rises slower due to the insulating effect of the tube. The sample expansion is zero by definition at the beginning. One observes that the foaming takes place in four stages: the first stage I is the heating of the sample up to its melting point without a notable expansion. After the melting point has been reached the expansion starts (stage II). The rate of expansion further increases as soon as the whole metal has been molten and the sample temperature further increases (stage III). Finally, as the maximum expansion is reached the foaming agent is exhausted and no longer releases hydrogen and the foam starts to collapse (stage IV).

Figure 6 shows a series of measurements on zinc foams. Here the content of the foaming agent ZrH_2 was varied from 0 to 1%. As one expects the, more foaming agent one uses the higher the maximum volume expansion is. With 1% foaming agent an expansion of 780% (factor 8.8) is achieved corresponding to a final foam density of 0.81 g/cm^3 (89% porosity). What can be further seen is the good stability of the semi-liquid foam. After the maximum expansion has been reached the foam collapses only slightly. This is a desirable behaviour because it facilitates filling complicated moulds with the foam uniformly, whereas a quick collapse of the liquid metal foam could lead to a partial collapse especially in the case of temperature gradients in the mould.

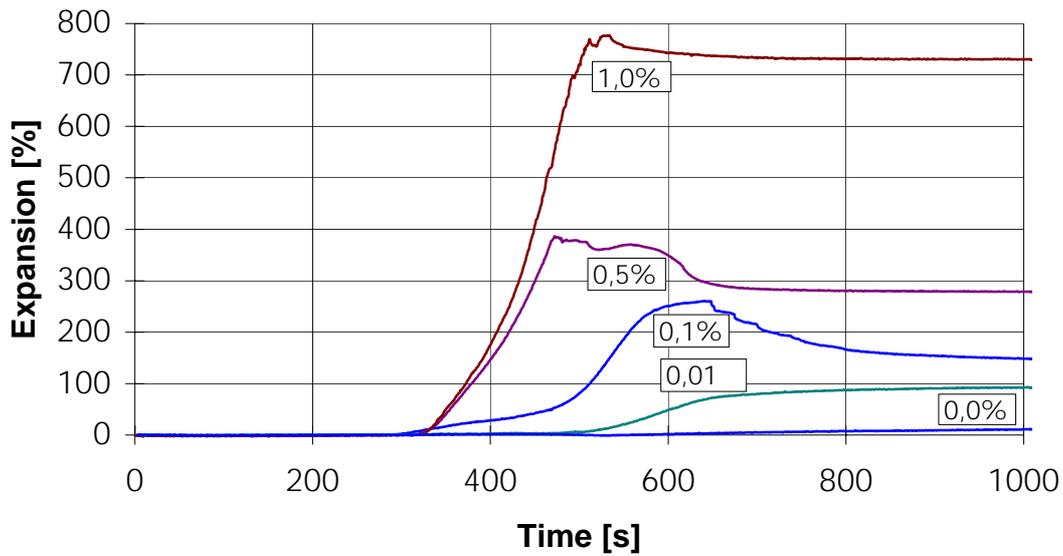


Figure 6: Expansion diagrams for zinc foams with a varying content of the foaming agent

Figure 7 shows the results of a similar investigation on aluminium and aluminium-silicon foams. Here the maximum expansion is plotted versus the content of foaming agent.

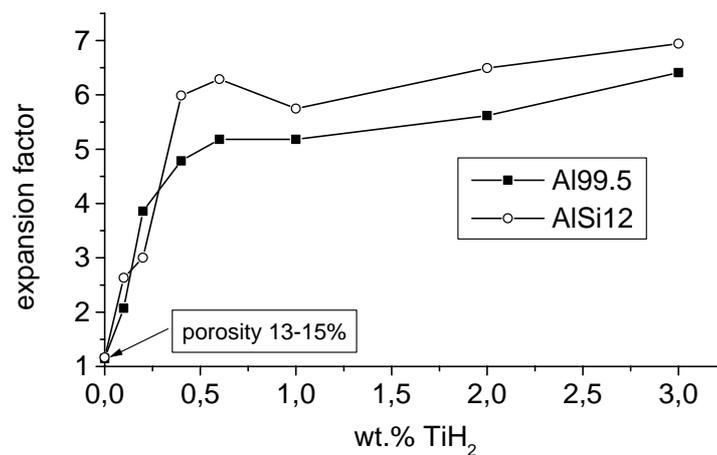


Figure 7: Maximum expansion of aluminium silicon and pure aluminium alloys

Clearly, higher contents of TiH₂ yield higher expansion factors, but with about 0,6% there seems to be a kind of saturation and a further increase of the foaming agent content merely causes a relatively small increase in expansion. Moreover, aluminium-silicon alloys lead to higher expansions (lower densities) as compared to pure aluminium. One reason for this might be the lower melting point of AlSi12 (577°C) which fits better to the decomposition range of titanium hydride than pure aluminium (melting point 650 to 660°C). One task of the work is to develop aluminium alloys which have a good volume expansion, do not collapse quickly and still have good mechanical and other physical properties when foamed.

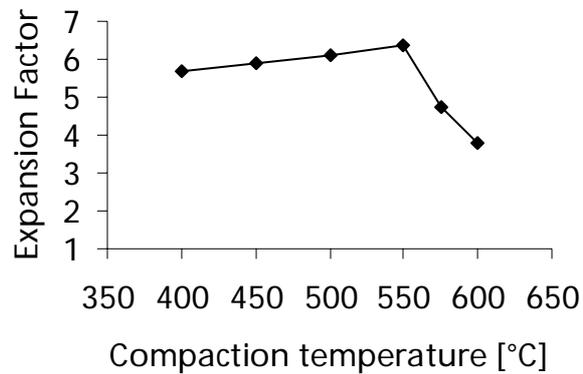


Figure 8: Expansion diagram for aluminium and various compaction temperatures

Figure 8 demonstrates the influence of a compaction parameter on the expansion behaviour of aluminium foams. Here powder mixtures containing pure aluminium powder (99.7%) and 0.8% titanium hydride are axially compacted at various temperatures. For each of the selected temperatures the maximum expansion has been measured in the dilatometer described above. Clearly, for temperatures up to 550°C the maximum expansion slightly increases, whereas for even higher temperatures the foamability of the material is degraded due to premature decomposition of the hydride during compaction.

3. Making aluminium foam parts

Foaming a piece of precursor material in a furnace results in a lump of metal foam with an undefined shape unless the expansion is limited in certain directions. This is done by inserting the precursor material into a hollow mould and expanding it by heating. In this way near-net shaped parts, such as the component shown in Figure 9 can be prepared.



Figure 9: Shaped part made by filling a hollow steel mould with aluminium foam

Sandwich panels consisting of a foamed metal core and face sheets can be obtained by gluing the face sheets to a sheet of foam. Alternatively, if a pure metallic bonding is required, conventional sheets of metal - aluminium or steel - are roll clad to a sheet of foamable precursor material [9]. The resulting composite can be deformed in an optional step, e.g. by deep drawing. The final heat treatment then leads to a sandwich structure (Figure 10).

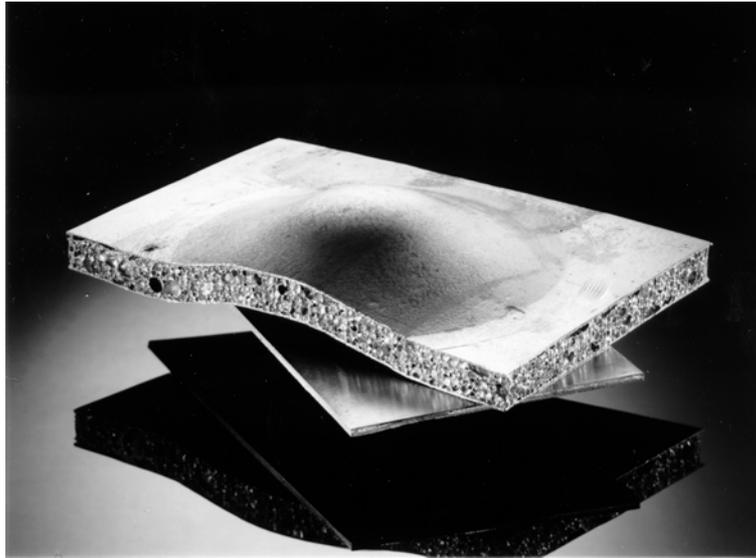


Figure 10: 3-D shaped sandwich panel. Face sheets: steel foam core:aluminium. The roll-clad precursor can be seen beneath the sandwich.

Tubes can be filled with aluminium foam in various ways as shown in Figure 11 [9].

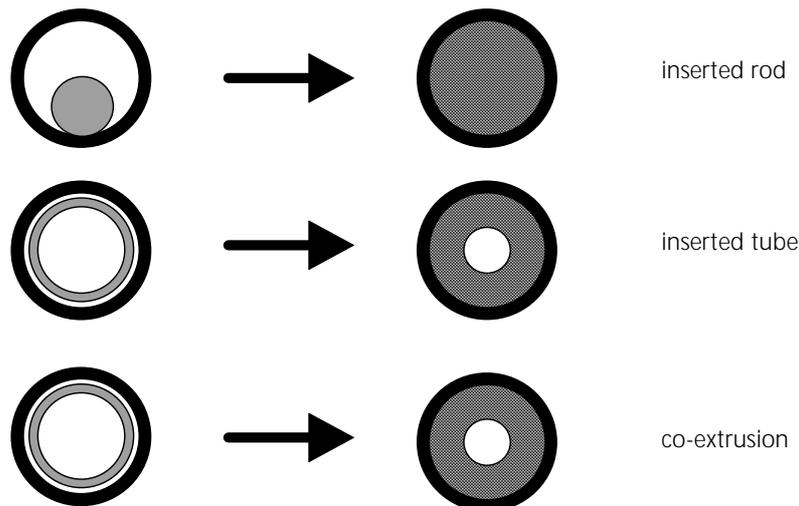


Figure 11: Methods for filling tubes with metal foam

The easiest way is to insert a rod of foamable precursor material into the tube to be filled and to place the tube into a furnace. The precursor material will start to foam and eventually fill the profile completely. The disadvantage of this method is, that only tubes with a significantly higher melting temperature as compared to the material to be foamed - e.g. steel tubes - can be used. If aluminium tubes are to be filled with foam the top of the tube will melt during foaming because it is not supported mechanically and the heat from the furnace can not be conducted into the precursor material. Thus a different way has to be chosen. One way is to insert a foamable tube into the tube to be filled. Then the foam will expand towards the centre of the tube. The foamable material is always in contact with the outer tube and therefore supports it. The expansion of the foam can be limited to a certain wall thickness by using a core in the centre of the tube. The third possibility is similar to the second but requires a co-extruded structure consisting of an outer tube of conventional aluminium and an inner tube of foamable precursor material. The two layers have a metallic bonding in contrast to the situation where the inner tube was merely inserted into the outer one. This bonding creates a better heat flow between the two tubes and therefore minimises the danger for the outer tube to be melted. Moreover, the metallic bonding between the foam and the outer tube will be better in this case as compared to the previous way, because between the inserted and the outer tube there are still oxide layers which partially prevent a metallic bonding even during foaming. Examples for foam-filled tubes are shown in Figure 12.

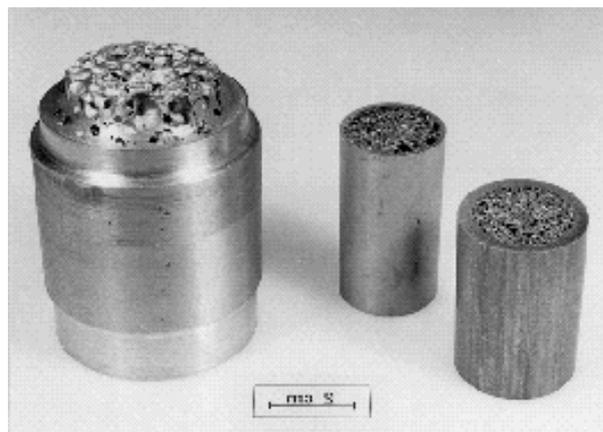


Figure 12: Foam filled aluminium tubes. Foam: AISi12 alloy, tube: 6061 alloy

Future developments

By modifying the preparation technology it could be possible to obtain open pored aluminium foams. 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 are being extended in this direction. An extension of technology to the foaming of metals such as steel or titanium will introduce a wider scope of applications which make use of the high temperature resistance, extreme strength and other properties of these materials. Due to their excellent bio-compatibility, titanium foams could be used in prosthetical applications. However, these developments are just being

worked out and are not yet in the advanced state-of-the-art of the closed cell aluminium foams.

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