Properties and applications of cast aluminium sponges

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Abstract

A casting method for producing metallic materials with open cells is described. Some samples and components manufactured by this method are presented. A selection of properties of these materials is given to allow for a discussion of possible application fields.

1 Introduction

Nowadays there are many possibilities for manufacturing cellular metallic structures [1]. Most structural applications for cellular metals, especially in vehicles, call for a closed cell morphology [2]. Functional applications, however, rely on a certain degree of open porosity. Open cell metals can be made by galvanic deposition onto a polyurethane foam [3] or by investment casting using a polymer foam as model [4]. Especially materials made by the latter method tend to be expensive: the foams made by investment casting are sold for „10 US $ per cubic inch“ (650 Euros per litre). A more inexpensive alternative could be the well-known infiltration process of space-holding fillers which allows for manufacturing metallic sponge-like structures at a price which is estimated to only 30 Euros per litre or less. Recent process improvements allow for making such materials in a very good quality.

2 Process

Open porous metal sponges can be manufactured by using a space-holding filler and casting the liquid metal into the remaining voids of the filler, after which the filler is removed. Figure 1 shows the three necessary process steps for making such materials.

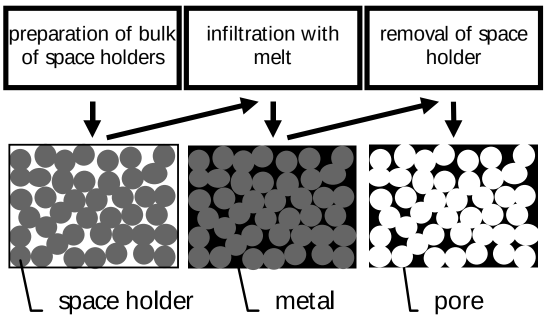

Figure 1: process for making porous metal sponges

1. preparation of space-holding filler: hereby one can use inorganic or organic granules;
2. infiltration of the filler with metal: an external pressure has to be applied to ensure a complete filling of the intersticies between the granules;
3. removal of filler granules by leaching or thermal treatment.

The advantages of the process are obvious:

- <u>low cost:</u> space holders and metal are cheap;
- <u>environmentally friendly</u>: removal of space; holders does not lead to harmful emissions, However, if polymers are used, care has to be taken to condense and collect the extracted polymers;
- <u>recyclable</u>: used components can be recycled in the same way as normal cast components;
- <u>composite structures</u>: sponge and non-porous metal parts can be bonded during casting;
- <u>near-net-shape manufacturing</u> of components is possible.

The pore structure of some of the materials made in this way is shown in Figure 2.

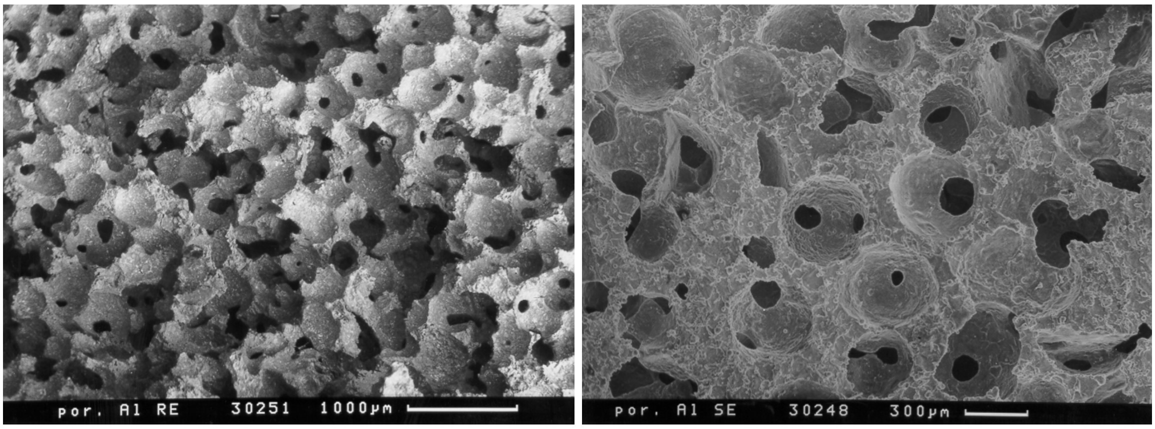

Figure 2: pore structure of cast aluminium sponges. Left: fracture surface, right: EDM preparation

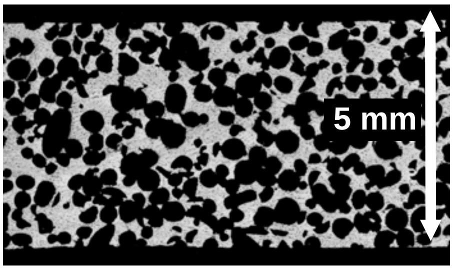

Figure 3: pore structure of an aluminium sponge.

That the materials indeed have open pores can be seen from Figure 3: to get an impression of the connectivity of the cell system, one of course has to take into account the third dimension. The coordination number of a single granule in three dimensions is high enough to ensure that there is always a sufficient number of neighbouring particles that touch the granule. The space holders can therefore be removed almost without any remnants. Figure 4 shows some aluminium sponge disks with various pore sizes.

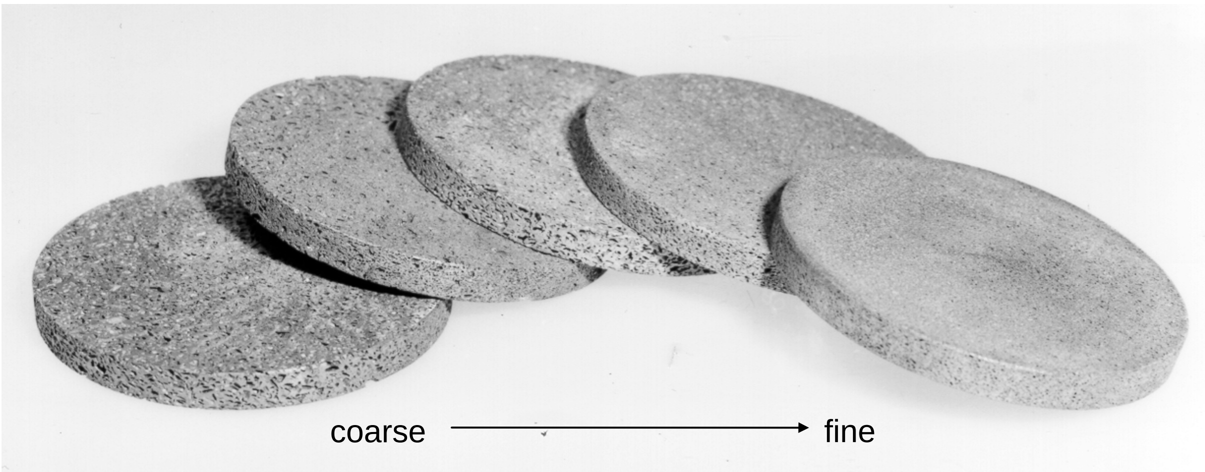

Figure 4: aluminium sponges with various degrees of coarseness (Ø 100mm, d= 10 mm).

3 Some properties

3.1 Density

The density of the aluminium sponges described usually range from 900 to 1200 kg/m^3. This corresponds to a porosity of 55 to 67%. For other metals similar porosity levels are expected.

3.2 Mechanical properties

The mechanical properties of aluminium sponges with open cells are less explored than the ones of closed cell foams [6].

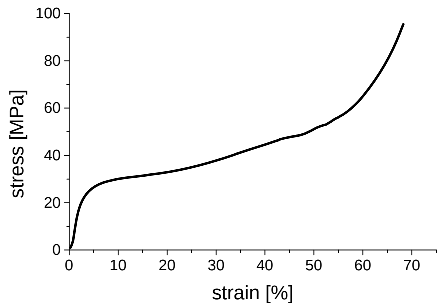

Figure 5: compression test on an Al sponge of density 1180 kg/m^3

A first impression of the mechanical behaviour of sponges can be obtained by a uniaxial compression experiment. One typical result is shown in Figure 5. One sees that the compression behaviour is very similar to that of closed-cell foams. There is an initial quasi-elastic increase of stress for small deformations, a strong plastic yielding for strains up to about 50% and a progressive densification for even higher strains. The compression strengths are comparable to the corresponding data for closed cell foams of the same density.

3.3 Flow resistance

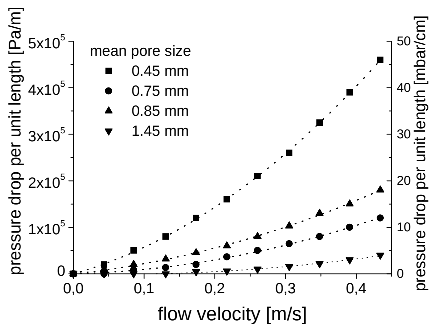

Figure 6: pressure drop in an aluminium sponge

For many applications a given degree of „openness“ is required. The flow of a gas or liquid through a porous medium is usually used to quantity this „openness“. One measures the pressure drop Δp along a sample of length L and constant cross section A as a function of the flow rate of the medium (which is proportional to its velocity v). For very low flow rates Darcy's law holds, i.e. $\Delta p \propto v$. For higher rates there is at least one quadratic contribution to be added describing the effect of turbulent flow. The curves shown in Figure 6 were measured on four different samples (corresponding to 4 of the samples shown in Figure 4) and illustrate this behaviour. One sees that one can influence the flow resistance by choosing some average cell size. The dashed lines in Figure 6 are fit curves of the measured data using the law $\Delta p/L = (\eta/\alpha)v + (\rho/\beta)\, v^2$, where η is the dynamic viscosity of air and ρ its density. The resulting filter parameters α and β are in the range $\alpha=4\cdot10^{-12}$-10^{-10} and $\beta=8\cdot10^{-7}$-$4\cdot10^{-6}$ m. These values are close to the data for sintered bronze filters.

3.4 Internal surface area

BET measurements were carried out to measure the total internal surface area of aluminium sponges. Values between 1 and 2 m^2/g were found for densities of 1100 kg/m^3.

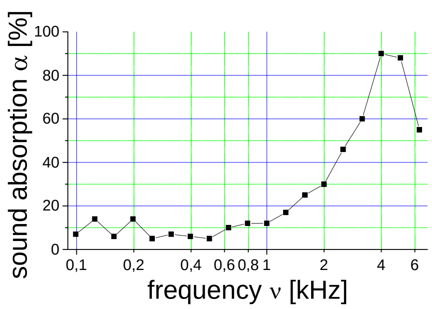

Figure 7: sound absorption curves measured on aluminium sponges

3.5 Sound absorption

The sound absorption coefficient was measured in a resonance tube. Low frequencies ($\leq$1600 Hz) were measured on disks with 100 mm diameter, high frequencies ($\geq$800 Hz, overlapping with high frequency range) on small disks of 30 mm diameter. The thickness was 10 mm in both cases. A typical example is shown in Figure 7. One sees the pronounced absorption peak with α>95% around 4 kHz, lower absorption values especially for low frequencies. This is not an excellent absorption behaviour, especially if compared with specially designed sound absorption materials. However, in combination with other properties, the material could show an interesting profile.

4 Applications

In searching for applications it is useful to study the application of traditional porous sintered products such as sintered bronze [7-10].

4.1 Silencers

Decompression of gases e.g. in pneumatic devices of compressors creates noise which could be reduced by appropriate silencers such as the ones shown in Figure 8. Such components can be attached to a gas outlet of a compressor e.g. with threads directly integrated into the dense part.

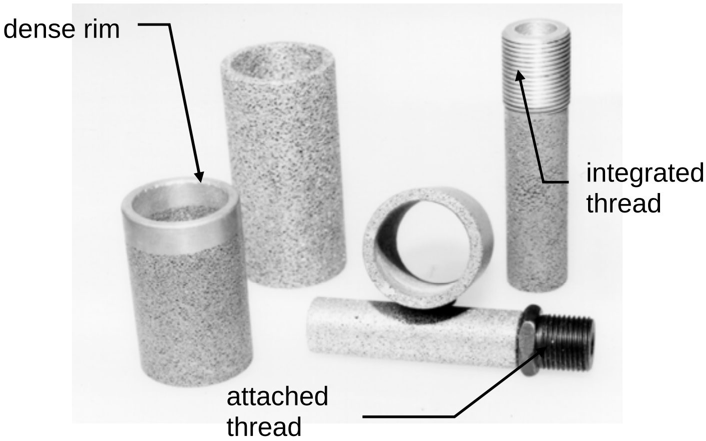

Figure 8: silencers made of aluminium sponge (all except the lying sample are closed on one side)

4.2 Filters

Separation of solid particles from gases or liquids, or separation of two liquids can be a task for which the aluminium sponges presented perform well because of their large depot volume.

4.3 Catalyst support

High internal surface in combination with a good heat conductivity could lead to applications, in which highly exothermal reactions have to catalysed and heat has to be removed, e.g. in the oxidation of ethylene to ethyleneoxide.

4.4 Other applications

Further application fields which have to be evaluated include: pressure reduction, self-lubricating bearings, reservoir for liquids, spargers, flame arresters, transpiration cooling, heat exchangers.

References

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