Electrical conductivity of metallic foams

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Abstract

The electrical conductivity of Al and Zn based foams prepared by powder metallurgical route with the porosity in the range of 60% - 90% was experimentally measured and modelled by means of percolation theory. It has been shown that electrical conductivity of metallic foams depends predominantly on the electrical conductivity of the matrix metal or alloy and the foam density. It was revealed that the simplified percolation model describes fairly well conductivity - porosity relationship. However, the characteristic exponents obtained experimentally have been found lower than the theoretically predicted value due to the effect of sample size, surface skin, heterogeneity of foam structure, and the setting of the percolation threshold to zero. The effects of surface skin, heterogeneity of the structure and sample size were further demonstrated.

1 Introduction

In distinction to polymer or ceramic foams metallic foams are electrically conductive. This alters the typical applications of them considerably: While ceramic and polymeric foams can be used for the insulation or structural enclosures that must transmit microwaves, metallic foams are good for the opposite purpose. The electrical conductivity of metallic foams, though reduced, is still enough to provide good electrical grounding and low voltage contacts or to absorb electromagnetic waves. Although the number of research works dealing with the mechanical properties of metallic foams increases rapidly during last two years, only a little attention was given to the study of the electrical properties of metallic foams. It is surprising, considering that the multifunctionality is often the requirement for their successful application. To partially fill this gap the electrical conductivity of metallic foams was studied in this work.

2 Experimental

Alulight® - Al (AlSi12, AlMg1Si0.6 and Al 99.96) and Zn (Zn and ZnAl4Cu1) based foams were prepared by powder metallurgical route of different geometry with and without surface skin. The porosity of samples was in the range of 60% - 90%. DC electrical conductivity of the foams, as well as that of the solid matrix material, was experimentally measured by the "four point method": The electrical conductivity was calculated according to Ohm's law

$$s = \frac{I}{\Delta U} . \frac{l}{S} , \tag{1}$$

where ΔU is a potential drop along the distance l when current I is applied to sample's cross section *S*. Measurements were done for a current of 6, 8 and 9 A and the average value of electrical conductivity and standard deviation were calculated for each sample.

3 Results and discussion

Effective electrical conductivity of metallic foam depends predominantly on the electrical conductivity of metal matrix. Generally, aluminium is one of the best conducting materials. When Mg and Si based alloys are used, the conductivity is significantly lower than that of pure Al, especially in the case of AlSi12 alloy. The situation is the opposite in the case of zinc. When good conducting elements (Al, Cu) are added the conductivity of such an alloy slightly increases (see Fig. 1). At the same porosity level the effective electrical conductivity of ZnAl4Cu1 foam is higher than that of pure Al foam due to the heterogeneity of ZnAl4Cu1 foam structure (Fig. 2). Further, it has been proved that the electrical conductivity - porosity relationship can be successfully characterised using the power-law scaling function on the basis of percolation theory [1-4]

$$s = s_0 \cdot \left(\frac{r}{r_0} \right)^t , \qquad (2)$$

where σ is effective electrical conductivity and ρ is apparent density of the foam, σ_0 is electrical conductivity and ρ_0 is density of the solid metal and t is characteristic exponent theoretically predicted for electrical conductivity.

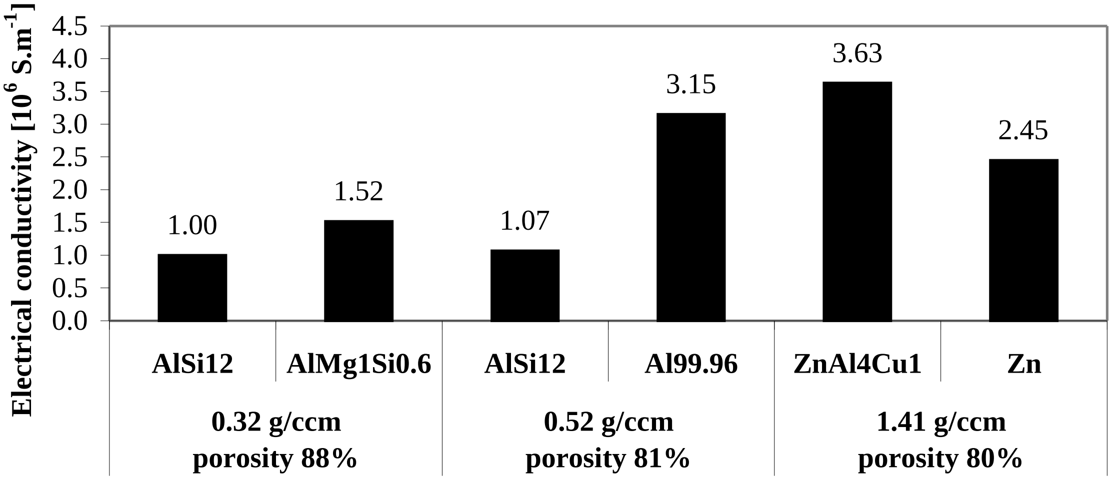

Fig. 1. Effect of the electrical conductivity of metal matrix on the resulting effective electrical conductivity of metallic foams (cylinders ϕ 35 x 50 mm without surface skin)

The characteristic exponents obtained experimentally ($t = 1.76 \pm 0.06$ for AlMg1Si0.6 foam and $t = 1.18 \pm 0.01$ for Zn foams) have been found lower than the critical exponent value theoretically predicted ($t = 2.00$) by the percolation theory. This is due to the model assumptions, because it does not take into account the finite size of foam, its surface, foam heterogeneity and anisotropy, foam defects such as cracks in pore walls, which influence the conductivity but the relative density do not. This is illustrated on Fig. 3 where highly non-uniform structure of zinc foams with almost whole metal concentrated in the vicinity of the sample surface, approach the rule of mixture conductivity dependence on the density.

As was previously stated, in contrast to the theory, the real experimental samples always have finite size and usually possess surface skins. There, the volume fraction of the surface skin increases with decreasing size of the sample. The high portion of surface skin diminishes the effect of the porosity on the degree of the effective electrical conductivity reduction of metallic foam. If the surface skin is removed from the sample the reduction of the foam cross section due to the increasing porosity is enhanced and effective electrical conductivity of the foam becomes lower (see Fig. 4). A similar effect can be observed when the sample size increases (see Fig. 5). It implies that the conductivity of the foam is not only a function of the porosity, but it is strongly affected also by the shape and size of foamed part.

Fig. 2 suggests that the measurement of the electrical conductivity of the metallic foam can be used as a non-destructive testing method for evaluation of the homogeneity, anisotropy or just simply the reproducibility [5] of foam structure. Furthermore, it seems to be a suitable quality control method for the mass production of metallic foams.

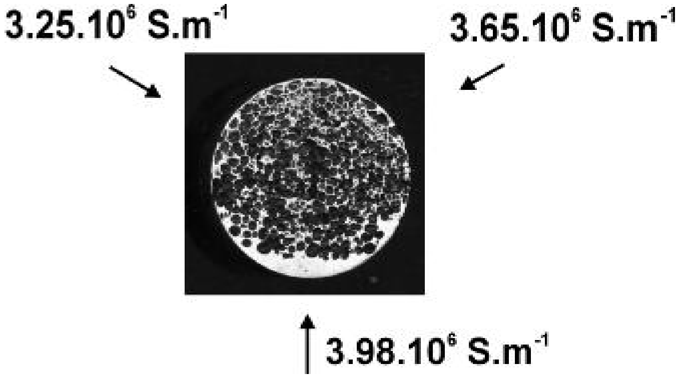

Fig. 2. Local values of effective electrical conductivity ZnAl4Cu1 foam (density 1.41 g.cm^{-3})

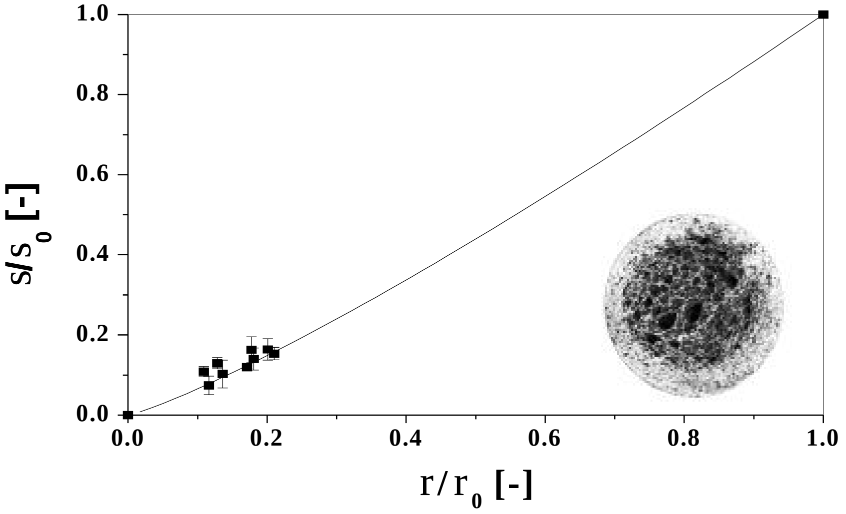

Fig. 3. Normalised effective electrical conductivity versus normalised density of the Zn foams (cylinders ϕ 38 x 50 mm with surface skin, $\sigma_0 = 15.0 \,.\, 10^6$ S.m^{-1}, $\rho_0 = 7.01$ g.cm^{-3}) and typical structure of zinc foam (density 0.96 g.cm^{-3})

4 Conclusions

The electrical conductivity of metallic foams depends predominantly on the electrical conductivity of metal matrix and foam density. At this level, conductivity-density dependence can be simply modelled using Eq. 2. However, the model must be further refined to incorporate into it the finite size of foam, its surface skin, possible heterogeneity, anisotropy and other structural defects. The measurement of the electrical conductivity of the metallic foam can be also used as a non-destructive testing method for evaluation of the foam structure. It is also a promising method for foam quality control during its mass production.

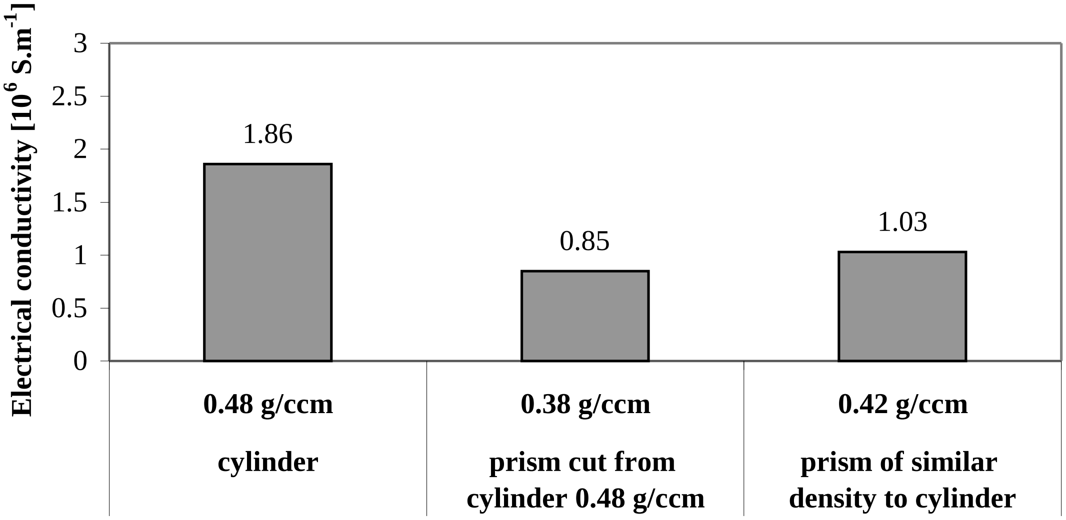

Fig. 4. Changes in the effective electrical conductivity and density of AlSi12 foams when surface skin is removed. Cylinder ϕ 40 x 50 mm with surface skin cut to prism 27 x 27 x 50 mm without skin.

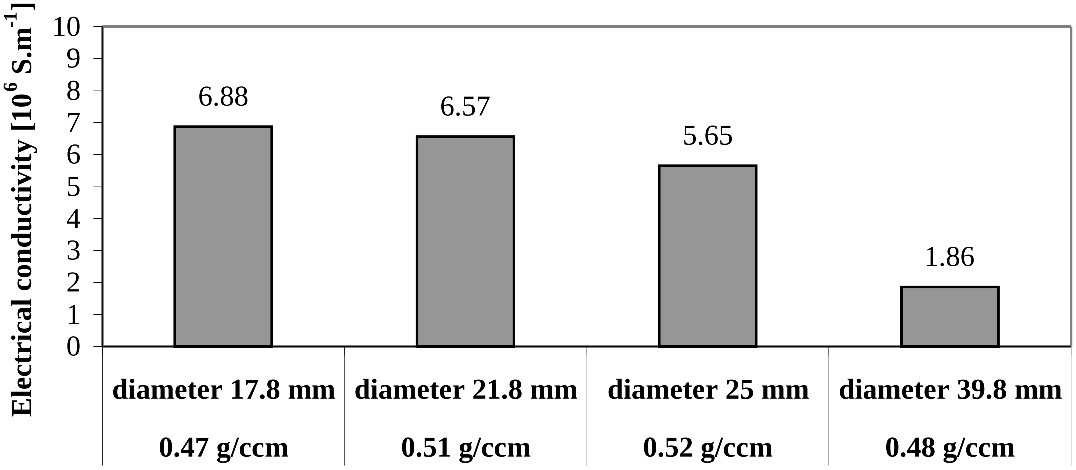

Fig. 5. Electrical conductivity dependence on the sample geometry for AlSi12 foams with surface skin at nearly constant density (diameter to length ratio is 0.8)

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