

FOAMING OF ALUMINIUM - TAILORING OF ITS ELECTRICAL AND THERMAL CONDUCTIVITY

J. Kováčik, F. Šimančík, J. Jerz, P. Minár

Department of Powder Metallurgy, Institute of Materials and Machine Mechanics, Slovak Academy of Sciences, Račianska 75, P.O. Box 95, 830 08 Bratislava 38, Slovak Republic

Heat insulating materials are usually based on the ceramic fibre mats, mineral wool, or on various polymeric foams. The main disadvantage of these materials is the difficulty in the preparation of complicated self-supporting parts. This problem has been overcome partly by creating the metal-ceramic compounds using metal cover-sheets on an insulating mat.

However, the use of metal cover sheets significantly diminishes the efficiency of the heat insulation and introduces also serious problems in recycling of such compounds. Accordingly, there is a high demand for an easily recyclable light weight material with good insulating properties, which possesses also enough rigidity to be self-supporting and flexibility to be manufactured into complicated shapes. Aluminium foam could be the promising candidate for this purpose [1].

Aluminium foam is, principally, a composite material consisting of aluminium alloy matrix and of pores, filled up with gas, distributed throughout the matrix. The average pore size varies between 0.5 - 8 mm depending on matrix composition and foaming procedure (see Fig.1), the typical density lies in the range of 300 - 1000 kg.m⁻³. This unique structure possesses unusual combination of properties, such as low thermal conductivity, high impact energy absorption capacity, very high specific toughness and good acoustic properties. Moreover, this exceptionally light weight material is fully recyclable and ecologically friendly.

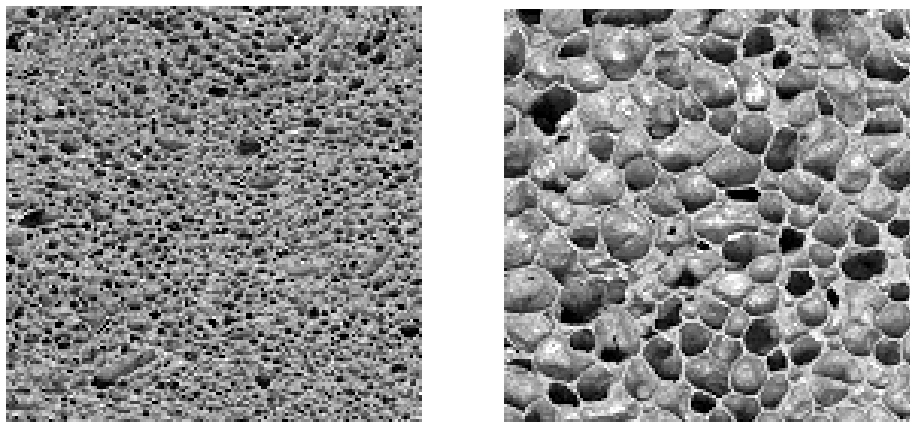


Fig. 1. Aluminium foam with different pore sizes (density 0.5 g/cm⁻³)

Aluminium foam can be prepared from aluminium powder [2] which is mixed with a foaming agent and continuously hot extruded into foamable precursor. Then the precursor is foamed into various products like panels, profiles or complex parts using recently developed techniques [1]. The foamed parts are covered by dense aluminium skin which significantly improves the mechanical properties and metallic appearance of the foam.

Experimental

The electrical conductivity s of aluminium foam was calculated from the geometry and the resistance of the sample. The resistance measurement was performed by the four points method. Cylindrical (diameter 17 mm, length 300 mm, various base Al alloys) and rectangular (140 x 140 x 8.5 mm, Al 99.7) specimens with various densities were used.

Thermal conductivity of aluminium foam was measured by comparative method for various temperatures up to 400°C. Cylindrical specimens (diameter 25 mm, length 20 mm, various base Al alloys) with various densities were used. The outer skin of the samples was removed by the electric discharge machining to eliminate the thermal flow along this skin which can significantly affect the conductivity of the sample.

Results and Discussion

Both thermal and electrical conductivity depend strongly on the cross sectional area enabling the thermal flow or electric current to flow through the specimen. Only a small portion of aluminium foam's cross-section is electrically and thermally conductive. These are the pore walls with the electrical and thermal conductivity according to the base alloy. The main part of the cross section is formed by the pores filled with an air which can be considered as an electrical and thermal insulator. Moreover, the pore walls are covered with non conductive alumina. Therefore, aluminium foam is significantly less electrically and thermally conductive than the bulk aluminium alloys. The way in which the metal is distributed throughout the foam, i.e. thickness of the pore walls, size and orientation of pores and the distribution of pores, determines the physical properties of the foam. According to the percolation theory the dependence of physical properties on the composition can be written as a power-law function [3]

$$\frac{K}{K_0} = a \left(\frac{r}{r_0} \right)^t$$

where K is the property and r is the density of foam, while K_0 and r_0 are the corresponding properties of bulk aluminium alloy. The exponent t is usually from the range of 1.6 - 1.8 [3-4] and the constant a ought to be 1. The experimental results for the normalised electrical (Fig.1) and thermal conductivity (Fig.2) are shown in Table 1. There c^2 is a minimisation function. The large value of c^2 for Al 99.7 foam is due to the weighting of c^2 by the standard deviation

for each measured value of the conductivity. It can be seen that the exponent t attains 1.6 for aluminium foam. This result is in a good agreement with the presumption of the percolation theory $t = 1.7$ [3]. The results for thermal conductivity at various temperatures are shown in Table 2. The exponent t seems to decrease with the increasing temperature. It is probably due to increasing thermal conductivity of the air in pores and also due to the thermal radiation of the pore walls which must also be taken into the account at this temperature.

Tab. 1. The dependence of normalised electrical and thermal conductivity on the density for various types of aluminium foam.

	a	t	c^2
s/s_0 (mix.)	0.9997 ± 0.0085	1.547 ± 0.015	$7.31 \cdot 10^{-5}$
s/s_0 (Al 99.7)	0.9942 ± 0.0230	1.599 ± 0.017	$4.18 \cdot 10^{-0}$
l/l_0 (mix., 20°C)	1.0000 ± 0.0055	1.602 ± 0.027	$2.97 \cdot 10^{-5}$

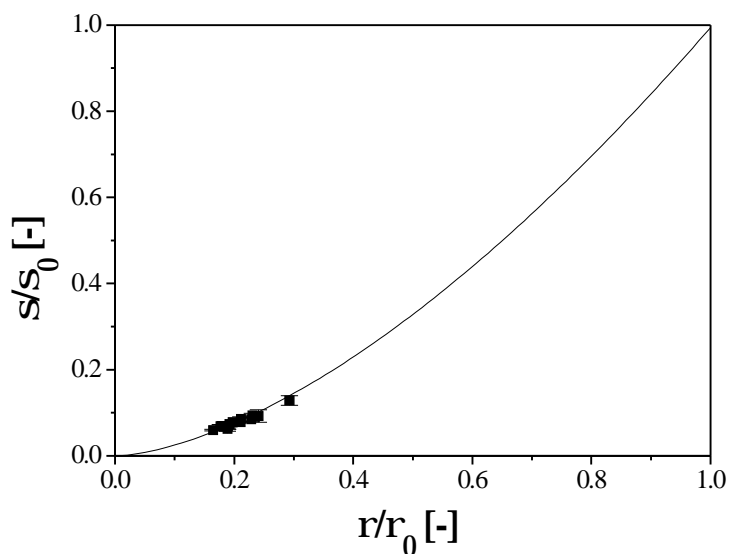


Fig. 1. The dependence of normalised electrical conductivity on the density for Al 99.7 aluminium foam ($s_0 = 37.6 \cdot 10^6 \text{ S.m}^{-1}$, $r_0 = 2700 \text{ kg.m}^{-3}$).

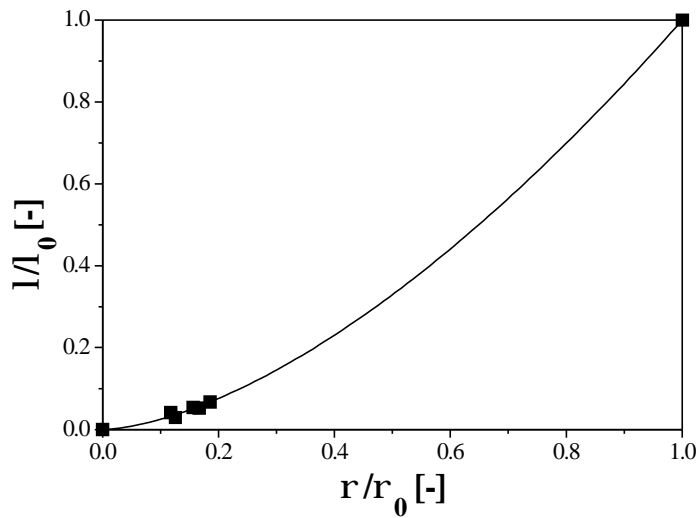


Fig. 2. The dependence of normalised thermal conductivity on the density for various types of aluminium foam at 293.15 K ($l_0 = 232 \text{ W.m}^{-1}.\text{K}^{-1}$, $r_0 = 2700 \text{ kg.m}^{-3}$).

Tab. 2. The dependence of normalised thermal conductivity of aluminium foam on the density for various temperatures.

T [K]	a	t	c^2
293.15	1.0000 ± 0.0055	1.602 ± 0.027	$2.97 \cdot 10^{-5}$
373.15	1.0000 ± 0.0075	1.553 ± 0.034	$5.66 \cdot 10^{-5}$
573.15	1.0000 ± 0.0096	1.477 ± 0.037	$9.10 \cdot 10^{-5}$
673.15	1.0000 ± 0.0053	1.509 ± 0.026	$4.00 \cdot 10^{-5}$

Conclusion

The power-law dependence of both electrical and thermal conductivity on the relative density of aluminium foam has been found. The value obtained for the exponent ($t = 1.6$) is in a good agreement with the percolation theory.

References:

- [1] F. Simančík, J. Jerz, J. Kováčik, P. Minár: Metallic Materials (1996), to be published
- [2] B.C. Allen: US Patent 3 087 807, (1963)
- [3] D. Stauffer, A. Aharony: Introduction to Percolation Theory, 2nd edition, Taylor & Francis, London (1992)
- [4] F. Simančík, H.P. Degischer, H. Wörz: Proc. 4th European Conference on Advanced Materials EUROMAT'95, Venice/Padua, Italy, 25-28 September (1995)