Thermal and Electrical Conductivity Measurements on Aluminum Foams

N. Babcsán¹, I. Mészáros², N. Hegman³

Metal foams are one of the most interesting types of materials although there is limited information concerning their thermal and electrical conductivity. Closed cell different density Alporas foams are investigated, which has one of the most homogeneous cell size distribution recently. Comparative method has been chosen to determine the thermal conductivity of the samples in the function of the temperature at 30, 100, 200, 300, 400, 500°C. For measuring the electrical conductivity of aluminium foams a special low frequency eddy current measuring apparatus was used. The ratio of thermal and electrical conductivity was calculated and shown an increasing function by the density of the foams.

Key words: cellular metals, metal foam, thermal conductivity, electrical conductivity

1 Introduction

Aluminum foams are cellular metals. Cellular materials [1] could be produced in different manners but the definition of foam can be used only when the cellular materials is made by foaming of liquids. The properties of cellular metals can be modified in a wide scale. This flexibility of the properties initiated different application fields. In this case the relatively low thermal conductivity is in pair with the relatively high electrical conductivity. Although this properties combination is not related with any application field yet, these properties are very interesting from the scientific point of view. In order to clarify the density and temperature dependence of thermal and electrical conductivity of metal foams, three different density aluminum foams were investigated with comparative and eddy current method respectively.

2 State of the Art

Thermal conductivity of cellular materials as polymeric foams is well known [2]. In the function of the density shows a minimum. Heat conductivity data of metal foams are only available from the metal foam producers collected in a good reference book of Ashby [3]. Because of the partly defined circumstances of the measurements there is a need to carry out precise thermal and electrical measurements. Good models to determine the transport properties from the cellular structure in metals foam already exist [4, 5, 6]. Some authors published those values in the function of density or in the function of a structural parameter. Both the density and the structure are very important and couldn’t consider independently during the interpretation of the measurements. Therefore systematic experiments were goaled and started with thermal conductivity measurements by the help of the AMTT [7]. It was followed by electrical conductivity measurements (published in this paper). In the future X-ray tomography investigations are planned on the same samples in order to serve good input (structure) and output (transport properties) for the model calculations.

3 Experimental procedure

3.1 Investigated materials

Alporas supported us with similar composition but different density aluminum foam block samples. The geometry of the samples was 50mmx300mmx300 mm with closed cells. The properties of the examined foam samples are shown in Table 1.

The relative density (ρrel = ρ / ρ0) is the quotient of the foam density (ρ) given in Table 1 and the matrix alloy density (ρ0) in this case 2.7 g/cm³.

3.2 Thermal conductivity measurements

For obtaining thermal conductivity of foam samples we used comparative thermal conductivity measurements, means determining the thermal conductivity comparing this property between the sample material and known reference materials.

Table 1. Properties of the examined foam samples

<table>
<thead>
<tr>
<th>Sample nmb.</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>m, kg</td>
<td>0.8</td>
<td>1.1</td>
<td>2.08</td>
</tr>
<tr>
<td>ρ, g/cm³</td>
<td>0.177</td>
<td>0.244</td>
<td>0.462</td>
</tr>
<tr>
<td>ρrel</td>
<td>0.066</td>
<td>0.090</td>
<td>0.171</td>
</tr>
<tr>
<td>Porosity, %</td>
<td>93.4</td>
<td>91</td>
<td>82.9</td>
</tr>
<tr>
<td>Cell size, mm</td>
<td>2</td>
<td>2.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

¹ University of Miskolc, Hungary, Materials Science Institute, e-mail: femnorbi@gold.uni-miskolc.hu
² Budapest University of Technology and Economics, Hungary, Department of Materials Science and Engineering, e-mail: mészaro@eik.bme.hu
³ University of Miskolc, Hungary, Materials Science Institute, e-mail: femheno@gold.uni-miskolc.hu

Mat.-wiss. u. Werkstofftech. 34, 391—394 (2003) 0933-5137/03/0404-0391$17.50 + .50/0 391 © 2003 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim
The condition of uniform and equal heat flux was satisfied by placing a test and reference materials of equal cross-section in intimate contact with each other and by holding the reference-test sample-reference stuck system between the heater and heat sink. The radial parasitic heat flow was depressed by placing the stack inside a cylindrical furnace built in the equipment providing linear temperature gradient along the length of the stuck set up. The space surrounding the stuck was filled with insulating powder. The thermal conductivity, \( \lambda \) for the sample sandwiched between two identical reference materials was figured out as follows (1):

\[
\lambda_s = \frac{1}{2} \left( \frac{\Delta X}{\Delta T} \right)_s \left( \frac{\lambda_s \Delta T}{\Delta X} \right)_{Tr} + \left( \frac{\lambda_s \Delta T}{\Delta X} \right)_{Br}
\]

(1)

Where the indexes mean: S is sample, Tr is top reference and Br is bottom reference. The \( \Delta T \) temperature difference was measured between thermocouples immersed in radial drilled holes with \( \Delta x \) distances between them for each parts of the sandwich. The other details regarding the experimental technique are documented in ref. [8]. Two samples with 25 mm diameter and 28 mm height were cut from every density and three repeated measurements per sample. At the beginning two measurements of the 0.066 relative density samples were carried out in vacuum and in air at 300°C.

### 3.3 Electrical conductivity measurements

For measuring the electrical conductivity of aluminium foams a special low frequency eddy current measuring apparatus was used. The measuring equipment was developed in the Department of Materials Science and Technology of the Budapest University of Technology. The measurement setting contains a solenoid excitation coil which produces perpendicular magnetic line forces to the surface of the sample. The lift-off of the coil was 3 mm. The excitation coil was supplied by sinusoidal current produced by a signal generator and a power amplifier.

For detecting the perpendicular magnetic field component of the induced eddy-currents a giant magneto resistive field sensor (GMR) element was applied. The sensitivity of the sensor element was 42 mV/Oe and the sensing direction was perpendicular to the surface. The distance between the centre of the coil and the sensor element was 25 mm.

The applied sensor element allow us the usage of low frequency excitation because the GMR sensor can be used in the frequency range of 500 Hz – 5 kHz. The estimated power amplifier.

\[ \text{For the calibration of the measuring equipment Al, Sn, Pb and Ti conductivity standard were used.} \]

### 4 Results and Discussion

#### 4.1 Thermal conductivity as function of the relative density and the temperature

In case of the 0.177 g/cm³ density samples the pressure of the gas environment did not influence significantly the thermal conductivity data (6.14 W/mK was determined in air and 6.20 W/mK in vacuum). Therefore the gas conduction is negligible in the pores of the foam. Presumably the radiation is also not so important below 500°C.

The repeated measurements on the same sample showed less than 5% reproducibility. Between samples from the same density branch a same reproducibility was observed (expect the 0.066 relative density case where different reference sample was used for the two tests). The foam thermal conductivity vs. density shows a linear behavior displayed in Fig. 1. In case of high relative density foams the dependence of thermal conductivity on temperature is found to be increasing as well (Table 2).

A slight increase of the heat conductivity was evaluated vs. temperature (in the RT-500°C range) in all the densities (Fig. 2-4), but in the case of 0.171 first a drop appeared up to 100°C (Fig. 4).
4.2 Electrical conductivity in the function of relative density

The results of the eddy current measurements can be seen in Table 3 and Fig. 5.

As it can be seen good linear connection was found between the relative densities of the foams and the electrical conductivity values measured by eddy current technique. The correlation between the heat conductivity values and the electrical conductivity values seems to be good as well. Therefore, the supposed low frequency eddy current measurement can be a useful and cost effective tool for the fast determination of heat conductivity of different aluminium foams.

<table>
<thead>
<tr>
<th>$\rho_{rel}$</th>
<th>30°C</th>
<th>100°C</th>
<th>200°C</th>
<th>300°C</th>
<th>400°C</th>
<th>500°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.066</td>
<td>5.88</td>
<td>5.91</td>
<td>5.76</td>
<td>5.78</td>
<td>5.86</td>
<td>6.13</td>
</tr>
<tr>
<td>0.090</td>
<td>9.07</td>
<td>9.16</td>
<td>9.09</td>
<td>9.15</td>
<td>9.69</td>
<td>9.93</td>
</tr>
<tr>
<td>0.171</td>
<td>17.77</td>
<td>16.68</td>
<td>16.95</td>
<td>17.21</td>
<td>18.1</td>
<td>18.77</td>
</tr>
</tbody>
</table>

Table 3. The measured electrical conductivity values

<table>
<thead>
<tr>
<th>Relative density</th>
<th>0.066</th>
<th>0.090</th>
<th>0.171</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conductivity [Ohm m]$^{-1}$</td>
<td>$1.66 \times 10^6$</td>
<td>$2.03 \times 10^6$</td>
<td>$3.43 \times 10^6$</td>
</tr>
</tbody>
</table>

| $\lambda/k$, [W m K$^{-1}$] | 3.54 | 4.47 | 5.18 |

Table 4. Ratio of thermal and electrical conductivity at 30°C

4.3 Ratio of thermal conductivity and electrical conductivity in the function of relative density

The ratios of thermal and electrical conductivities are increasing by the increase of the relative density of the foams (Table 4).

Fig. 2. Thermal conductivity in the function of the temperature in the case of 0.066 relative density

Fig. 3. Thermal conductivity in the function of the temperature in the case of 0.09 relative density

Fig. 4. Thermal conductivity in the function of the temperature in the case of 0.171 relative density

Fig. 5. The measured conductivity values vs. the relative densities of the foams
5 Conclusions

Different density Alporas aluminum foam was investigated by comparative and eddy current method. The results showed that:
- In case of the 0.177 g/cm³ density samples the pressure of the gas environment did not influence significantly the thermal conductivity data.
- A slight increase of the heat conductivity was found vs. temperature (in the RT-500 °C range) in all the densities.
- The foam thermal conductivity vs. density shows almost linear behaviour.
- Good linear connection was found between the relative densities of the foams and the electrical conductivity values measured by eddy current technique.
- The low frequency eddy current measurement can be a useful and cost effective tool for the fast determination of electrical conductivity of different aluminum foams.
- The ratios of thermal and electrical conductivities are found to be increasing by the increase of the relative density of the foams.

Further X-ray tomography experiments are planned in order to compare theses results with the foam structure itself.

6 Acknowledgements

The authors would like to thank for Tetsuji Miyoshi who provided the Alporas aluminum foam samples. This investigation is funded within contract HPRI-CT-1999-00024 of the “Improving Human Potential” program of the “European Commission”.

7 References


N. Babcsán, University of Miskolc, Materials Science Institute, H-3515 Miskolc, Hungary, e-mail: femnorbi@gold.uni-miskolc.hu

Received in final form: 11/21/02 [T 568]