Flash Techniques to Measure Thermal Diffusivity and Thermal Conductivity of Metal-Foam-Materials

W. Hohenauer, D. Lager

AUSTRALIAN INSTITUTE OF TECHNOLOGY, 3444 Sierlersburg (A)

INTRODUCTION:
Metallic foams represent a specific class of materials in engineering and design. Therefore one has to know their basic thermo-physical properties: thermal expansion, heat capacity and thermal conductivity. In former measurement campaigns a comparative set-up was used. It manages the relatively high thermal conductivity of ~10 W/m.K in a sufficiently wide temperature range of [T₁, T₂] = [-400°C]. But the method suffers from its dependency of a highly accurate temperature measurement of a set of 6 thermocouples minimum. Therefore an alternative technique to perform conductivity data was searched. Here a method to measure thermal diffusivity of foamy materials with a laser flash (LF) is described. The requirement of a coplanar specimen is met by filling the surface near porosity with a ceramic paste. The thermal conductivity is calculated from diffusivity data using λ = c₁ε₁a₁.

Comparative Set-Up versus Laser Flash:
Methods and the basic equations to determine thermal conductivity (Comparative Set-Up) and thermal diffusivity (Laser Flash) are illustrated. In accordance to the GUM (Guide to Express Uncertainty in Measurement Results: ENV 13005) the mathematical models to estimate the Equipment Uncertainties ESU are given. The dependency of the ESU in case of a comparative conductivity measurement ESU(a) strongly correlates to the uncertainty of the model since the temperature a(T) is about 10% of the measured conductivity under optimum conditions. By contrast flash results show a rather low measurement uncertainty ESU(a) around 2%. To consider effects from the fit-quality the standard deviation SDV² of the individual measured results SDV²(a) is added. To derive the ESU(a)/Parks law is applied. In general specific theories are used to examine thermal diffusivity a(T) from the detected T(t) curve. The accuracy of the value a(T) strongly depends on the fit-quality from this theoretical approach. In the theoretical model to estimate the standard uncertainty a(T) the standard deviation SDV²(a) is used to capture effects from the fit-quality.

FEM SIMULATION OF FOAMY SAMPLES:
The images show the transient temperature response of the magnesium foam structure (blue) and the SiC filler (green) for three characteristic types of samples with approximately the same height (~10 mm). Additionally the radiation dependent detector signal (red) is shown. Image I shows a sample with a pore size of 1 mm. Compared to the sample size this represents a type quasi-homogeneous metallic body. No significant differences in the temperature responses of the metal, the SiC filler and the detector occur. Image II shows a typical sample with a pore size of 2.3 mm. The IR-detected temperature could be verified by measurement. It is significantly different from the real temperature response of the metallic structure. Thus the half time t₁/₂ has to be corrected by a factor R = k(EOSU/a)(ESU/a) giving the characteristic radius of the pores r following to r = [R(EOSU/a)(ESU/a)]¹/₂ (µm). Therefore the radius R of the sample measures 20 mm and is approximately twice it’s characteristic radius. Thus the number of pores (mono-sized pores are assumed) in the volume can be calculated with n = V/n₀ V is the volume of the sample, n₀ is the number of pores visible at the top surface of the sample. Equation [1]: n = Vn₀/2πr²h gives the characteristic radius of the pores r following to r = [R(EOSU/a)(ESU/a)]¹/₂ (µm). For n = 100 one estimates r ~2 mm. This corresponds to a FE-model with 5 layers as illustrated in image I. From a first view no correction seems to be necessary. But the FE-analysis shows that a half time correction of about 10% should be done. The corrected characteristic radius of the pores r is shown in image II. Here the un-corrected and the un-corrected conductivity data are both corrected and the un-corrected conductivity data are shown in green above. In comparison to conductivity results from a comparative set-up LFA based data are about 10% to 15% higher. LFA based data and Comparative data give results in the uncertainty levels of both methods. Comparative data were attributed with a constant uncertainty of 15% from their supplier. Therefore here is assumed that either a rough description of the ESU with an uncertainty of the temperature of ±2°C was used for the set-up or no statistics from a set of measured samples was done. To correct this a(T) ~ (ESU/ESU)² · 20% · ε is assumed. LFA based conductivity data show an uncertainty level (95% Conf. Int.) k = 2 from ~10%.

FEM BASED CORRECTION OF FLASH RESULTS IN COMPARISON WITH COMPARATIVE DATA:
A foam from a Magnesium-ally as shown in the figure above was measured. Its density at 20°C is ρMg = 0.411 ± 0.015 g/cm³ = 25% ρMg. The radius R of the sample measures 20 mm and is approximately twice its characteristic radius. The number of pores (mono-sized pores are assumed) in the volume can be calculated with n = V/n₀ V is the volume of the sample, n₀ is the number of pores visible at the top surface of the sample. Equation [1]: n = V/n₀ = 2πr²h gives the characteristic radius of the pores r following to r = [R(EOSU/a)(ESU/a)]¹/₂ (µm). For n = 100 one estimates r ~2 mm. This corresponds to a FE-model with 5 layers as illustrated in image I. From a first view no correction seems to be necessary. But the FE-analysis shows that a half time correction of about 10% should be done. The corrected characteristic radius of the pores r is shown in image II. Here the un-corrected and the un-corrected conductivity data are both corrected and the un-corrected conductivity data are shown in green above. In comparison to conductivity results from a comparative set-up LFA based data are about 10% to 15% higher. LFA based data and Comparative data give results in the uncertainty levels of both methods. Comparative data were attributed with a constant uncertainty of 15% from their supplier. Therefore here is assumed that either a rough description of the ESU with an uncertainty of the temperature of ±2°C was used for the set-up or no statistics from a set of measured samples was done. To correct this a(T) ~ (ESU/ESU)² · 20% · ε is assumed. LFA based conductivity data show an uncertainty level (95% Conf. Int.) k = 2 from ~10%.