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Effective thermal conductivity of sintered metal foams: Experiments and a model proposal

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The foams investigated are intended to be used in advanced high efficiency gas turbines as actively cooled wall elements of the combustion chamber (effusion cooling, Fig. 1). Since critical temperatures must not be exceeded, temperatures inside the foam must be precisely calculated. For this, thermophysical data of this new material is required at temperatures of up to 1000°C. Here, thermal conductivity (TC) data is presented. Since the various pore size level heat transfer effects contribute to the overall thermal transport, an *effective thermal conductivity (eTC)* is considered to describe these effects by volume averaging.

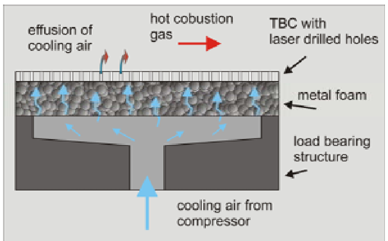

Figure 1: Cross-sectional view of the combustion chamber wall

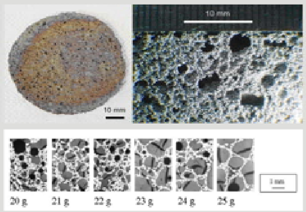

Figure 2: Metal foams investigated (top), different porosities by varying the amount of solvent (bottom)

The investigated metal foams (Fig. 2 top) have heterogeneous open porosities ranging from 0.55 to 0.85. They are manufactured with a powder metallurgical method called *Slip Reaction Foam Sintering (SRFS)*. In this process, a fine metal powder with grain sizes of up to 150 mm and a slurry-stabilizing dispersant are mixed with a solvent and a certain amount of acid. The metal acid reaction generates gaseous hydrogen, which causes the slurry to foam (Angel et al. 2005). Various porosities are possible (Fig. 2 bottom). There are large pores (primary pores, ∅ 1- 3 mm) caused by the foaming process and secondary pores (∅ 10- 50 µm) as the natural cavities between the adjacent metal powder particles. For comparison, samples with only secondary pores were manufactured. *Inconel 625*, Hastelloy and Iron were used as powders.

For the determination of the eTC the *Transient Plane Source Technique,* also known as *Hot Disk* was employed (Gustavsson et al, 1994). It is based on a theory, which assumes that a flat, circular sensor, which acts as a heat source as well as a thermometer, is placed between two half-infinite heat sinks consisting of sample material (Fig. 3 top). The sensor itself consists of an electrical heated nickel double spiral. The sensor temperature is collected by exploiting the temperature-dependent electrical resistance of nickel. For temperatures up to 200°C, the nickel spiral is Kapton insulated. Above 200°C, Mica insulation is applied (Fig. 3 bottom). The maximum application temperature is 700°C. Measurements at temperatures higher than room temperature are carried out in a furnace with precise temperature control.

The eTC is determined for a large number of materials with various porosities. Fig 4 shows the eTC at room temperature as a function of primary porosity. The validity of a simple rule of mixture using the eTC of the matrix material is shown. To explain the eTC of the matrix material itself, a model from Hsu was adapted (Fig 5, Fig 6). Additionally, the high temperature eTC of various foam materials was determined. For the temperatures considered the radiative contribution to the eTC may be neglected. Therefore these results can be explained with the modified rule of mixture as well.

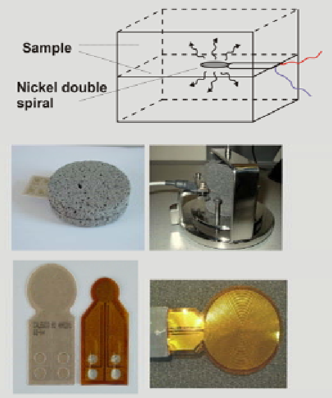

Figure 3: Schematic of the Hot-Disk Technique (top), installation of samples (middle), mica sensor (bottom left) Kapton sensors (bottom middle and right)various samples

Compared to dense metals, the values are smaller by a factor of 20-40. This is mainly caused by the matrix structure consisting of adjacent grains with only small contact areas. The Hsu model yields some rough information on the mechanism of heat flow in so far that the effective cross-sectional area for heat flow is approximately 1/16 of the full cross-section.

For the matrix material the *Hot Disk* results have been additionally validated with a *Laser Flash* instrument, which fails for the measurement of foams with larger pores due to the limited sample size.

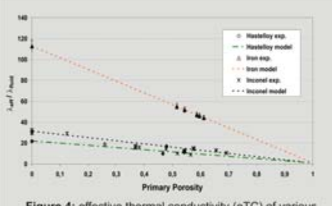

Figure 4: effective thermal conductivity (eTC) of various metal foam materials as a function of primary porosity

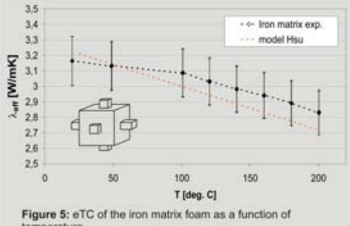

Figure 5: eTC of the iron matrix foam as a function of temperature

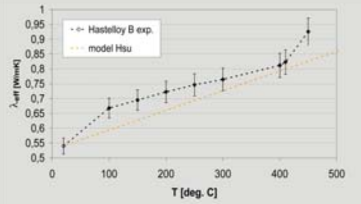

Figure 6: eTC of the Hastelloy matrix material as a function of temperature

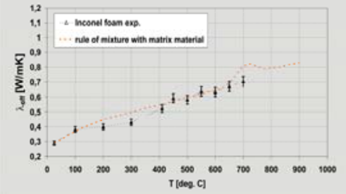

Figure 7: eTC of an Inconel foam as a function of temperature

ACKNOWLEDGMENTS

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