Thermal Diffusivity of Metals as a Function of Grain Size

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Introduction

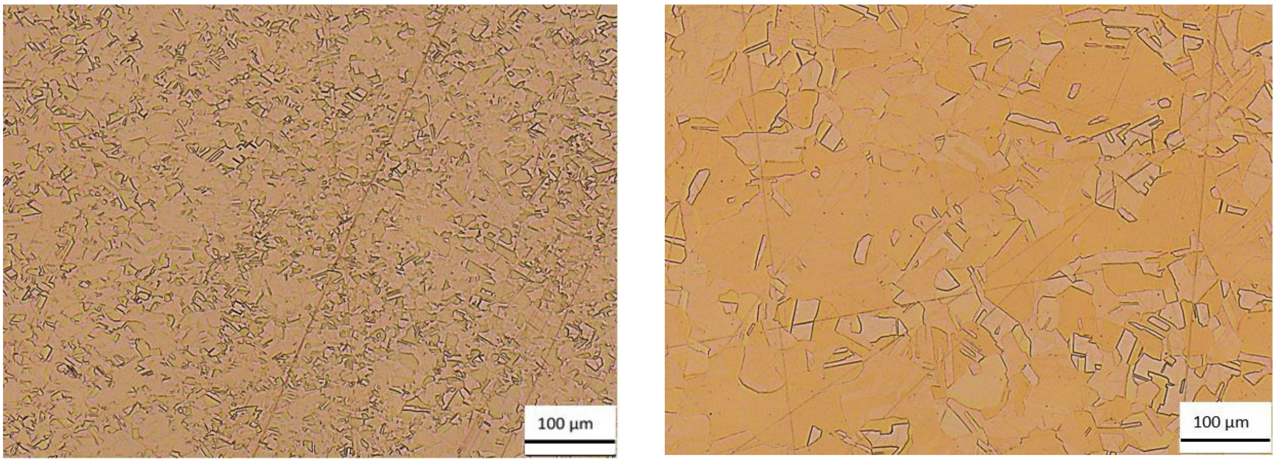
Along with the thermal conductivity, λ, the thermal diffusivity, a, is an important thermophysical parameter. In contrast to thermal conductivity, which describes stationary heat transfer, thermal diffusivity, α, is a parameter for a material's transient heat transfer. To calculate of the thermal conductivity, the thermal diffusivity, a, is required in addition to the specific heat capacity, c_p, and density, ρ:

$$\lambda = \alpha \cdot c_p \cdot \rho$$

The specific heat capacity is only dependent on the chemical composition. The density is a function of the macroscopic structure of a material (e.g., pores). The thermal diffusivity depends on the macrostructure, but also partly on the microstructure of a sample.

In the following, the thermal diffusivity of a copper sample is shown as a function of grain size. As a rule, the smaller the grain size (= the more grain boundaries), the lower the thermal diffusivity.

The structure of a copper sample, produced by means of additive manufacturing is characterized by many small grains and thus many grain boundaries, due to the relatively short heating and fast cooling cycles. Tempering the sample (1 h at 1000°C) yields a structure with significantly larger grains and thus fewer grain boundaries. A comparison of the microstructures is depicted in figure 1.



1 Structure of a high-purity copper sample (99.3%) produced by means of additive manufacturing.
Left: copper directly after production; right: tempered copper (1 h @ 1000°C)

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Measurement Conditions

Measurement of the thermal diffusivity at room temperature of the two copper samples was carried out with the LFA 467 *HyperFlash*®. The LFA samples had a diameter of 12.7 mm and a thickness of 3 mm. The samples were lightly, but not opaquely, coated with graphite prior to the measurement to improve the emission and absorption properties of the copper samples.

Measurement Results

The results are summarized in table 1. The tempered sample, at 116.88 mm²/s, exhibity nearly the literature value of pure copper, at 117 mm²/s [1]. The copper sample directly after additive manufacturing, with a smaller-grained microstructure, shows a significantly lower thermal diffusivity of 108.97 mm²/s.

Conclusion

LFA is a non-contact measuring method that can reliably resolve even small differences, such as those caused by a change in microstructure, without the disturbing influence of contact resistances.

Acknowledgement

We would like to thank Infinite Flex GmbH for the additive manufacturing and tempering of the copper samples and the University of Bayreuth, Department of Metals, for providing the micrographs.

Literature

[1] Y.S. Touloukian; Thermophysical Properties of Matter – Volume 10 – Part 1 – Thermal Diffusivity

Table 1 Thermal diffusivity of pure copper with different structures at room temperature

Sample	Thermal Diffusivity/mm²/s	Deviation from the Literature Value of Pure Copper
Copper, directly after additive manufacturing	108.97	-6.8%
Copper, tempered (1 h @ 1000°C)	116.88	-0.1%