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TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

MEASURING THERMAL CONDUCTIVITY - PART 3 – KOHLRAUSCH AND LASER FLASH METHODS

Laser Flash Isn't a Superhero! – Two more methods to indirectly measure the thermal conductivity of a material.

- Thermal Conductivity
- Kohlrausch Method
- Laser Flash Method
- Specific Heat
- Thermal Diffusivity

The next issue of Technical Tidbits will discuss specific heat.

This is a discussion of two more methods to determine the **thermal conductivity** of a material. Again, these are indirect measurements. The first calculates thermal conductivity by measuring 3 temperatures and 1 voltage. The second measures thermal diffusivity, and back-calculates conductivity from the material's specific heat and density.

The **Kohlrausch method** measures another set of parameters. This method runs a known current (I) through a sample of known length (L) and cross sectional area (A), while heating the center of the sample to a set temperature and cooling the sample to another set temperature at each end. (This is equivalent to the assumptions used for the temperature rise equation from Technical Tidbits Issue No 23 – Temperature Rise.) By measuring the temperature at the center (T_2) of the sample and at the two equidistant points on either side of the center (T_1 and T_3), as well as the voltage drop across the sample (V_3-V_1) at the temperature probes, you can calculate the temperature rise over the length.

The thermal conductivity (κ) and the electrical conductivity (λ) are unknown, but you can solve for the product of the two.

$$\kappa \cdot \lambda = \frac{(V_3-V_1)^2}{4[2 \cdot T_2-(T_1+T_3)]}$$

Using the voltage drop through the sample, you can calculate the electrical resistance (R) along the same path, and thus the resistivity.

$$\lambda = \frac{A}{L} \cdot R = \frac{A}{L} \cdot \frac{(V_3-V_1)}{I}$$

You then calculate the thermal conductivity by dividing the first result by the second. Furthermore, by heating the center of the sample (T_2) to different temperatures, you can also determine electrical and thermal conductivity vs. temperature, which is very useful data.

$$\kappa = \frac{LI\,(V_3-V_1)}{4A[2 \cdot T_2-(T_1+T_3)]}$$

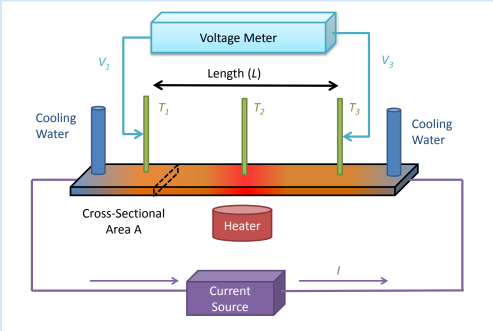

Figure 1. Kohlraush Method. The cooled edges maintain a parabolic temperature distribution through the bar due to the heating effect of the current passing through. The heater is used to maintain the steady state temperature by balancing out heat lost by convection and radiation. The temperature is measured at the three thermocouples (T_1, T_2, and T_3) shown in green, and the voltage drop between the first and third thermocouple is also measured.

KOHLRAUSCH AND LASER FLASH METHODS (CONTINUED)

The laser flash method does not directly measure thermal conductivity either, but it measures the thermal diffusivity (*D*). Thermal diffusivity is the ratio of the thermal conductivity to the product of the specific heat and density. $D = \frac{\kappa}{(\rho \cdot c_p)}$

Note that thermal diffusivity is often designated a "*α*", but I am using the notation "D" to avoid confusion with the coefficient of thermal expansion, which is also designated as "*α*".

In the laser flash method a short pulse of laser light is aimed at one surface of the material, and the laser flash is absorbed by that surface (radiative heat transfer), generating heat. The heat conducts through the sample, and is then radiated out the back surface (radiative heat transfer). By comparing the temperature vs. time data of the back surface to the expected behavior for materials of known diffusivity at the sample thickness, you can determine the diffusivity of the sample. If you have previously measured the density (ρ) and specific heat (c) of the test specimen, you can then calculate the conductivity. $\kappa = D \cdot c \cdot \rho$.

There are a couple of caveats to this method. For one, you will also need to have a reasonably accurate value for the reflectivity of the surface, so you can determine how much thermal energy was input. It can help to place a thin black, highly conductive coating like graphite on the front surface to maximize absorption of the laser.

Secondly, if the material has large grains of different phases extending through the entire sample, then the results may be skewed by the more conductive phases. In this case, the Kolrausch method might be better, since the overall thermal conductivity will be the sum of all the phases within. This will probably give a more real-world view of what the effective thermal conductivity would be in service.

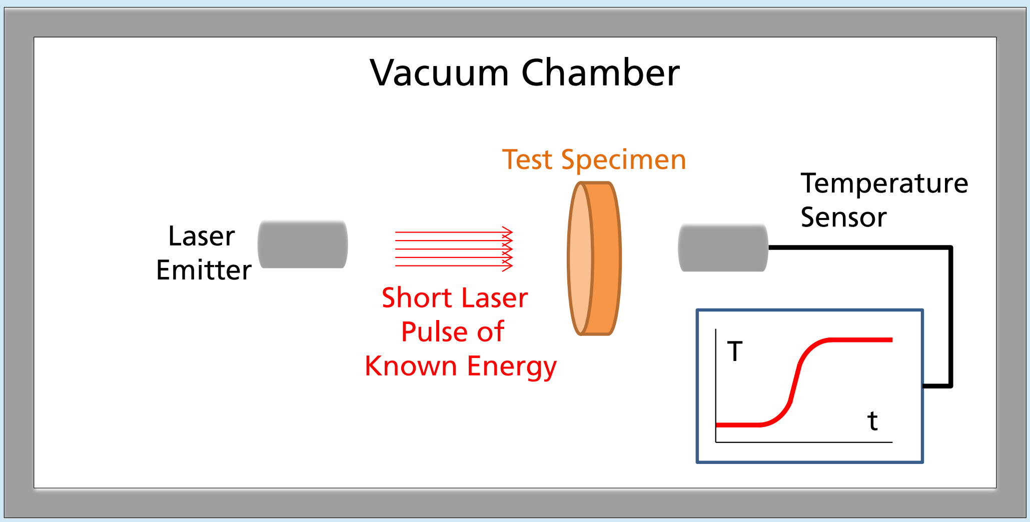

Figure 2. Laser Flash Method. If done in a vacuum chamber to prevent heat loss by convection, most of the energy of the flash is conducted through the sample. The output of the device is a curve of temperature vs. time for the back surface.

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References:

ASTM E-1461-13 Standard Test Method for Thermal Diffusivity by the Flash Method
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ASTM E-2585-09 Standard Practice for Thermal Diffusivity by the Flash Method
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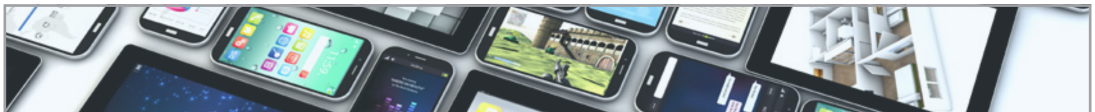

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