MATERION

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TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

MEASURING THERMAL CONDUCTIVITY – **PART 2 - BAR AND DISK METHODS**

Best method, bar none? – Determining thermal conductivity by measuring total heat transfer.

- **Thermal Conductivity**
- **Lee's Disk Method**
- **Searle's Bar Method**

Recall from last month that under steady state conditions, the 1 dimensional heat transfer through a sample of constant cross section is as follows:

$$q = -\kappa \cdot A \frac{dT}{dx} = \kappa \cdot A \, \frac{({}^{T}\mathrm{Hot} - {}^{T}\mathrm{Cold})}{L}$$

where A is the cross sectional area of the specimen, L is the distance between the hot face and the cold face, q is the heat flow, and κ is the thermal conductivity. To obtain the thermal conductivity from a measurement, you can rearrange the equation to solve for conductivity as a function of specimen thickness, area, measured heat flow, and measured temperature difference:

$$\kappa = \frac{q \cdot L}{A({}^{T}\mathrm{Hot} - {}^{T}\mathrm{Cold})}$$

The time to achieve steady state conditions, with a given temperature differential will be inversely proportional to the heat flow. So, the equilibrium time is proportional to $\frac{1}{\kappa} \cdot \frac{L}{A}$. If the material to be tested has a low conductivity, then the ratio of the cross sectional area to the length needs to be high. Therefore, disk-shaped samples are used. This principle is used in **Lee's disk method.**

However, higher conductivity metals achieve steady state quickly no matter what the sample size and shape are. However, the resolution of the heat flow and temperature gradient is proportional to L/A. Therefore, relatively long cylindrical or rectangular prisms are used for the test specimen. This principle is used in **Searle's bar method.**

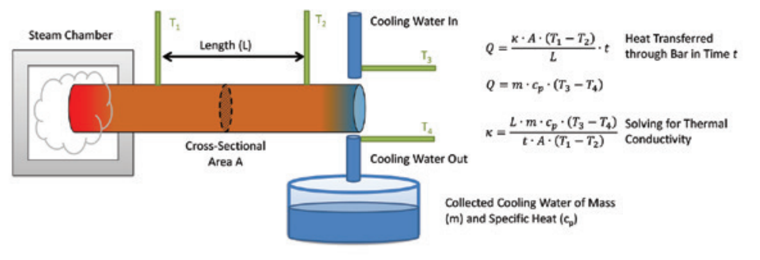
Now, instead of measuring the rate of heat flow (q), these two methods measure the total heat transferred (Q). In that case, the governing 1-D steady state heat transfer equation becomes:

$$q = -\kappa \cdot A \, \frac{({}^{T}\mathrm{Hot} - {}^{T}\mathrm{Cold})}{L} \cdot t$$

where t is the total time over which the heat is transferred. Note that in both the Searle's bar method and Lee's disk method, you are assuming that there is no heat lost in the radial direction from the edge of the disks or the cylindrical face of the bar. This assumption requires that the apparatus be well insulated on the sides to prevent heat loss in this direction.

Searle's bar method works as follows: You heat the hot end of the bar with steam and simultaneously cool the other end with water at a known temperature. You measure the temperature of the bar at two points of known distance, and measure the temperature of the cooling water before and after it cools the end of the rod. Once it reaches steady state (no change in temperature), begin collecting the cooling water. You can easily calculate the total heat (Q) absorbed by the volume of water from its **specific heat (heat capacity)**, its mass, and by how much its temperature rose during the test of time (t).

Figure 1. Searle's Bar Method. The only measurements are the mass of the collected cooling water (m), the distance between the thermocouples on the bar (L), the cross sectional area of the bar (A), and the temperature at the 4 thermocouples (T_1, T_2, T_3, & T_4) shown in green. The insulation that would be around the bar and the cooling apparatus are omitted from the drawing for clarity.



The next issue of Technical Tidbits will discuss measuring thermal conductivity by the Kohlrausch and laser flash methods.

MEASURING THERMAL CONDUCTIVITY – **PART 2 - BAR AND DISK METHODS** (CONTINUED)

For lower conductivity materials, **Lee's disk method** is used instead. It is not, however, done by simply replacing the bar in the above method with a disk. You measure neither the total heat transferred (Q), nor the heat transfer rate under steady state conditions (q) directly on the specimen. In fact, the final measurement is done without the specimen present at all!

To start, you must take a thin disk (of area A and thickness x) of the material to be measured. Place it between two brass disks of known mass (m) and specific heat (c). Heat the open face of one of the brass disks with a steam, and let the bottom face of the lower disk cool naturally. By continuously measuring the temperatures of the two brass disks (T_{hot} and T_{cool}), you can determine when the arrangement reaches steady state. The temperatures of the surrounding disks will give you the temperature gradient through the specimen

1-D Conduction Equation: $Q = \kappa \cdot A \left[\frac{T_{Hot} - T_{Cold}}{x}\right]$ (Q unknown, κ unknown,)

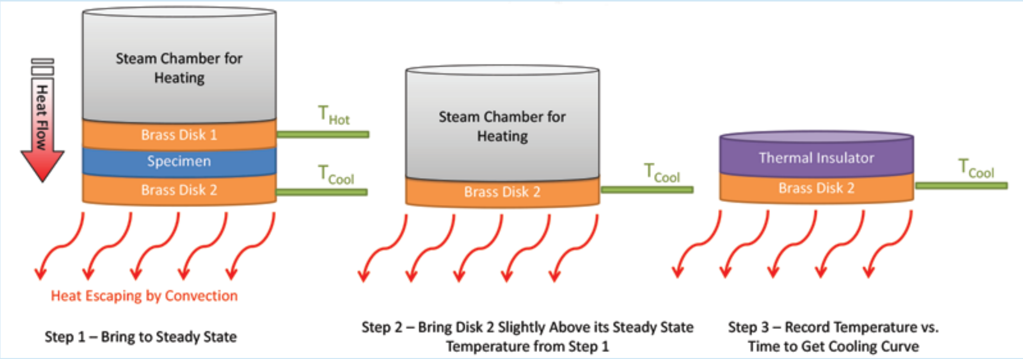


Figure 2. Lee's Disk Method.
The insulation that would be around the circumference of the stack is omitted for clarity.

Next, remove the test specimen and allow the cooler disk to heat up to slightly above the heated disk's temperature. Turn off the steam, and replace the heated disk with an insulator. By continuously measuring the temperature of the remaining disk as it cools, you can generate a cooling rate curve (dT/dt), and you can pick off the cooling rate when the disk reaches the temperature it had at steady state when the test specimen was present.

1-D Cooling Equation: $Q = m \cdot c \frac{dT}{dt}$ (Q unknown, dT/Dt at T_{cool})

The rate of heat radiated by the lower disk at T_{cool} is the same in both cases, and is the same as the heat conducting through the test specimen. By combining the 1-D steady state conduction equation with the 1-D steady state cooling equation, you can calculate the thermal conductivity of the test specimen, as it is the only unknown in the set of equations.

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References:

ASTM C-518-15 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
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ASTM E-1225-13 Standard Test Method for Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique
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ASTM E-1952-11 Standard Test Method for Thermal Conductivity and Thermal Diffusivity by Modulated Temperature Differential Scanning Calorimetry
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