MEASUREMENT OF THE THERMAL CONDUCTIVITY OF POWDERS BY TWO DIFFERENT METHODS

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Abstract

The thermal diffusivities and thermal conductivities of powders, especially PMMA-coated silicon carbide, at various temperatures, have been tested by two different dynamic methods, the water-bath method and the laser-heated method. The thermal conductivity data found by these two techniques are found to be consistent with each other.

A Review of the Two Techniques

A Differential scanning calorimeter (DSC), DSC-7 made by the Perkin-Elmer Company, has been used [1] to measure the heat capacities at various temperatures for all of the powders used. The heat capacities of the powders were found to be functions of temperature. The specific heats of all the powders are found to be the same as those of the corresponding solids.

The thermal conductivities of powders are measured by an unsteady state method with two water baths of small temperature differences[1,2,3]. The range of the temperatures investigated, limited by the boiling point of water in the water-bath method, was mainly from 30-90°C, i.e. below the sintering temperatures of the powders. During the process of raising the temperature, sometimes bubbles of air were seen to adhere to the outside surface of the sample tube which obviously decreases the rate of the transfer of heat. The authors found that the formation of air bubbles may be avoided by the addition of some soap solution into the water baths to decrease the surface tension of the water used. Only small changes in temperature, typically 10°C, are used. This is necessary to account for the temperature dependent thermal properties at the powder beds.

As the temperatures used during the SLS process are not limited to the ambient temperatures, a laser-heated method [5,6,7] was adopted to study thermal conductivity at the higher temperatures. This technique uses a laser to heat the surface of a sample powder bed while a thermocouple at a certain depth inside the powder bed records the rise of temperature against time.

Figure 1 shows the basic experiment. The powder bed is contained in a 1 inch diameter by 5 inch long glass tube. The bed temperature is maintained at the desired temperature by a 675 watt Tempco Co. coil heater (MHS1255BL02). That is controlled by a pulsed DC output temperature controller (Omega CN76120). The pulsed output is used to switch a solid state relay connected a the heater AC power line. The powder samples completely fill the sample tube. The center temperature, 1 cm below the bed surface, is measured with a thermocouple. The tube is wrapped with thin aluminum foil and placed inside the coil heater.

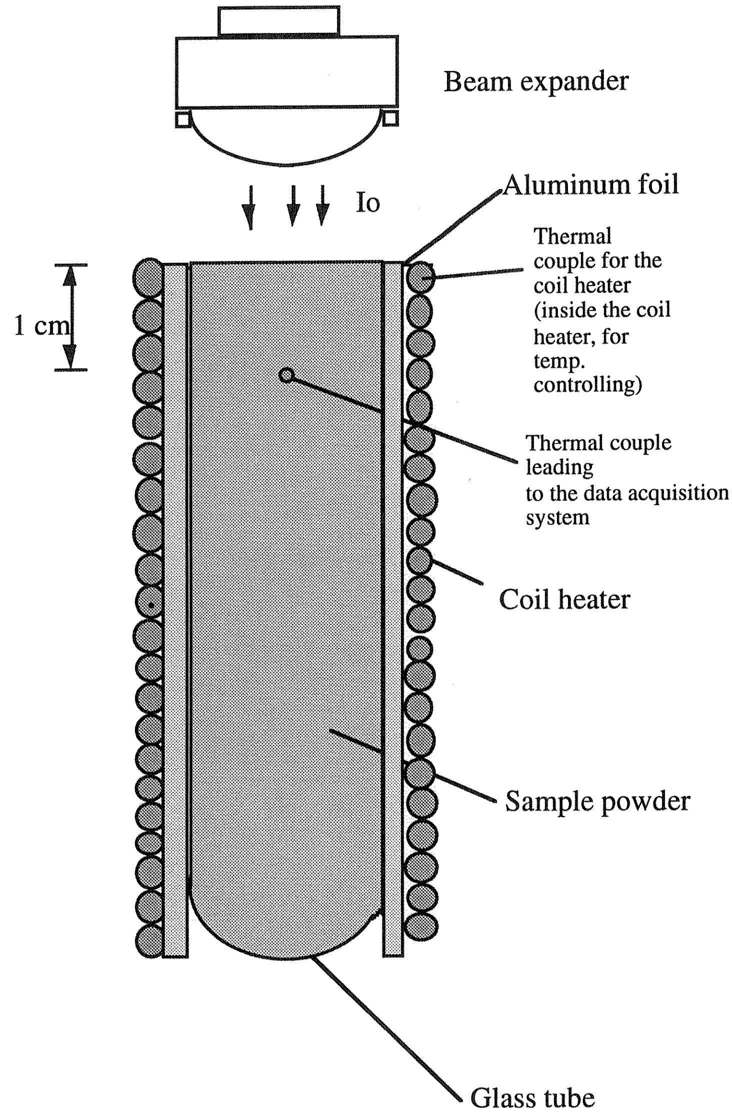

Figure 1. The laser and the powder sample

One might have the worry whether the heat energy supplied through the coil heater might interfere with the energy supplied by the laser power. But actually, with the short incidence of the laser light (from 1 min. to about 4 min.) and with the small change in temperature caused by the laser, the coil heater generally sends in little energy, if any.

Experimental Results

The PMMA-coated SiC, prepared by Neal Vail, has 19.3 vol% of the polymer. The solid density for PMMA is 1.2 g/cc, the solid density of SiC is 3.217 g/cc. So the solid density of the PMMA-coated SiC is 2.827 g/cc.The bulk density of the powder sample we used for the water bath method was 1.328 g/cc. Consequently, the porosity of the powder sample was 0.530. The temperature range for the water bath method was 30-90°C. One of the temperature vs. time curve of water bath runs is shown below. (See Figure 2.)

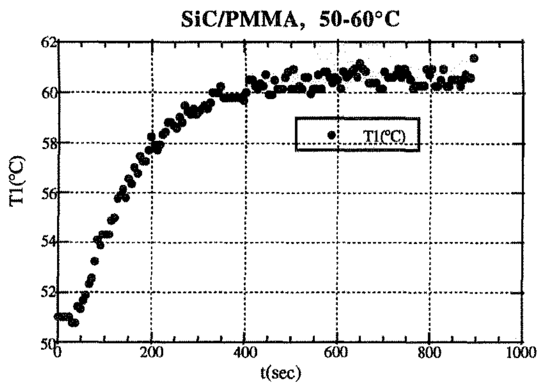

Figure 2. PMMA-coated SiC powder temperature rising curve, 50-60°C

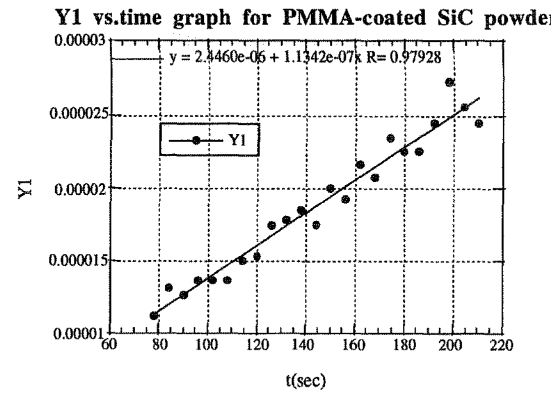

Figure 3. Y1 vs time graph for the same powder and same heating cycle

The analysis of the water bath data is done according to the procedure discussed before. [1] The Y1 vs time graph for the PMMA-coated SiC powder, from 50-60°C is shown in Figure 3. (See Figure 3.)

The heat capacity of the PMMA-coated SiC powder vs. temperature is shown in Figure 4. (See Figure 4.) The resulting thermal conductivity of the PMMA-coated SiC powder vs temperature is shown in Figure 5.

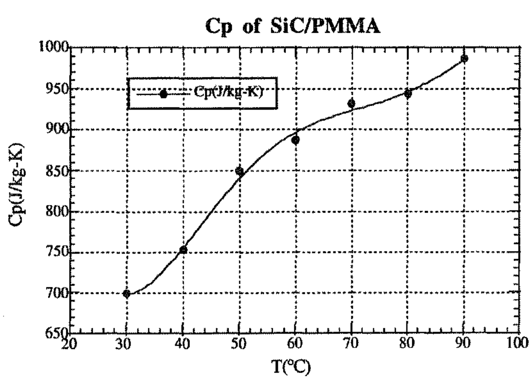

Figure 4. The heat capacity vs. temperature curve of PMMA-coated SiC powder

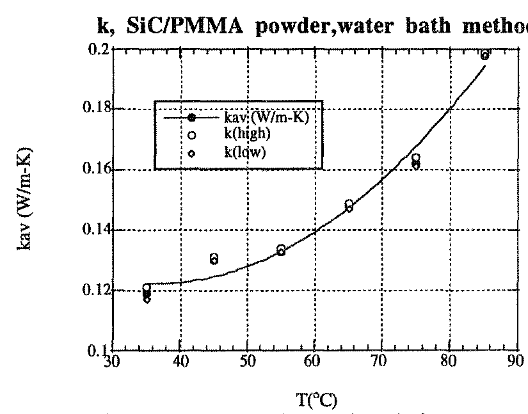

Figure 5. The thermal conductivity vs. temperature curve of PMMA-coated SiC powder

The porosity of the powder of the PMMA-coated SiC which we tested through the laser-heated method was also 0.530. The temperature rise vs. time curve of one of the runs of the laser-heated method is shown in Figure 6.

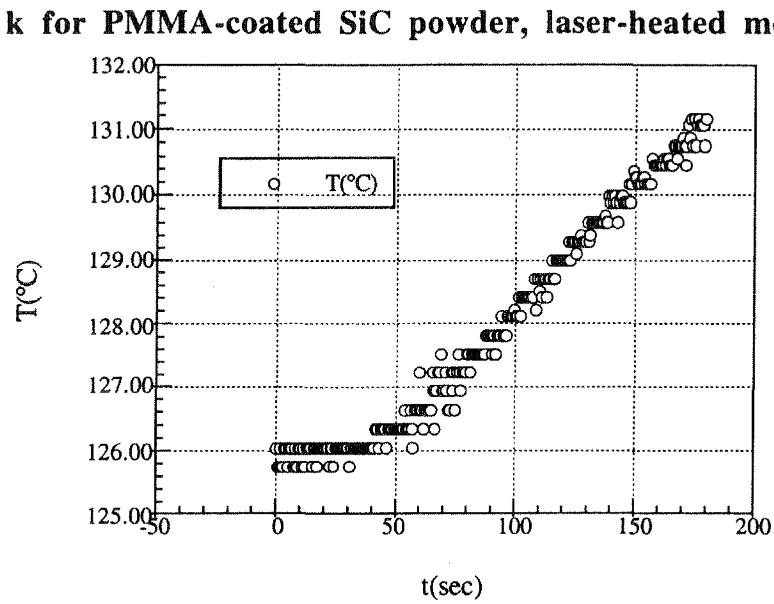

Figure 6. The temperature rise vs. time curve of PMMA-coated SiC powder in the laser-heated method.

The data are analyzed by the ratio method as discussed before [5]. For the run of Figure 6, the reading of the temperature at 90 sec. was 127.82°C, and the reading of the temperature at 180 sec. was 131.15°C. (The reading of the numbers were obtained not through the graph, but through the output of the data acquisition system.) As the initial temperature of the run was 126.05°C, the ratio, R, of the two temperature differences at the two time periods is

$$R = \frac{131.15 - 126.05}{127.82 - 126.05} = 2.88 \qquad (1)$$

The mathematical solution for this semi-infinite 1-D heat conduction problem [5] is

$$\Delta T(z,t) = \frac{2\varepsilon Io}{k}\sqrt{\alpha t}\; ierfc\left[\frac{z}{2\sqrt{\alpha t}}\right]$$

$$R = \frac{\Delta T(L, 2t_1)}{\Delta T(L, t_1)} = \frac{T_2 - T_0}{T_1 - T_0} = \frac{\sqrt{2}\, ierfc\left[\frac{L}{2\sqrt{\alpha t_2}}\right]}{ierfc\left[\frac{L}{2\sqrt{\alpha t_1}}\right]}$$

$$= \frac{\sqrt{2}\, ierfc\left[\frac{1}{2\sqrt{2}\sqrt{Fo}}\right]}{ierfc\left[\frac{1}{2\sqrt{Fo}}\right]} \qquad (2)$$

In the above equation, the Fourier number, $Fo = \alpha t_1/L^2$, and L is the depth of the point beneath the surface at which the thermocouple is placed.

The authors wrote a Fortran program for the above relationship and got a table to find out the value of Fo for every definite R value, in Equation (2). For the value of R = 2.88, we found Fo = 0.322. Therefore,