Effect of Grain Size upon the Thermal Behavior of Copper and Diamond Powders using Differential Scanning Calorimetry (DSC)

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Abstract

Objectives: In this study, the heat capacity and heat flow of varied grain size of copper and diamond powders were investigated. Methods: Heat capacity and heat flow of varied grain size of copper (1 µm-70 µm) and diamond powders (2 µm-300 µm) were measured using differential scanning calorimetry (DSC). The thermal properties of copper and diamond powders were determined in a temperature range of 0-500°C, with a heating rate of 5k/min in a nitrogen environment. Findings: Heat capacity and heat flow of copper and diamond powders increases with grain size and it is consistent with earlier researchers. Heat capacity of copper and diamond powders also increases with grain size. The heat capacity and heat flow was 1.4 J/gk and 0.24 mW/mg respectively for 60-70µm grain size of copper powder, whereas the values of the same were found to be 0.9 J/gk and 0.4 mW/mg for diamond powder of grain size in the range of 270 to 300 µm is determined. This study reveals that the diamond powders show better thermal performance over copper powder. Application/Improvements: Determination of thermal behavior is critical in determining the amount of heat transferred in micro electronics and solar thermal based applications.

Keywords: Copper, Diamond, Differential Scanning Calorimetry, Grain Size, Thermal Behavior

1. Introduction

Differential Scanning Calorimetry (DSC) measures the temperature and quantum of heat transfer with respect to the transition of materials as a function of time and temperature in a controlled ambience. DSC measurements are essential in determining thermal conductivity, thermal diffusivity and to quantify the physical and chemical changes1,2. Thermal conductivity plays a vital role in determining the amount of heat transferred and essential in thermal management of micro-electronics and performance of solar thermal based applications. In micro electronics, the laser diode and integrated circuits generate more heat, where effective cooling is achieved by providing efficient heat transfer materials3. The solar thermal based applications improve the efficiency even at lower temperatures4. Copper and Diamond powders are widely used in many heat transfer applications, owing to higher thermal conductivities, \[K_{Cu} = 400\text{W/mK},\ K_{Dia} = 2000\ \text{W/mK}\] and lower Co-Efficient of Thermal Expansion [CTE]. Various researchers determined the thermal conductivity of quartz and compressed metal powders5,6,7,8, and lower Co-Efficient of Thermal Expansion [CTE]. Various researchers determined the thermal conductivity of quartz and compressed metal powders, aluminium7 using DSC. However, the studies on the effect of grain size on the thermal behavior of diamond and copper powder is limited and is attempted here in.

1.2 Theory

A calorimeter measures the heat into (or) out of a sample, but DSC measures the heat flow in varied temperatures

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and change in heat capacity. Heat capacity is a measure of additional energy the material stores at the molecular level when heated. When heat capacity of a metal is low, molecules can only vibrate where as the molecules can also rotate and translate when the heat capacity is high.

Heat capacity \((C_p)\) of a material in DSC model is determined\(^8\), using

\[
C_p = \lambda_{Cp} \left( \frac{Q_{amp}}{T_{amp}} \right) \left( \frac{\text{Modulation period}}{2\pi} \right) \quad (1)
\]

Whereas the, \(\lambda_{Cp}\), \(Q_{amp}\), \(T_{amp}\) are heat capacity calibration constant, heat flow amplitude \((\text{W/g})\), temperature amplitude \((\text{K})\). Heat Capacity \((C_p)\) relate the change in enthalpy \((Q_p)\) to the change in temperature \((\Delta T)\)

\[
Q_p = C_p \Delta T \quad (2)
\]

Thermal conductivity \((K_o)\) is measured by using the heat flow to measure the material transitions,

\[
K_o = \frac{8LC^2}{C_pMd^2p} \quad (3)
\]

Whereas the, \(K_o\), \(L\), \(C\), \(C_p\), \(M\), \(P\) are observed thermal conductivity \((\text{w/mK})\), Sample thickness \((\text{mm})\), Apparent heat capacity \((\text{mJ/K})\), Specific heat capacity \((\text{J/kgK (or) J/gK})\), Specimen mass \((\text{mg})\), \(d\)-Specimen diameter \((\text{mm})\), Period of measurement \((\text{s})\). From Equation 3, it is observed that, Heat Capacity \((C_p)\) is inversely proportional to thermal conductivity.

### 3. Results and Discussion

Non Isothermal heating of diamond powder was carried out from 0° to 500°C, with a heating rate of 5 K/min. The heat capacity and heat flow of varied size diamond powders are shown in the Figure 2 and Figure 3 respectively. At relatively below 100°C, heat capacity and heat flow results in the negative sign indicating the effect of internal stresses on each grain sizes during manufacturing leading to defects viz., vacancies, non diamond carbon, nitrogen, hydrogen, metallic impurities and the pressur-
izing diamond powders below 1% defects degrades many properties.

Heat capacity is inversely proportional to the grain sizes Equation 3 above room temperature up to 500°C, as the amount of heat stored in the boundary is low. Using when the grains are smaller, the thermal diffusivity and thermal conductivity decreased drastically as reported by earlier researchers. Heat flow increases with increase in grain size Figure 3 owing to enhanced absorption and reduced phonon scattering and is consistent with Morelli and Uher. This phenomenon results in higher heat flow and there by enhances heat transfer through the higher grain boundaries. The heat capacity and heat flow 0.9 J/gK and 0.4 mW/mg respectively for 270-300 µm grain size of diamond powder.

The thermal characteristics of different sizes of commercial pure copper powder heat capacity and heat flow are shown in Figure 4 and Figure 5 respectively. In Figure 4, the heat capacity depends on the grain size, as only the minimum amount of heat is stored, when the grain size is higher. The lower heat capacity indicates, less energy transfer due to the absorption of heat utilized to raise the temperature of material.

\[
a = \frac{K}{\rho C_p}
\]

Whereas \(a\), \(K\), \(\rho\), \(C_p\) are Thermal diffusivity (m²/s), Thermal conductivity (w/mK), Density (kg/m³), Heat capacity (J/kgK (or) J/gK).When the thermal diffusivity is higher, heat diffusing through the material is higher due to higher thermal conductivity and lower heat. When the temperature is increased, heat flow linearly increases with grain size. It is evident in Figure 5 that, there is a linear dependence of heat flow on grain size. This becomes due to grain boundary conductance of each grain. The heat capacity and heat flow was 1.4 J/gK and 0.24 mW/mg respectively for 60-70 µm grain size of copper powder.

4. Conclusion

- The heat capacity of the diamond and copper depends on the particle size. The higher size of diamond and copper particle indicates lower heat storing capability and higher heat transferring potential is high.
- The particle size is directly proportional to the heat flow and inversely proportional to the heat capacity.
- Heat capacity and heat flow has influencing over thermal conductivity and thermal diffusivity.
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