HIGH TEMPERATURE THERMAL CONDUCTIVITY OF CARBONACEOUS CHONDRITES AND THE RELATIONSHIP TO METEOR ATMOSPHERIC ENTRY.

D. R. Ostrowski[1,2] and J. B. Haskins[2], [1]Bay Area Environmental Research Institute, Ames Research Center, Moffett Field, CA, USA, [2]NASA Ames Research Center, Moffett Field, CA, USA.

Introduction: Thermal properties are an important fundamental characteristic of meteorites, an indicator of both their physical and chemical nature. Thermal physical properties of the carbonaceous chondrites are needed to determine the likelihood of the meteoroids survivability during atmospheric entry. They are used to determine ablation rates [1] and thus, the ablation is one input for mass loss and energy deposition into the atmosphere from meteor breakup [2]. Higher ablation rates could expose internal fracture that could cause the meteor to air burst. Combination of ablation and fracturing results in most meteorites losing greater than 80% of their mass during entry [3].

Thermal conductivity is the fundamental ability of an object to conduct heat. For meteorites, this can cause quite a variance within a class based off of the differences in mineralogy and physical condition, such as density, porosity, shock state, and weathering. Meteorites contain both high and low thermally conductive material. Most of thermal conductivity has been measured below 350K and mostly on ordinary chondrites [4], with a few at elevated temperatures which are needed to more accurately model atmospheric entry. Of these meteorites most have thermal conductivity of ~3W/m-K or less [4].

Experimental: Thermal conductivity for selected carbonaceous chondrites, across multiple groups. Measurements are made at six temperatures over the range of 300K up to 850K. The thermal conductivity is measured using a Unitherm model 2101 Comparative Cut-bar Thermal Conductivity meter. The comparative cut-bar method entails placing the sample of known size and shape between two identical standards of known size, shape, and thermal conductivity. Fused quarts cylinders of length 2.4 cm are used as standard. Meteorite samples used are 1.5 cm in length. Holes are drilled near the top and bottom of both standards and samples to allow thermocouples to be placed at the center of the material. Thermal conductivity is measured using equation 1:

$$k_s = 0.5\left[\frac{d_s}{A_s * \Delta T_s} * \left(\left(k_{tr} * \frac{A_{tr} * \Delta T_{tr}}{d_{tr}}\right) + \left(k_{br} * \frac{A_{br} * \Delta T_{br}}{d_{br}}\right)\right)\right]$$

where K is thermal conductivity, d is length of material, A is cross section area of material, ΔT is change of temperature across material, and subscript tr and br are top and bottom reference.

Surface temperature simulations are performed with the Icarus material response solver code, and a one-dimensional grid that represent the stagnation point on the surface of a large meteoroid. The surface is treated with an aerothermal boundary condition using the typical assumption of radiative equilibrium. Simulations of carbonaceous chondrites are performed. The physical properties of carbonaceous chondrites are approximated to be similar to those examined by ablation experiments [5].

Results: All meteorites analyzed in this study have thermal conductivity at 300k dissimilar to the major minerals of composition (Fig 1.) The CM chondrite Jbilet Winselwan as temperature increases starts to mimic the thermal conductivity profile of pyroxene at low temperatures and olivine at high temperatures. The ALH 83108 and MIL 090001 at low temperatures have thermal conductivities at the high end of stony meteorites [4]. Early-stage heating shows steep decline in thermal conductivity, but values still above major mineral components at similar temperatures. Porosity can affect conductivity, porosity of samples: Jbilet Winselwan 29.5%, Allende 24% [6], ALH 83108 9.7%, and MIL 090001 8.3%.

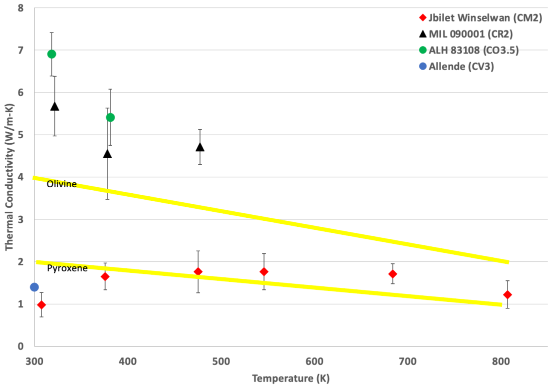

Figure 1. *Thermal conductivity profile of carbonaceous chondrites. Allende (CV3) data comes from Szurgot et al 2011.*

Values of material temperature and radiative heat transfer rate are needed to perform material response simulations of meteor entry. Meteors in space temperature is strongly dependent on the solar radiation flux and their optical properties. Investigations indicate that stony meteoroids have temperatures around 261K. Aerothermodynamic environment of meteors during entry has been examined on the basis of chemically reacting computational fluid dynamics coupled with radiation transport and surface ablation [7]. The radiative heat flux for a 10 m meteor with a 20 km/s velocity at 50 km was determined to be 7800 W/cm^2.

Material response simulations of surface heating during entry have been performed to evaluate the influence of the temperature-dependent, solid optical properties on entry, on the preheating stage of the meteor (Fig. 2). Surface temperature increases to the melting point (near 1800 K) of Jbilet Winselwan within 0.01 s. The heritage is an average of optical property dataset for carbonaceous chondrites is similar to that measured in the present work, exhibiting a maximum variation of. Heritage thermal conductivity value is from calculated and modeled values starting at 275K. Comparation of the heritage and the direct measured high temperature thermal conductivity values shows minimal difference (Fig. 2). This suggested that initial surface heating is so great that a thermal conductivity change of ~1 W/m-K has negligible effect.

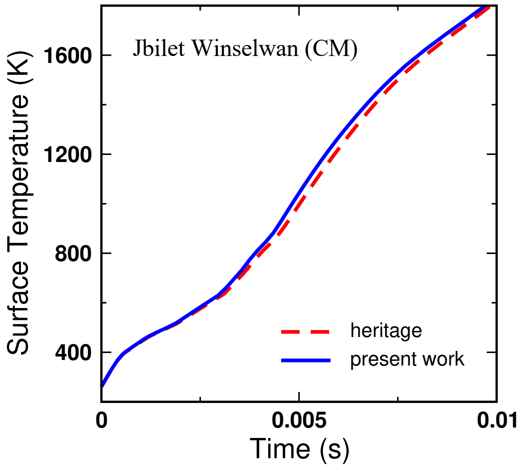

Figure 2. *Material response modeling of the surface temperature of Jbilet Winselwan (CM) as a function of exposure time to the radiation flux expected for a 10 m diameter specimen entering the atmosphere at 50 km. The profile is examined up to the approximate melting points of meteoritic materials (1800 K).*

Conclusion: Thermal conductivity of studied carbonaceous chondrites covers a wide range between 300-400 K of ~1-7 W/m-K. Porosity is a major factor, below 10% porosity have conductivity at the top of the range and porosity above 20% is at the bottom of the range. As temperature increase the Antarctic meteorites show a decline in conductivity towards the profile of olivine. Whereas non-Antarctic Jbilet Winselwan slightly increases than decreases, but always stays above the 300 K of 0.98 ±0.29 W/m-K. As temperature increases the effect of porosity becomes less.

Time to surface melt like conditions during atmospheric entry is minimally affected at high temperatures by the change in thermal conductivity values as temperature increases. This is most likely a result of heating being very intense rapidly.

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References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

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