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Thermal properties of meteorite and their relationship to atmospheric entry

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Abstract

Thermal properties are an important fundamental characteristic of both a meteorite's chemical and physical nature. Thermal properties are needed to determine the likelihood of meteoroids survivability during atmospheric entry. As emissivity changes with temperature it shows minimal effect on time to melt conditions for chondritic meteoroids, but has major effect on iron meteoroids cutting time in half.

1. Introduction

Most meteors bombarding Earth are small and burn up in the atmosphere, but a few are large enough to survive entry and cause notable damage. Between ablation and fracturing means most meteorites lose greater than 80% of their mass during entry [5]. Ablation models require meteorite emissivity and thermal conductivity as inputs [2], which have direct input on the time it takes for the surface to reach melt conditions. Material with low emissivity at high temperatures will increase the surface temperature and thus increase the ablation rate. Nonmetals in meteorites are poor thermal conductors with high emissivity, as temperature increases the thermal conductivity tends to increase and emissivity decrease [1].

2. Experimental

Thermal properties measured are a study of the whole meteorite. Samples are cut into polished cubes of 1.5 cm^3 to minimize surface roughness effects and variance from individual grains. Thermal emissivity for the studied meteorites is measured over a broad wavelength range of 8-14 µm from 20°C-1000°C. A comparative cut-bar thermal conductivity meter, ranging from 50°C-1000°C, is used to measure the thermal conductivity in steady-state condition. Values are studied up to atmospheric entry temperatures are needed for modelling material response of meteor entry.

Surface temperature simulations are performed with the Icarus material response solver, which is a fully implicit, parallel finite volume code, and a one-dimensional grid that represents 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 for a wide variety of iron and stony meteoroids are performed.

3. Thermal Emissivity

Elevated temperatures cause a fluctuation in the emissivity of the different meteorite classes. As temperature increases to 100°C the emissivity decreases then stabilizes for the next 100°C (Fig. 1). Lowest emissivity between 300°C-350°C, nearly all values below 0.90. Heated chondrites range in emissivity between 0.85-0.95. When comparing values between ordinary chondrite falls and Antarctic meteorites no notable differences are observed. Of the studied meteorite classes only the iron meteorites fallow a drastically different emissivity profile as a function of temperature [4]. This different profile is caused by the phase transitions in kamacite as heated.

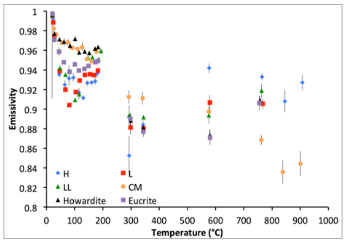

Figure 1: Thermal emissivity profiles for stony meteorites.

4. Thermal Conductivity

Most thermal conductivity of meteorite has been historically measured at 300K and below for asteroid comparison. At 300K the average value for H chondrites is 2.5±1.1 (W/m-K), 1.6±1.2 (W/m-K) for L chondrites, and as high as 42.9±15.5 (W/m-K) for iron meteorites [3]. These values are used for heritage simulations. Generally the conductivity decrease as in meteorites from 300-500K [6]. The lower thermal conductivity would mean slower heat transport during entry, keeping the surface temperature of meteoroids higher [1].

5. Surface Simulations

Material response simulations of surface heating during entry may be performed. To evaluate the influence of the temperature-dependent, solid optical properties on entry, the preheating stage of the meteor is evaluated. In the iron meteorite (Fig. 1A) simulation using heritage values result in the surface temperature reaching the melting point within 0.2 s of entry, while the present work values leads to the time to surface melted being cut in half. The reduction in the time to melt is a result of the 0.5 increase in emissivity of the Sikhote-Alin sample above 300°C. The simulation for Tamdakht (H5) (Fig. 1B) reaches melted surface within 0.02s from heritage dataset and 0.018s for present work. Both heritage and present work for Jbilet Winselwan (CM) time to surface melted in 0.02s.

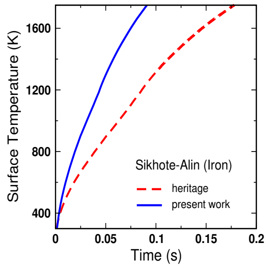

Figure 2: Material response modeling of the surface temperature of Sikhote-Alin (IIAB). Heritage results based on class average optical properties evaluated at 20°C temperatures. Present work takes into account fluctuating emissivity as temperature increases.

6. Conclusions

Simulation results, based only on thermal emissivity profile, show time to meteor surface melt conditions have minimal dependence on ordinary and carbonaceous chondrite. Changing thermal emissivity alone has a major effect on time to surface being melted for iron meteors by cutting time in half to 0.1 second. Time to melt is slower for iron meteorites compared to chondrites because of iron meteorites higher thermal conductivity, which leads to rapid transport of heat from surface into interior.

7. Acknowledgements

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