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Enhancement of impact heating due to friction and plastic deformation during collisions

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Abstract

Hypervelocity impacts cause significant heating of planetary bodies. By using 2D iSALE shock-physics code, we show that effective conversion from kinetic to internal energy in the bodies with strength occurs due to friction and plastic deformation during impacts. We find that this additional heating reduces the impact-velocity thresholds required for Ar-Ar age resetting and melting. We also confirm that this happens in an oblique impact by using 3D iSALE code. Considering this additional heating, we discuss the fates of hydrous materials in parent bodies of carbonaceous chondrites like Ryugu and Bennu during disruptive collisions.

1. Introduction

Collisions between two planetary bodies at speeds of several km/s cause significant heating of materials[1], resulting in a loss of Ar, dehydration, and/or the generation of impact melts. Since the degree of impact heating depends strongly on the impact velocity, detailed geochemical analyses of such heated samples allow us to characterize the impact environment in the solar system through its history.

2. Effect of material strength

Recently, [2] reported that the degree of heating in low-velocity impacts (<10 km/s) is expected to be much higher than previously expected. Here, we introduce the significance of the strength effects on the degree of impact heating based on the results by [2].

We used the two-dimensional model of the iSALE shock physics code [4]. The strength model for rocks and ANEOS for dunite were applied for both projectile and target. The detail of the numerical simulation is described in [2]. We found that the post-shock temperature in strength-supported media could be much higher than that in the case without strength, i.e., purely hydrodynamic (Fig. 1). Plastic deformation of the pressure-strengthend comminuted rocks dissipates the energy, and converts the kinetic energy of the flow field to internal energy. Thus, the required impact velocities for producing the unique features produced mainly by the rise in temperature is greatly lowered.

This additional heating can also be observed in an oblique impact (Fig. 2) by using the three dimensional version of the iSALE code. The enhancement at oblique impacts becomes larger than the case at vertical impacts to the tangent plane. Although it is widely accepted that the degree of heating correlates well with the vertical component of the impact velocity, our preliminary results show that oblique impacts (45º) produce nearly the same amount of heated volume as vertical impacts do even for the same impact velocities.

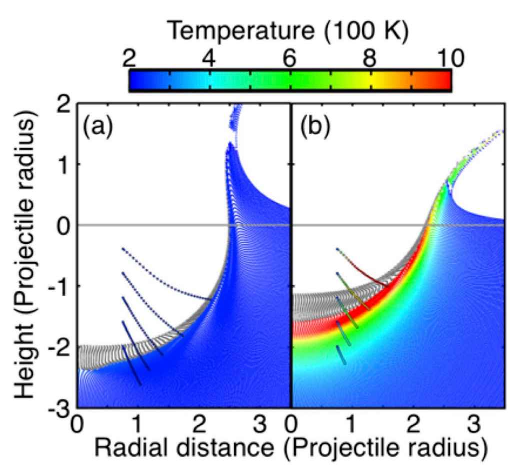

Figure 1: Snapshots of the iSALE simulations for a head-on impact between a spherical impactor and a flat target at 3 km/s in the case without strength (left panel) and with strength (right panel). Color represents the temperature.

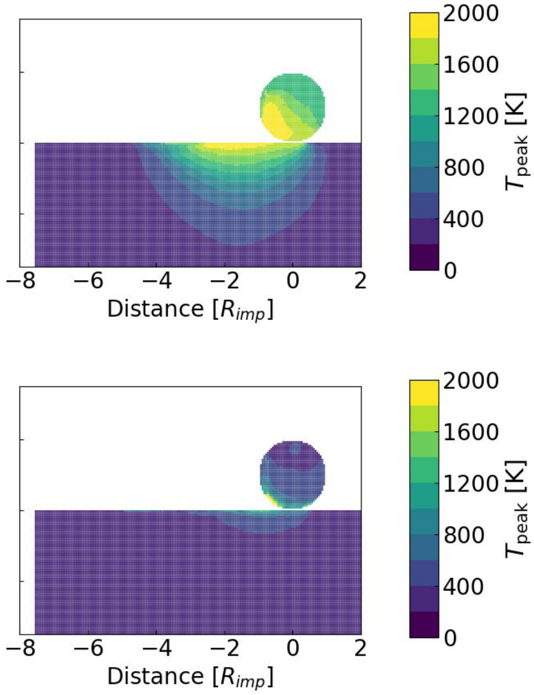

Figure 2: Peak temperature after a 45º impact at the impact velocity of 5 km/s in the case with strength (top panel) and without strength (bottom panel). Cross section at the impact point of horizontal and vertical direction is shown at the original position.

3. Dehydration during collisions

We numerically perform head-on planetesimal collisions. The target planetesimals are assumed to be 100 km in radius with 90 km sized core of hydrous materials and 10 km anhydrous layer. In our numerical calculations (see [3] in detail), we vary the size of impactor that does not contain hydrous materials and impact velocity. Here, we focus on occurrence of dehydration reaction in hydrous core triggered by planetesimal collisions. We assume the dehydration reaction occurs at 600ºC based on experimental works.

The mass fraction of surviving hydrous materials in ejected materials and remaining largest body are plotted in Figure 3. In most cases, nearly half of the ejecta seems to be hydrous material. On the contrary, the ratio of hydrous materials forms a major component in the remnant. We can conclude that

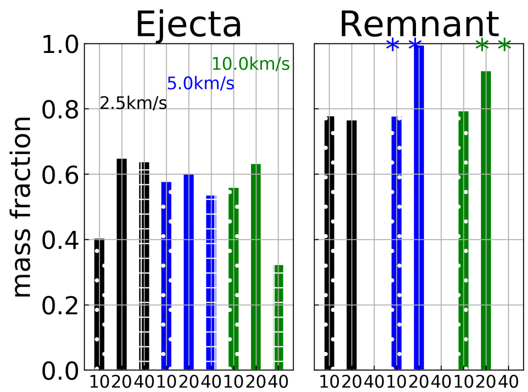

Figure 3: The mass fraction of hydrous materials in ejecta (left) and remnant (right) for various impact velocities (2.5, 5.0, and 10 km/s) and impactor radii (10, 20, and 40 km) after the collisions with 100-km sized target planetesimal.

hydrous materials can avoid the dehydration reaction and also be ejected from the system of planetesimal collisions for a typical impact velocity (~ 5 km/s) in the current asteroid belt.

Acknowledgements

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