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Velocity measurements of impact jetting during oblique impacts

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Impact jetting is a widely-known phenomenon in both hypervelocity impact experiments and hydrocode calculations. There are two important features in impact jetting, which are (1) extremely high velocity greater than the impact velocity and (2) the high degree of shock heating. Jetting has been considered as a mechanism for the origin of chondrules, tektites and impact glasses, Pluto, and the Moon. Jetting during a symmetric collision between two thin plates has been well studied. However, the understanding of jetting for spherical impactors is essential for planetary applications and it has not been obtained. One of the reasons for this is the lack of the experimental data of hypervelocity jetting of obliquely-impacted spherical projectiles. Although the temperature of jetted vapor has been investigated under a wide range of experimental conditions, only 3 data points, including unpublished data, have been reported as the jet velocity, which is one of the important anchors for developing a jetting model.

In this study, we conducted a series of oblique impact experiments using spherical projectiles and 3 different targets and investigated the jet velocity as a function of impact velocity and target materials. The frame rate of a high-speed imaging was 100 ns/frame to resolve the jetting initiation during projectile penetration. We found that the velocity ratio of the jet velocity to the impact velocity increases as the shock impedance of target increases at a given impact velocity and decreases with as impact velocity increases.

We obtained the first systematic data set for the jet velocity of spherical projectiles during oblique impacts. Using the data set, we constructed a physical model to explain the observed jet velocities. We found that (1) a classical phenomenological model constructed by Ang (1990) predicts well observed jet velocities if we use the vertical component of impact velocity instead of impact velocity in his model and that (2) observed jet velocities can be obtained by the sum of the horizontal component, the deformation velocity of the shocked projectile, and the particle velocity after isentropic release. The latter model may provide a physical basis of the jet formation

Both the standard and our physical model predict the jet velocity during oblique impacts reaches 2.5 times than the impact velocity. Although the mass of jetted materials must be small for energy conservation, the aerodynamic interaction between such hypervelocity jet and an ambient atmosphere may be significant because the heating rate of aerodynamic ablation is proportional to the cube of the velocity. In the case for an oblique impact on Titan, the jet velocity may reach 30 km/s in the case of typical cometary impacts and may generate strong EUV radiation from produced high-temperature plasma in the N2CH4 atmosphere via aerodynamic interaction near the surface of Titan. Active chemical reactions of C-bearing species may be driven by the produced EUV. The available energy source near the current Titan surface is only cosmic rays. Thus, hypervelocity jetting may be a new energy source for atmospheric chemistry on Titan.

Keywords: Hypervelocity impacts, Oblique impacts, High-speed video camera, Ultrafast imaging observation, Impact jetting, Titan