Impact-driven flow-field: Hypervelocity material ejection from the interference zone

*Kosuke Kurosawa[1], Takaya Okamoto[1], Hidenori Genda[2]

1.Planetary Exploration Research Center, Chiba Institute of Technology, 2.Earth-Life Science Institute, Tokyo Institute of Technology

The scaling relationship of the excavated mass at a bin of ejection velocity has been widely explored to understand the effect of hypervelocity impacts on the material distribution on the planetary surface. The high-velocity component from the vicinity of the impact point, however, has not been investigated well probably because the mass of high-velocity component is likely to be a few orders of magnitude lower than the entire mass of impact ejecta. Nevertheless, such high-velocity component would mainly contribute to the material exchange between planets/satellites and the production of unique samples in strata on the Earth via aerodynamic heating during their flight in the atmosphere because there is a threshold velocity in such problems.

We meet three difficulties in the problems. Among them are (1) The point-source approximation cannot be applied because the excavation flow is expected to be driven by a shockwave generated during a projectile penetration, (2) a propagating shockwave interacts with a rarefaction wave from the free surface, leading to produce a complex flow field, which is referred to as the interference zone, and (3) the flow field cannot be solved analytically because of the non-linear nature of such flow field. Although Melosh (1984) approximately estimated the thickness of the interference zone and the ejection velocity under several assumptions, his model cannot be directly applied to the vicinity of the impact point within ~2-fold impactor foot print as pointed out by himself.

In this study, we analyzed such complex flow field using the iSALE shock physics code to obtain the highest velocity form the target surface. For simplicity, we calculated only vertical impacts. A cylindrical coordinate was employed. We used the Tillotson EOS for granite to treat the effects of thermal pressure due to irreversible shock heating on the change in the particle velocity. Although we assumed a spherical projectile with 10 km in diameter for reasons of expediency, the results can be converted to any size of projectile through appropriate scaling calculations because we did not include material strength and gravity in this calculation. The impact velocity was set to 12 km/s, which is a typical value of that to Mars and the Moon. Lagrangian tracer particles were inserted into each computational cell to obtain the change in the position, pressure, and energy as a function of its initial position. We analyzed the particles ejected within 3 seconds after the impact.

The particle motions are qualitatively consistent with the predictions by Melosh’s model. It is important that the incidence angles of the shockwave and the rarefaction wave become nearly perpendicular in the interference zone. Thus, the accelerated materials by the shockwave suffer a further acceleration due to rarefaction wave in the upward direction. At this time, the stored internal energy due to the shock heating is converted to the kinetic energy of the upward motion. The highest ejection velocity determined by such acceleration is ~2-fold particle veloctity at the shocked state, which can be calculated using the Rankine-Hugoniot relations. Numerical calculations allow us to investigate the peak pressure at each position in the interference zone. The highest ejection velocity under the condition is ~5.5 km/s, which is about half of the impact velocity. The ejected mass at higher than 5 km/s is ~0.1 wt% of the projectile mass and they suffer the peak pressure of 40 GPa.

We are planning to do a series of numerical calculations to obtain the velocity-mass relation of the ejecta from the interference zone.

Keywords: Hypervelocity impacts, Impact ejecta, Martian meteorite