Cratering on iron alloy: Temperature and impact velocity effects

*Ryo Ogawa[1], Akiko Nakamura[1], Ayako Suzuki[2], Sunao Hasegawa[2]

1.Graduate School of Science, Kobe University, 2.Institute of Space and Astronautical Science

Introduction: Planetary differentiation could occur on planetesimals with diameters more than 20 km to form iron cores (Moskovitz and Gaidos, 2011). It is noted that the core formation occurred 0.3-0.6 million years after the most primitive material "CAI" was formed (Kruijer et al., 2014). That is, the core formation is a very primitive event and important to understand the early stage of the planetary evolution.

Currently, much attention is paid to an M-type asteroid 16 Psyche. Psyche may be the exposed iron core of a protoplanet and the Psyche orbiter mission is one of five Discovery Program semifinalist proposals. In order to get better understanding of planetary formation and evolution through such space mission, we have to understand about impact process on the surface of iron bodies. We performed impact experiments and simulations and examined the effects of temperature, impact velocity, on a cratering on iron material to collect basic data and examine model parameters (Ogawa et al., Shototsu Kenkyukai (in Japanese) 2016). In this study, we performed impact experiments and simulations with copper projectile which has well-defined material parameters to examine the effect of the projectile material. Furthermore, we performed numerical simulations of planetary scale cratering and compared them with the laboratory-scale ones.

Experimental method: We performed impact experiments with velocities of 6.8-7.3 km/s under 0.5-5.0 Pa using a two-stage light-gas gun at the Institute of Space and Astronautical Science (ISAS). Our targets were iron alloy (SS400) cubes with 50 mm each side. Projectiles were copper spheres of 3.2 mm in diameter. We used room-temperature (298 K) and low temperature (150 K) targets. The target material has brittle-ductile transition temperature at about 200 K. We simulated the cratering on the iron alloy using a shock physics code "iSALE" under the same conditions as the experiments. We used the Johnson-Cook strength model parameters of oxygen-free copper (Johnson and Cook, 1983) for projectiles and SS400 which we determined in our previous study for the targets. Moreover, we simulated planetary scale impacts with the stainless steel impactors of 0.02-5 km in diameter and SS400 targets of 0.2-200 km in diameter and examined the effect of the size using PI scaling.

Results of experiments: The craters of the low-temperature targets were shallower than the room-temperature targets at low impact velocity (2 km/s). However, the effect of temperature on depth couldn't be seen at high velocity (4-6.5 km/s). Moreover, we also couldn't find the effect of the temperature on diameter. Some of the iron alloy's strength increases by cooling (e.g. Petrovic, 2001). Therefore, the craters on the room-temperature targets were deeper than the low-temperature targets. On the other hand, the adhesion of the projectiles on the craters were seen in the experiments and simulations. In order to explain why the effect of temperature on depth wasn't seen at high impact velocity, we have to examine other effects than the strength-increase by cooling.

Results of simulations: The effect of temperature on the crater depth was less than those of the experiments. We haven't found why but it might be because the copper's Johnson-Cook parameters were 1/3-1/5 of those of SS400. A comparison between the simulation and laboratory results using PI scaling shows that craters were deeper in planetary scale than laboratory-scale at low impact velocity. Moreover, the craters on the low-temperature targets were as deep as room-temperature targets in planetary scale.

Keywords: Iron, Crater, Impact

