Effect of oblique impact on impact strength of icy planetesimals

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Water ice is one of the most important constituents for icy satellites, ring particles, KBOs, and comets. In the evolution of solar system bodies, proto-planets were formed by the collisional disruption and the re-accumulation of planetesimals, In order to study the formation processes of icy bodies, the impact condition of catastrophic disruption for icy planetesimals should be clarified. During the collisional evolution of planetesimals, they collided obliquely with each other, and the probability of collisions at an impact angle of 45º was the maximum. However, there are few experimental studies of collisional disruptions of water ice and the effects of oblique impact. Therefore, we conducted impact experiments of ice spheres and snow balls simulating icy planetesimals and examined the effects of impact angle on the collisional properties such as impact strength and ejection velocity of impact fragments.

The targets were an ice sphere and a snow ball with a porosity of 50%, and they had diameters of 60–80 mm. A spherical polycarbonate projectile with diameters of 2 or 4.7 mm impacted the target at 0.8–4.2 km/s at an impact angle ranging from 90º (head-on impact) to 15º. We did impact experiments by using a two-stage light gas gun in a cold room at Kobe University. The cold room temperature set at -15 ºC. The collisional phenomena were observed by using a high speed camera to measure the impact angle and the ejection velocity of impact fragments. The impact fragments were recovered after each shot and measured their number and mass.

The impact strength, Q^*, is defined as the specific energy, Q, when the largest fragment mass, m_l, is one-half of the original target mass, M_t, and the specific energy, Q, is defined as the kinetic energy of projectile per unit mass of target, that means, $Q=m_p v_i^2/2M_t$, where v_i is the impact velocity. We obtained the impact strength of ice and snow targets at a head-on impact as 13.5 J/kg and 489 J/kg, respectively. At high Q which means that the normalized largest fragment mass, m_l/M_t, was 0.03 at a head-on impact, the m_l/M_t of icy targets increased abruptly at the impact angle smaller than 30º, and that of snow targets increased gradually at <50º when the impact angle decreased. At low Q which means that the m_l/M_t was 0.3 at a head-on impact, the data of both ice and snow targets were scattered and the m_l/M_t increased with the decrease of the impact angle.

We assumed that the velocity component normal to the impact surface could contribute to the damage to the entire target, so we reanalyzed our experimental results by using the effective specific energy, Q_{eff} ($=m_p(v_i \sin\theta)^2/2M_t$). As a result, the relationship between the Q_{eff} and the m_l/M_t could be fitted by one power law equation, irrespective of the impact angle, and the impact strength, Q_{eff}^*, which is independent of impact angle, could be obtained as 15.6 J/kg and 462 J/kg for icy and snow targets, respectively. Similarly, the relationship between the antipodal velocity, which means the velocity of impact fragment ejected from the antipodal point of the impact point on the target, and the Q_{eff} could be also fitted by one power law equation, irrespective of the impact angle.

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