The shapes of fragments and the impact energy: Implication for asteroid Itokawa

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Laboratory impact experiments have found that the shapes of fragments as defined by axes a, b, and c, these being the maximum dimensions of the fragment in three mutually orthogonal planes ($a \geq b \geq c$) are distributed around mean values of the axial ratios $b/a \simeq 0.7$ and $c/a \simeq 0.5$, i.e., corresponding to $a:b:c$ in the simple proportion $2:\sqrt{2}:1$. This result indicates a general property of collisional fragments which is repeated with great regularity in widely different experimental conditions such as projectile velocity, target shape, composition and strength [1–6]). In general, the shape distributions of small asteroids less than tens of kilometers in diameter are considered to be similar to distributions obtained for fragments generated in laboratory impact experiments [1,5,6]. The shape distributions of the boulders on asteroid Eros and the small- and fast-rotating asteroids (diameter $<$ 200 m and rotation period $<$ 1 h) are similar to those of laboratory fragments [7]. However, the shapes of fragments in the laboratory are produced by the catastrophic disruption. The shapes of fragments in the impact cratering are different from those in the catastrophic disruption. In the past experiments, there is no study to research systematically the shapes of the fragments ranging from the impact cratering to the catastrophic disruption.

The impact experiments on cubic basalt targets with various sizes ranging from 5 cm to 15 cm on a side were carried out in order to investigate the shapes of fragments from the impact cratering (low impact energy) to the catastrophic disruption (high impact energy). A total of 12 impact experiments were performed using a two-stage light-gas gun at the Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS, JAXA). A spherical nylon projectile (diameter 7 mm) is shot perpendicularly into the target surface at velocities of 1.6 to 7.0 km/s. The fragments ($b >$ 4 mm) generated in each impact experiment were measured with a vernier caliper. The number of the fragments measured is larger than 5700. In our experiments, the mean values of b/a in each impact are almost constant ($\simeq 0.7$), independent of impact energy. On the other hand, the mean values of c/a in each impact decrease with decreasing the impact energy. For instance, the mean value of c/a in an impact cratering is nearly 0.3, which is smaller than that ($\simeq 0.5$) of c/a in a catastrophic disruption.

Although relating our laboratory experiments to real collisions in asteroids may not be straightforward, the data presented here can provide an important implication to interpret the formation of asteroid Itokawa. We investigated the shapes of boulders on the Itokawa surface using several images by the Hayabusa spacecraft. The mean value of c/a in 21 arbitrary selected boulders ($>$ 8 m) is 0.46, which is similar to the value of the catastrophic disruption (high impact energy) in the experiments. This result implies that the parent body of Itokawa would have experienced a catastrophic disruption rather than a weak disruption. Investigations of the Itokawa particles on the mineral chemistry suggest that Itokawa is an asteroid made of reassembled pieces of the interior portions of a once 20-km sized asteroid [8]. Thus, our experimental result supports this suggestion.

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