ULTRA-HIGH-SPEED IMAGING OF THE IMPACT EJECTA: COMPARISON WITH A SPH SIMULATIONS. T. Okamoto[1], K. Kurosawa[1], H. Genda[2], and T. Matsui[1], [1]Planetary Exploration Research Center, Chiba Institute of Technology (PERC/Chitech) (2-17-1, Tsudanuma, Narashino, Chiba 275-0016, Japan, tokamoto@perc.it-chiba.ac.jp), [2] Earth-Life Science Institute, Tokyo Institute of Technology.

Introduction: High-speed ejecta are important for the transfer of materials to extremely far from the impact point. Tektites are located within a few hundred kilometers of the craters [1]. An aerodynamic interaction is considered to be a formation mechanism of the tektites [2]. It is pointed out that the surface of a Martian satellite, Phobos, contains Martian materials ejected by impacts [3]. It is necessary to understand the maximum velocity of the ejecta and its mass for knowing how much the ejecta can transfer to those regions.

Although previous studies have been studied the velocity distribution of ejecta from the position beyond the impactor's radius [e.g. 4, 5], high-speed ejecta from just below the impact point have not been observed well. Numerical simulations of impact ejecta were carried out in a study which model the ejection behavior [6]. The simulation results, however, have not been validated through a comparison with the results of hypervelocity impact experiments.

In this study, we performed impact experiments to observe the highest ejecta and to investigate the ejection velocity from near the impact point using ultra-high-speed video camera. While the ejection velocity can be measured from the obtained images, it is difficult to determine the mass of the ejecta from impact experiments. We used SPH method to simulate the impact ejecta, compared with the impact experiments, and calculated target component in the ejected material.

Experiments: We used polycarbonate spheres of 4.8 mm in diameter as projectiles. Polycarbonate plates (5 cm x 5 cm x 2 cmt) were used as targets. Impact experiments were conducted using a two-stage light gas gun at PERC/Chitech. Impact velocities, v_i were 4.18 km s^{-1} for an impact angle of 90 degrees (vertical impact), and 3.56 km s^{-1} for an impact angle of 45 degrees, respectively. The angle in the oblique impact is the most likelihood value for an impact angle in natural impact events [7]. The pressure in a chamber was less than 50 Pa prior to the shots. A high-speed video camera (Shimadzu, HPV-X2), and a stroboscopic lamp or a light laser with a Fresnel lens as back-light illumination were used. The frame rate was 0.2 μs frame^{-1}.

Simulations: Impact simulations were carried out with a three-dimensional (3D) SPH code [e.g. 8]. The calculation conditions almost correspond to the experimental conditions conducted in this study. The Tillotson EOS for polycarbonate was adopted [9]. We use 10^4 and 10^5 SPH particles for a projectile. The results for higher SPH particles reproduced the experimental results better than those for lower SPH particles. Thus, we present only the result for 10^5 SPH particles here.

Results and Discussions:

Experimental results. Figures 1a and 1b show high-speed images. The material ejection from the contact surface was observed 0.2 μs after the initial contact, showing that we could capture the high-speed ejecta from the very near impact point because this time was much shorter than the time for a projectile penetration. A pattern of the ejecta curtain for the vertical impact was almost axial symmetry like an umbrella, while that for the oblique impact was asymmetry. Figures 1c and 1d show examples of binary images. Two components of direction of ejected material can be observed in Figure 1d. One is the component moving along the target surface to the downrange. This is considered to be jetting [10]. The other is the component expanding to the upward of the target surface. The boundary of the two component createds a kink in Figure 1d(iii). From the binary images we measured some examples of the ejection velocities; the velocity of the edge of the ejecta curtain in Figure 1c(i), that of the edge of the downrange stream along the target surface in Figure 1d(ii), and that of the kink in Figure 1d (iii), are 6.51±0.10 km s^{-1} (1.56±0.02v_i), 9.98±0.08 km s^{-1} (2.80±0.02v_i), and 5.34±0.05 km s^{-1} (1.50±0.01v_i), respectively. The velocity of (ii) is slightly lower than the theoretical prediction of velocity of jetting [10]. The ejected material for jetting and the subsequent ejecta is considered to be continuously connected, and the kink may be the boundary of them. Thus, the ejecta faster than the velocity of the kink obtained here are expected to exist.

Comparison with SPH simulations. Figure 2 shows a direct comparison of the snapshot of the experiments and that of the SPH simulations. The results of the SPH simulations are different from those of the experiments, especially at far from the impact point. It would be small number of SPH particles to reproduce such farther materials. Figure 3 shows the mass ratio of the target material to both of the target and projectile material projected in a two-dimensional plane in each grid for time of 2.4 μs after impact. A lower ratio is observed around the symmetry axis for the vertical impact. The ejecta curtain consists of the target material. On the other hand, the component moving along the target surface to the downrange is dominated by the projectile material for the oblique impact.

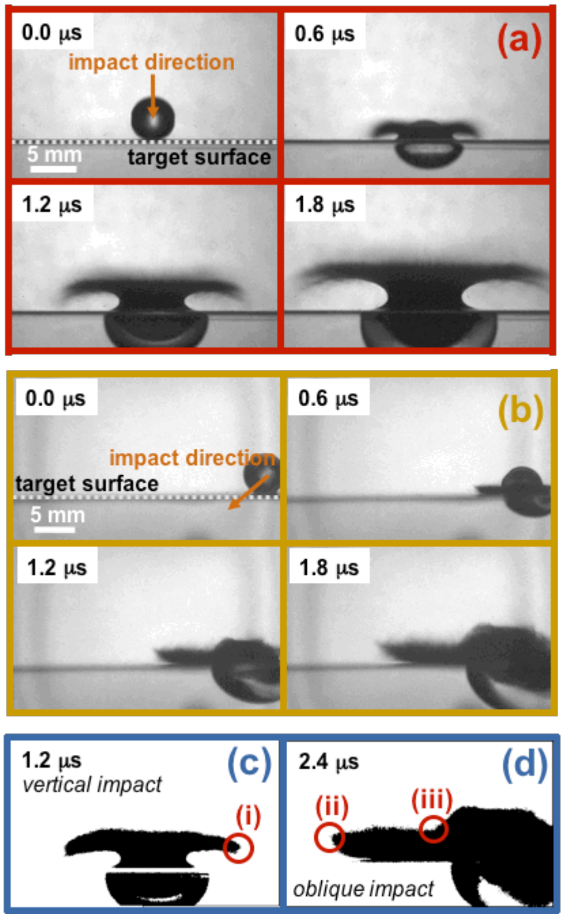

Figure 1. High-speed images are shown in (a) and (b), for the vertical impact, and the oblique impact, respectively. The time after the impact is given in the figures. Examples of binary images are shown in (c) and (d). The velocities of (i), (ii), and (iii) are described in the text.

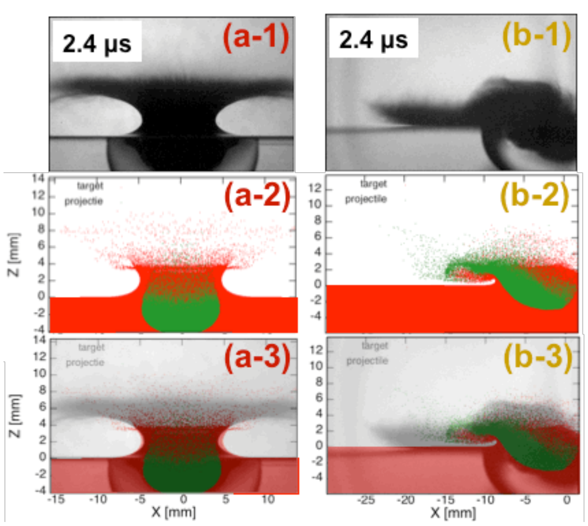

Figure 2. Comparison of the snapshot of the experiments and that of the SPH simulations. (a) The results for the vertical impact. (b) The results for the oblique impact. (a,b-1) The original images obtained high-speed video camera. (a,b-2) The results of SPH simulations. Both the projectile material (green) and the target material (red) are shown in these graphs. (a, b-3) Superimposed images of the original image and the results of SPH simulations.

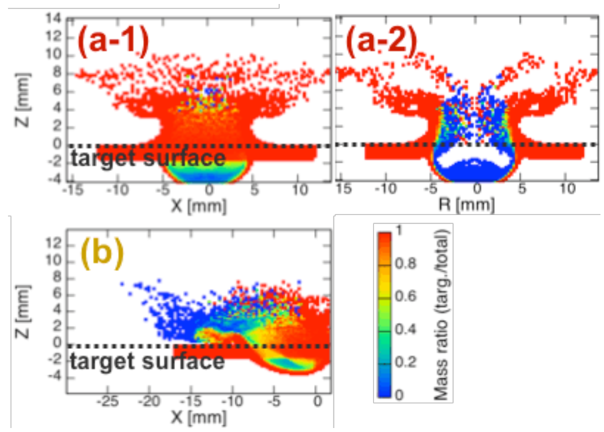

Figure 3. Mass ratio of the target material to both of the target and the projectile material projected in a two-dimensional plane in each grid for time of 2.4 μs after impact. The origin corresponds to the impact point. (a) The results for the vertical impact in the X–Z cartesian coordinates in (a-1), and in the R–Z cylindrical coordinates in (a-2). (b) The results for the oblique impact in the X–Z cartesian coordinates.

Summary: We conducted impact experiments to investigate the high-speed ejecta from near the impact point. It is revealed that the maximum ejection velocities can exceed the impact velocity. We also conducted SPH simulations and compared the results with those of impact experiments. The ejecta curtain consists of the target material for a vertical impact, whereas the edge of the moving along the target surface is dominated by projectile material for the oblique impact.

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