HIGH-VELOCITY OBLIQUE IMPACT EXPERIMENTS ON WET SAND TARGETS SIMULATING HABITABLE PLANETS.

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Introduction: In order to clarify the effects of asteroid impacts on habitable planets like Mars and Earth, it is important to study impact phenomena on the surfaces including liquid water. It has been known that cratering on wet sand is different from that on dry sand and it cannot be scaled in the gravity dominated regime [1]. Systematic impact experiments using targets with various water contents have shown that the penetration depth of impactor can be expressed as a power law of the shear yield strength of wet sand at an impact velocity of ~m/s [2].

However, the previous study [2] was insufficient to clarify the effect of water content on the cratering processes of habitable planets because systematic impact experiments at high impact velocities of ~km/s, which are range of impact velocity on planetary bodies, are lack. Therefore, we conduct high-velocity impact experiments on wet sand with various water contents to study the effect of water contents on the crater size scaling law .

In addition, impacts ground experiments at 2 km/s by using SCI (Small Carry-on Impactor of Hayabusa2) on wet sand formed an impact crater ~1.6 m in diameter, and a plume that looked like a water vapor cloud was observed [3]. In this study, we also studied the generation process of a water vapor plume from wet sand by using the target inclined. This inclined target is suitable for distinguishing the water vapor plume that erupts vertically from the target surface and the jetting materials in the downstream.

Method: We used wet sand targets composed of quartz sand (diameter of 500 μm) mixed with liquid water at a water content of 0 to 13 wt.%. The porosity of dry sand is ~0.45.

All experiment were performed using two-stage light gas gun at Kobe University and ISAS, at impact velocities of 2 and 4 km/s. The target was inclined 30˚ from horizontal and a spherical aluminum projectile with the diameter of 2.0 mm was impacted (Fig. 1). The experiments were under near-triple-point conditions simulating the surface of Mars so that a part of water inside the target existed in a liquid state. All experiments were observed by two high-speed cameras, and several experiments were also observed by using a high-speed infrared camera to study ejecta and plume temperatures.

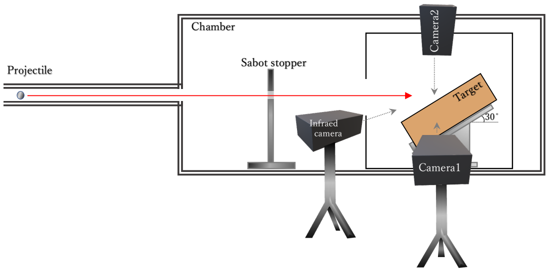

Figure 1. Set up of impact cratering experiments for a horizontal two-stage light gas gun.

Results:

Plume observations. Just after the impact (<100 μs), a white diffuse plume ejected vertically to the target surface was observed, which was different from jetting in the direction of a projectile motion (Fig. 2a). In addition, a large area on the ejecta curtain was observed to be at >100 ˚C: This area was not clearly recognized by high-speed camera images in visible light (Fig. 2b). This suggests that the oblique impact might have ejected hot ejecta in a specific direction, or that the water in the target might have vaporized and ejected above.

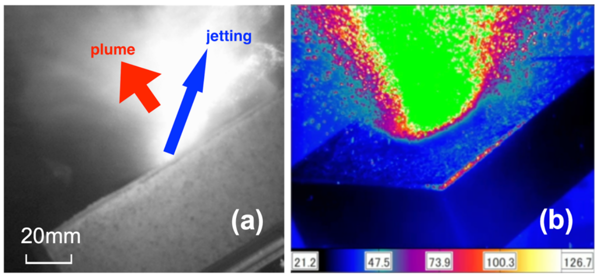

Figure 2. Snapshots of water vapor plume in (**a**) visible light at 40 μs after impact and (**b**) infrared light at 12 ms after impact. The color bar shows the temperature in ˚C.

Crater size. The ratio of the crater depth (d) to the diameter (D) was larger as the water content increased, while the crater diameter was smaller with the increase of the water content (Fig. 3). At the water content over ~5 wt.%, they were almost constant. Considering the previous results that the wet sand shear yield strength increases up to ~5 wt.% and then was nearly constant [2], the crater size in wet sand is expected to depend on the target shear strength. This means that π-scaling law in the strength dominated regime, $\pi_{\mathrm{R}} = k{\pi_3}^{-\mu/2}{\pi_4}^{(1-3\nu)/3}$, could be applicable to the crater size formed on the wet sand (Fig. 4): $\pi_{\mathrm{R}} = R(\rho/m)^{1/3}$, $\pi_3 = Y/\rho u^2$, and $\pi_4 = \rho/\delta$, where R is the apparent crater radius, ρ the target density, m the projectile mass, Y the target strength, u the impact velocity, and δ the projectile density. The parameters, k, μ, and ν are scaling parameters determined by laboratory experiments. We assumed to $\pi_4 \sim 1$ so that π_R can be expressed as a function of π_3. By using power-law fitting, we can obtain the scaling relationship for wet sand as $\pi_R = 0.078\,\pi_3'^{-0.12}$, where $\pi_3' = Y/[\rho(u \sin 30^\circ)^2]$ considering the effect of the impact angle. (indicated by the black line in Fig. 4). The result for dry sand is also shown in Fig. 4 as a red symbol, and the crater size does not change by the target strength but by the gravity [1], so it can be expressed as a red line in Fig. 4. This suggests that the cratering in sand might occur in the gravity dominated regime until the target strength reaches the intersection of red and black lines (Fig. 4). As the water content increases, that is, the π_3' becomes larger, the cratering might occur in the strength dominated regime.

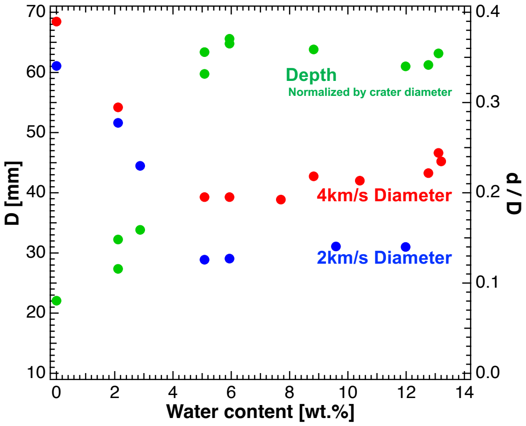

Figure 3. Crater size vs. target water content.

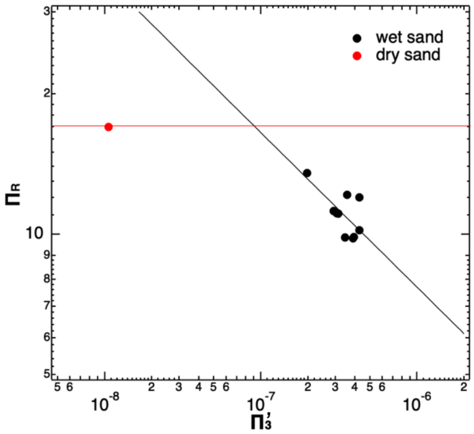

Figure 4. π-scaling relationship for the crater diameter in the strength dominated regime. π_R and π_3' are non-dimensional parameters related to crater diameter and target strength [1]. Black line shows the power-law fitting of wet sand, and red line shows the scaling fitting of dry sand in gravity dominated regime.

Ejecta curtain. In most of the experiments, the ejecta curtain angles were constant (Fig. 6a, b): The curtain angle at downstream (●) was larger than that at upstream (△) (refered to Fig.5). This asymmetry is consistent with previous studies for dry sand target and might be caused by the shift of the crater center from the impact point on the target surface as a result of oblique impact [4]. This shift might distort the crater flow-field from being symmetrical. However, at the impact velocity of 4 km/s, the asymmetry disappears when the target water content > ~5 wt.%, and the shape of ejecta curtain is nearly symmetrical to a line perpendicular to the target surface from the point of impact at >~9 wt.% (Fig. 6b). These results suggest that the projectile might not penetrate into the target at >~5 wt.% because the high impact pressure at 4 km/s would disrupt or deform the projectile and these fragments might be difficult to penetrate into the target due to the high shear yield strength of target.

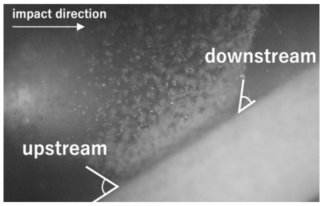

Figure 5. A Snapshot of Ejecta curtain. We measured two angles (upstream and downstream) at the crater formation time.

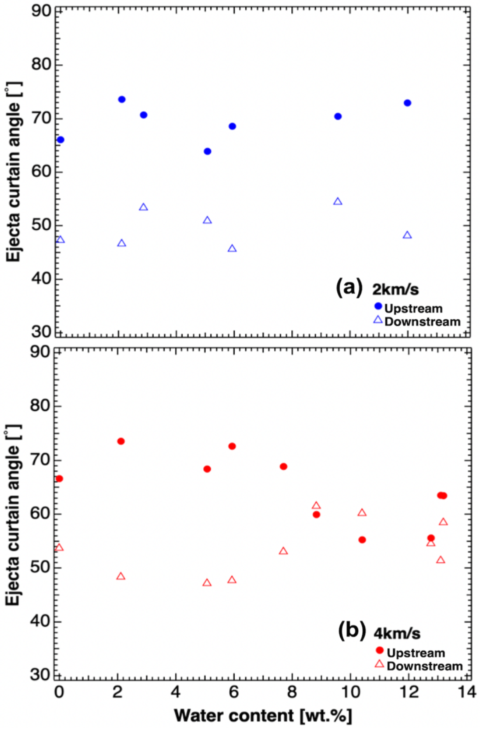

Figure 6. Ejecta curtain angle vs. the target water content at (**a**) 2 km/s and (**b**) 4 km/s.

References: [1] Schmidt & Housen, *Impact Engng,* 5, 543, 1987. [2] Takita & Sumita, *Physical Review, E88*, 022203, 2013. [3] Wada *et al.*, *LPSC XXXXV* (abs.) #1768, 2014. [4] Anderson *et al.*, *LPSC XXXV* (abs.) #1529, 2004.