LARGE SCALE IMPACT EXPERIMENTS SIMULATING SMALL CARRY-ON IMPACTOR (SCI) EQUIPPED ON HAYABUSA-2.

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Introduction: A crater scaling law has been investigated for a few decades based on laboratory experiments. Although the impact velocity in laboratory experiments are widely changed from m s^{-1} to km s^{-1}, the scale is very limited to be changed in a few ten cm for the crater size and from mm to cm for the projectile size. This laboratory scale is smaller than those of impacts taking place in planetary systems by several orders of magnitude. It is insufficient to study the scale dependence of the crater formation process, especially for a large scale. Therefore, it is very important to change the projectile scale as large as possible in experiments to confirm the crater scaling law.

Hayabusa-2, the Japanese next asteroid exploration mission, equips a small carry-on imapctor (SCI) to launch a decimeter scale projectile on an asteroid surface [1]. This is a novel apparatus to excavate the asteroid surface, and hopefully it will enable us to observe a fresh surface without space weathering and thermal alteration. Furthermore, we will be able to recover the asteroid sample excavated from several 10 cm depth at the deposit of the impact ejecta. The SCI impact on the asteroid is very good chance to examine the projectile scale on the crater scaling law in addition to the study on the gravity effect on the crater formation process. In order to maximize the science outputs by the SCI impact, we have conducted real scale SCI impact experiments in a field on the earth: this test was actually planned to confirm the SCI operation.

Experimental method: The SCI experiments were conducted in a special field, where a large scale explosion is permitted, at Kamioka-area in middle Japan. We prepared a sand mound with a height of 4m and a width of 8m, and the inclination of the sand slope was 34 to 44 degrees. A projectile was launched horizontally, so that the oblique impact was carried on the sand surface with an impact angle θ of 56 - 46 degrees from the surface normal. The mean density ρ of the sand mound is 1500 kg m^{-3}, and the mean size of the sand particles are a few hundred μm. The sand was slightly wet depending on the depth because the surface was dried by sunshine but the interior was wet by past rain. The mean water content was a several weight %, so the sand mound had weak cohesion strength. The SCI accelerates a 30cm copper disk liner to ~2 km s^{-1} as a projectile by explosion of explosive. The liner with mass m ~ 2 kg is deformed to be a spherical shell with a diameter of ~ 15cm during the acceleration (Fig.1). Finally, the spherical shell projectile is impacted on the sand mound at the impact velocity v_i ~ 1.5 - 1.6 km s^{-1} reduced by air drag (The running distance of the projectile is ~100 m in air from the launching position to the sand mound). The crater formation process was observed by two high-speed video cameras at a recording speed of 10^4 FPS (NAC memrecam fx K3) and 300 FPS (CASIO EX-F1), a infrared video camera (FLIR A20) with a recording speed of 15 FPS, and a SONY digital video camera. In total, 5 experiments were conducted at the same impact condition. After each shot, we measured the crater morphology and recovered the disrupted copper projectile penetrated into and dispersed on the sand mound.

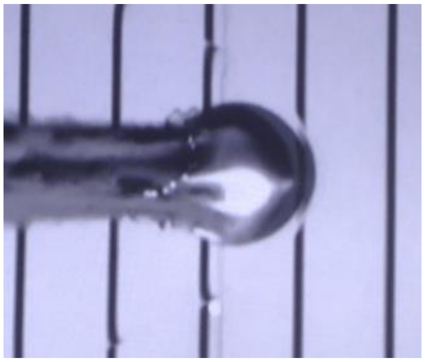

Fig.1: Spherical shell projectile with a diameter of ~15cm.

Results: We succeeded to observe 5 impact experiments by our videos and measure the crater morphology formed by these impacts. The crater shape was rather deformed after the excavation stage because the crater was formed on the inclined sand surface: the crater rim on the top run out toward the down slope and filled the crater cavity. Therefore, the final crater shape is usually elliptic with the long axis directed to the gravity: The typical crater size is 2m x 1.7m, and the depth is 25cm. Then, we assumed that the short axis was the original crater diameter D just after excavation, which was measured to be 1.6 to 1.9 m. We can compare this result with the crater scaling law summarized by Housen and Hosapple (2011) [2] for dry sand. Fig. 2 shows the relationship between pi-scale parameters and the line shows the calculated scaling law for dry sand established from laboratory experiments. The

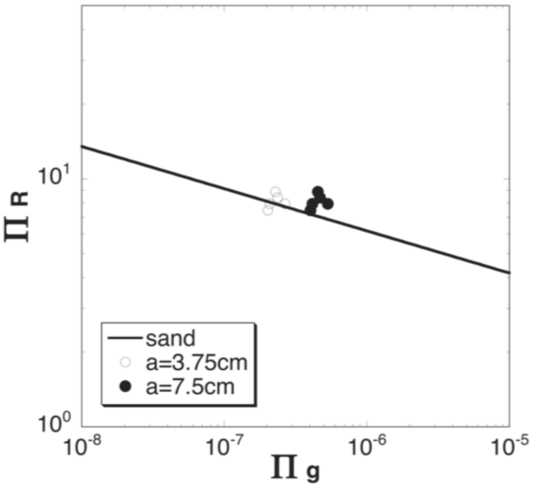

Fig. 2: Comparison of the crater diameter formed on the real scale SCI experiments with the scaling law derived from laboratory ones.

scaled crater size π_R is given by $(D/2)(\rho/m)^{1/3}$ and the scaled gravity π_g by ga/u^2 , where a is a projectile radius, g is gravity, and u is impact velocity. We consider the effect of oblique impact on the sand and the inclination of gravity, using the normal components on the sand surface, i.e., $v_i \cos \theta$ and $g \sin\theta$, instead of u and g, respectively. In Fig. 2, our results shown by closed symbols are not consistent with the calculated line. In plotting the closed symbols, we directory use the projectile diameter of 15cm (i.e., a = 7.5cm) of the spherical shell projectile. On the other hand, using the projectile diameter of 7.5 cm (a = 3.75 cm) corresponding to the copper ball with a mass of 2 kg, our results are plotted very close to the calculated line as shown by open symbols. Further study is necessary to conclude which size is suitable for the scaling law because we are not sure that the physical properties of our sand mound are exactly the same as that of the sand adopted in the summarized scaling law [2].

The high-speed video images showed us the crater formation process, and the excavation process will be analyzed to compare the laboratory scale results. The observed ejecta can be separated into two parts: they are an asymmetric thick ejecta made of sand debris and a plume rising from the center of the impact crater (Fig. 3). The temperature of the plume was measured by the infrared video camera to be the maximum of more than 60 degrees C (Fig. 4). This means that this plume could be originated from the water vapor caused by the impact heating. We speculate that the water included among sand particles might be vaporized to expand into the atmosphere. Further analysis of these video images has been conducted in our team.

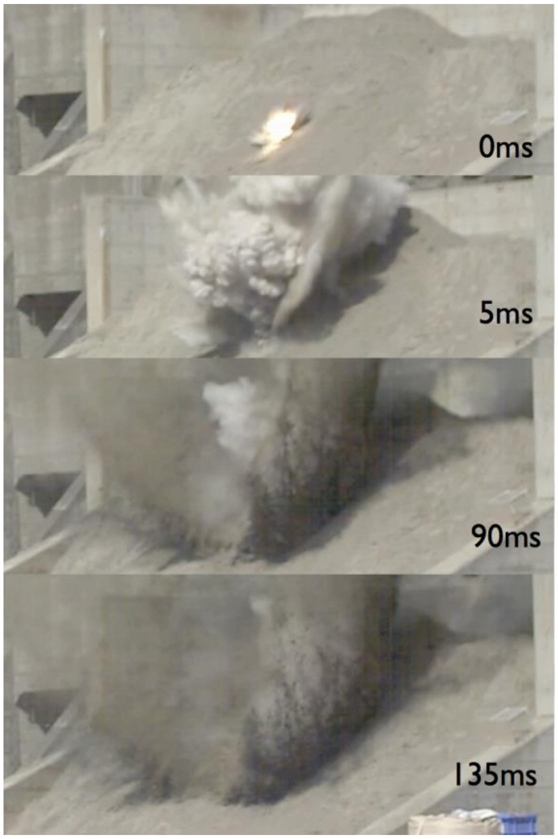

Fig. 3: Time sequence of high-speed video image of the crater formation process. Elapsed time after the impact is shown in each image.

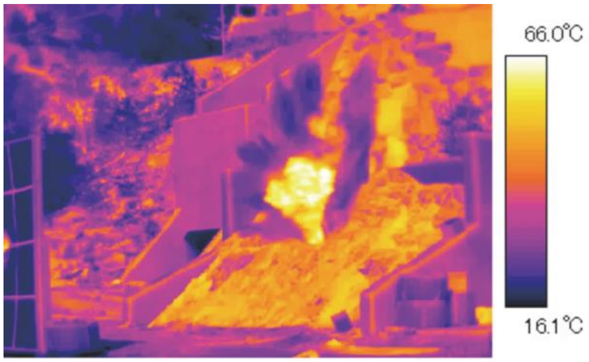

Fig. 4: Infrared video image of the crater formation process.

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References: [1] Arakawa M. et al. (2013) *44th LPSC*, abstract #1904. [2] Housen K. R. and Holsapple K. A. (2011) *Icarus*, 211, 856-875.