ENERGY PARTITION INTO COMPACTION OF A TARGET IN IMPACT CRATERING ON A GYPSUM TARGET. N. Onose[1], K. Okudaira[2], and S. Hasegawa[3], [1]Japan Aerospace Exploration Agency / Aerospace Research and Development Directorate (7-44-1, Jindaiji Higashi-machi, Chofu, Tokyo 182-8522, JAPAN, onose.naomi@jaxa.jp), [2]The University of Aizu, [3]Japan Aerospace Exploration Agency /Institute of Space and Astronautical Science.

Introduction: Pore crushing is an important process during the impact cratering on porous targets. This process results in the compaction of the target, which efficiently absorb shock waves. Housen and Holsapple (2003) [1] reported on the impact cratering experiments on porous materials as representing the cratering process on Mathilde. They suggested that compaction is an important mechanism to understand the surface features and internal structure of porous objects like Mathilde.

Compaction of targets is one of the important candidates for redistribution of the impact generated energy. In this paper, amount of impact energy consumed in target compaction will be discussed.

Experimental backgrounds: Nylon spheres, 7.1 mm in diameter, were shot at velocity range from 1 to 4.5 km/sec, by use of a two-stage light-gas gun in the Institute of Space and Astronautical Science onto gypsum targets. An original density of targets (ρ_{0t}) is 920 ±44 kg/m^3. The porosity of targets is about 60%, and the compressive strength of them is 12 MPa.

In total, 5437 fragments were measured within the observational limit of 0.1 to 100 m/sec in velocity and 0.03 mg to 1 g in mass by use of two high-speed video cameras (Onose 2007) [2] . In contrast to a large number of fragments, they account for only 0.02 to 0.08 % of the initial kinetic energy of the projectile. Maximum ejection velocity of an ejecta cloud consisting of fine and fast fragments ejected just after the impact is measured to be 1 km/sec in this impact conditions. Assuming a total amount of this ejecta cloud to be 0.1 g, which is about a half of the projectile's mass, the ejecta cloud can carry 3 % of the impact energy.

Compaction of the target can be estimated by comparing two kinds of mass measurements. One consists of filling the crater with glass beads and measuring the volume of the crater (V_c) and calculating its corresponding mass ($V_c \times \rho_{0t}$), the other is provided by the difference in the target's mass measured before and after the impact (ΔM_t). The discrepancy between the two measurements provides an indication of the degree of compaction.

Contribution of compaction, which can be expressed by $(V_c\rho_{0t} - \Delta M_t) / (V_c\rho_{0t})$, corresponds to around one-fourth of each evacuated mass, which is calculated from each crater's volume. Given that the averaged crater volume is about 14 ml, compaction of the target material makes a major contribution, 3 g in average.

Targets were also cut in half in a plane including the projectile trajectory, to observe the cracks and damaged region of the target (Fig. 1). To enhance the visibility of the surface roughness associated with cracks and clashed pores on the surface, it was rubbed by use of a brush, and fine gypsum powder was removed by a vacuum cleaner. The floor of the crater was so fragile that some crumbs of the crater floor might collapse when we cut the target.

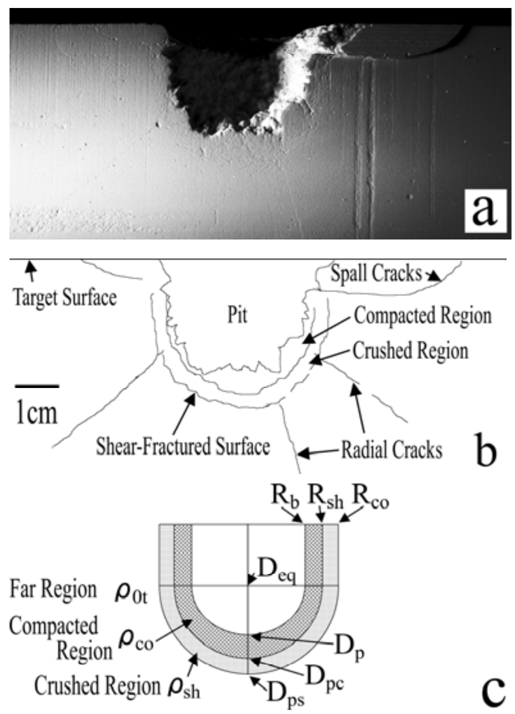

Fig. 1 Cross section of a target: a sample of bisected target cratered by a normal impact at 4.2 km/sec. Note that part of the compacted region crumbled away. a) and b) are a picture and drawing of the target, respectively. c) is a set of definitions of dimensions.

As shown in Polansky and Ahrens(1990) [3], the cross section of the target has three regions: (1) a shear-fractured region, which is located just around the bowl-shaped pit, (2) a spalled region, which lies along the original surface of the target surrounding the central pit, and (3) a far region, which is located farther from the impact site. In the far region and the spalled region, many voids and spherical pores are preserved intact, and most part of the gypsum target are kept cohesive. This indicates that the pressure of the compression wave was not high enough to crush a portion of the gypsum target in these areas.

On the contrary, pores are totally crushed in the shear-fractured region. A center of this ellipse was fitted on the cross-sectional surface, and it was identified as an equivalent center (D_{eq}), in this study. A suit of impact conditions and crater dimensions is listed in Table I and II, respectively. This shear-fractured region can be divided further according to surface features as shown in Fig. 1-b and c.

Table I. Impact Conditions

Projectile's Diameter	D_{proj}	7.14	±0.05	mm
Impact Velocity	v_i	4.2	±0.05	km/s
Density of Projectile	ρ_{0p}	1150	±50	kg/m^3

Table II. Crater Dimensions

Depth of the Pit	D_p	22.4	±0.5	mm
Depth of the Compacted Region	D_{pc}	30.1	±1.4	mm
Depth of the Shear-Fractured Region	D_{ps}	33.9	±0.5	mm
Radius of the Pit	R_b	11.7	±0.5	mm
Radius of the Compacted Region	R_{co}	17.1	±0.5	mm
Radius of the Shear-Fractured Region	R_{sh}	20.4	±0.5	mm
Crater Volume	V_o	14	±2.4	ml
Difference in Target Mass	ΔM_t	3.2	±1	g
Initial Density of Target	ρ_{0t}	920	±46	kg/m^3
Target Density in Compacted Region	ρ_{co}	1300	±100	kg/m^3

Simplified model: An impact induced spherical shock wave, which originates in the equivalent center and propagates outwards, is considered in a spherically-symmetrical coordinate system. Work applied to an element of volume, which was at position r_a in the undeformed configuration, is calculated by multiplying the amount of reduction in volume $\Delta V(r_a)$ by the shock pressure $P(r_a)$.

Densities before and after the impact, and maximum pressure applied to each element of volume, along with the distance from the equivalent center is shown schematically in Fig.2. For the sake of simplicity, a density of the gypsum target after the impact (ρ_{co}) is assumed to be 1300 kg/m^3.

We assumed the density of crushed region (ρ_{sh}) from 940 to 1300 kg/m^3. Employing these values of densities, in accord with a simple mass conservation, the boundary between the compacted and crushed region in the undeformed condition (R'_{co}) are calculated. An assumed set of these variables is listed in Table III. Note that W_{hem} and W_{sph} denote amount of energy consumed in compaction of the target in hemi-spherical and spherical region, respectively.

Pressure of the isobaric core (P_{core}) was set 14GPa (Onose 2007). Some different value were calculated for the diameter of the isobaric core and the decay constants, because it is difficult to measure directly.

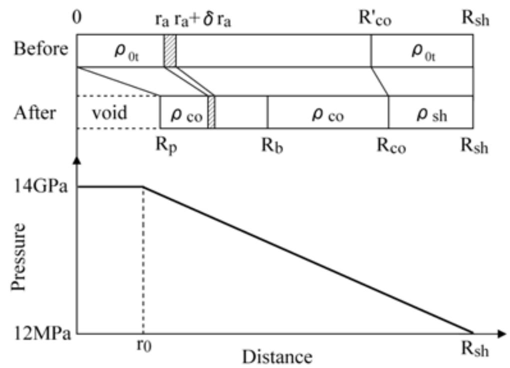

Fig. 2 Compaction of the target in a polar coordinate: The horizontal axis represents a distance from the equivalent center. An upper and a lower column graphs show the positions and densities of the target material before and after the impact. In this figure, R_p represents an imaginary inner end of the compacted target, though it value is not used in calculation. The vertical axis of the bottom part of this figure indicates the pressure of the shock wave.

Table. III Assumed densities, radii and Results

ρ_{sh}		kg/m^3	920	940	1000	1300
R'_{co}		mm	17.1	17.0	16.7	15.3
W_{hem}	r_0=2.2, β=3.2	J	525	527	530	555
	r_0=4.3, β=4.6	J	1843	1844	1849	1878
W_{sph}	r_0=2.2, β=3.2	J	1050	1054	1062	1110
	r_0=4.3, β=4.6	J	3686	3689	3699	3757

Conclusions: Considering a kinetic energy of projectile is 1852 J, this calculation indicate that 28 to 56 % of the impact energy consumed by compaction.

References:

[1] Housen K. R., and Holsapple K. A. (2003) *Icarus* 163:102-119. [2] Onose N. (2007) thesis. [3] Polansky C. A., and Ahrens T. J. (1990) *Icarus* 87:140-155.

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