

EFFECTS OF TARGET MATERIAL PROPERTIES ON TRANSIENT CRATER GROWTH

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Introduction: It has been reported that even in the gravity regime, a scaling relation of impact cratering may depend on target material properties, such as porosity or the angle of repose [e.g. 1, 2]. However, it is unknown how target material properties are related to the scaling relation. In order to investigate this issue, we need direct observation of transient crater growth. From our recent observations of a temporal change in diameter of a crater cavity (hereafter, diameter growth) [3, 4], we found that the rate of increase in diameter of a crater cavity at early times follows a power-law relation, but the rate of increase at late times deviates from the power-law relation. In addition, the power-law exponent at early times and the degree of the deviation from a power-law (hereafter, the degree of deviation) at later times were shown to depend on target material properties [4]. Thus, in order to formulate a scaling relation taking into account target material properties, we need to investigate quantitatively how the power-law exponent and the degree of deviation are related to target material properties. In this study, we thus measured the power-law exponent and the degree of deviation for various targets.

Experiment: We used the following five targets: soda-lime glass spheres whose mean diameters are 36 μm , 220 μm , and 1.2 mm (hereafter they are referred as TA, TC, and TE targets, respectively), dry sand with mean diameter of 300 μm , and liquid water. The porosity and the angle of repose for these targets are listed in Table 1. Polycarbonate projectiles (10 cm in diameter and 0.49 g in mass) were impacted vertically into a target by a single-stage light-gas gun.

We measured the diameter growth as follows: for soda-lime glass and dry sand targets, we used the laser method [3, 4] in which a vertical laser-sheet illuminates the target at the impact site, and the temporal change of a laser line on the target surface during the transient crater growth is observed by a high-speed video camera set above the target. From the shape of the laser line, we can estimate the diameter of a crater cavity at each time step. For water target, we measured directly the diameter of a crater cavity through a transparent target container by the camera [see, 5]. All the experiments were conducted under the condition with the ambient pressures <50 Pa (glass sphere and dry sand targets) or <2000 Pa (water target).

Analysis: Fig. 1 shows an example of the diameter growth (this is the case of TA target). We can see that the data at early times (<0.01 s) follows a power-law, but the data at late times deviates from the power-law. We determined the power-law exponent and the degree

of deviation as follows: In our previous study [4], we proposed the following model to explain the diameter growth: In Maxwell's Z-model [6], the radial component of the excavation flow velocity u_r at the distance r is given as $u_r = \alpha(t)/r^Z$, where Z is a constant and $\alpha(t)$ is a function of the time t . When we assume $\alpha(t) \propto e^{-\beta t}$, the diameter $d(t)$ of a crater cavity is derived as:

$$d(t) \propto (1 - e^{-\beta t})^\gamma, \quad \dots (1)$$

where β is a constant and a power-law exponent $\gamma = 1/(Z+1)$. This equation can represent well the data of diameter growth, as shown in Fig. 1 (red solid curve). Since the values of γ and β correspond to the power-law exponent and the degree of deviation, respectively [4], we can use γ and β to study quantitatively how the power-law exponent and the degree of deviation are related to target material properties.

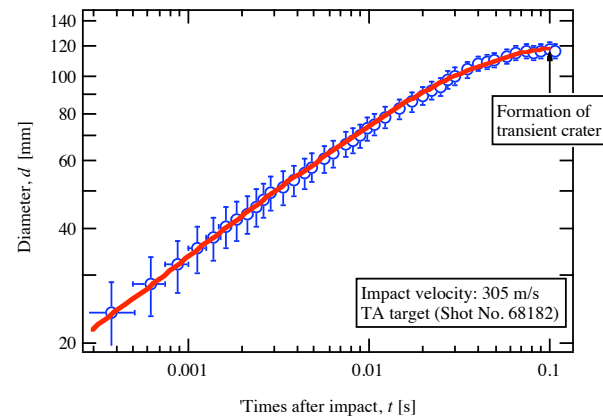


Figure 1: A temporal change in diameter of a crater cavity for impact velocity of 305 m/s into TA target (open circles). A red solid curve is the best-fit one by Eq. (1).

Results: Using the least-square fit with Eq. (1), we determine γ and β for various targets. The average values of γ and β for each target are summarized in Table 1.

In Fig. 2, the results of γ (red circles) are plotted against the porosity and the angle of repose. We cannot see clear dependence in γ on the porosity nor the angle of repose. This may indicate that the value of γ is not dependent on target material properties. On the contrary, when γ is plotted against the mean grain diameter (Fig. 3, red circles), we can see that γ increases with increasing the mean grain diameter (we do not plot γ for water in Fig. 3, because we cannot define the grain size for water). This suggests that the power-law exponent γ depends mainly on the grain size.

In Fig. 2 are also plotted the results of β (blue circles) against the porosity and the angle of repose. We may see that β increases with increasing the porosity and the

angle of repose. On the other hand, the value of β does not show the grain size dependence, as shown in Fig. 3 (blue circles). This may suggest that the degree of deviation depends mainly on target material properties.

Discussion: We found in Fig. 2 that β increases as porosity and the angle of repose increase. The reason why the target with larger porosity or larger angle of repose has larger β may be explained as follows: Larger porosity or larger angle of repose may result from larger cohesions among target grains such as van der Waals force for granular targets (molecular forces for water) [7]. The excavation flow in target with larger cohesion would weaken more rapidly than that in targets with smaller cohesion. This corresponds to a rapid decrease in u_r with time t , that is, larger β , because of $u_r \propto e^{-\beta t}$.

We next consider the dependence in γ . We found in Fig. 3 that the target with larger grains (larger grain target) has larger γ and smaller Z ($=-1+1/\gamma$). This means that the larger grain target has lower rate of decrease in u_r with the distance r , because $u_r \propto 1/r^Z$. Since u_r depends on the intensity $P(r)$ of shock (stress) wave [see, 1], it may be suggested that the larger grain target also has lower rate of decrease in $P(r)$ with r . For the reason of such lower rate of decrease in $P(r)$ for larger grain targets, we propose that the total number of grain boundaries may be important in determining the rate of decrease in $P(r)$; the shock (stress) wave in a homogeneous target (that is, no grain boundary in a target) would travel with lower rate of decrease than that in a target with a large number of the grain boundaries. Since total number of grain boundaries per a unit length of shockwave ray path is in inverse proportion to target grain size, the larger grain target (the smaller number of the grain boundaries) may have lower rate of decrease in $P(r)$. Although we need more studies to examine this idea, it should be noted that this idea is consistent with the results of γ for water; the value of γ for water is larger than those for other targets (Table 1) and the number of the grain boundaries in water is zero.

Summary: We found that the power-law exponent γ shows the grain size dependence, while the degree of deviation β depends on target material properties such as porosity or the angle of repose. It is future problem how we formulate a scaling relation in the gravity regime based on the data on γ and β listed in Table 1.

Table 1: The porosity, the angle of repose, and the average values of γ and β for each target.

	Porosity [%]	Angle of repose [°]	γ	β [1/s]
TA	35	29±3	0.36±0.02	25.8±2.3
TC	34	22±1	0.38±0.01	21.1±1.1
TE	34	22±1	0.42±0.02	25.0±3.9
Dry sand	41	32±2	0.39±0.02	45.0±4.5
Water	0	0	0.45±0.12	7.4±0.5

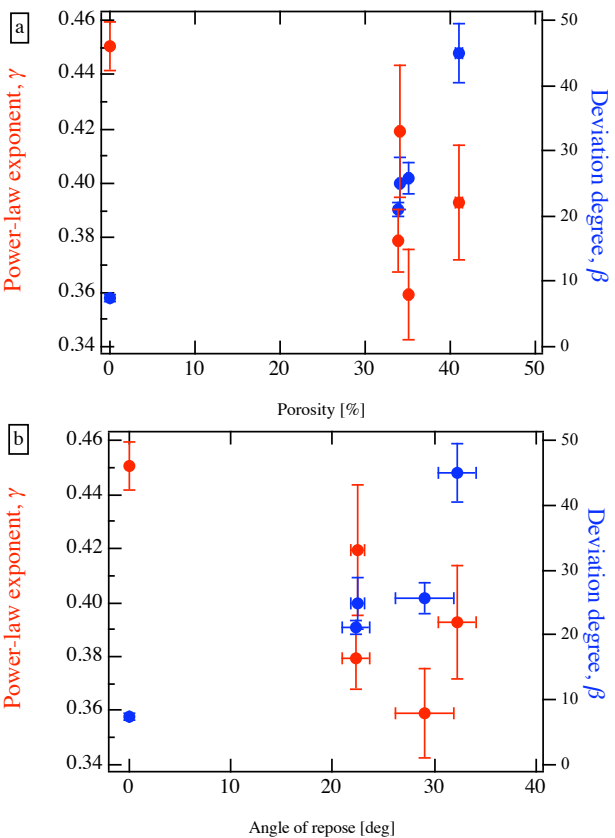


Figure 2: The power-law exponent γ (red circles) and the degree of deviation β (blue circles) are plotted against (a) the porosity and (b) the angle of repose.

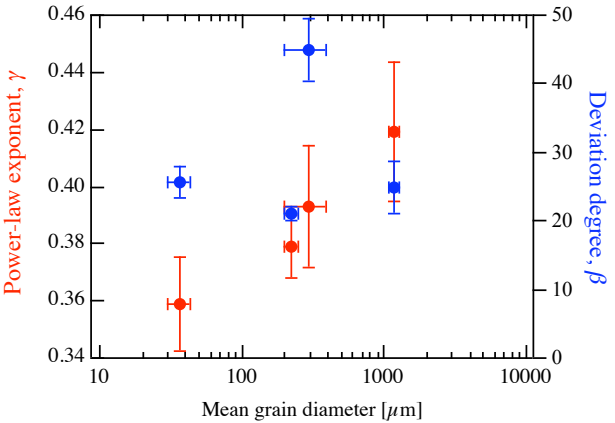


Figure 3: The power-law exponent γ (red circles) and the degree of deviation β (blue circles) are plotted against the mean grain diameter.

References: [1] Melosh H.J., *Impact cratering*, Oxford Univ. Press, New York, 1989. [2] Yamamoto S. et al., *Icarus* 183, 215, 2006. [3] Barnouin-Jha O.S. et al., *Icarus*, 188, 506. [4] Yamamoto S. et al., 38th LPSC abst. 1452, 2007. [5] Gault D.E., Sonett C.P., *Geo. Soc. of America Special Paper* 190, 69, 1982. [6] Maxwell D.E., *In Impact and explosion cratering* (Roddy D.J. et al. Eds.), Pergamon press, New York, 1003, 1973. [7] Yu A.B. et al., *Powder Technology*, 130, 70, 2003.