Probability distribution of impact strength on the target simulating meteorites and implication for the size dependence of asteroid strength

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Impact strength of asteroids is one of the most important physical parameter to control the size frequency distribution of asteroids in the main belt. The impact strength has been studied in the laboratory using cm-scale targets simulating various type asteroids such as rocky, icy and metal bodies, and these previous studies revealed that the impact strength strongly depended on materials and internal structure such as porosity. However, actual collision among asteroids happen at the scale of several orders of magnitude larger than that at the laboratory scale. Therefore, the size dependence of the impact strength is quite important to consider the asteroid collision. There is a traditional theory for material strength and it is well known that the material strength follows probability distribution: it scatters according to Weibull distribution. This probability distribution of the material strength is theoretically connected to the size dependence of the material strength: so called the Weibull statistical fracture theory. This size dependence is confirmed at the static deformation condition so far, then we try to extend this Weibull theory to the dynamic deformation condition corresponding to high-velocity impact for the purpose of asteroid collisions.

We made impact disruption experiments by using a vertical type gas gun set at Kobe University. A nylon ball projectile with the diameter of 10mm was launched at the velocity from 65 to 208 ms^{-1}, and was impacted on the target surface normally. The targets were a gypsum-glass beads mixture (GG) with the mean density of 1.9gcm^{-3} or a gypsum-bentonite mixture (GB) with the mean density of 0.77 gcm^{-3}; both had a shape of cylinder whose dimeter was 30mm. CG and GB targets were analogues of chondritic meteorites, so the glass beads with the size of 1mm simulated a chondrule. The impact experiments were conducted 10 times at the same impact condition for each target: the constant energy density (Q: the kinetic energy of projectile divide by target mass) was applied to the target, and we measure the mass of the largest fragment (LFM) at each time, then we noticed that the resultant 10 data were so scattered. We studied the probability distribution of the largest fragment mass, and then we obtained the impact strength (Q^*) from the largest fragment mass on the basis of the typical relationship between LFM and Q. Impact experiments at two different energy densities were conducted for each target. We also measured the tensile strength of GG and GB targets more than 10 times by the static deformation test to study the probability distribution of the tensile strength.

We obtained the Weibull parameter (Φ) to characterize the probability distribution of the strength for the tensile fracture: Φ=7 and 8 for GG and GB target, respectively; they are similar to the values obtained for basalt and granite. The cumulative probability, P, of the fracture for the materials is shown as follows according to the Weibull theory, $P=1-\exp(-V/V_0(\sigma/\sigma_0)^{\Phi})$ (eq.1), where V is volume of the target and σ is strength, and the suffix 0 shows the standard condition. The largest fragment mass recovered from impact experiments was found to scatter so much; e.g. GG target showed the scattering in one order of magnitude. The average impact strength of GG and GB target for 20 experiments in each was obtained to be 34 and 158 Jkg^{-1}, respectively, and we tried to make the relationship between P and Q^* according to eq.1 by substituting Q^* for σ, where Q^* was determined from each LMF using the typical relationship between LFM and Q, then Φ was obtained from the probability distribution of the impact strength: Φ is 1.8 and 2.6 for GG and GB target. Thus, the size dependence of the impact strength could be estimated from

eq.1 setting P=0.5: $Q^*=Q_0\ D^{-n}$, where D is the target size and n is 1.6 and 1.2 for GB and GG target, respectively.

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