
Mode of collision is of importance for the evolution of planetesimals as well as impact cratering of the surface of planets, satellites and chondrite parent bodies. Strength (or impact strength) of impacting bodies is one of the key properties in collision processes. Because of high scarcity values of extraterrestrial samples, experimental studies on the strength of meteorites have been very few (1). A new strength measure named “vibrational fracturing rate” (2), which is suitable for small rocks, is applied to ordinary chondrites (L3, L6 and LL6) from Antarctica and Allende (C3).

VIBRATIONAL FRACTURING RATE - A fragment of chondrites was embedded in resin and made at least 5mmx5mm flat surface. Using a ultrasonic machine, the sample surface is excavated by a vibrating 2mm-diameter steel rod (Fig. 1). The rate of excavation is measured by a differential transformer (D.T.) and recorded on a strip chart, under a constant normal stress (on~0.6MPa) and mechanical impedance matching condition. More detailed description of the measurement is reported elsewhere (2). Excavation experiments were made several times on each sample. Examples of excavated depth versus time curves are shown in Fig. 2. An inclusion with about 2mm-diameter is found in the border of the surface of Allende. Allende (m) and (i) in the figure 2 indicate the difference of the location of excavation in the same specimen. Excavation versus time curve of Allende (i) is obtained at the location of excavation within a few millimeter distance from the inclusion. The highest rate of excavation with large variation for the curve of Allende (m), which is obtained in other part of the specimen, indicate that this portion is highly heterogeneous and loose. At the moment of a steep gradient of the curve, small fragments are often removed from the excavated hole, suggesting the occurrence of large fracture nearby the hole. In constrast, Allende (i) shows a smooth and low rate of excavation which is similar to that of Yamato-74191(L3). Yamato-75298(LL6) and ALHA 77231(L6) show intermediate rate of excavation. Single crystal of calcite with the excavation direction perpendicular to r(1011) shows a similar rate of excavation to that of ALHA 77231. Furthermore, basalt shows about half a rate of excavation when compared to those of Allende (i) and Yamato-74191. It is obvious that the higher rate of excavation is always associated with the larger variation of the excavation depth versus time curve. Gradients of the curves obtained for each sample show relatively small variations within ±10% except Allende (m). We take an average gradient for each curve as the vibrational fracturing rate of the sample. Because the absolute value of the vibrational fracturing rate would be affected by normal stress, size of tool tip, and amplitude of vibration, only a relative value has its meaning. Figure 3 shows logarithmic ratios of the vibrational fracturing rate of calcite (Vc) relative to those (V) of single crystals (□), terrestrial rocks (○) and chondrites (○). Fragments of sample itself hit the sample surface vertically and behave as grinding power at the resonant vibration condition. The vibrational fracturing rate corresponds well with the relative hardness (2). Cleavages, cracks, and adhesion between grains would play an important role in the vibrational fracturing process. Pouring of water between sample surface and the tip of steel rod is necessary in this measurement to keep good matching of mechanical impedance. So the application of this method would be limited to the samples with too high porosity or including water-soluble minerals such as clay unless further improvements would be made.

DIFFERENCES OF RELATIVE STRENGTH AMONG CHONDrites - Although a small fragment would not represent bulk mechanical properties for chondrite nor for petrologic type, it may temporarily be assumed that Allende, Yamato-74191,
ALHA 77231, and Yamato-75258 represent petrologic type C3, L3, L6 and LL6, respectively. The observations of grain boundaries by scanning electron microscope (SEM) indicate that large grains (>50μm) are rounded and fitted each other in L6 and LL6 whereas in L3 they are embedded with fine angular grains (2). It may be reasonable if petrologic types were caused by thermal metamorphism (3). The vibrational fracturing rates for chondrites, however, show the lowest rate for L3 (Yamato-74191) and the highest and lowest rates in the same specimen of C3 (Allende). The strength represented by the vibrational fracturing rate is likely to depend on grain-to-grain adhesion and cementing condition between grains. When large grains (or accumulation of grains) are sparsely disturbed, the vibrational fracturing rate would be high for the matrix and low for the large grains. This may be the case for Allende sample. Crushing strengths of several ordinary chondrites have wide variety from 38MPa to unmeasurable small value that it is crushed between thumb and figures (1). Effects of shock and fragmentation history may differ among chondrites both in space and on earth's surface. Unless mechanisms and physical processes of these effects on the lithification of chondrites could be solved, there will be little confirmation whether the strength of chondrites would closely relate to petrologic types or not. It is, however, apparent that the presence of inter-grain fine minerals in chondrites causes significant change in adhesive strength as well as other mechanical properties (2,4). Adhesive condition by small fraction of amorphous material and hydrous minerals at grain boundaries affects the strength of chondrites and lithification of planetesimals and chondrite parent bodies in the case when they had not undergone the melting of silicate minerals (2,5,6). Adhesive strength of olivine powder (<250μm) is increased by the addition of serpentine powder and albite glass (4). Further investigations for different petrologic types of chondrites and for the effects of intergrain fine minerals on the mechanical properties are obviously indispensable.

We are indebted to Drs. Hiroshi Takeda and Yoji Kobayashi for their discussions and encouragements. We express our thanks to the National Institute of Polar Research, Japan, for offering chondrites from Antarctica and to Dr. N. Nakamura for Allende sample.

References:

Fig. 1. Schematic diagram of the vibrational fracturing measurement, D.T.: Differential transformer, P.U.: pick-up, (1).
Fig. 2. Examples of excavation depth versus time curves for chondrites. As a reference, curves for calcite and basalt (1) are also indicated.
Fig. 3. Logarithmic ratios of the vibrational fracturing rate (Vo) of calcite relative to those (V) of single crystals (☐), rocks (☐) and chondrites (☐). Allende (i) and (m) indicate the location of excavation nearby an large inclusion and other part of matrix, respectively.
VIBRATIONAL FRACTURING RATE

Fujii, N. et al.

Fig. 1

Fig. 2

Fig. 3

\[ \log \left( \frac{v_0}{v} \right) \]

Quartz, \( \perp \) to \( c\{001\} \)
Olivine
Anorthite, \( \perp \) to \( b\{010\} \)
Calcite, \( \perp \) to \( r\{011\} \)
Basalt
Serpentinite, \( \perp \) to shistosity
Pyrophyllite
Talc
Yamato-74191 (L3)
ALHA 77231 (L6)
Yamato-75258 (LL6)
Allende (C3)

\( v_0 \) = vibrational fracturing rate of Calcite.