Mechanical strength of chondrules

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Chondrules embedded in chondrites recorded physical processes in the early solar system such as impact compression of the chondrite parent-bodies. Some fractions of chondrules were found to be fractured in chondrites (Nelson and Rubin, 2002). If such fraction and the strength of chondrules are combined, the level of the applied stress to the chondrite parent-body due to impact compression could be inferred (Beitz et al., 2013). Here we report the results of our laboratory study on the strength of chondrules and compare them with those of specimens of dunite, basalt, and two different sandstones.

We conducted static and dynamic compression tests of chondrules and rock specimens, because brittle materials tend to respond differently to the static stress and dynamic stress. Chondrules of Allende (CV3) were removed from a block using tweezers and files, while those of Saratov (H4) were separated from a block by means of freeze-thaw method. Crushing strength of chondrule was determined using a compression testing machine installed at Kobe University with loading rate of 1 μm s^{-1}. Crushing strength Y_c is determined as follows:

$$Y_c=2.8F/\pi d^2, \qquad (1)$$

where F is the peak value of the applied force and d is the mean diameter of chondrule or rock specimen.

Impact disruption experiments of chondrules and rock specimens were conducted using a gas-gun with 3 mm bore diameter at Kobe University. Chondrules and rock specimens were impacted onto plate targets. Those smaller than 2 mm in diameter were accelerated using polycarbonate sabots of 3 mm in diameter. The material of the plate targets were nylon, aluminum, and stainless-steel to cover a range of impact pressure. The impact velocities for the chondrules were from 25 to 101 m s^{-1}. We defined the impact strength as the impact pressure at which the maximum fragment mass fraction to the initial mass of chondrule or rock specimen becomes 0.5.

Fracture patterns varied depending on materials in both static and dynamic tests. For example, as for impact disruption, specimens of two sandstones were more finely fragmented than other materials and numerous sand grains were generated. We found that the crushing strength of chondrules was roughly 10 MPa and lower than igneous rocks, i.e., dunite (13 MPa) and basalt (17 MPa), but higher than two sandstones (both ~3 MPa). We also found that the impact strength of chondrules was about 160 MPa and more than a magnitude larger than the static strength as are the cases of rock specimens. The strength of chondrules determined in this study would give the lower limit to those of the initial ones because the chodrules would have been weakened by stresses they have experienced in the chondrites.