CATASTROPHIC DISRUPTION OF SOLID BODIES BY COLLISION — EXPERIMENTAL APPROACH —

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ABSTRACT.   The results on mass, velocity, shape, and rotation of the fragments produced in the disruption experiments by impact are surveyed. Some future works are also suggested.

1. Introduction

Study of the outcomes of collisions between the solid bodies is crucial to understand the nature, origin, and evolution of interplanetary dust particles in many respects: (1) Some of the dust particles are undoubtedly supplied as the outcome of the asteroid-asteroid, or asteroid-dust collisions as found as IRAS dust bands, which are closely connected with some of asteroid families, and the structure and evolution of the dust bands are controled by the collisional processes (Sykes *et al.*, 1989). (2) Collisions among dust particles are believed to play an important role to supply the β-meteoroids, which are observed in the recent direct detection of dust particles by spacecrafts. (3) Dust particles are considered to be the end products of the collisional processes among the solid components of various size classes since the formation of the solar system.

To solve these collisional evolution and identify the sources of the interplanetary dust particles, the most fundamental quantities to be investigated on the collisional outcomes are: (1) mass (size) distribution of the fragments, and (2) velocity distribution of the fragments. Other quantities are also useful for some purposes; for examples, informations of the fragment shape is useful to identify whether dust particles are collisional origin or not, by the recovered samples or scattering properties of the dust particles, and to evaluate the Yarkovski effect working on the spinning dust particles, rotational frequencies of the collisional fragments must be known. Impact phenomena are classified into two classses: cratering and disruption. Concerning the size and velocity distribution of the fragments in cratering, Gault and Heitowit's (1963) classical work is still useful and valuable, although more systematic works are strongly desired. On the contrary, studies concerning the impact disruption have made great progress in the past decade. In this review, we mainly focus on the outcomes of the impact destruction found through experiments. Main

experimental results and scaling laws in the context of the catastrophic collision of asteroididal bodies until 1989 are summarized in Fujiwara *et al.*(1989). In this paper, some of the important points and recent topics are reviewed.

2. Experimental Methods

Most commonly made experiments are laboratory impact experiments using powder guns and sigle-stage or two-stage light-gas guns which can launch typically cm-sized projectiles up to several km/s. Shaped charge method is also used in higher velocity experiments (about 9km/s)(Capaccioni *et al.*,1986). Materials used for the projectiles and the targets are metals, rocks, and ices. Recently disruption experiments in the open air using explosives have been conducted by an Italian group (Martelli *et al.*, 1990). In these experiments aerodynamical drag for small fragments should be taken into account, while the experiments using guns are carried out in the vacuum state. For the dust particles, electrostatic dust accelerators are used, but the studies for the disruption are quite limited (McDonnell, 1976).

3. Fragment size

3.1. ENERGY FOR DISRUPTION AND THE LARGEST FRAGMENTS

Impact energy required to disrupt the targets consisting of various kind of materials and the degree of fragmentation were investigated by many authors (See Fujiwara *et al.*, 1989). Most of rocks start to disrupt at E/M-value (E; impact energy, M; target mass) of about several times 10^6 erg/g, while ices disrupt at one order of magnitude smaller value. For metals (*e.g.* iron) disruption occurs at around 10^8 erg/g. The mass fraction of the largest fragment to the target mass is roughly inversely proportional to the E/M-value for various materials.

3.2. SIZE DISTRIBUTION OF THE FRAGMENTS

It has been traditionally assumed in many papers that the size distribution is expressed by a power law;

$$n(m)dm = Cm^{-\alpha}dm,$$

where n(m)dm is the number of fragments of mass in the range of m to m+dm. The index has been conventionally assumed to be 0.8 in many references. However, the detailed studies show that is a function of fragment size and impact energy or more appropriate scaling parameters. Takagi *et al.*(1984) showed that the size spectrum consists of three segments and the power indices for these segments are expressed as a function of a scaling parameter P_I which is proposed as a good scaling parameter by Mizutani *et al.*(1990) and expressed as $P_I = P_0 V_{0p}/Y V_{0t}$ (V_{0p} ; initial volume of a projectile, V_{0t}; initial volume of a target, Y; yield strength of the target). The results show that the exponent changes with the parameter P_I. In the regime III (the small size region) most of data are slightly less than 0.8, while in the regime I (region of the largest fragment size), they take very large values and increase with the parameter P_I.

4. Velocity Distribution

Many investigators consider that velocity distribution of the fragments (relation between mass and velocity of individual fragments) is the most fundamental quantity to understand the collisional evolution of the solid particles in the solar system. However, the distribution in the whole size range has not yet been understood because of the experimental difficulties. Recently Nakamura and Fujiwara (1990)
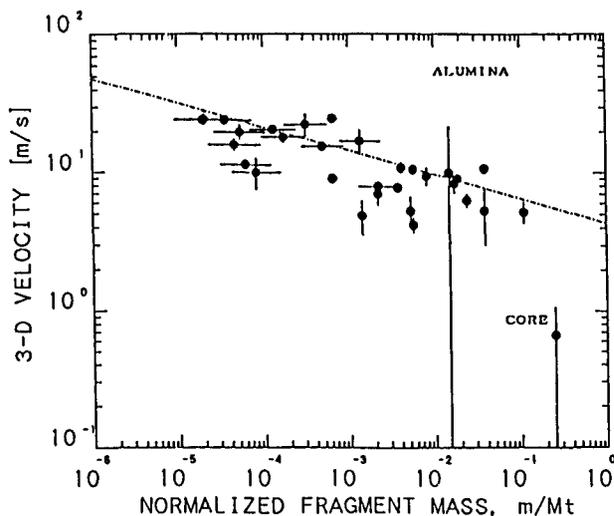

Figure 1. Velocity distribution of the alumina fragments. Velocity and mass of the projectile are 3.8km/s and 0.7g, respectively. Target diameter is 6cm. Nakamura and Fujiwara(1990).

took high-speed movie pictures of the fragmentation of an alumina ball and a basalt ball impacted by the nylon projectiles of 0.7 cm in diameter in the vacuum space. The 2-D velocity and 3-D velocities were determined for the fragment size down to a few mm. The example of the 3-D velocity distribution for the alumina target is shown in Fig.1. The best-fitted line is expressed by -1/6 th power of the fragment mass. These results are not inconsistent of the results by Davis and Ryan(1989). It is still not clear how this velocity distribution depends on the various impact parameters (masses and material properties of both the target and the projectile, and collisional velocity). However, the data on the velocity of the antipodal points of the target were obtained as a representative velocity (Fujiwara and Tsukamoto, 1980; Takagi *et al.*,1984), where the antipodal point is the opposite point on the target of the impact point. The data are shown in Fig.2. The velocity depends on the 0.76th power of E/M , and it is found from the figure that the data are well scaled by the Mizutani scaling parameter.
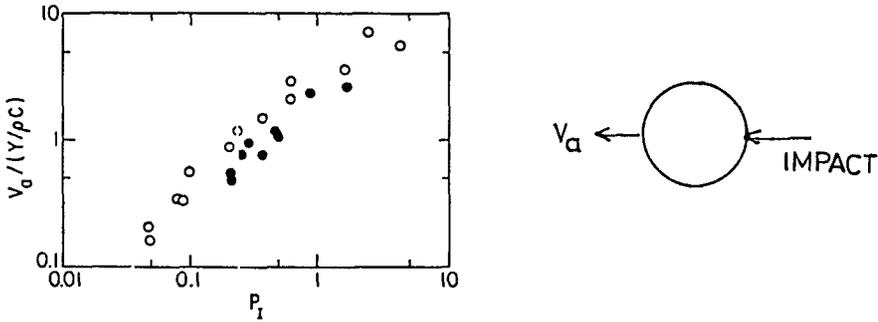
Figure 2. Velocity of fragments from the antipodal point V_a. PI is Mizutani parameter. C and ρ are sound velocity and density of the data (2.7km/s). Filled circle; the Takagi and Mizutani data (<1km/s). From Fujiwara *et al.*(1989).

5. Shape of the Fragments

Shape of the fragments is especially of interest for the study of dust particles, because it affects the scattering properties of the dust particles and it also becomes a clue to assign the origin of the dust particles. Many laboratory experiments show shapes of the fragments distributing around a very peculiar average shape(Fig.3); the average ratio for the longest, intermediate, and short axis is 2: $2^{1/2}$:1. Hence,
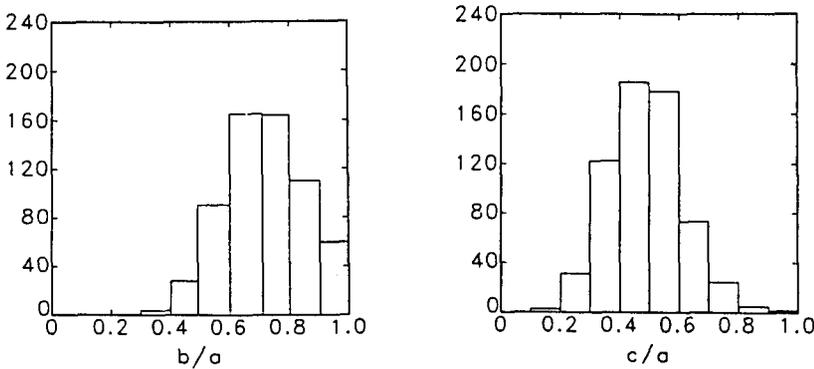

Figure 3. Histogram for b/a and c/a. Fujiwara *et al.*(1989).

if the dust particles are originated from collisional processes, the most probable shape of the dust particles will take this average value. There are two experiments which violate this very stable rule; one is Lange and Ahrens (1981) for ice targets, and another is the recent large scale experiments made by using explosives in the open air by Martelli *et al.* (1990). The reason of the deviation from the standard

shape rule in these experiments is not clear, but the possibility that the original samples may have some anisotropy is not excluded.

6. Rotation of the Fragments

Rotational properties affect on the dust particles through Yarkovski effect. The data on the rotational frequency of the fragmented bodies are still limited to the one obtained by Fujiwara and Tsukamoto(1981). It is noted the fragments rotate at very high frequencies; for example, the fragments of several mm size rotate as high as a few hundreds rps. The maximum frequency rate is almost one order-of-magnitude less than the frequency for the rotational burst.

7. Future Works

There are many works to be done in the future on the impact phenomena connected with the interplanetary dust particles.
(1) Data of the impact experiments for wide varieties of physical parameters; varying density, size, strength of both targets and projectiles are required.
(2) Kinematical data of the fragments (velocity and spin distribution of the fragments, energy partition rate into various energy modes, angular momentum and momentum transfer rate) are still deficient.
(3) Impact experiments using various kind of icy and organic bodies are required.
(4) Collision between core-mantle bodies is of interest, because interstellar dust particles are considered to have such structure and also cometary dust particles may have similar structures.
(5) Most of experiments are aimed at the applications to the collisional evolution of asteroidal bodies. Semi-empirical laws or scaling laws proposed(Paolicchi *et al.*, 1989; Housen and Holsapple, 1990; Mizutani *et al.*, 1990) are intended to know how the laboratory scale experiments (10cm order bodies) can be extended to the 10^{6-7}cm-sized bodies. From the viewpoint of the interest in the dust particles, it is necessary to extend the scaling law to an order of 10^{-4}cm bodies. Especially interesting is to know how the disruption phenomena change for the object whose size is less than the fundamental size of the grains which constitute the body. McDonnell(1976) impacted 10^{-11}g particles (velocity 4km/s -15km/s) on a previously raised chip-essentially free standing- of a polished lunar sample. He suggested the catastrophic rupture limit of the body size is < 4 times the primary crater diameter. More experiments are required in this size range.
(6) Some of the Brownlee particles are aggregates of less smaller particles. Therefore collisions for these aggregates or rubble piles should be of great importance. Some experiments using rubble pile targets were made in the slow velocity range (Hartmann, 1980), and the results suggest the outcomes are strongly dependent on the initial size distribution of the rubbles. Moreover, recently, fractal structure is also proposed for the grain. To determine the cross sections for accretion or destruction using fractal grains are necessary in the discussion of growth rate of the grain in the space.

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