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Influence of petrographic textures on the shapes of impact experiment fine fragments measuring several tens of microns: Comparison with Itokawa regolith particles

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ABSTRACT

In 2010, fine regolith particles on asteroid Itokawa were recovered by the Hayabusa mission. The three-dimensional microstructure of 48 Itokawa particles smaller than 120 µm was examined in previous studies. The shape distribution of Itokawa particles is distributed around the mean values of the axial ratio $2{:}\sqrt{2}{:}1$, which is similar to laboratory impact fragments larger than several mm created in catastrophic disruptions. Thus, the Itokawa particles are considered to be impact fragments on the asteroid's surface. However, there have never been any laboratory impact experiments investigating the shapes of fine fragments smaller than 120 µm, and little is known about the relation between the shapes of fine fragments and the petrographic textures within those fragments. In this study, in order to investigate the relation between the petrographic textures and the shapes of fine fragments by impacts, the shapes of 2163 fine fragments smaller than 120 µm are examined by synchrotron radiation-based microtomography at SPring-8. Most samples are fine fragments from basalt targets, obtained in previous laboratory impact experiments by Michikami et al. (2016). Moreover, two impacts into L5 chondrite targets were carried out and the shapes of their fine fragments are examined for comparison. The results show that the shape distributions of fine fragments in basalt targets are similar regardless of impact energy per target mass (in contract to the shape distribution of relatively large fragments, which are affected by impact energy), and are similar to those in L5 chondrite targets and Itokawa regolith particles. The physical process producing these fine fragments would be due to multiple rarefaction waves in the target. Besides, the petrographic textures do not significantly affect the shapes of fine fragments in our experiments. On the other hand, according to Molaro et al. (2015), the shapes of the fragments produced by thermal fatigue by the day-night temperature cycles on the asteroid surface are influenced by the petrographic textures. Therefore, we conclude that the Itokawa particles are not the products of thermal fatigue but impact fragments on the asteroid surface.

1. Introduction

Since the pioneering work of Fujiwara et al. (1978), the shapes of fragments in laboratory impact experiments have often been characterized by axes *a*, *b* and *c*, these being the maximum dimensions of the fragment in three mutually orthogonal planes ($a \geq b \geq c$). In catastrophic disruption, the axial ratios of fragments are distributed around mean values of the axial ratios b/a ~0.7 and c/a ~0.5, i.e. corresponding to $a{:}b{:}c$ in the simple proportion $2{:}\sqrt{2}{:}1$ (Fujiwara et al., 1978; Capaccioni et al., 1984, 1986; Durda et al., 2015; Michikami et al., 2016). In impact cratering, on the other hand, the shapes of fragments are flatter, i.e. the mean axial ratios of b/a and c/a are ~0.7 and ~0.2, respectively (Michikami et al., 2016). Thus, the shapes of fragments in impact cratering are different from those in catastrophic disruption.

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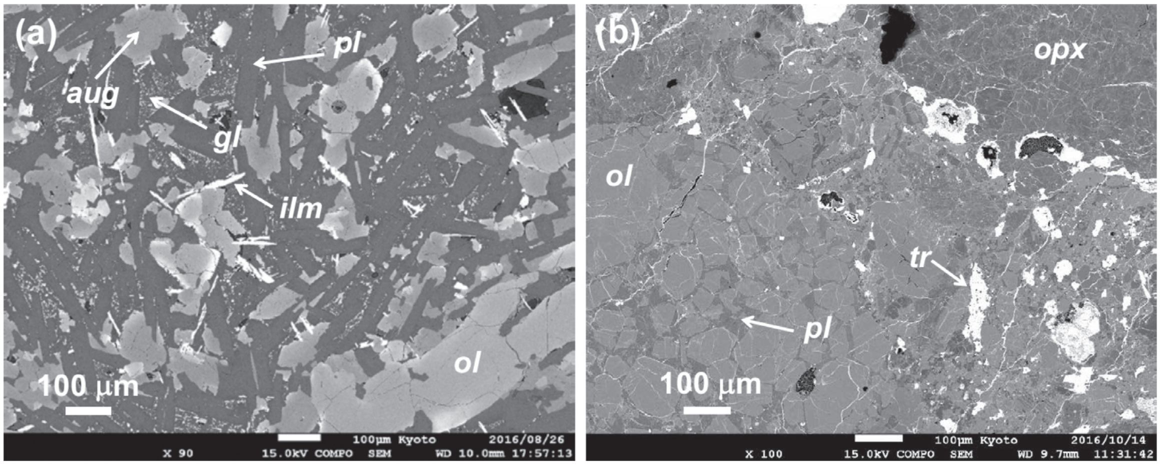

Fig. 1. Back-scattered electron images by a scanning electron microscope (JEOL JSM7001F) of the thin sections for the samples of the targets used. (a) Basalt sample (Linxi, Inner Mongolia). (b) L5 chondrite sample (Sayh al Uhaimir 001 meteorite, Oman). *ol*: olivine, *aug*: augite, *pl*: plagioclase, *ilm*: ilmenite, *gl*: mixture of glass and small mineral grains (mostly magnetite and ferroan augite), *opx*: orthopyroxene, and *tr*: troilite.

However, in laboratory impact experiments, only the shapes of fragments with sizes larger than several mm were investigated. In previous studies, there have only been very few laboratory impact experiments investigating the shapes of fragments with sizes less than 1 mm.

In 2010, regolith fine particles on asteroid Itokawa were recovered by the Hayabusa mission. Most of these sub-mm particles range from sub-micrometer to several tens of micrometers. Tsuchiyama et al. (2011, 2014) have examined the three-dimensional microstructure of 48 Itokawa regolith particles with sizes from 13.5 to 114.3 μm using synchrotron radiation (SR)-based microtomography at SPring-8 (they used the sphere-equivalent diameter, calculated from the particle volume, to define the size of these small particles). They suggested the Itokawa particles are fine fragments that originated primarily from impact phenomena. The Itokawa particles are consistent with LL chondrite material not only in terms of modal abundance as well as elemental and isotopic composition (Tsuchiyama et al., 2011; Nakamura et al., 2011; Yurimoto et al., 2011) of minerals but also in terms of their three-dimensional microstructure (Tsuchiyama et al., 2011). The shape distribution of the Itokawa particles (47 in total) is similar to fragments created laboratory experiments that resulted in catastrophic disruption of the target: their mean *b/a* and *c/a* ratios, calculated using the *EA* (*ellipsoidal approximation*) method (see Appendix A), are 0.72 and 0.44, respectively (Tsuchiyama et al., 2014). However, at less than 120 μm, the Itokawa particles measured using SR-based microtomography are significantly smaller than the relevant laboratory fragments, which were larger than several mm.

When comparing the Itokawa regolith particles with laboratory impact fragments or ordinary chondrites, we have to take into account (1) the effects of the mechanical process generating the fragments and (2) the petrographic characteristics of the particles themselves.

(1) Fragments of different shapes are affected in different ways by the mechanical process of the impact in that fragments are generally produced during the development of the rarefaction wave, which is the reflection of the shock wave on the target surface. For a given target size, relatively small fragments would be the products of a more complicated destruction as a result of multiple rarefaction waves in the targets (e.g., Fujiwara, 1980; Kadono and Arakawa, 2002). The multiple rarefaction waves in the targets would occur during catastrophic disruption. Therefore, it is necessary to investigate the relation between the degrees of destruction and the fine fragments.

(2) The shapes of very small fragments could be more dependent on petrographic characteristics than large fragment shapes. The size of the Itokawa particles is comparable to or less than the dimensions of petrographic textures and crystal grains, i.e. they are considerably smaller than the typical textural features of LL chondrites (e.g., a typical chondrule diameter is approximately 570 μm: Nelson and Rubin, 2002). It is necessary to investigate whether the petrographic textures and the crystal grain boundaries affect the shape of the Itokawa regolith particles because there might be a relationship between the two; for instance, Molaro et al. (2015) have shown that the grain distribution strongly influences the resulting size and shape of disaggregated material produced in thermal fatigue by the day-night temperature cycles on an asteroid.

In this study, most samples are fine fragments of basalt targets, obtained in previous laboratory impact experiments by Michikami et al. (2016). The shapes of these fine fragments, produced by impact events from cratering to catastrophic disruption, were systematically examined by SR-based microtomography. In order to investigate the relation between the petrographic textures and the shapes of fine fragments, the fine fragments in basalt targets were classified into three types: phenocryst-rich, groundmass-rich and intermediate. The shape distributions of each type were investigated. Moreover, two impacts into L5 chondrite targets were carried out for comparison. We used an L5 chondrite rather than LL5 or LL6 chondrites because it is difficult to obtain a large block of LL chondrites and the texture and mineralogy of these chondrites are not very different. Arguably, these represent better compositional analogues for the Itokawa regolith particles. The resulting shape distributions from basalt and L5 chondrite impacts are compared with that of the Itokawa particles. The research described here is intended to develop a deeper understanding of the formation of impact products and to constrain current interpretations of the origin of the Itokawa regolith particles.

2. Experimental method

2.1. Target properties

As mentioned above, we used basalt and L5 chondrite as target materials. Several samples of those target materials were reserved to investigate their petrographic textures and measure their