IMPACT EXPERIMENTS OF METAL CORE-ROCKY MANTLE TARGETS SIMULATING COLLISIONAL DISRUPTION OF IRON METEORITE PARENT BODIES. C. Okamoto[1], M. Arakawa[2] and S. Hasegawa[1], [1]Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-Sagamihara, Kanagawa 252-5210, Japan (okamoto.chisato@jaxa.jp), [2]Graduate School of Science, Kobe University, Japan.

Introduction: The collisional processes of differentiated parent bodies in the solar nebula play an important role to clarify the origin of iron meteorites and M-type asteroids. Meteorite parent bodies could have experienced the thermal evolution followed by pressure sintering, melting and gravitational differentiation of the constituent materials in the planetary accretion process. As a result, the interiors of these bodies could be separated into metal cores and silicate mantles. Chronological measurements by short-lived isotopic systems (e.g., ^{26}Al-^{60}Fe) for differentiated meteorites originated from metal core-silicate mantle bodies indicate that the differentiation process could occur at the early time in the solar nebula [1]. Thus, it could be possible that a lot of core-mantle bodies would spread over in the solar nebula during the planetary accretion process. In this process, the core-mantle bodies would be experienced the collisional fragmentation, which produced various types of meteorites such as basaltic meteorites and irons. Spacecraft missions and telescopic observations also clarified that the asteroids have the variety such as V-type and M-type. Thus, we should understand the collisional behavior of the core-mantle bodies to understand the origin of differentiated meteorites such as irons.

A lot of impact experiments and numerical simulations on homogenous materials (e.g., rock and ice) have been conducted to study the collisional fragmentation of asteroids: They showed the impact strength, the size distributions and the velocities of disrupted fragments [e.g., 2, 3]. Meanwhile, we have insufficient data to understand collisional phenomena of the core-mantle bodies although a small number of impact experiments and numerical simulations using core-mantle targets were conducted to study the effect of layered structure[e.g., 4, 5, 6].

In this work, we conducted impact experiments on metal core-rocky mantle targets simulating iron meteorite parent bodies in order to study the collisional disruption and the formation condition of differentiated meteorite such as irons. We investigated the impact strength, the destruction mode and the fragment velocities of the core-mantle targets with different core/target mass ratios.

Experimental Methods: We prepared metal core-rocky mantle targets as an analog of iron meteorite parent bodies. We used gypsum or mortar as the mantle material and a spherical steel as the core material. We also prepared the homogenous gypsum spheres, mortar spheres and steel sphere targets to compare the collisional outcomes with the core-mantle targets.

Gypsum and mortar have been used in impact experiments as an analog of asteroids and satellites. Steel could be a good analog of iron meteorites because the impact strength is similar to that of the iron meteorites [7]. The densities of gypsum, mortar and steel are 1200 kg/m^3, 1900 kg/m^3 and 7800 kg/m^3, respectively. Gypsum and mortar can be flexibly shaped from its slurry. They were cast into a spherical mould in which the steel sphere was set accurately at the center. The targets were then dried for a few days at room temperature, and they were removed from the moulds before the shots. We changed the target mass from 20 to 300 g in order to control the mean energy density, kinetic energy per unit target mass. We also controlled the ratio of core mass to total target mass (R_{CM}) that is a crucial parameter characterizing the internal structure of a core-mantle body. R_{CM} is from 0 to 1 by varying the sample mass and the core diameter. In the case that R_{CM} is 0 or 1, the targets are homogenous gypsum or mortar spheres for 0 or steel sphere targets for 1.

Impact experiments on the core-mantle targets and the homogenous targets were performed by using two-stage light-gas guns at Japan Aerospace Exploration Agency (JAXA) and Nagoya University. A head-on collision within 2 - 6 km/s was carried out between the nylon projectile whose density and mass were 1100 kg/m^3 and 200 mg and the target in vacuum at a pressure less than 10 Pa. The impact velocities (V_i) were determined by using a pair of laser beams perpendicular to the direction of impact. The collisional disruption was observed using a high-speed digital video camera at 1×10^4-1×10^5 frames per second (Fig. 1).

Results and discussion: The largest fragment mass normalized by the original target mass (m_l/M_t) is frequently used to show the degree of impact disruption [2]. The m_l/M_t of homogenous targets (gypsum, mortar and steel) depended on the mean energy density: the m_l/M_t simply decreased with the increase of the mean energy density. The impact strength is defined as the mean energy density at a half of the initial target mass [2]. The impact strength of our homogenous gypsum, mortar and steel spheres were 2.1x10^3 J/kg, 1.8x10^3 J/kg and 7.0x10^4 J/kg, respectively. The impact strength of our steel spheres showed a good agreement with the previous data of cooled iron meteorite [7]. This indicates the steel is suitable to simulate an iron meteorite. We also examined the largest fragment masses of our metal core-mortar (or gypsum) mantle targets to clarify the effect of the internal structure. The largest fragments were almost metal cores, irrespective of the degree of core destruction. The degree strongly depended not only on the mean energy density but also on internal structure (R_{CM}) even at the same mean energy density. The metal core destruction appeared at high R_{CM} whereas the core intact occurred at lower R_{CM} range at a similar mean energy density. The mean energy density needed to disrupt the core was also larger than that of a bare metal sphere: This shows that the effective energy density given to the core is reduced by the absorption of the impact energy in the mantle. The core was disrupted when the energy given into the core in the target exceeded the threshold of impact energy required for the disruption of a bare metal target (~$4x10^4$ J/kg).

The fragment velocity at the antipode of the impact point (V_a) has frequently been studied as a representative fragment velocity of the disrupted target. We measured the V_a of the homogenous targets and the core-mantle targets using high-speed photography to investigate the effect of the core-mantle structure. We can describe the relation between the V_a and mean energy density (Q_t) by the following empirical equation by least-square fits;

$$V_a = aQ_t^b \quad (1)$$

where a and b are constants which depend on materials. The V_a of homogenous targets simply increased with an increase in the mean energy density. The power law index (b) of Eq. (1) was approximately 0.9, irrespective of materials. The V_a of mortar is ~ two times faster than gypsum. The V_a of steel is several times slower than that of mortar. For example, the V_a of steel is ~20 m/s whereas that of mortar was ~80 m/s at $7.0x10^4$ J/kg. Meanwhile, the antipodal velocity of core-mantle targets obviously depended on the internal structure (Fig. 2). The V_a increased with an increase of R_{CM} (>0.3) even at the similar mean energy density whereas the V_a of metal core-mortar (or gypsum) mantle targets with low R_{CM} (<0.3) were similar to the data of homogenous mortar (or gypsum) sphere at the constant mean energy density. This indicates that the impact energy partitioned into the mantle could be enhanced with the mantle mass reduction by the increase of the core mass. The energy fraction applied to the core and the mantle is controlled by R_{CM} [6]. We estimated the energy density partitioned into the mantle (Q_m) using the energy fraction. As a result, the V_a increased with the Q_m. Therefore, the internal structure is a crucial parameter to control the collisional outcomes of the core-mantle bodies.

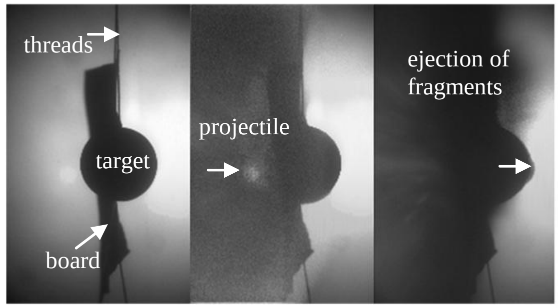

Fig. 1 The observation of impact fragmentation by high-speed photography. The target was suspended by threads in a target chamber. A board for protection from fine fragments near the impact site is set to be able to observe the phenomena during a long time. The left is the core-mantle target before impact. The center shows the moment of a head-on collision between the projectile and the target. We can observe that fragments are ejected toward the right.

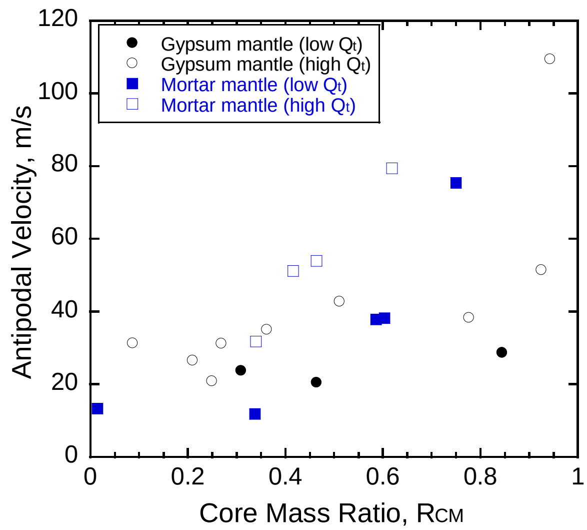

Fig. 2 The relationship between antipodal velocities and core mass ratios of core- mantle targets. The circle and square are a metal core-gypsum mantle target and a metal core-mortar mantle target, respectively. The opened symbol shows the mean energy density (Q_t) is a high value ($5 x10^4$ -$2 x10^5$J/kg). The closed symbol shows the Q_t is a low value ($1 x10^4$ -$5 x10^4$J/kg).

References: [1] Bizzarro et al., (2005) *Astrophysical Journal*, *632*, L41–L44. [2] Fujiwara and Tsukamoto (1980) *Icarus*,*44*, 142–153. [3] Asphaug et al. (1998) *Nature*, *393*, 437–440. [4]Benz et al. (1988) *Icarus*,*74*, 516–528. [5]Watts et al. (1991) *Icarus 93*, 159–168. [6]Okamoto and Arakawa (2008) *Icarus*,*197*, 627–637. [7] Holsapple et al. (2002) in *Asteroids III* (Univ. of Arizona Press, Tucson), pp. 443–462.