MOMENTUM TRANSFER DURING IMPACTS INTO ROCKY RUBBLE-PILE ASTEROIDS.

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Introduction: We are studying the efficiency of momentum transfer for hypervelocity collisions into asteroids for a wide range of impact conditions and for a variety of geological materials that comprise the target body. Although the primary application of this work is deflection of potentially hazardous objects, it also provides useful insights into the collisional history of small solar system bodies. We have previously reported on experiments involving competent rock, dry sand and highly porous pumice targets (1-4).

During a hypervelocity collision, the momentum delivered to the target body is the sum of the projectile normal momentum and that due to the surface material ejected at speeds above the body's escape speed. Therefore, the delivered momentum depends on the mass and speed of the ejected material, which in turn depend on the properties (density, cohesion, porosity, etc) of the surface material. Our experiments have shown that, relative to a dry sand, a solid rock target has a relatively high momentum transfer efficiency, because impacts in rock eject material at much higher speeds than in sand. On the other hand, impacts into highly porous materials have very poor transfer efficiencies because of the low mass and speed of the ejected material. In the present study we consider impacts into particulate targets that simulate rubble pile objects, such as asteroid Itokawa (Figure 1). Specifically, the objective of the present experiments is to determine how the size of the impactor relative to the size of the rubble pile constituent "particles" affects the momentum transfer.

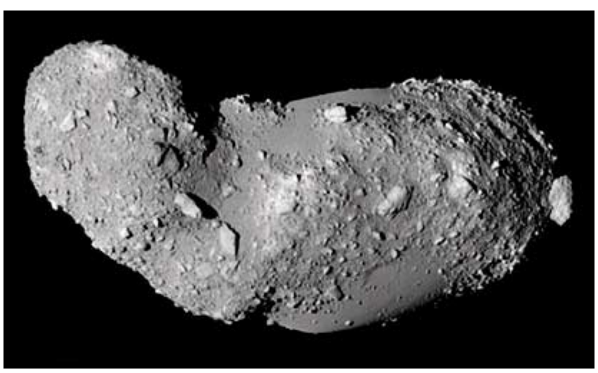

Fig 1. Asteroid Itokawa

Experiments: The impact experiments were conducted *in vacuo* at the NASA Ames Vertical Gun Range. The impactor was a 6.35-mm diameter aluminum sphere which struck the target surface at normal incidence at speeds in the range of 5.35±0.20 km/s. Target materials were dry sand, and three types of angular gravel obtained from a local landscape supplier. Although we have not yet measured size distributions of the materials, the maximum particle size for the sand was 0.2mm. The three gravels had maximum sizes of approximately 5mm, 15mm and 55mm. Figure 2 shows samples of the three gravels along with the aluminum projectile for scale. The ratio of projectile diameter to maximum particle diameter ranged from about 30 for sand down to 0.12 for the coarsest gravel.

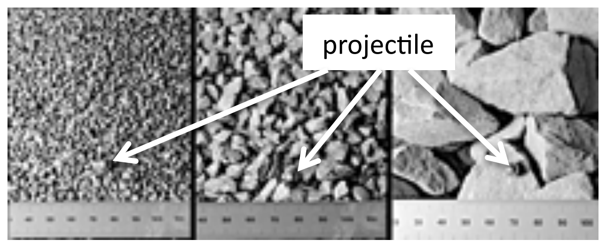

Fig 2. The three gravels used in the present experiments.

An experiment was also performed in a roughly 50/50 mix of the fine (5mm) gravel and the coarse (55mm) gravel. As in our previous experiments, the target material was contained in a steel bowl 38.5 cm in diameter and 15 cm deep. The bowl rested on an aluminum plate that was suspended from four springs mounted to a sturdy support frame. Figure 3 shows the target bowl filled with this mixture.

Fig 3. Mixture of fine and coarse gravel.

After impact, the target oscillated vertically. The oscillations were recorded with a Keyence LK-H152 laser displacement sensor connected to a digital oscilloscope. The impulse, I, delivered to the target was determined from $I=H\omega M/2$, where H and ω are the amplitude and frequency of the oscillation, and M is the target mass.

The momentum transfer efficiency, β is defined as $\beta = I/mU$, where m and U are the impactor mass and speed respectively. Note that if there is no contribution from the ejecta (a perfectly plastic collision), $\beta=1$.

Results: Figure 4 shows the results of the present experiments along with those from our earlier tests. The dry quartz sand baseline is shown by the orange data points and curve. As noted above, targets composed of solid rock (blue points and curve) exhibit much larger values of β than sand due to high ejecta velocities in rock. The results for the gravel targets fall between those for sand and for solid rock, although one might have expected that the large disparity between projectile and grains size could have had a large effect.

It is interesting that β for the 5mm gravel is quite close to that for the much finer sand. Therefore, an impact into a rubble pile whose rubble is comparible in size to the impactor (or smaller) will exhibit about the same momentum transfer as a body made of very fine grained material, all else being equal.

Surprisingly, the two coarser gravels (15mm and 55mm) produced β values only about 25% larger than for sand. Hence β is fairly insensitive to the size of the rubble pile constituents, even when the rubble is nearly an order of magnitude larger than the impactor. It may have been that the macroscopic properties such as the angle of repose accounts for the differences, but that is not yet tested.

One might expect that the results for very coarse materials would depend on whether the impactor struck directly on a large fragment, or in a hole between fragments. Unfortunately, the exact point of impact on the target was difficult to predict, or even observe due to the impact flash. However, a second experiment into the coarsest gravel produced nearly the same value of β as the first test in that material. That suggests an invariance to the exact impact location. Additional experiments in the coarse material will be performed to further assess the scatter due to the impact location.

Interestingly, the experiment with the target made from a 50/50 mix of the fine and coarse gravel produced a β value that was higher than for either solitary gravel type or sand. We are unsure at this time if this is due to scatter depending on the impact location with respect to the large fragments. Alternatively, the fact that β is larger than for the 5mm gravel may be due to enhanced coupling of the projectile energy by striking a large fragment. Furthermore, β could be larger than for the large gravel alone because of the added mass of the fine gravel that fills the interstices of the coarse gravel. These possibilities will be explored in future experiments.

We currently have only a handful of experiments in gravel targets. However, the results suggest that the momentum transferred to an object, such as Itokawa, will be fairly insensitive to whether the impact occurs in a patch of very coarse or very fine material, or on a rock or on a smooth surface.

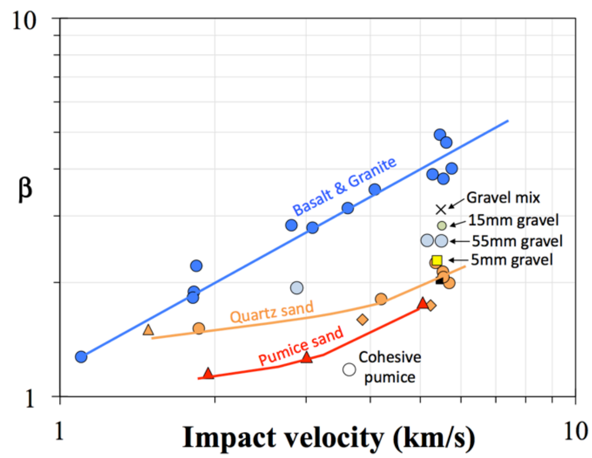

Fig 4. Measurements of β from previous experiments and from the current experiments in gravel targets.

References:

[1] Housen K.R. and Holsapple (2011) LPSC 42nd, Abstract 2363.

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[4] K.A. Holsapple and K.R. Housen (2012) Icarus 221, 875-887.

Acknowledgement: This research was supported by grants from the NASA NEOO Program under the direction of Mr. Lindley Johnson.