COEFFICIENT OF RESTITUTION / LEEB REBOUND HARDNESS FOR SIX METEORITES AND HCCL-1 SIMULANT.
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Introduction: The coefficients of restitution (CoR) of asteroid lithologies are germane for asteroid geology and asteroid formation and evolution. For example, they will influence reaccumulation behavior of coalescing clasts after disruption events [e.g., 1], and landing/bouncing characteristics of impact ejecta. CoR are also becoming of increasing interest as efforts are made to land and hop spacecraft (and other hardware) on small body surfaces [e.g., 2, 3, 4]. We have begun measuring CoR on a range of asteroidal meteorite lithologies.

Methodology: A variety of techniques exist to measure CoR. One is the Leeb Hardness test (Leeb Hardness Number = Rebound Velocity/Impact Velocity X 1000) which can be performed with a relatively simple handheld tool. We generally followed the procedures outlined in [5]. The small size of the chosen equipment allows measurement of comparatively small samples (with caveats as noted below), and is relatively nondestructive although small indentations are left in the measured surface. The equipment is easily accommodated in a laminar flow bench.

This dynamic test device consists of a housed travelling rod tipped with a spherically shaped hard metal ball indenter striking a surface with known velocity followed by rapid measurement of its recoil velocity. Different orientations are possible with some tools, but all our measurements were vertical down onto horizontal surfaces. Multiplying the ratio of the two velocities by 1,000 results in the quantity known as the Leeb Hardness (or HL; the device used was an Equotip Piccolo 2 in the device D category so that the industry standard refers to these measurements as data designation HLD). Calibration of the tool measurements is maintained by repeated measurement of a standard disk of metal supplied with the tool.

Our meteorite test conditions weren't always ideal because of sample size limitations. This test being of the rebound type depends upon the elastic as well as plastic properties of the sample. The length of time for tool interaction requires samples of a certain size to avoid interference from boundary effects/reflected seismic waves. The minimum sample mass required is ~2 kg and minimum sample thickness is 3 mm [5]. Some of the meteorite samples measured, particularly small slabs, were only tens of grams in mass; an option exists to couple thin slabs to underlying masses, but this wasn't done to avoid contamination – instead clamping was done where practicable to aid coupling. However, measurements for the smaller samples are likely still compromised to some extent. The tool needs a planar surface; some meteorite slab surfaces were polished, but some were unpolished sawn surfaces. Measurements need to avoid edges of samples and our experience is that internal cracks should also be avoided. Measurements were made at room temperature conforming to specified practice [5]. All data reported below represent sequences of ten individual measurements with repeat sequences by two different operators in some cases.

Results: Figure 1 shows results for six meteorite examples (three ordinary chondrites (EH4, L6 & H4); two irons IIIAB & unclassified iron); one carbonaceous chondrite (CM2)) and one Hydrated Carbonaceous Chondrite Lithology (HCCL-1 [6]) simulant. The CoR values range from ~0.7 to 0.4 for these lithologies and may be nonintuitive; CoR for ordinary chondrites and carbonaceous chondrite are higher than for iron meteorites. The measurement by

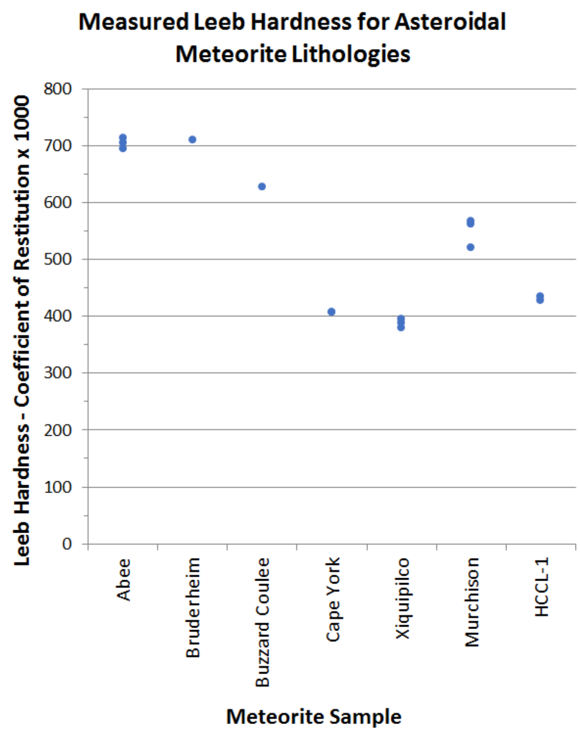

Figure 1: Blue dots represent Leeb Hardness (HLD) equivalent to CoR X 1,000 for six meteorites and one carbonaceous chondrite simulant. Some samples were measured more than once.

this tool reflects a combination of samples' elastic properties plus its plasticity; the iron meteorites are more plastic than the silicates so the tool rebounds less after making a larger indentation. Murchison, a carbonaceous chondrite showed larger indentations than the iron meteorites but a higher CoR as well. In contrast the HCCL-1 simulant showed the largest indentations of ~1 mm diameter (See Figure 2).

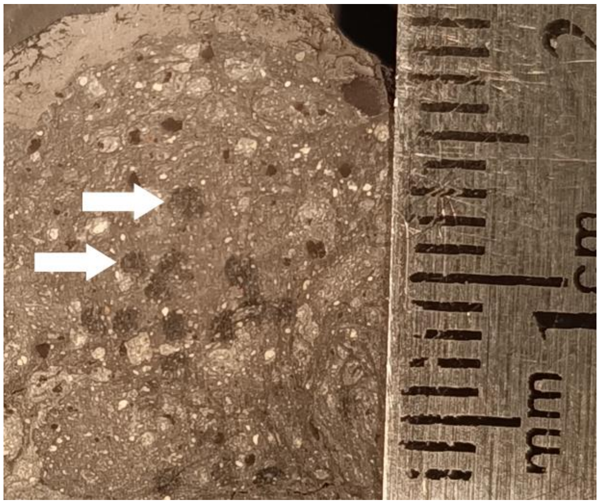

Figure 2: Image of an HCCL-1 simulant slab showing indentations from the Equotip Piccolo tool used to measure CoR. The simulant is a softer lithology than any of the meteorites tested resulting in indentations approximately three times greater diameter than those formed in the Murchison meteorite.

To avoid potential effects from absorbed atmospheric water (in phyllosilicate-bearing lithologies) both the simulant and the Murchison specimen were measured after storage overnight in vacuum (as well as before vacuum exposure). No significant difference was found for the simulant, but Murchison's CoR was found to increase from ~0.35 to ~0.55; the pre vacuum exposure data may have been compromised by a large crack in the Murchison slab near the measuring sites but we will further test carbonaceous chondrite lithologies for possible atmospheric water perturbation.

The measurement technique is close to nondestructive and can potentially be generally performed on meteorite slabs (or any flat surface on an otherwise irregular meteorite individual) in collections, but does leave indentations (diameter depending upon specimens' plasticity) on the slab surface. Relatively smooth planar surfaces are also required.

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