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Uniaxial stress/strain of meteorites

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Abstract

We have begun a project of measuring the stress vs strain relationship and fracture strength of an assortment of meteorites. This information will be valuable in modeling the response of asteroidal surfaces to cratering, accretion, and disruption events, and the interpretation of meteors and bolides. It could also provide insights into the nature of meteorite lithification.

1. Introduction

The mechanical properties of meteorites are an important but essentially unstudied parameter in understanding the physical state and evolution of asteroids and other small solar system bodies. The bulk modulus (which is directly related to the sound speed), thermal expansion coefficient, and the cohesive strength of the target material are essential parameters in modelling impact cratering. Likewise, the fracture strength of such material is important in interpreting the light curves of meteors and the break-up of bolides. Knowing how asteroidal material behaves under different conditions of stress is important in modelling both how asteroids accrete, and how they behave during catastrophic collisions.

Most models to date have assumed that asteroidal material has mechanical properties similar to typical terrestrial materials. Compressive measurements have been reported for a few meteorites, including the L5 Tsarev [1] and the L5 desert meteorites Sayh al Uhaymir 001 and Ghubara [2]. The authors of the latter study concluded that “there are no analogues among terrestrial igneous and sedimentary rocks and ores [for the] physical and mechanical properties of the meteorites.”

Measuring these properties involves applying stress to a sample of the material and observing its effects (strain). Stress is the object’s internal ability, due to intermolecular/atomic and lattice forces, to resist external force. *Strain* is relative change in dimension (length) of shape of a body subjected to stress.

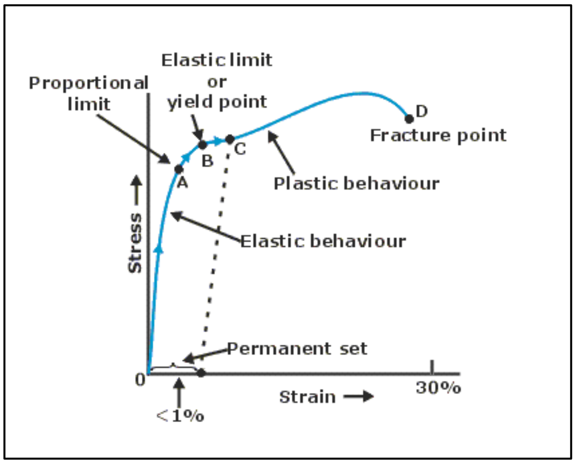

Figure 1: Generic stress vs strain diagram

A material is said to be elastic if it is able to return to its original shape or size immediately after being stretched (tensile stress) or squeezed (compressive stress). Almost all materials are elastic and thus obey Hooke’s law to some degree as long as the applied load does not cause it to deform permanently. The flexibility (stiffness) of any material depends on its elastic modulus and geometric shape of the sample.

The Young’s modulus (elasticity) for a material is basically the slope of its stress/strain plot within the elastic range prior to deformation and failure. If the material is loaded to any value of stress in this part of the curve, it will return to its original shape. Stressing the sample beyond this point, the material eventually enters the deformation region where applied stress permanently deforms the sample. Beyond that point, continued application of stress ultimately moves the material to its fracture point, where all its mechanical properties fail and the sample breaks.

2. Technique

Small uniform meteorite samples of known length and cross sectional area are held at room temperature in compressive (or tensile) stress created by turning a large right-handed screw up or down at the top of the probe. The force developed in the screw is measured with a force monitor gauge (Omega stainless steel beam load cell); a constant input voltage (10-15 Vdc) activates the piezo-electric transducer in the load cell. A differential voltage measurement is monitored by an Agilent 43310A DMM, and the load cell (dc voltage to force conversion) was calibrated to within ≤ 1% error using known masses. As force is applied to the meteorite, the strain developed in the material is monitored by a strain gage attached to the side of the meteorite with strain gage adhesive, monitored by a LakeShore 370 AC resistance bridge.

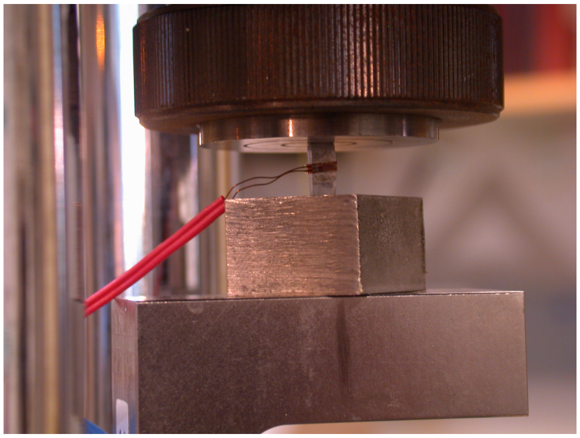

Figure 2: Experimental setup.

3. Initial results

Our first results are illustrated in Figure 3. The L6 chondrite Holbrook has the cleaner data, but was not stressed to the point of failure. The slope of this line (Young's modulus) is 48 GPa. The H6 chondrite La Cienega shows a stress vs. strain curve that parallels that of Holbrook, but the scatter at lower pressures leads to a slightly steeper slope of 67.5 GPa when fitting all the data (except the failure point). La Cienega reached compressive failure at 250 MPa.

The values found here are higher than those in [1] and [2], who measured a Young's Modulus of 17.1 GPa for Sayh al Uhaymir 001 and compressive failure at 97 and 77 MPa for Sayh al Uhaymir 001 and Ghubara respectively. Their measurements were on significantly larger samples, several cm in each dimension, compared to the mm dimensions of the samples measured here. Previous work [1] has also shown that larger samples break more easily (a 1 cm sample of Tsarev broke at 46 MPa while a 10 cm sample broke at 26 MPa). But they found that Young's modulus increased with sample size, counter to the trend of our results vs. those in [2].

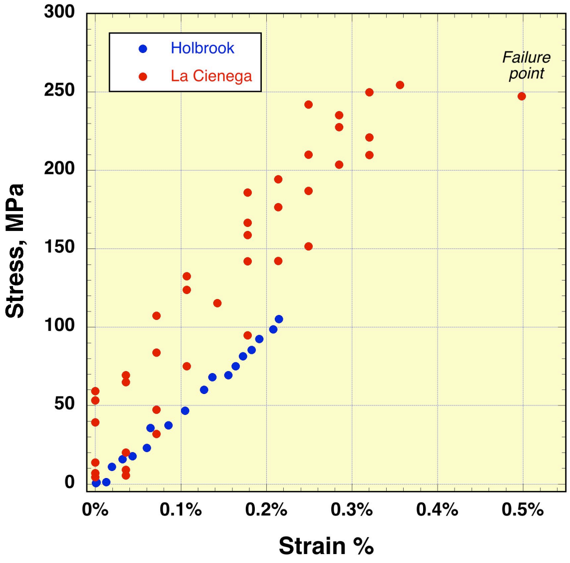

Figure 3: Stress vs strain under compression, Holbrook (L6) and La Cienega (H6).

With the collection of more data we hope to determine if this variation results from differences in the sizes of the fragments measured or if it reflects physical differences from meteorite to meteorite, and if a relationship can be made between these values and the density, porosity, or other physical parameters of the meteorite. In addition, future work will address how these values vary with temperature especially at temperatures applicable to the asteroid belt and the outer solar system.

Acknowledgements

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References

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