DYNAMIC STRENGTH MEASUREMENTS OF L5 CHONDRITE MACALPINE HILLS 88118.

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Introduction: Limited data on the compressive strength of meteorites exist in the literature. Previous researchers have performed laboratory measurements on stony meteorites [1, 2, 3, 4, 5, 6, 7], as well as iron meteorites [8, 9]. These studies were mostly designed to determine the strength of meteorites with regard to understanding the breakup of meteors entering the Earth's atmosphere. The process of traversing the Earth's atmosphere takes place on the time scale of seconds, and the strength under low rate (quasistatic) loading conditions is expected to control the failure process. Thus the laboratory measurements performed were conducted at quasistatic loading rates. The only measurements performed at high strain rates to date were performed on specimens of an iron meteorite [9].

For applications where the loading conditions are more dynamic (e.g. impact cratering), the quasistatic strength may not provide an accurate description of material response. Terrestrial rock specimens often exhibit an increased strength when compressed at strain rates higher than 10^2 s^{-1} [10, 11, 12, 13]. Stony meteorites are expected to exhibit similar rate dependence, but no measurements exist. To begin to fill this gap in data we have chosen to investigate the compressive strength of the meteorite MacAlpine Hills 88118 (MAC 88118) at strain rates ranging from 10^{-3} to 10^3 s^{-1}.

Experimental Method: MAC 88118 has been characterized as a L5 chondrite with microstructural features consistent with a shock state S1. Cube shaped specimens with edge lengths of approximately 5mm were cut from larger slabs of the meteorite specimen. Specimens were compressed in the direction normal to the surface of the parent plate to isolate any effects of specimen anisotropy [6]. Loading faces of the specimen were polished to ensure that the faces were parallel to within 5 μm across the specimen.

The quasistatic compression experiments were conducted using a MTS servohydraulic uniaxial testing machine, while the dynamic compression experiments were conducted using a Kolsky (split-Hopkinson) bar [10, 14] as shown in **Fig. 1**. In all of the experiments the specimens were loaded until material failure. For all experiments images were recorded in real time to capture the evolution of failure in the specimen.

Experimental Results: The stress-strain response of a specimen subjected to quasistatic compression (strain rate 10^{-3} s^{-1}) is shown in **Fig. 2**. Here the specimen stress was calculated from the recorded load data, and the specimen cross sectional area. The strain was measured with an electrical resistance strain gage bonded to the surface of the specimen. For strains below 0.01, the stress–strain curve follows a linear trend. The slope of this portion of the data corresponds to the Young's modulus, *E*, of the meteorite which is determined to be 3.2 GPa. For strains greater than 0.01 we observe a large increase in stress without a corresponding increase in strain. We interpret this as a failure of the strain gage. Here we see that the specimen stress increases to a peak value of 50 MPa before dropping off to zero. This peak corresponds to the quasistatic compressive strength of the meteorite.

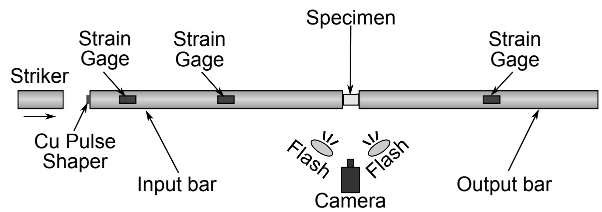

Fig. 1. Experimental configuration of the Kolsky bar used in the dynamic compression experiments.

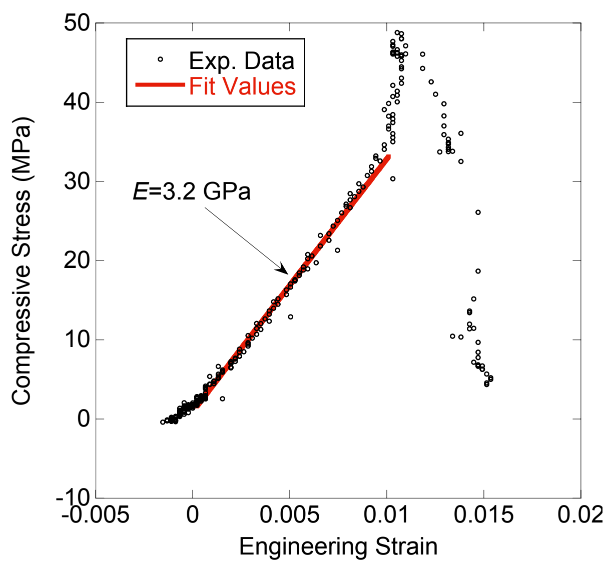

Fig. 2. Stress–strain response of a specimen compressed to failure at a strain rate of 10^{-3} s^{-1}.

Similar experiments were conducted at high strain rates using the Kolsky bar. The stress–strain response of a specimen compressed at a strain rate of 500 s^{-1} is presented in **Fig. 3**. Here the specimen stress and strain were determined using the methods of Kolsky bar analysis for brittle materials [10]. The slope of the linear region before the peak stress corresponds to a Young's modulus of 8.5 GPa. Thus a significant increase (2.6x) in elastic modulus is observed when the compressive strain rate is increased from 10^{-3} to $5x10^{2}$ s^{-1}.

A similar increase in failure strength was also observed; the peak stress measured for the specimen compressed at 500 s^{-1} was 161 MPa. Multiple experiments were performed in the range of strain rates from 10^{-3} to 10^{3} s^{-1} and the resulting values of compressive strength are presented as a function of applied strain rate in **Fig. 4**. For strain rates less than 10^{-1} s^{-1} there is a slight increase in strength with increasing rate. For rates greater than 10^{2} s^{-1} there is a very steep increase in compressive strength with increasing rate. Similar trends have been observed in terrestrial rocks in which there exists a transition strain rate, above which significant increases in strength are observed with increasing rate [13]. One interesting observation is that these meteorite specimens show nearly a four-fold increase in strength whereas most terrestrial rock specimens typically show a factor-of-two increase in strength across a similar range of strain rates [10, 11, 12]. This may indicate that the transition rate in meteorite specimens is an order of magnitude lower than is typically observed in Earth rocks.

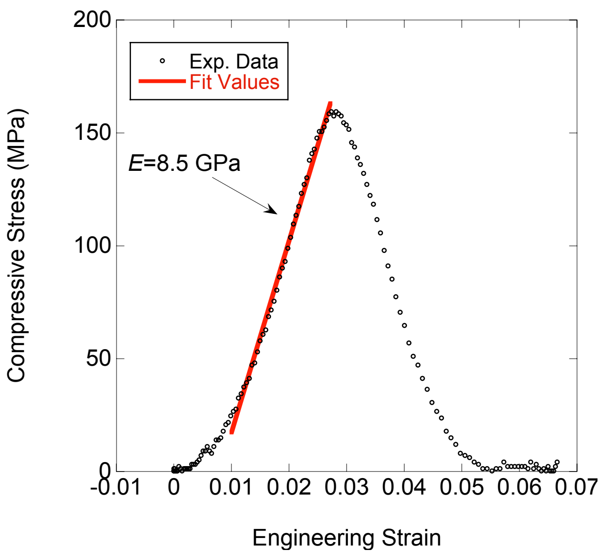

Fig. 3. Stress–strain response of a specimen compressed to failure at a strain rate of 500 s^{-1}.

We have performed the first high-rate compression experiments on material recovered from a stony meteorite. In addition to adding to the existing data sets for quasistatic compression strength of meteorite materials the results show that significant changes occur in both the elastic modulus and failure strength when specimens are compressed at higher strain rates. These rate effects may play an important role in determining the outcome of processes related to impact events, especially disruption of/impact cratering on asteroidal bodies.

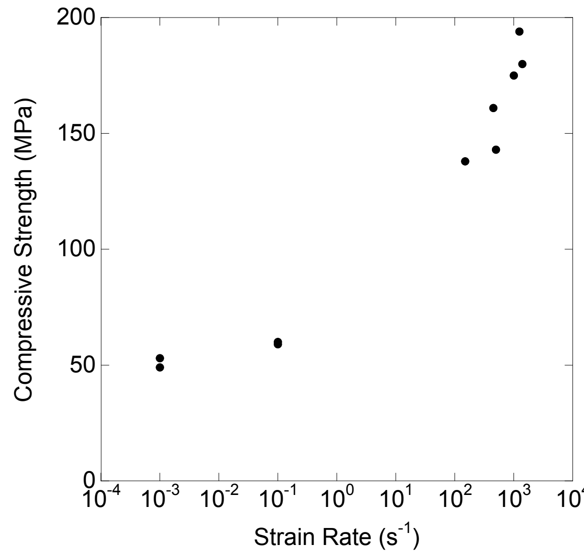

Fig. 4. Rate dependence of compressive strength for samples of MAC 88118. The gap in data from 10^{0} to 10^{1} s^{-1} is due to limitations of the testing equipment.

References:

[1] Buddhue, J. D. (1942) *Pop. Astron.,* 50: 390-391.
[2] Baldwin, B. & Sheaffer, Y. (1971) *J. Geophys. Res.,* 76: 4653-4668.
[3] Svetsov, V. V. et al. *Icarus,* 116: 131-153.
[4] Flynn, G. (2004) *Earth, Moon, and Planets,* 95: 361-374.
[5] Miura, Y. N. et al. (2008) *Proc. Japan Geoscience Union Meeting,* Abstract #P168-P002.
[6] Nikitin, S. M. et al. (2009) *LPS XL*, Abstract #1051.
[7] Tsuchiyama, A. et al. (2009) *MAPS Supplement* 72: 5189.
[8] Gordon, R. B. (1970) *JGR* 75: 439-447.
[9] Furnish, M. et al. (1995) *Int. J. Impact Engr.* 17: 341-352.
[10] Frew, D. J. et al. (2001) *Experimental Mechanics* 41: 40--46.
[11] Lindholm, U. S. et al. (1974) *Int. J. of Rock Mech. and Mining Sci. & Geomech. Abstr.* 11: 181-191.
[12] Green, S. J. & Perkins, R. D. (1969) *NIST Technical Report:* 1-44.
[13] Kimberley, J. & Ramesh, K.T. (2010) *LPS XLI.*
[14] Kolsky, H. (1949) *Proc. Physical Soc.. Sect. B* 62: 676-700.