MECHANICAL AND ELASTIC PROPERTIES OF CHONDRITE LITHOLOGIES. F. Ciceri[1], A. R. Hildebrand[1], L. T. J. Hanton[1], [1]University of Calgary, Calgary, AB, Canada T2N 1N4 (fabio.ciceri@ucalgary.ca)

Introduction: The extent of knowledge of mechanical and elastic properties of meteorites is very limited compared to those of terrestrial lithologies. This is mostly due to material availability and the challenges that come with working with very small samples. However understanding the mechanical and elastic properties of asteroids is becoming of greater practical importance. As more spacecraft interact with asteroids (e.g. OSIRIS-REx, Hayabusa 2, DART), material properties (at all scales) are becoming more useful in understanding the geological evolution of asteroids and planning future missions. While missions like Haybusa 2 and OSIRIS-REx are allowing us to do direct measurements on asteroid material, meteorites still represent the biggest collection of rocky bodies of the Solar System. The current knowledge on mechanical and elastic properties of meteorites is vague and sparse. As well described in [1], it is difficult to cross-reference data since methodologies and properties definitions are not always well described. Also, some previous studies did not always conform to technical standards (e.g. ASTM).

Objective: The main goal of this study is to measure mechanical (Ultimate Compressive Strength, Direct Shear Strength) and elastic (Young's Modulus, Proportional Limit) properties of meteorites. For this study we decided to measure only falls since they provide more information on terrestrial weathering time and curation conditions increasing our level of data confident. We also conformed with ASTM (American Society for Testing Materials) standards since these technical standards are derived from a long and in depth experience of material testing.

Methods: The measurements were performed following ASTM procedures [2] and [3]. The meteorites were cut into regular cuboids with a minimum 2:1 (length/width ratio) [2] for compression and into regular cubes (5x5 mm, 2.5x2.5 mm and 10x10 mm) for direct shear using guillotine-style fixtures; a diamond wire saw was use to dry-cut the samples. A Test Resources (Model 313Q) electromechanical press was used to measure the compressive and the shear strength. The displacement (Strain) was measured with an Epsilon 3542 extensometer. Samples were outgassed overnight in vacuum (to reduce potential effects from absorbed water) before testing at ambient conditions. From the strain and the stress curve we calculated the Static Young Modulus and the Proportional Limit (using method 2 in [2]).

Shear Strength: We measured the Direct Shear Strength (τ) of Moss (CO3), Golden (L,LL5), Murchison (CM2) and Buzzard Coulee (H4). Buzzard Coulee samples have shown the biggest range among the others, ranging from 35.8 MPa to 59.7 MPa; this likely reflect variations in the rock since the sample cube sizes were the same (10x10 mm). Also interestingly, Murchison shows some similar values to the lower values of Buzzard Coulee, but a significantly smaller range from 29.4 to 34.8 MPa. Golden and Moss share almost the same average value, but the latter has a smaller range from 8.3 to 10.7 MPa while the former a bigger one between 6.4 to 18.4 MPa. Both Golden and Moss are significantly weaker in shear then Murchison and Buzzard Coulee.

Compressive Strength, Young Modulus and Proportional Limit: We measured the Ultimate Compressive Strength ($\sigma_{ultimate}$), the Young's Modulus (E) and the Proportional Limit (σ_p) (limit of proportionality between stress and strain, approximately the Elastic Limit) of samples of Murchison, Buzzard Coulee and Golden. Young's Modulus correlates well with the Ultimate Strength as expected (Figure 1). Buzzard Coulee shows the highest values for both $\sigma_{ultimate}$ and E. Interestingly, while the shear strengths values for Murchison and Buzzard Coulee are partially shared, for compressive strengths they significantly differ. Murchison show a big range of ultimate compressive strengths from 34.0 to 121.4 MPa, but the absolute values are significantly lower than Buzzard Coulee (that ranges from 162.5 to 227.5 MPa. Golden is among the weakest compressive strengths for the surveyed meteorites in this study.

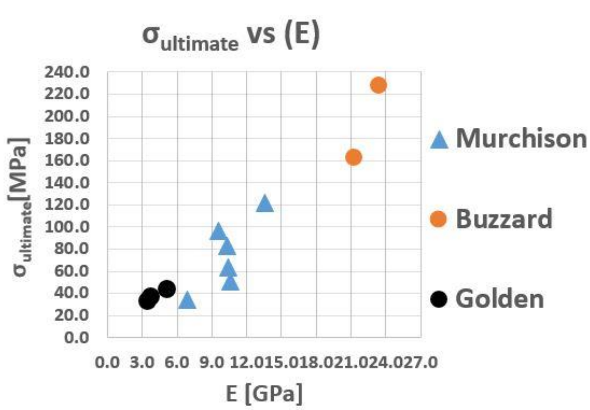

Figure 1: Static Young's modulus vs Ultimate Strength values for Murchison (CM), Buzzard Coulee (H4) and Golden (L,LL) meteorites.

The Proportional Limits are determined from the strain and stress curves [2]. Figure 2 plots the ratio between the Ultimate Strength and the Proportional Limit; the ratio is helpful in understanding deformation styles and in dividing meteorite types into different mechanical behavior classes; this likely partially reflect the mechanical behavior on their parent bodies.

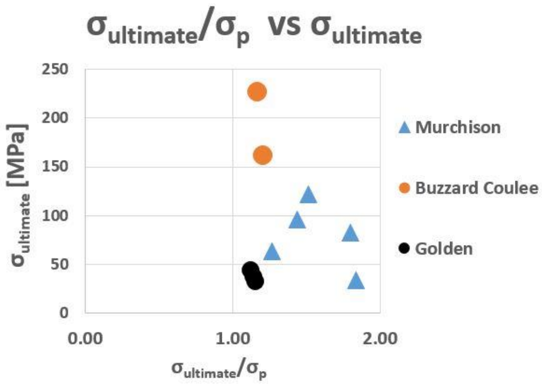

Figure 2: Ultimate Strength plotted vs. the ratio between Ultimate Strength and Proportional Limit.

The Ordinary Chondrites, Buzzard Coulee and Golden, show a ratio closer to 1, indicating a relatively brittle behavior while Murchison is significantly distinct showing higher ratios therefore a more ductile behavior; further investigations are needed to understand how much structural vs mineralogy differences would be responsible for the differences in the mechanical behaviors.

Future Studies: We are currently proceeding to measure mechanical properties of Tagish Lake (C2-Ungrouped) , Aguas Zarcas (CM) and Abee (EH4). Adding different meteorite lithologies will provide wider context to assessing differences of mechanical behavior among the chondrite lithologies/asteroid classes.

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References: [1] Pohl and Britt (2020) *Meteoritics & Planet. Sci.*, *55*, Nr 4, 692-987. [2] ASTM International D7012-04 (2004). [3] ASTM International D5607-16 (2016).