THE MECHANICAL ATTRIBUTES CHARACTERIZATION (MAC) INSTRUMENT: LINKING ROCK PROPERTIES TO IN-SITU DRILL DATA. T. E. Caswell1, G. H. Peters2, E. M. Carey2, L. R. Shiraihi2, R. E. Milliken1, K. M. Brown2, L. Panossian1, 1Brown University, Providence, RI (tess_caswell@brown.edu), 2Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, 3Cal Poly Pomona, Pomona, California, 91768.

**Introduction:** The coring drill on Mars 2020 has the potential to acquire more than cores. The drill separates rock cores from the bottom of the bore hole by shearing the core at its base; in effect, the drilling operation includes a shear strength test on the rock in question. By carrying out appropriate experiments on the ground – namely, correlating rock properties to drill data through analog tests conducted with the 2020 engineering testbed – data obtained from in-flight drilling can be used to determine the physical properties of rocks on Mars.

Such properties can be used to estimate the degree of lithification of the rock or the conditions under which rocks may have been deformed. For example, *Caswell and Milliken* (2015) estimated the tensile strength and cohesion of rocks at Yellowknife Bay, Gale Crater, to constrain the burial depth of lacustrine mudstones explored by *Curiosity* [1]. That study, however, was limited by the lack of easily quantifiable rock properties based on rover drill data/parameters.

The Mars 2020 drill’s capability to perform shear strength tests provides a unique opportunity to fill in such gaps in our knowledge. Fully utilizing in-flight drill data, however, requires characterizing the link between drill performance and rock strength. We are thus conducting rock mechanics experiments on cores obtained using the Mars 2020 engineering testbed. By measuring the physical properties of rocks drilled by the testbed, we link these properties to drill performance data such as power and rate of penetration. Armed with these correlations, drilling on Mars becomes a science instrument for Mechanical Attributes Characterization (MAC).

**Methods:** Sample preparation. Samples for mechanical testing are obtained from both manufactured rocks (which allows us to constrain their properties) and natural rock, including tuff, basalt, sandstone, and gypsum. The samples tested span a range of structural components and cohesion appropriate for the variety of rocks likely to be encountered on Mars.

Samples for Unconfined Compressive Strength (UCS) measurements are cut into cubes by two methods: diamond-bladed wet-saws for crystalline, glassy and well-cemented sedimentary rocks, and dry-cutting methods using reciprocating saws and a band saw for weaker mudstones and pyroclastic rocks. Other tests, such as tensile strength and direct shear, are carried out on sections of cores cut with the 2020 engineering testbed. In these cases, drilling data can later be directly correlated to the measured rock properties.

**Rock strength experiments.** A pair of tests are planned for each rock type: Unconfined Compressive Strength (UCS) and tensile strength (“tensile tests”). UCS experiments are carried out in a Gilson hydraulic press in the Extraterrestrial Materials Simulation Laboratory (EMSil) at JPL. Cubic samples are deformed in compression (see Fig. 1a) until failure. Load is recorded throughout the test, allowing UCS to be calculated from the maximum prior to failure.

![Figure 1: Fixture configurations for (a) UCS, and (b) Brazil tests.](image)

Brazil-type tensile tests (“Brazil tests”) measure the tensile strength of a rock through diametral line compression (Fig. 1b) [2,3]. Samples are cut from the cores into disks with thickness/diameter of $\frac{1}{2}$ [2]. As in UCS tests, the sample is deformed in compression in an Instron Model 1361 Materials Testing Apparatus. However, diametric compression generates hoop stresses within the cylindrical sample that lead to tensile failure of the center of the samples [3]. The maximum strength during diametric compression is then converted to tensile strength in a straightforward manner. These tests are a standard method for measuring the tensile strength of rock [2]. Other rock mechanics tests (e.g., direct shear) may be performed as time and resources are available.

**Analysis.** MAC core breakoff utilizes an eccentric/offset configuration within the drillbit mechanism. During drilling, the drill bit body remains concentric with the borehole and an internal sample tube. Once at depth, core break-off occurs when the sample tube is rotated relative to the drill bit, when the eccentricity of the inner bit-wall applies shearing forces at the base of
the forces necessary to perform the break-off operation are expressed in the motor current, which may be used to correlate the (direct) shear strength of the rock being sampled.

**Preliminary Results:** As of this writing, UCS has been measured on the suite of natural rocks described above. Correlating UCS to rock type requires consideration of several factors, including rock structure and degree of lithification and cementation.

**Factors affecting rock strength.** Rock strength depends upon the stresses needed to promote the growth of seventh-order discontinuities [4]. These discontinuities are generally microscopic inconsistencies, such as lattice defects and incomplete grain boundaries, which lead to microscopic stress concentrations where, under sufficient load (generally less than the theoretical yield strength), the rock begins to fail. These scales of weakness are orders of magnitude smaller than the stresses acting within these rocks during a core break-off operation. Assuming a rock that is not fractured prior to core break off due to rotary-percussive drilling, the peak strength seen at core break-off will represent the bulk shear strength of the rock. For sedimentary rocks, however, the extrapolation to shear strength may not be so straightforward. Primary factors affecting the bulk (shear) strength of sedimentary rocks include binder maturity and clast size; For a given sample size, one can imagine a point where clast size within a sedimentary rock, such as a conglomerate, becomes so large that it is the clast (and not the composite) that is being measured. Determining the scaling factors (binder strength, mean clast size combinations) for the scales at which we can make this measurement in situ is an important goal of the team.

**Discussion:** Our current data set shows promise in correlating drill data to the physical properties of rocks. Ongoing work will improve and strengthen these correlations, as well as explore rock properties beyond UCS. For example, we are in the process of exploring the repeatability of drill power measurements for a single rock type by drilling numerous cores from the same, large rock sample. Numerous measurements of drill power from a single rock type also builds a statistically significant dataset upon which to base our correlations.

Further mechanical tests may also be conducted as time and resources allow. For example, direct shear tests may be carried out on cores drilled by the engineering testbed. Perhaps most directly correlated to the core break-off process, these tests require new fixtures be constructed for use in the available deformation apparatus.

Finally, a large amount of data has been collected from drilling operations with the engineering testbed. Exploring this wide dataset will allow us to identify the parameters most strongly correlated with rock properties, perhaps guiding the selection of parameters to be downlinked from the flight vehicle.

**References:**

**Acknowledgements:** This work has been conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.

**Figure 2:** Shows core break off torque per rock type when the rocks are classified according to their structure and Unconfined Compressive Strength.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Core Breakoff Torque (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODP</td>
<td>50</td>
</tr>
<tr>
<td>BTI</td>
<td>40</td>
</tr>
<tr>
<td>CRG</td>
<td>30</td>
</tr>
<tr>
<td>NBS</td>
<td>20</td>
</tr>
<tr>
<td>USB</td>
<td>10</td>
</tr>
<tr>
<td>NJD</td>
<td>0</td>
</tr>
</tbody>
</table>

Old Dutch Pumice (ODP): Pynclastic  
Bishop Tuff Intermediate (BTI): Pynclastic  
China Ranch Gypsum (CRG): Chemical Sediment  
Napa Basaltic Sandstone (NBS): Fluvial-like Sediment  
Uniform Saddleback Basalt (USB): Igneous Extrusive  
New Jersey Diabase (NJD): Igneous Plutonic