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Powder-Based 3D Printing Application for Geomechanical Testing

Exceptional service in the national interest

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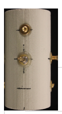
Why 3D printing? 3D printing of fractured and porous analog geomaterials has the potential to enhance hydrogeological and mechanical interpretations by generating engineered samples in testable configurations with reproducible microstructures and tunable surface and mechanical properties. For geoscience applications, 3D printing technology can be co-opted to print reproducible structures derived from CT-imaging of actual rocks and theoretical algorithms. In particular, the use of 3D printed samples allows us to overcome sample-to-sample heterogeneity that plague rock physics testing and to test material response independent from material variability.

Gypsum powder-based 3D printing was used to print cylindrical core samples and block samples with and without a pre-existing flaw geometry. All samples were printed in three different directions to evaluate the impact of direction on mechanical properties.

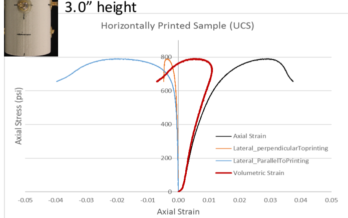
Unconfined Compressive Strength (UCS) testing was performed on cylindrical and block samples. Samples printed parallel to loading direction were stronger during UCS testing than those printed perpendicular or at 45 degrees. Amount of binders used for printing has a significant impact on porosity and UCS peak strength, which also has different responses (e.g., compaction and dilation turn) of printed samples.

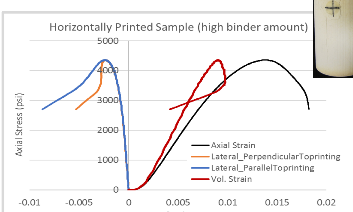
Micro-CT images of the printed samples reveal the impact of printing options such as directional layers, uneven spreading of binder, and complex failure planes. In particular, the layered feature with binder causes the strong anisotropic properties. This was also confirmed by the wave velocity. For the small block samples (~6.1cm wide, ~10cm high, and 1.25cm thick) with an inclined flaw, uniaxial tests coupled with an array of acoustic emission sensors and digital image correlation revealed that cracks were developed at/near the tip of flaw as expected. Although acoustic events were detected, localization was not detectable mainly due to strong attenuation.

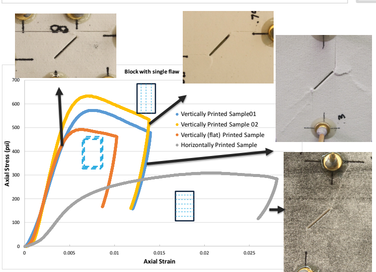
UCS testing results

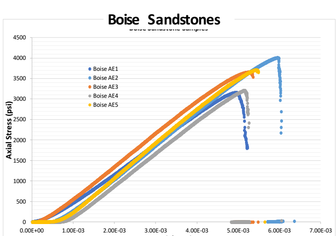


1.5” diameter
3.0” height



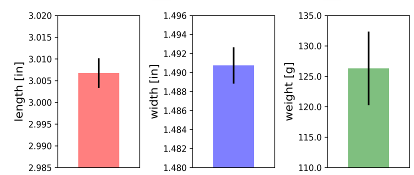




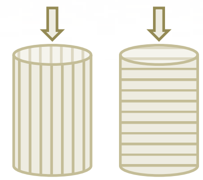


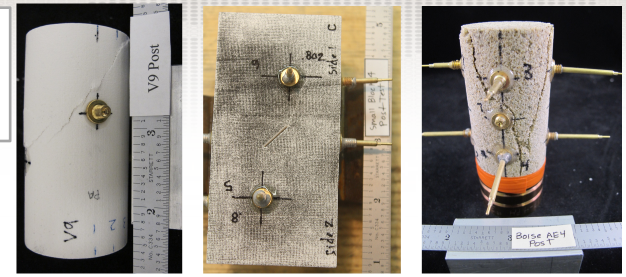
Testing Methods: Small block and cylindrical samples with and without flaws were 3D printed with gypsum powder. 3D printed samples were printed in three directions: parallel, perpendicular, and 45 degrees to loading direction. Velocity measurements were taken of 3D printed rock and cylindrical Boise Sandstone, and UCS tested on an MTS 22kip load frame. Some samples were instrumented with AE pins and marked for digital image correlation to attempt to monitor failure geometry.

Comparison of sample length, width, and weights of 4 printed samples



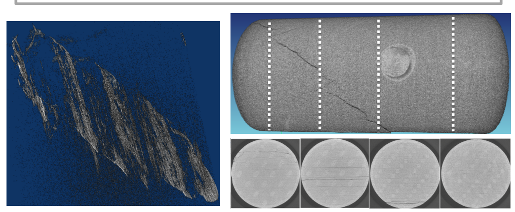
- using samples V9, V10, H9, H10



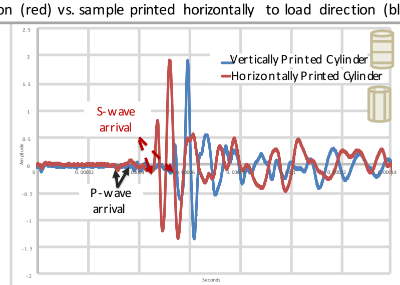


Sample printed vertical to loading direction (labelled with “H” ex: H9) vs. sample printed horizontal to loading direction (labelled with “V” ex: V9)

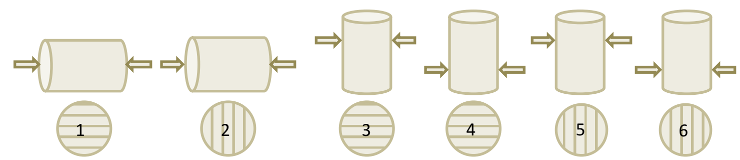
Micro CT Imaging: Post-test Micro CT images show fracture plane and cross-sectional slices of a vertically printed sample (loaded horizontally)

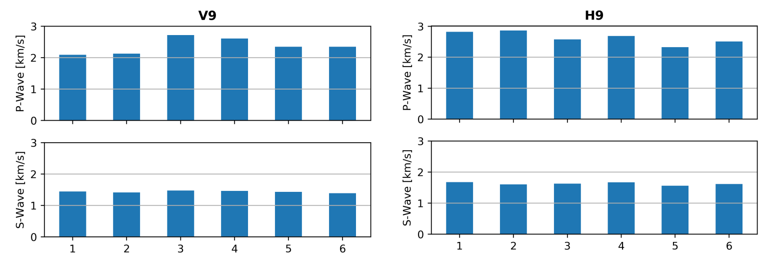


Waveforms: Waveforms of sample printed vertically to load direction (red) vs. sample printed horizontally to load direction (blue)



Velocity measurements: P and S-wave velocities were measured before UCS testing on all samples. Two samples are shown below with orientations of measurements.





Conclusions:

- Strong effect of printing direction on geomechanical properties: peak strength, velocities, and failure geometry
- Some 3D printed samples have dilation behavior (volumetric strain) similar to natural samples (depending on printing conditions, i.e. amount of binder, etc.)
- Optimal printing conditions will produce more consistent sample reprintablity suitable for geomechanical testing

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