Geomechanical characterization of Geoarchitected Rocks using Gypsum-based 3D Printing

Exceptional service in the national interest

Sandia National Laboratories

Michelle Williams[1], Hongkyu Yoon[1] (hyoon@sandia.gov)

Geomechanics Department, Sandia National Laboratories, Albuquerque, NM, USA

MR21C-0085

Why 3D printing? 3D printing of geoarchitected rocks has the potential to enhance mechanical interpretations by generating engineered samples in testable configurations with reproducible microstructures and tunable directional mechanical properties. 3D printing can allow us to overcome sample-to-sample heterogeneity that plague rock physics testing.

3D Printing Process

- Powder-based 3D printing was used to make "geo-architected rock" samples using commercially available bassanite powder (calcium sulfate hemihydrates, $CaSO_4{\cdot}0.5H_2O$).
- A commercial 3D printer (ProJet 360) was used to build a 3D structure of geo-architected samples by depositing a thin layer (100 microns) of bassanite powders onto build chamber.
- Layering direction, binder spray direction, amount of binder, and post-sample modification were tested to control the strength of printed rocks
- 3D printing process is a reactive crystallization process from bassanite to a hydrated form of calcium sulfate (i.e., gypsum) when bassanite is in contact/mixed with the water-based binder solution as $CaSO_4{\cdot}0.5H_2O + 1.5H_2O = CaSO_4{\cdot}2H_2O$.

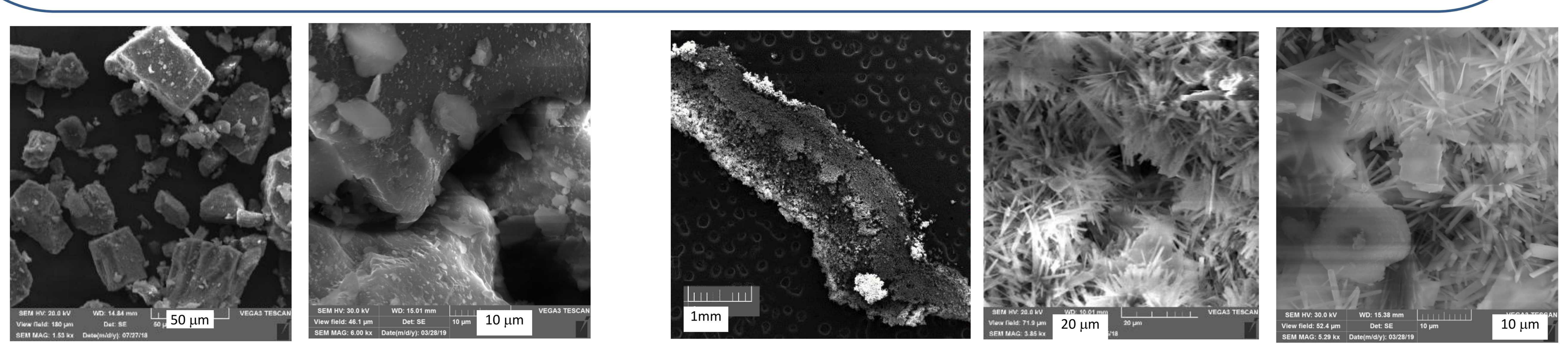


Figure 1. Scanning electron microscope (SEM) images: (left) bassanite powders and (right) a solid powder after reaction with a binder solution with rod shape gypsums, and a mix of rod shape gypsum and unreacted thin plates

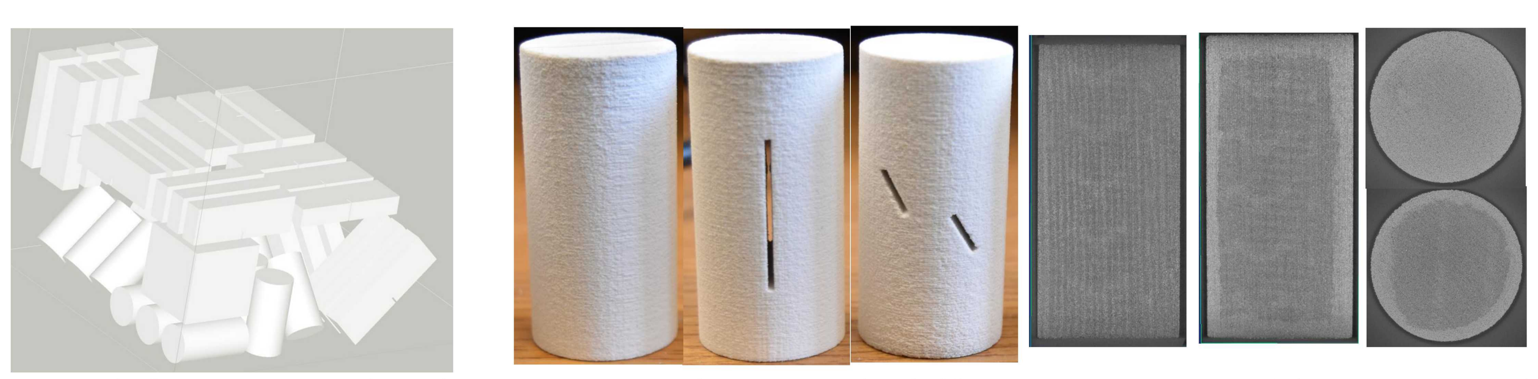
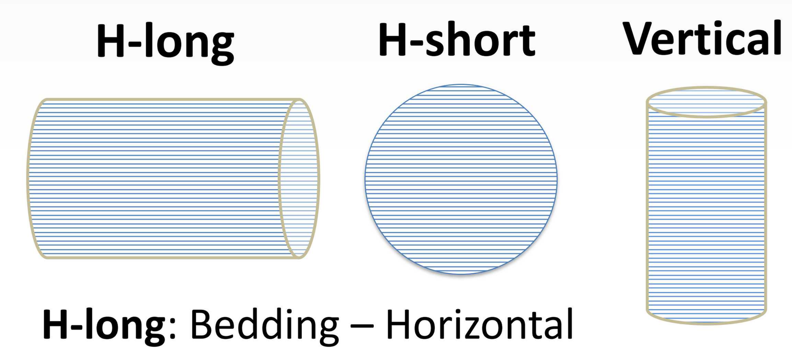


Figure 2. (left) an example of 3D printing design with different geometries. To minimize the sample-sample variability, a batch of samples was printed together. (right) Examples of 3D printed cylinder samples (1" diameter and 2" height) and microCT images of 3D printed samples (left: vertically layered sample, middle: horizontally layered sample, right: horizontal image slices of horizontally layered sample at the top and in the middle.

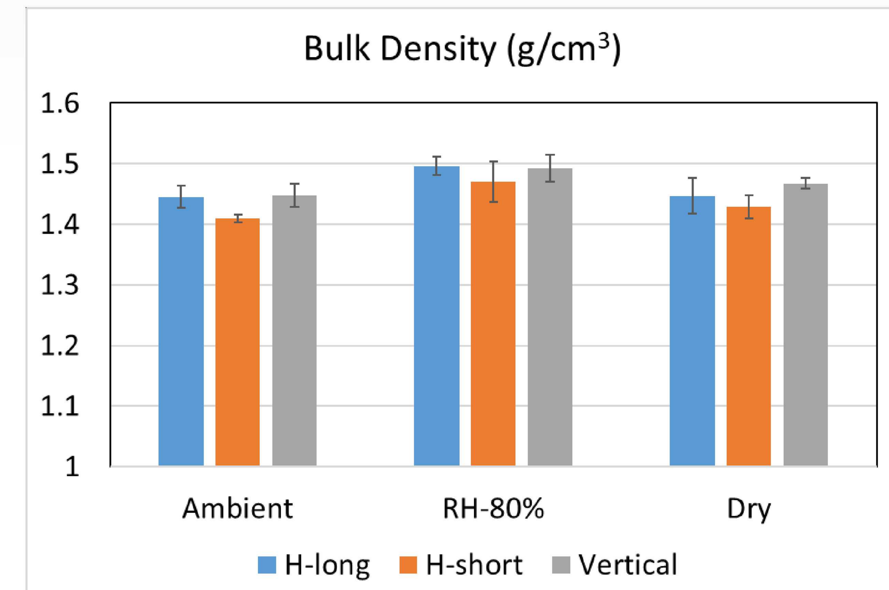
Characterization and Testing of 3D Printed Rocks

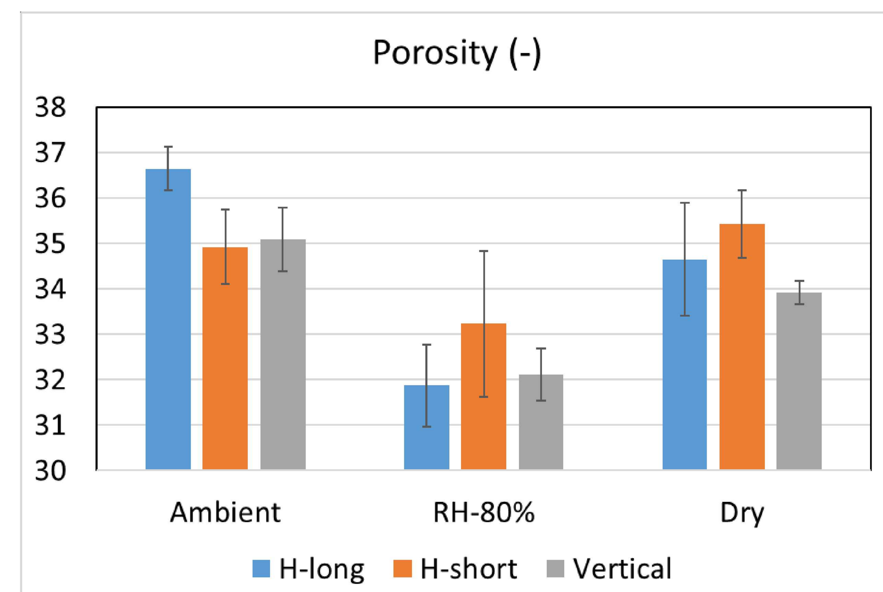
- Cylindrical samples: dimensions (diameters, heights with at least 3 different locations) and weight
- Porosity and P-&S-wave velocities
- MicroCT imaging of samples before and after testing
- Mechanical testing: **Unconfined compressive strength**, 3 point-bending, triaxial testing
- Variations in 3D printing: Binder amount, different 3D printers, different printing conditions
- **Variation in post printing conditions (e.g., relative humidity)**
- **SEM image analysis of fracture surface characteristics**

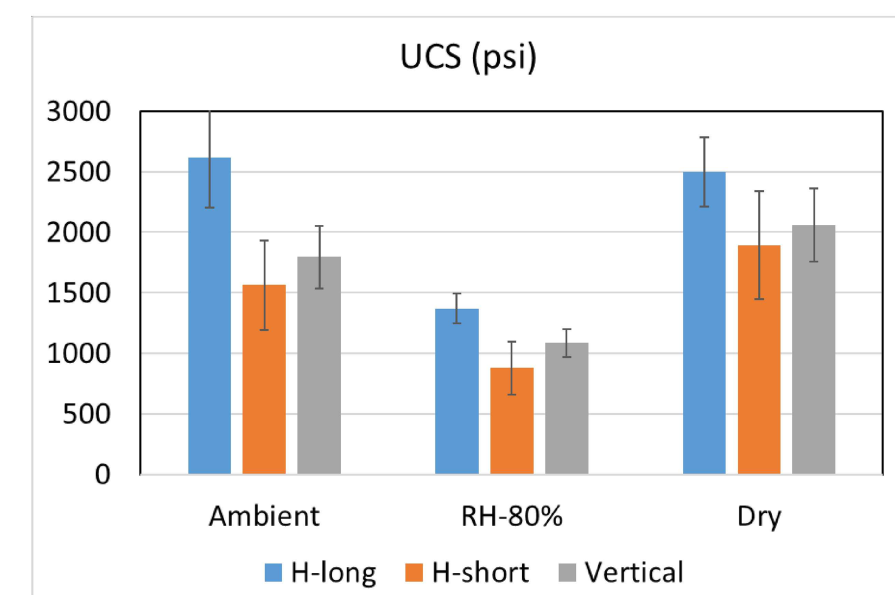
Bulk Density and Porosity of 3D printed rocks: Dimensions of 3D printed rocks were consistency within less than 1% variability. For printed samples in three different directions with respect to bedding layer and texture layer (i.e., binder spray direction), printed samples were stored under three different relative humidity conditions (ambient, RH80%, and oven dry at 45 degree C)



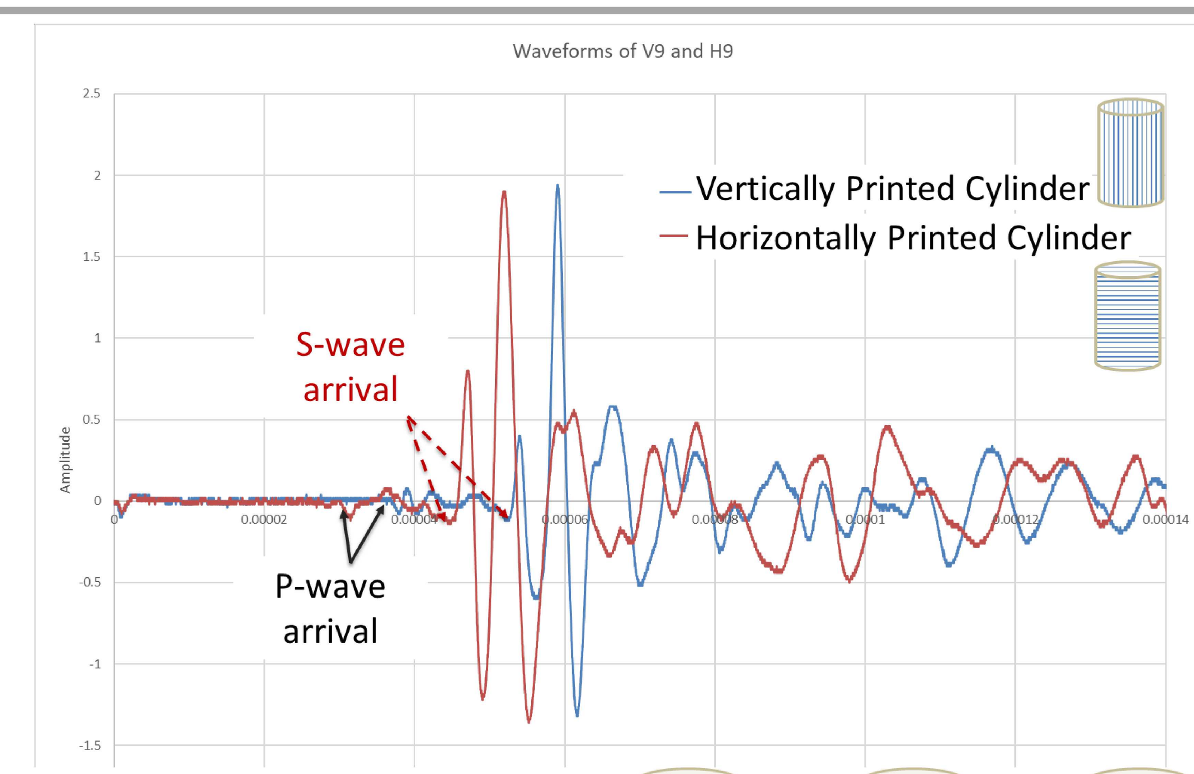
H-long: Bedding – Horizontal
Texture – Parallel to Loading
H-short: Bedding – Horizontal
Texture – Perpendicular to Loading
Vertical: Bedding – Vertical
Texture – Perpendicular to Loading

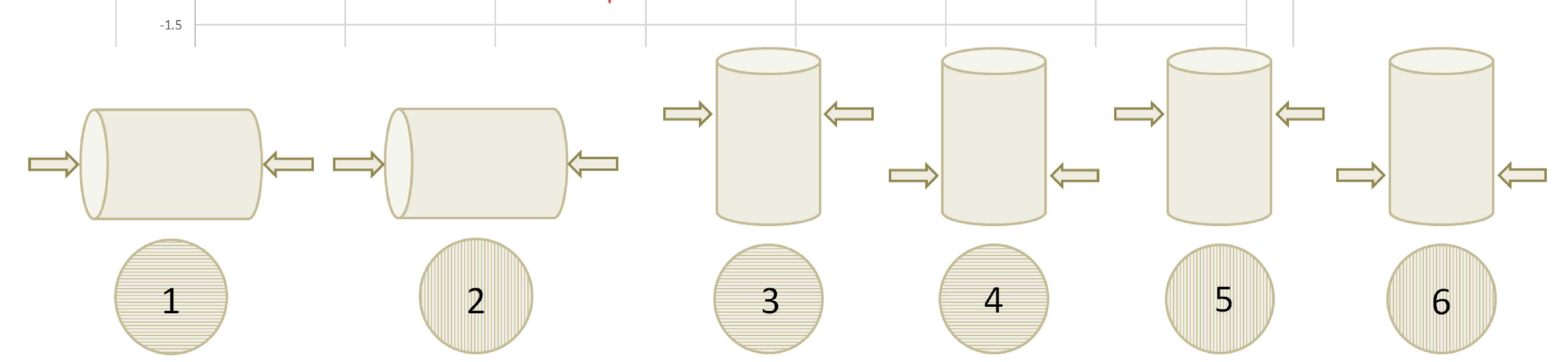




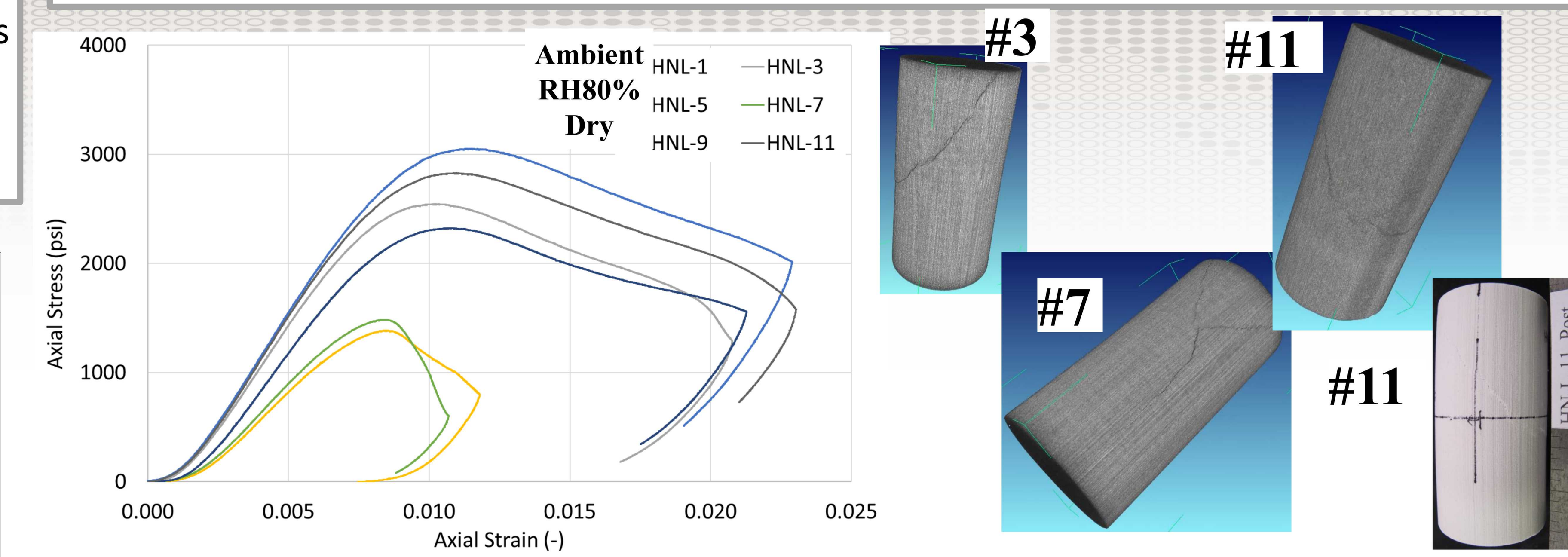


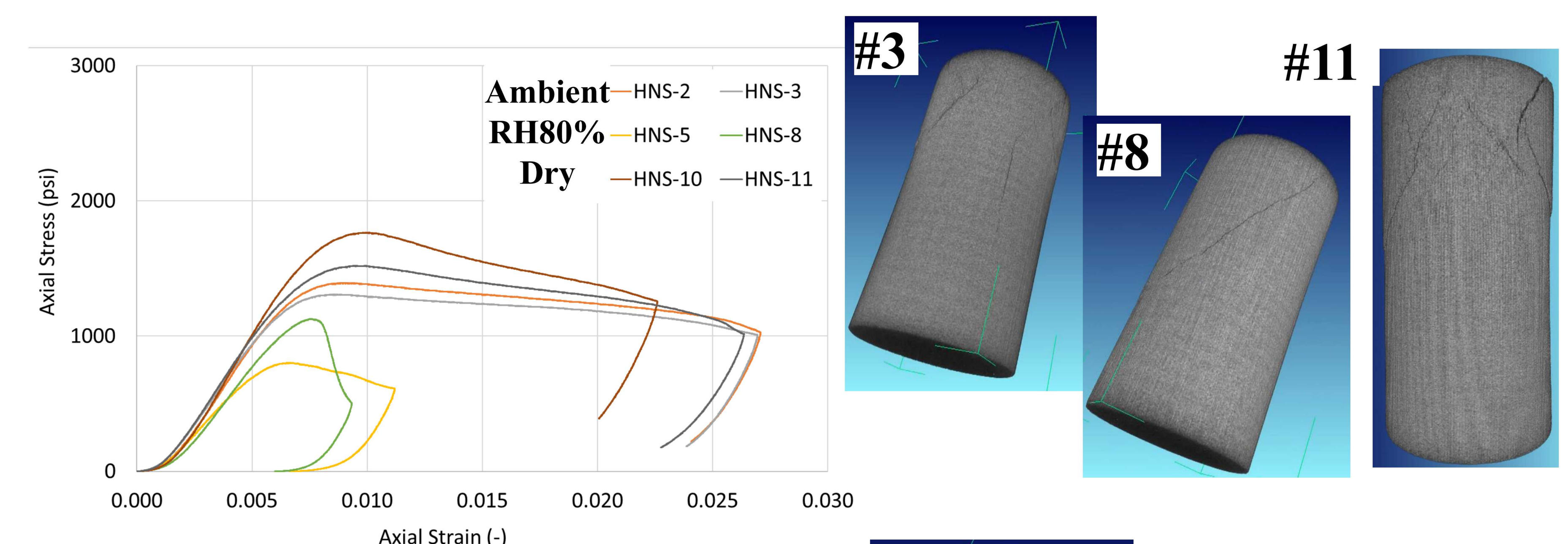
Waveforms: Waveforms of three different directional samples were measured along the axial and radial directions. S-transducers were used to generate the waveforms and arrival times were decided as below:

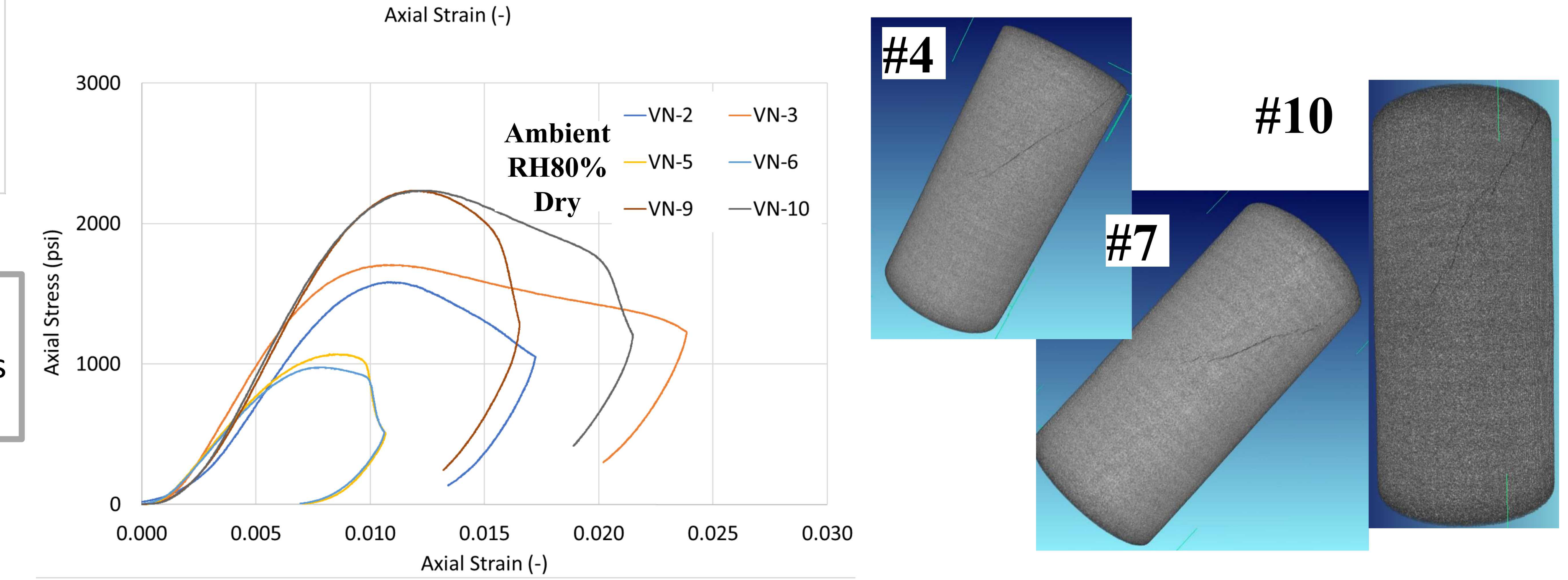




UCS testing results and MicroCT images







Conclusions:

- Strong effect of printing direction on geomechanical properties (peak strength, velocities, and failure geometry). Bedding layer and texture direction (binder spray direction) resulted in directional mechanical properties of the printed rocks
- Relative humidity affects the porosity of printed rocks (water adsorption) and weakened the strength of the printed rocks significantly
- Optimal printing conditions will produce more consistent sample reprintablity suitable for geomechanical testing

Related Presentations:

MR23C-0110-Damage Mechanics Challenge: Simulation of Failure Load and Crack Geometry

MR23C-0112-Mixed-Mode Fracture Propagation in Layered Printed Rocks with Oriented Texture

MR23C-0120-Acoustic emission analysis of fracture initiation and propagation using physics-informed machine learning methods

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories.