MR23C-0112

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

SAND2019-14915C
AGU 100 FALL MEETING San Francisco, CA | 9–13 December 2019

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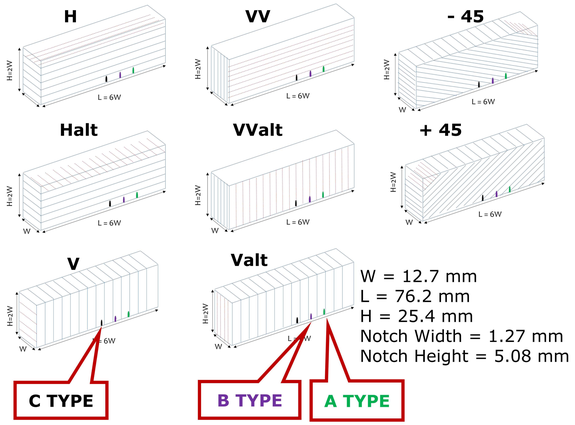
Introduction

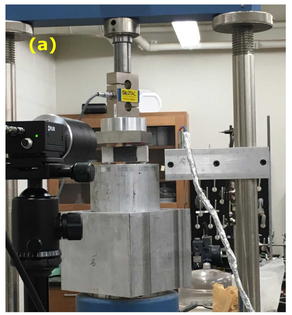
Anisotropy in the mechanical properties of rock is often attributed to bedding and mineral texture. This work explores the effects of layers and in-plane mineral texture on fracture evolution under mixed Mode I and Mode II loading conditions in three-point bending (3PB) experiments on 3D printed gypsum samples.

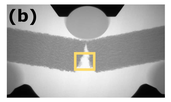
Samples and 3PB Test Setup



W = 12.7 mm
L = 76.2 mm
H = 25.4 mm
Notch Width = 1.27 mm
Notch Height = 5.08 mm

Figure 1: Sketch of 3D printed anisotropic gypsum samples with different notch locations. Red lines: binder print direction (MT – mineral texture orientation). Blue lines: layer orientation. Layer thickness ~ 100 microns (BL – bedding layer orientation). Notch locations are given below.





Notch Locations from Center

MODE I

Type C (black) = 0 mm

MODE I & II

Type B (purple) = 9.53 mm

Type A (green) = 19.05 mm

Figure 2: 3-point-bending test setup (a) on full scale samples and (b) on a Type C sample in 3D X-ray microscope.

Sample Strength

Maximum peak loads were observed when both the BL and MT orientations were perpendicular to the fracture plane. While, minimum P occurred when both BL and MT orientations were parallel to the fracture plane. For samples with the same BL and MT orientations, the ratio of the minimum to maximum *P* increased as the notch location moved away from the center.

Table 1: the ratio of the minimum and maximum *P* for different notch locations, i.e. modes of failure

Type A	Type B	Type C
0.6845	0.6271	0.5452

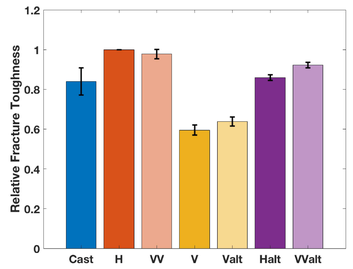


Figure 3: Repeatability of fracture toughness from 3PB Tests for Mode I failure (Type C).

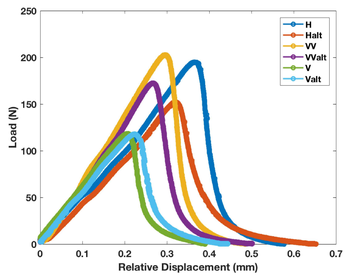


Figure 4: Load displacement curves of the samples under Mode I and II fracturing (Type B)

Surface Roughness

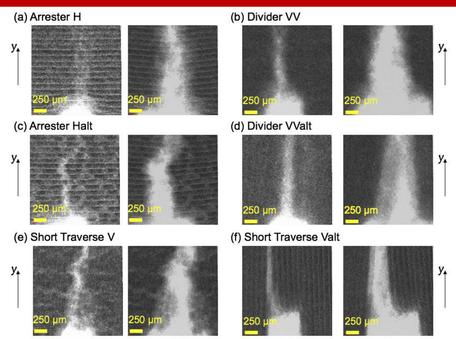


Figure 5: 2D x-ray radiographs of the small printed samples with Type C notch at post peak (5% of peak load) and just prior to complete failure. The direction of fracture propagation from the notch (at the bottom of each image) is in the y-direction.

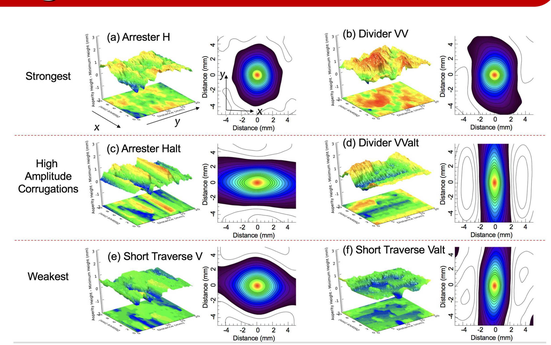


Figure 6: 3D surface and 2D contour of surface roughness and the normalized 2D autocorrelation function for the printed samples' fractures from Mode I failure (Type C).

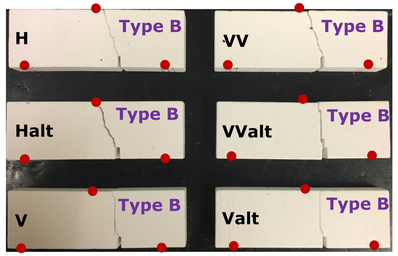


Figure 7: Fracture path for samples with different bedding layer (BL) and mineral texture (MT) orientations under mixed Mode I and II loading.

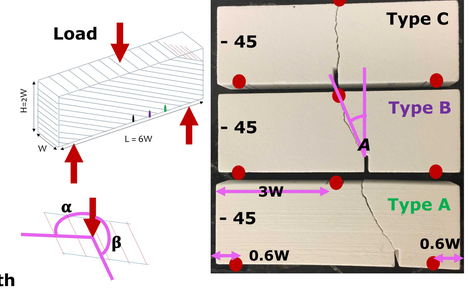


Figure 8: Fracture path for samples with the same BL and MT orientations but with different notch locations.

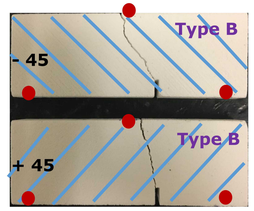


Figure 9: Fracture path when bedding direction rotates by 90°.

Angle of the Fracture Trace

For samples with the same notch locations , the angle, *A*, of the fracture trace (taken relative to direction of loading) decreased with decreasing angle between BL and the loading directions. For samples with the same BL orientation but with different MT orientations, these two orientations also affected *A*. For the samples with the same BL and MT orientations, as the notch location moved away from the center of the sample, *A* increased.

Table 2: *A*, α, β, and notch locations for Type B samples. Angle locations are given in Figure 8.

Sample Geometry (Type B notch)	H	VV	Halt	VValt		Valt	+ 45	- 45
α (degree)	90	90	90	90	0	0	+45	-45
β (degree)	90	90	90	0	90	0	90	90
A (degree)	15	16	17	7	9	9	15	30

Notch Location (- 45 samples)	Type A	Type B	Type C
A (Degree)	25	20	0

Conclusions

As the notch moves away from the center, the failure mode transitions from Mode I to mixed Mode I & II failure, resulting in

***an increase in *A* of the fracture trace;**
***an increase in minimum to maximum peak loads.**

However, the isotropic or anisotropic nature of the surface roughness remained unchanged.

The differences in induced fracture path, toughness and roughness provide a potential method for the assessment of orientation and relative bonding strengths of minerals in a rock. With this information, we have the potential to predict flow path, flow rate and isotropic or anisotropic properties along fractures, which are vital to induced fracturing, geothermal and CO_2 capture applications.

Acknowledgements

Acknowledgements: Sandia National Laboratories is a multi-mission 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 poster describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the poster do not necessarily represent the views of the U.S. Department of Energy or the United States Government. We also acknowledge the 3D X-Ray Microscope Facility in the Department of Physics for the images shown in this presentation, which were acquired on a Zeiss Xradia 510 Versa 3D X-ray Microscope that was supported by the EVPRP Major Multi-User Equipment Program 2017 at Purdue University.

Related Presentations: MR23C-0110 - Damage Mechanics Challenge: Simulation of Failure Load and Crack Geometry
MR23C-0120 - Acoustic emission analysis of fracture initiation and propagation using physics-informed machine learning methods