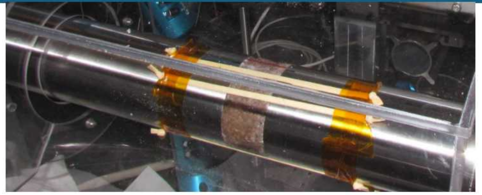
SAND2019-12152C

Dynamic Compressive Strength of Rock Salts



Society of Engineering Science

Presented by Scott Broome

Authors: Stephen Bauer, Bo Song, Brett Sanborn

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SAND 2019-XXXXX PE

Dynamic compressive strength of rock salts

Motivation

- Rock salt formations are well-suited to house materials from gas to liquefied hydrocarbons, oil, and solid nuclear waste.
- Knowledge of mechanical properties of salt rock material is critical for safety assessments of structural integrity of storage facilities.
- Understanding high strain rate loading is pertinent as rapid loading rates may be encountered from:
  - Earthquakes
  - Underground explosions
  - Used to estimate energy consumption requirements from drilling, mining, etc.

Dynamic compressive strength of rock salts

Motivation

- Once dynamic mechanical properties are known, improved constitutive models can be developed leading to improved facility design including enhanced drilling or mining practices.

Introduction

- For rock salt, fracturing is readily suppressed and crystal-plastic deformation mechanisms dominate with increasing temperature, decreasing strain rate, and increasing confining pressure.
- Quasi-static UCS range for bedded salt is 16 to 32 MPa
- Quasi-static UCS range for domal salt is 12 to 29 MPa

Dynamic compressive strength of rock salts

Introduction

- Available studies on the effect of strain rate on the strength of rock salt have been limited to the quasi-static regime (10^{-7} s^{-1} to 10^{-3} s^{-1}).
- Within this regime, increasing strength was observed with increasing strain rate.
- For this study:
  - At quasi-static strain rate, domal salt was deformed parallel to the foliation plane
  - At high strain rate (~50 s^{-1}), salt were deformed parallel and perpendicular to bedding (bedded salt) and foliation (domal salt) planes.

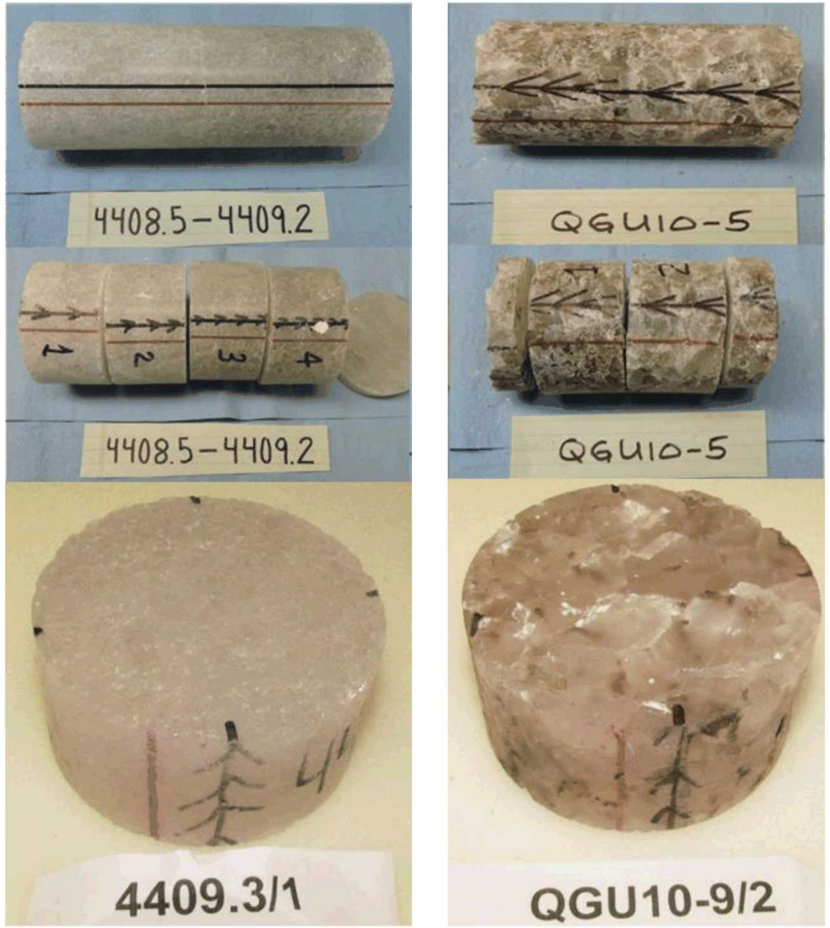
Dynamic compressive strength of rock salts

Materials and specimens

- Domal and bedded rock salts were prepared from cores from two separate locations.
- Bedded salt taken from the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico.
  - Previous quasi-static UCS of WIPP salt at 10^{-4} s^{-1} used for comparison in this study.
- Domal salt taken from a salt dome in southern Louisiana. Vertical core originating at depths ranging 1.2-1.6km.
  - Quasi-static specimens for domal salt were tested only in the parallel to foliation direction in this study.

Dynamic compressive strength of rock salts

Materials and specimens



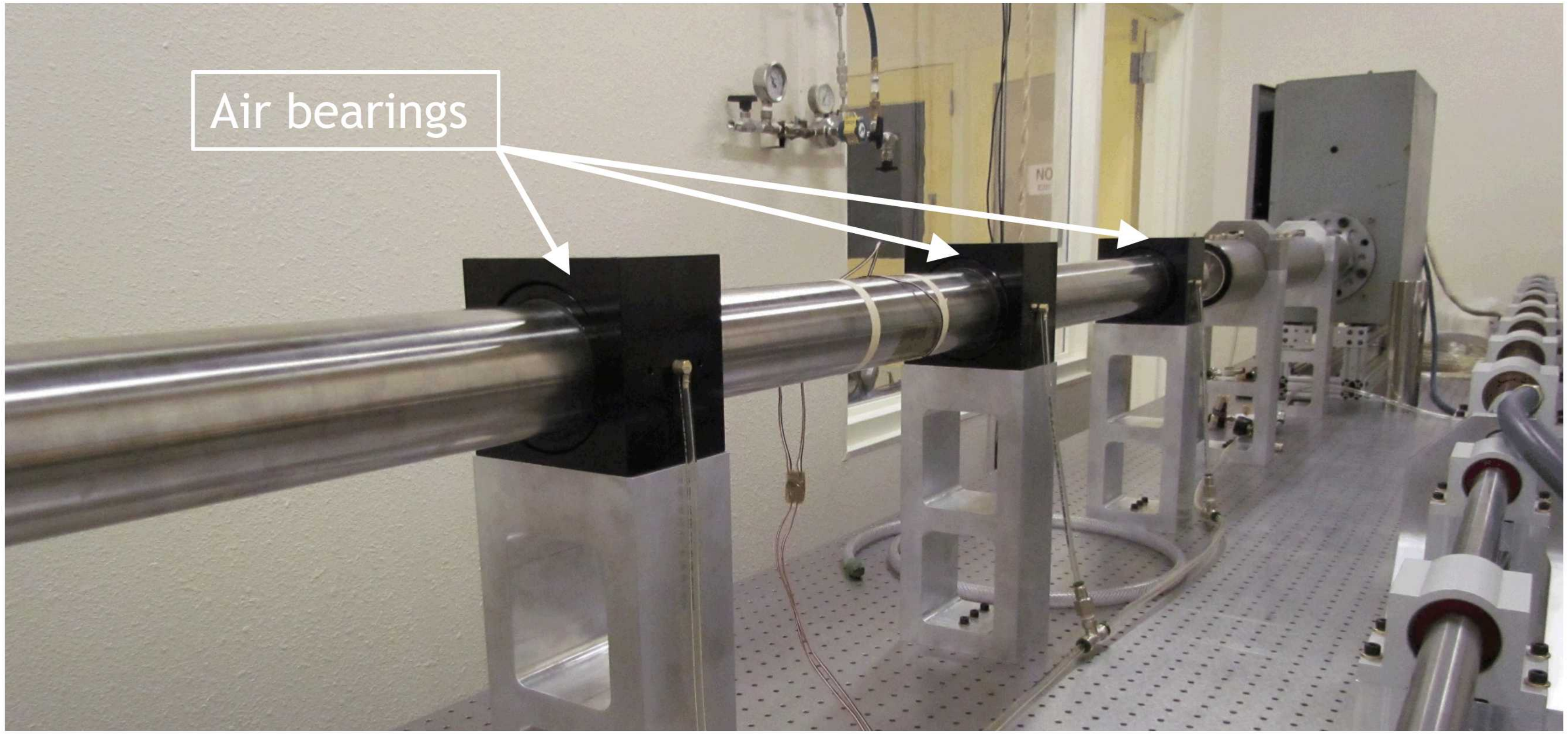
- Cylindrical salt samples parallel to foliation/bedding direction; top: as received core, middle: cut pieces, bottom: end-ground samples after being subjected to a hydrostatic pressure of 68.9 MPa for 72 hours.

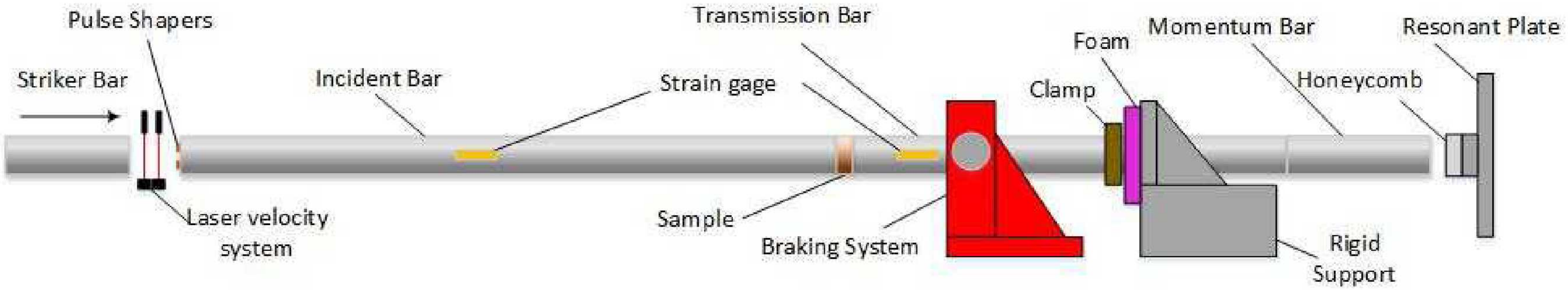
- Density of bedded salt (average 2.11 g/cc) was lower and less consistent (standard deviation 1.7%) than the domal salt (average density 2.15 g/cc and standard deviation 0.4%) due to impurities.

Dynamic compressive strength of rock salts

Experimental setup

- UCS at $10^{-4}\ s^{-1}$ conducted using a servo-hydraulic load frame
- Dynamic compression conducted with a 7.62 cm diameter Kolsky compression bar.

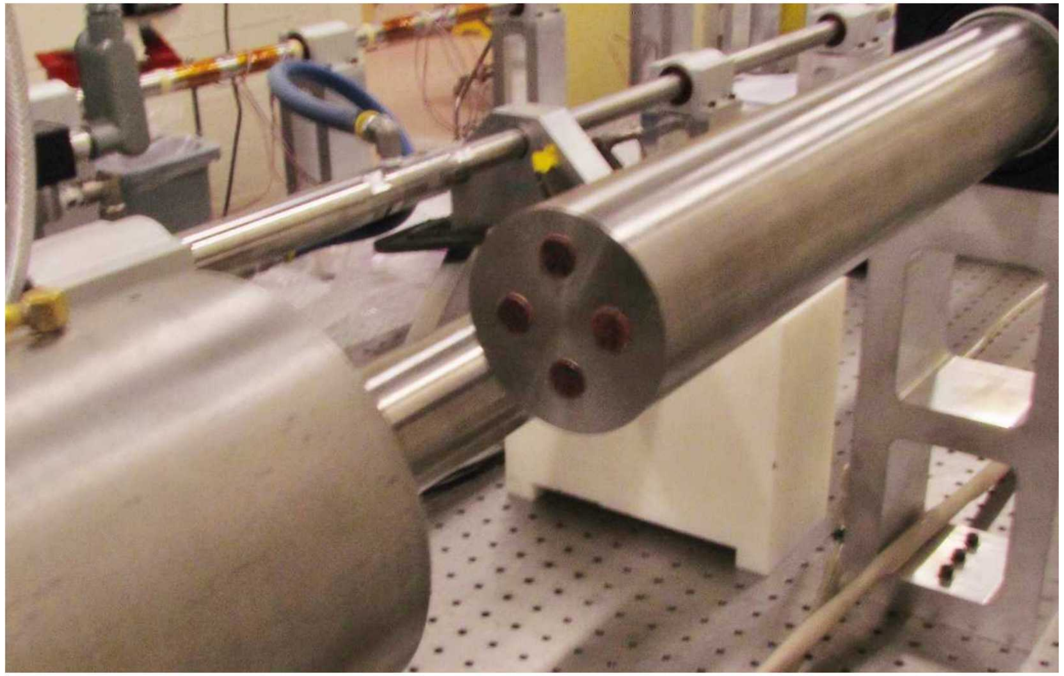


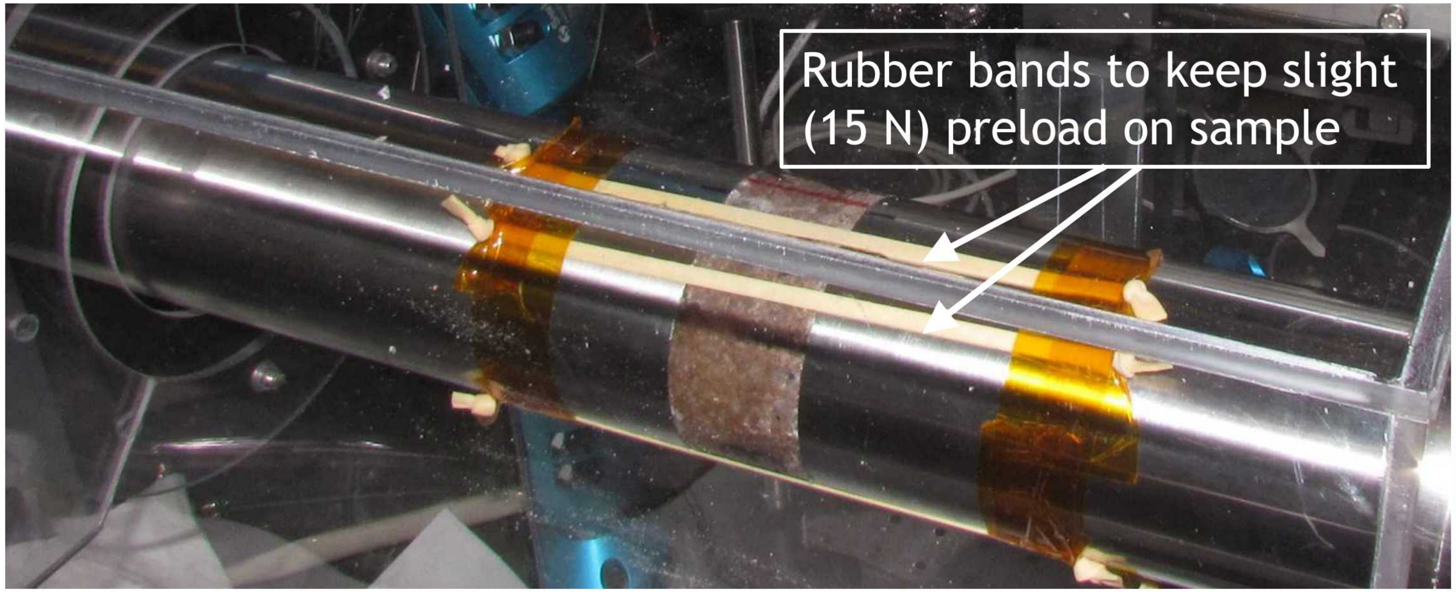


Dynamic compressive strength of rock salts

Experimental setup

- Pulse shaping enables constant strain rate in the specimen during dynamic loading through changing the profile of the incident pulse.
- Four annealed copper discs arranged in a 2 cm diameter ring.

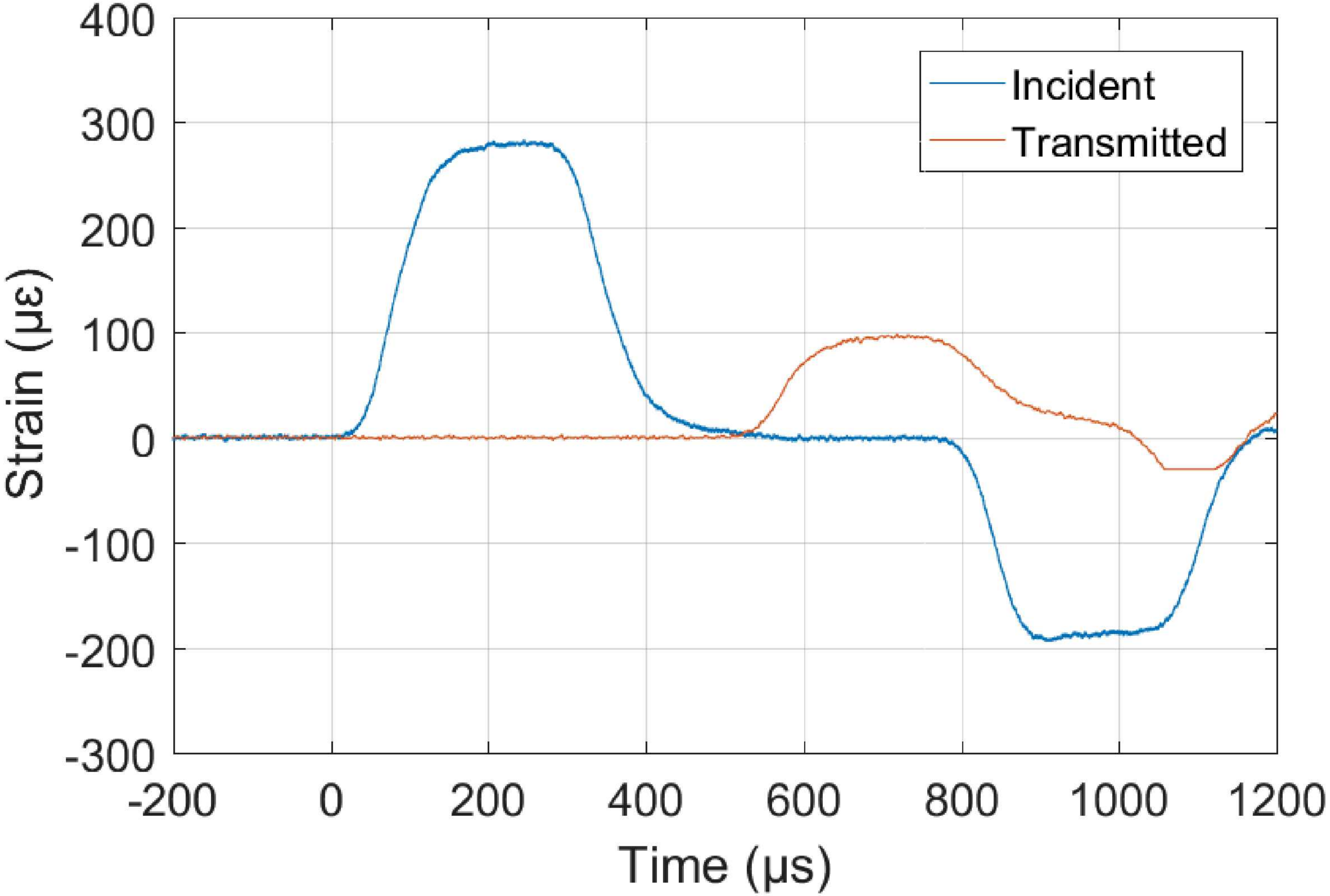




Dynamic compressive strength of rock salts

Experimental setup

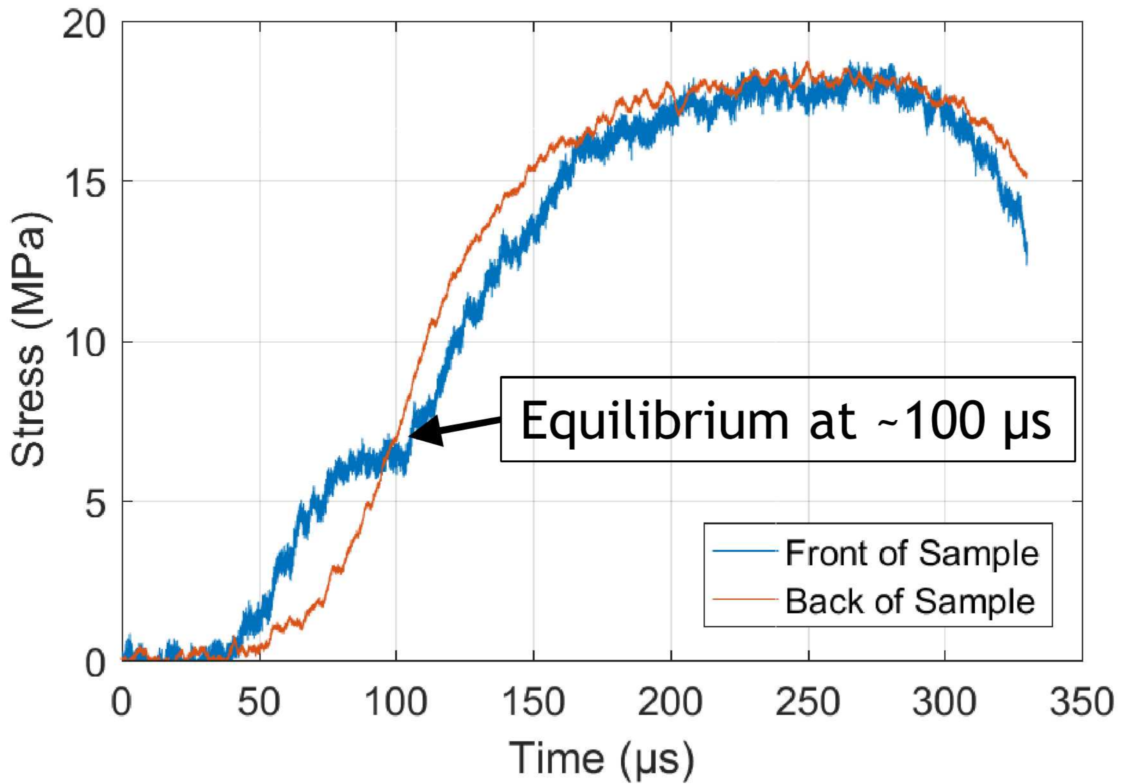
- Typical set of incident, reflected, and transmitted signals from domal salt tested parallel to foliation.
- Through pulse shaping, the incident pulse rises in 150 µs (non-pulse shaped rise time ~40 µs).

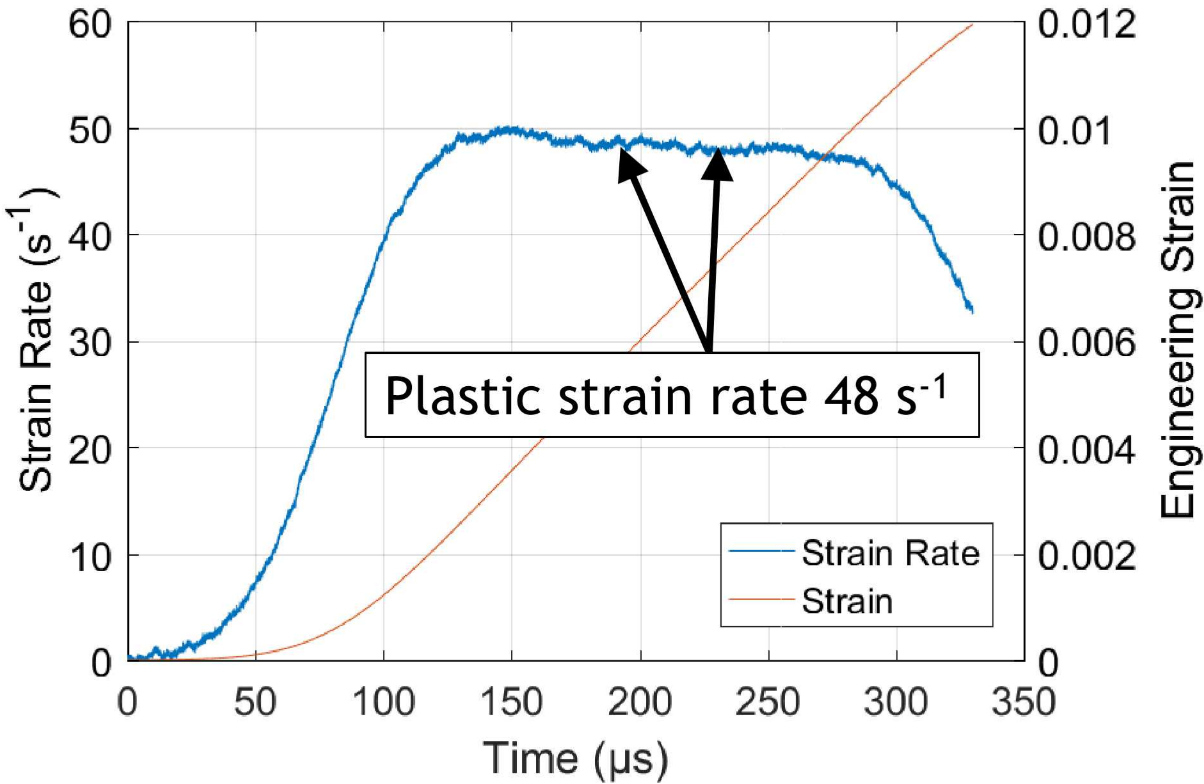


Dynamic compressive strength of rock salts

Experimental setup

- Stress calculated using: $\sigma_1 = \frac{A_B}{A_s} \cdot E_B(\varepsilon_i + \varepsilon_r) \quad \sigma_2 = \frac{A_B}{A_s} \cdot E_B \varepsilon_t$
- Strain rate and strain calculated using: $\dot{\varepsilon} = -2\frac{C_B}{L_S}\varepsilon_r \quad \varepsilon = -2\frac{C_B}{L_S}\int_0^t \varepsilon_r dt$

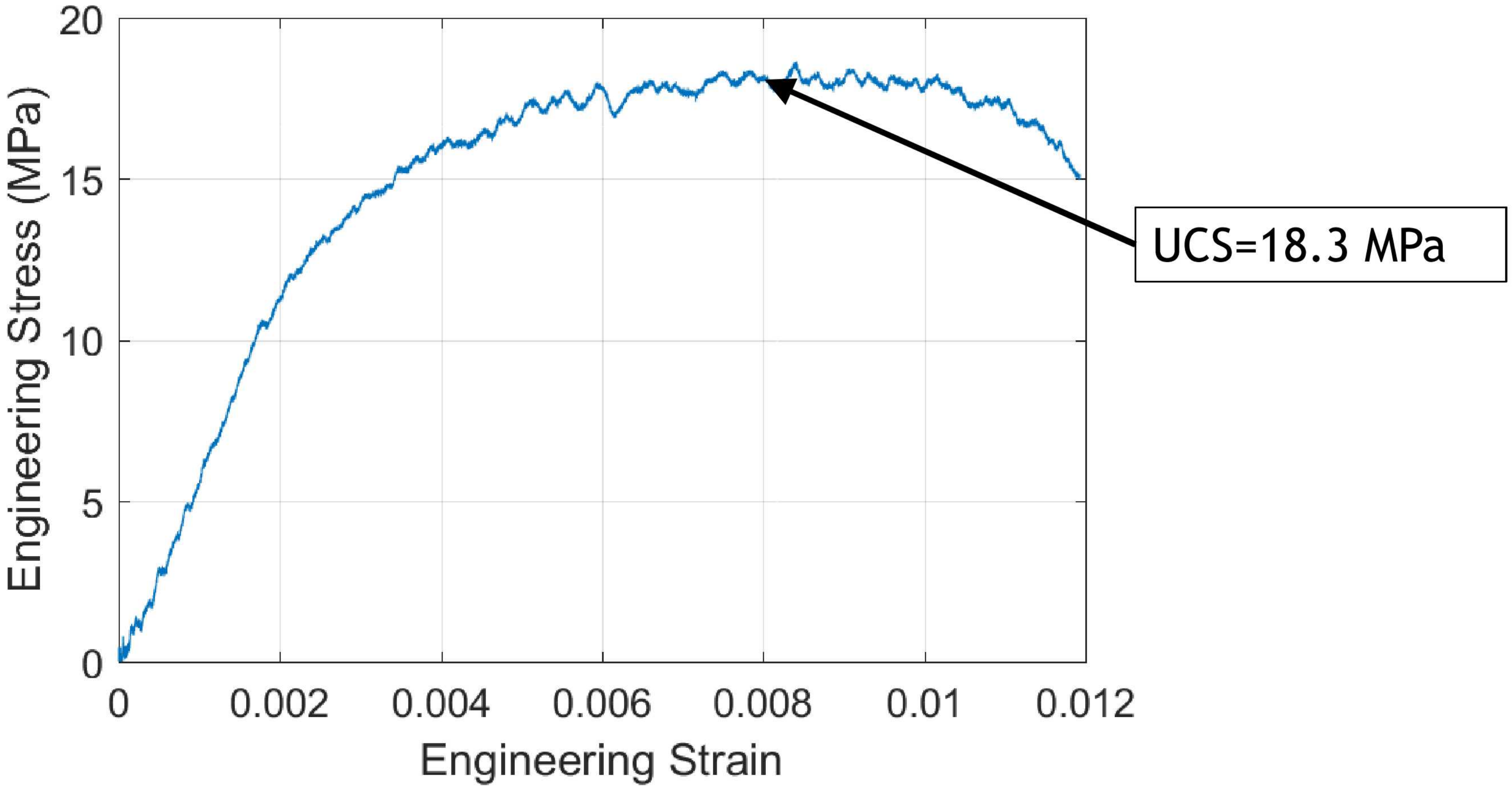




Dynamic compressive strength of rock salts

Experimental setup

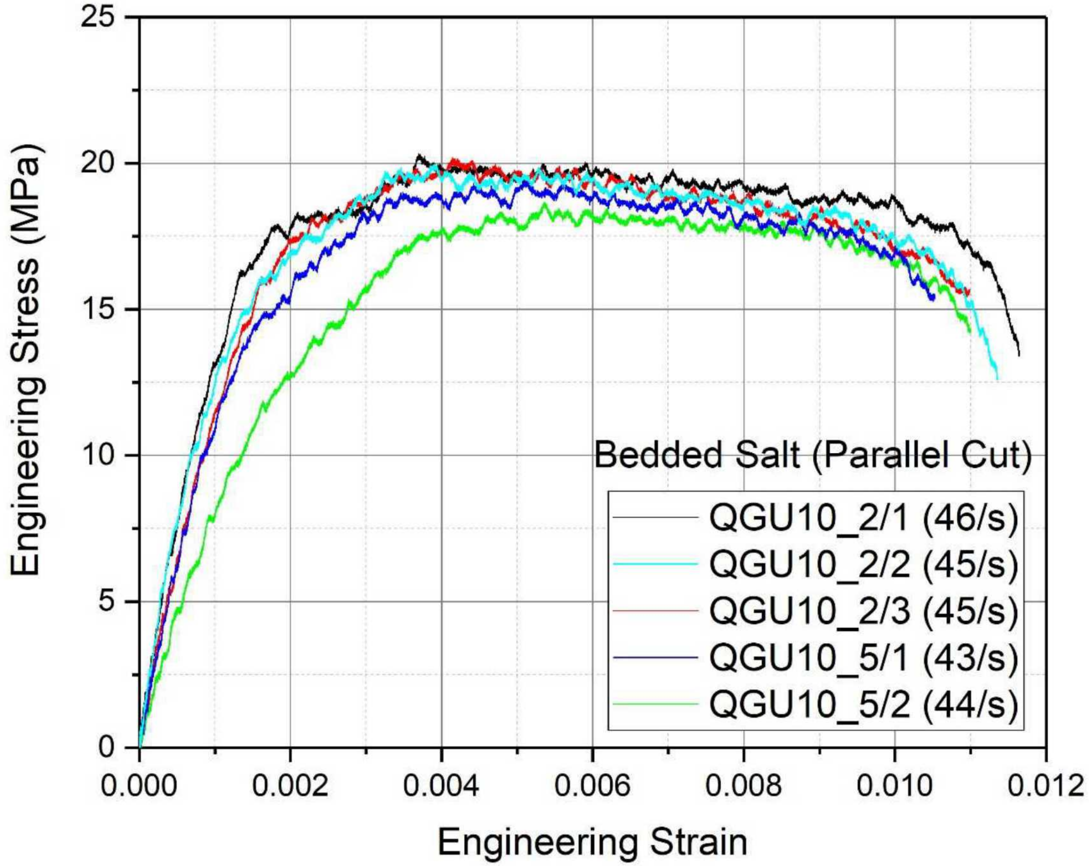
- Eliminating the time term of specimen stress and strain histories, the dynamic compressive stress-strain curve is obtained.

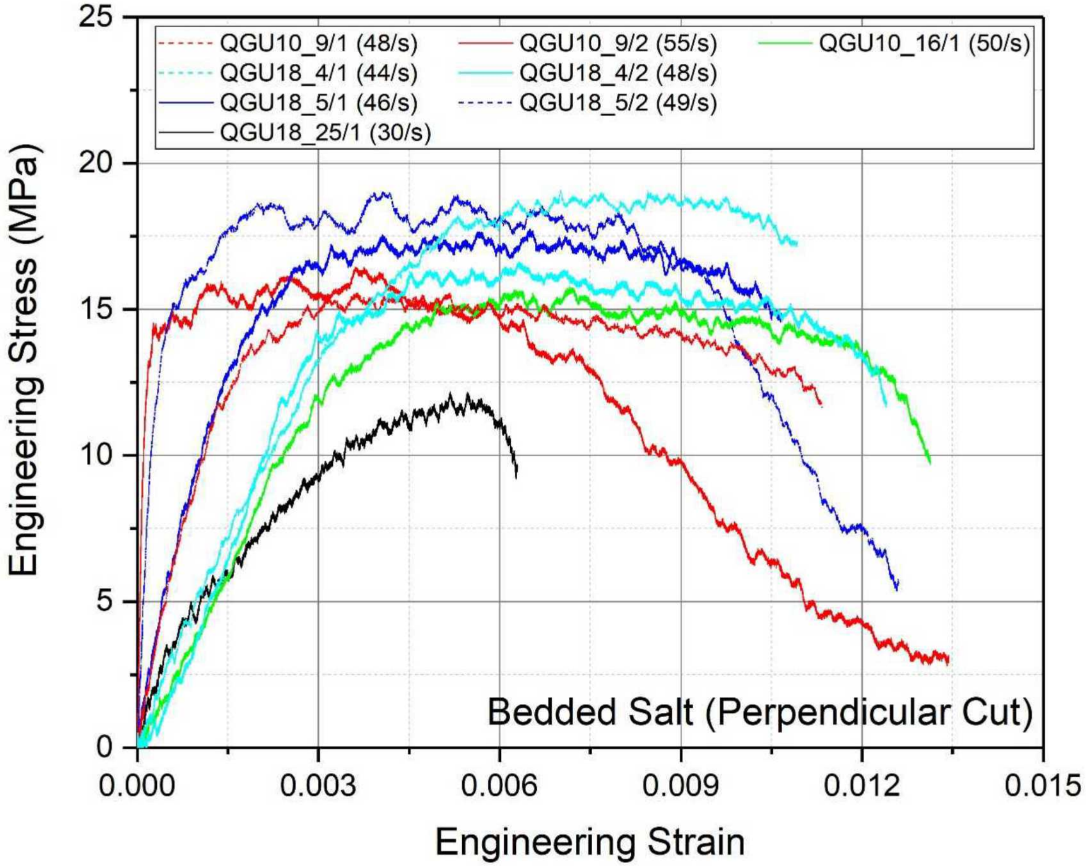


Dynamic compressive strength of rock salts

Experimental results

- Bedded salt parallel and perpendicular to bedding
- Exhibited small failure strain of ~1%, regardless of loading direction

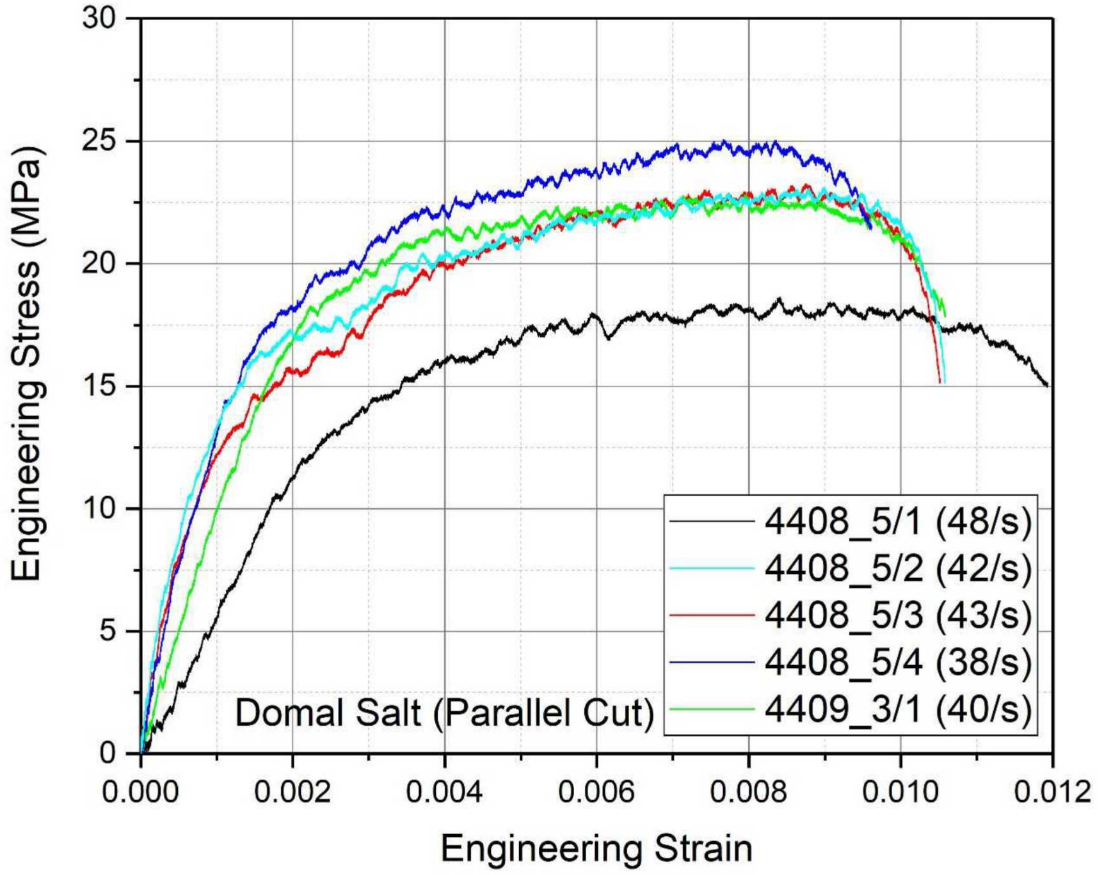


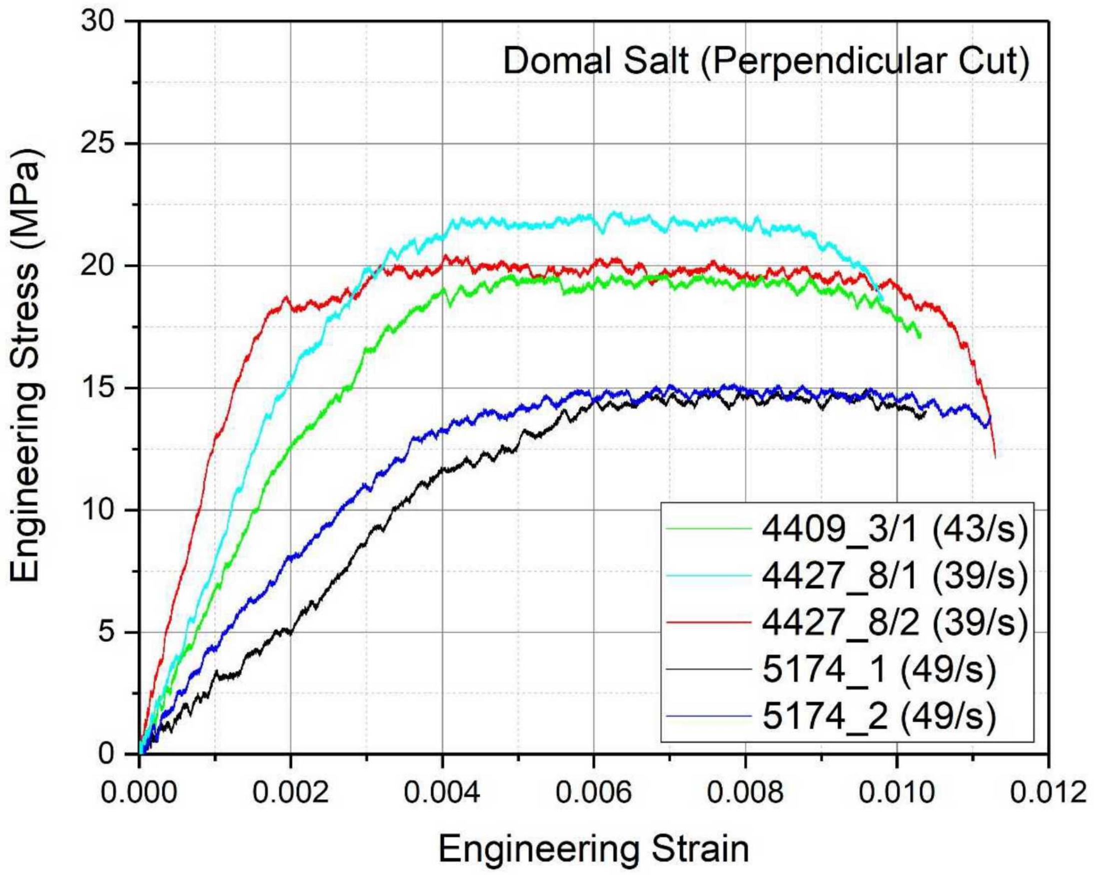


Dynamic compressive strength of rock salts

Experimental results

- Domal salt parallel and perpendicular to foliation
- Like bedded, failure strain of ~1%, regardless of loading direction

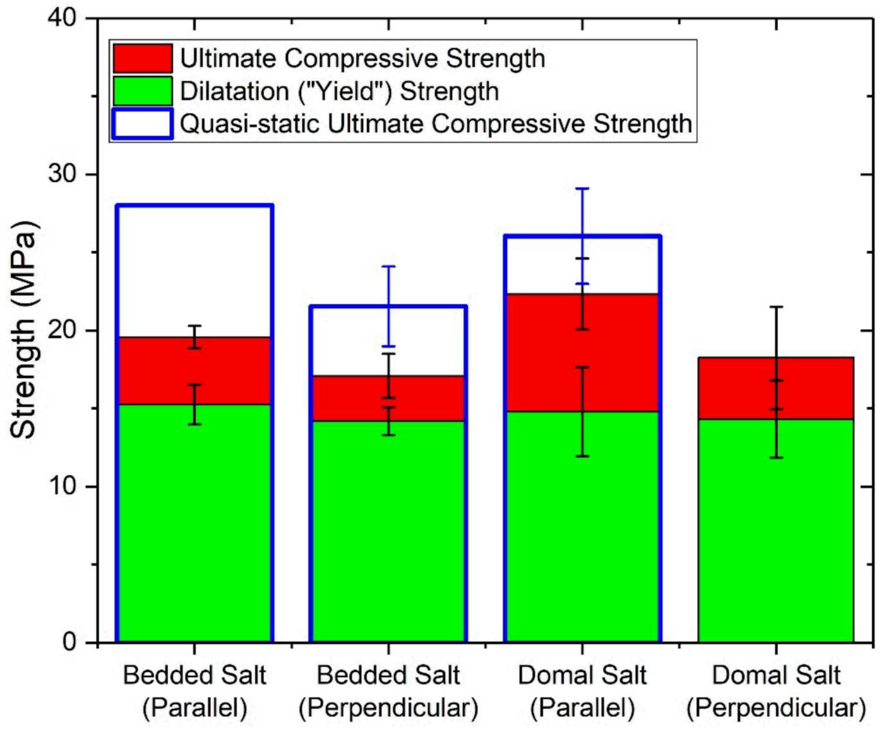




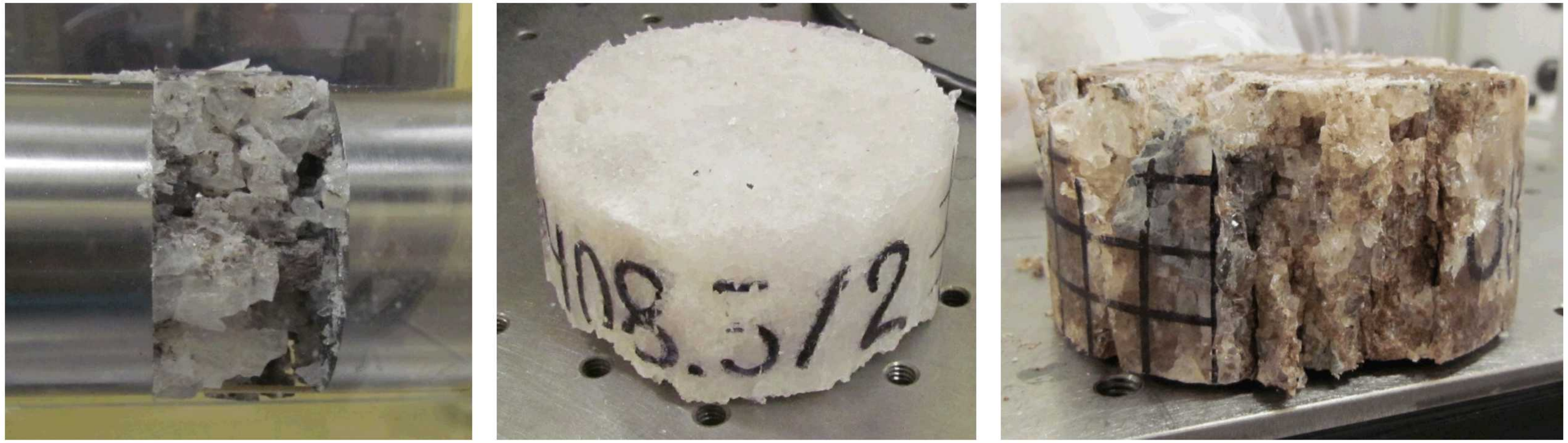
Dynamic compressive strength of rock salts

Experimental results

- Dynamic UCS ratio (parallel to perpendicular direction) of bedded and domal salt were 1.15 and 1.23 (significant anisotropy).
- DIF bedded salt parallel and perpendicular 0.7 and 0.79.
- DIF domal salt parallel 0.86 (no perpendicular quasi-static values).



DIF < 1 represents negative strain rate effect

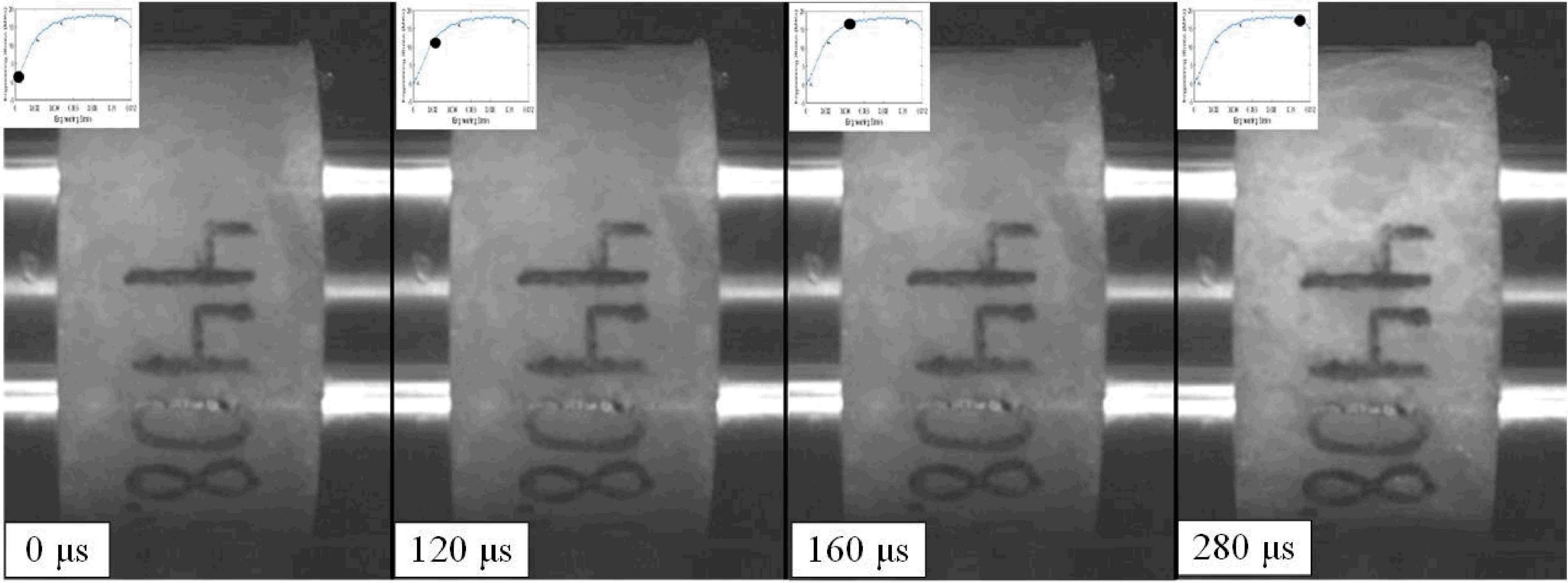


Post-test samples (a) in Kolsky bar, (b) domal salt, (c) bedded salt

Dynamic compressive strength of rock salts

Fracture behavior

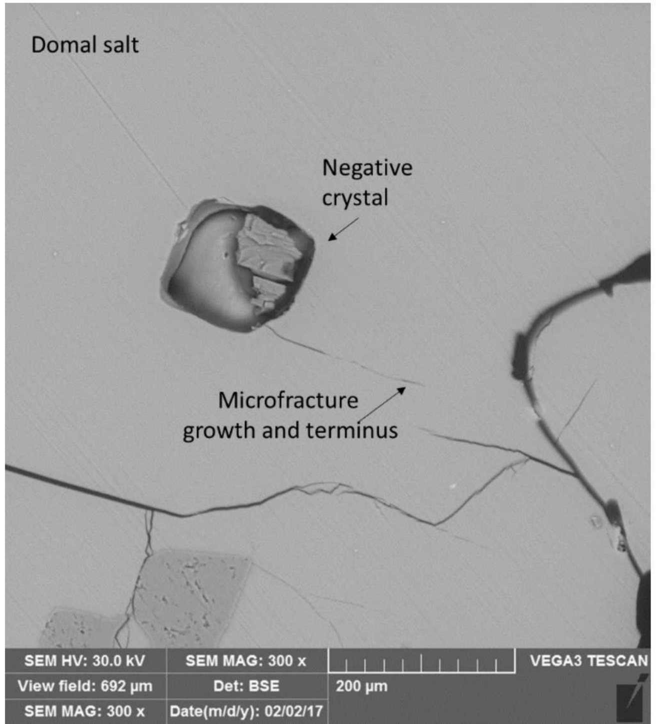
- Image below 25,000 fps for domal rock salt
- Cracks begin at 160 µs and coincides with yield stress

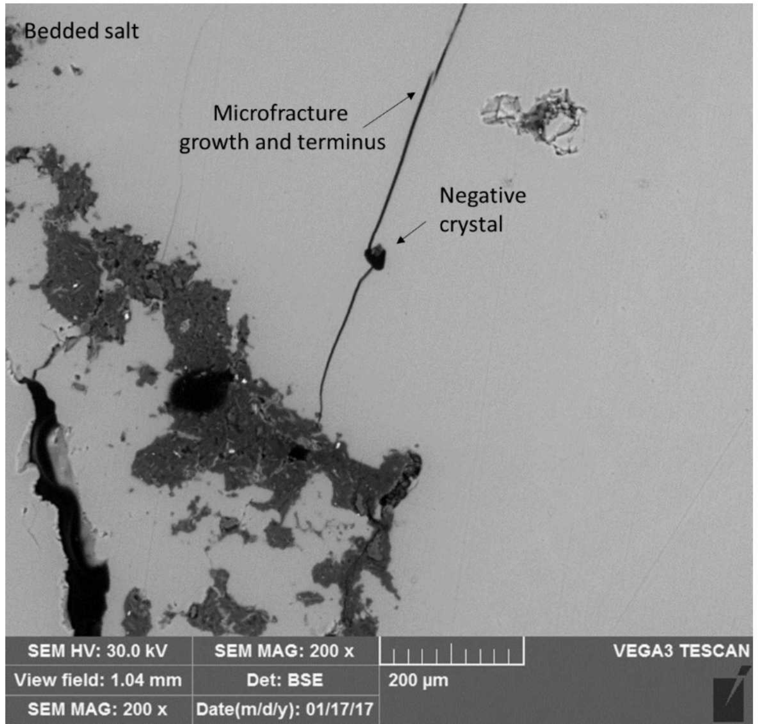


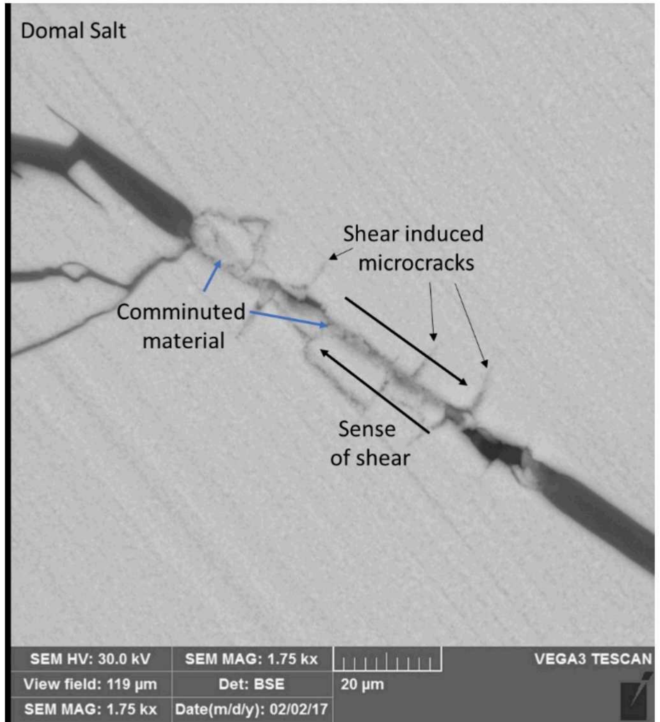
Dynamic compressive strength of rock salts

Fracture behavior

- Microstructure analysis revealed at least two mechanisms which may explain the reduction in strength seen in high rate experiments.
  - Negative crystal pressurization leading to hydraulic fracturing
  - Comminution process may have introduced frictional heating





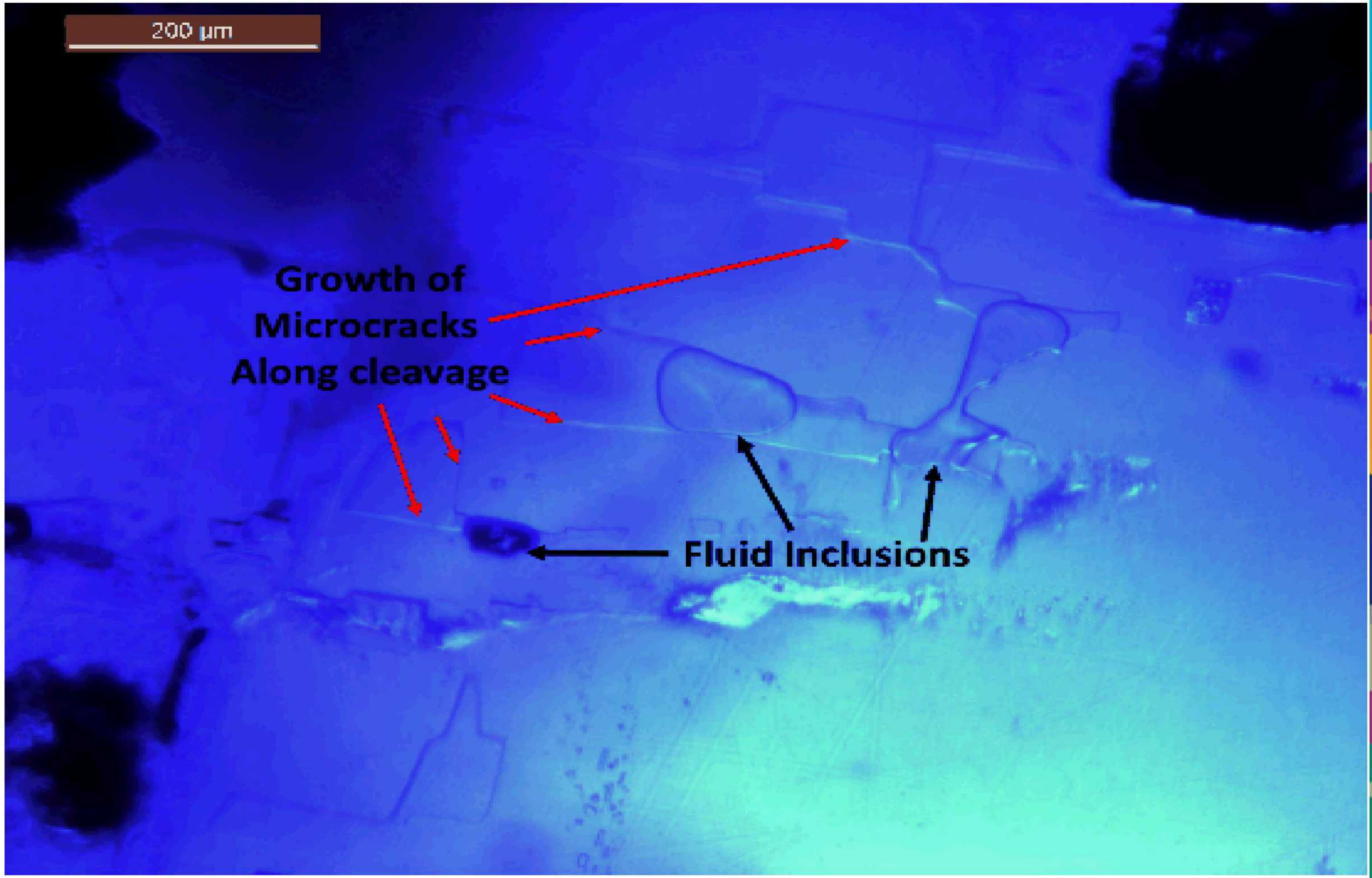


Dynamic compressive strength of rock salts

Combination of:

- Cleavage plane fractures
- Discordant fractures
- Fluid-filled pore fracture
- Comminution at shear zones

Most likely caused crystal plasticity which lead to the observed decrease in strength at high strain rates.



Summary

- Bedded and domal salts had similar σ_y and different σ_{ult}.
- Domal salt parallel and perpendicular to foliation: UCS 22.3 and 18.2 MPa.
- Bedded salt parallel and perpendicular to bedding: UCS 19.6 and 17.1 MPa.
- Significant anisotropy with parallel to perpendicular strength ratios of 1.23 and 1.15 for domal and bedded.
- Negative strain rate effect: DIF of 0.86 parallel domal, 0.7 and 0.79 parallel and perpendicular bedded.
- Primary deformation mechanism observed was fracturing.
- Combination of hydraulic fracturing and localized heating likely caused crystal plasticity leading to negative strain rate effect.