S43C-2282: Laser-based excitation and diagnostics of planar fractures

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I - Introduction

- Faults and fractures are of interest to earth scientists at various scales
  - control fluid flow: water, magma, hydrocarbons...
  - remote sensing of faults ⇒ invert seismic data for fracture properties
  - wave field directly excited at fracture ⇒ similar to acoustic emissions or micro-earthquakes
- Generation of elastic waves at fracture location
  - excitation by focusing laser light onto fracture in transparent material
  - measured displacement field shows fracture tip diffractions
  - tip diffractions confirmed from incident waves scattered by the fracture
- Potential for more detailed studies of fracture properties
  - stress load and/or fluid content

II - Laboratory sample: fractured plastic cylinder

Fracture generation using a high-power laser

- PMMA cylinder, 150 mm high x 50 mm in diameter
- high-power pulsed laser beam focused inside the sample
- light absorption ⇒ thermal expansion ⇒ fracture
- fracture parallel to cylindrical axis, diameter $2a \approx 7$ mm

(Zadler and Scales, 2008; Blum et al., 2011)

III - Experimental setup: laser generation and detection of P-waves

- Pulsed infrared laser source
  - low energy pulsed laser beam focused on source location
  - optical contrast leads to energy absorption ⇒ localized heating
  - thermal expansion results in elastic waves
- Laser interferometer receiver details
  - measures absolute displacement (nm)
  - wide bandwidth (20 kHZ — 20 MHz)
  - fixed with respect to the source location, $\delta = 20^\circ$
  - measures displacements in order of Å
- PMMA sample mounted on a rotational stage
  - sample rotates while source and receiver are fixed in the laboratory frame
  - source and receiver focused in an $(x - y)$ plane normal to the cylinder axis
  - acquires one trace per degree
  - automated acquisition using computer-controlled stage and acquisition board

IV - Measured displacements

- Fracture source event (in purple)
  - travels a distance equal to the cylinder radius R
- Surface source event (in orange)
  - energy scattered from the fracture
  - travels a distance $2R$

surface excitation **fracture excitation**

V - Tip diffractions travel-time: fracture size

- Both arrivals show tip diffractions from fracture edges
- Distance from each fracture tip to receiver depends on angle $(\theta + \delta)$
- Arrival times can be predicted from geometry
  - for fracture source: $t_{\text{frac}} = \frac{R}{\alpha}\left(1 \pm \frac{a}{R}\sin(\theta)\right)$
  - for surface source: $t_{\text{surf}} = \frac{R}{\alpha}\left(2 \pm \frac{a}{R}(\sin\theta(1+\cos\delta) + \sin\delta\cos\theta)\right)$
  - a = fracture radius, R = cylinder radius, α = P-wave velocity
- Best fits overlain on both arrivals: estimated diameter $2a \approx 6.8$ mm

VI - Scattering amplitudes: fracture properties

- Amplitude of scattered arrival can be used to estimate fracture properties
  - radius of the fracture (a)
  - orientation of the fracture (θ)
  - compliance of the fracture (η), assuming linear-slip model (Schoenberg, 1980)
- we estimated normal compliance $\eta_N \approx 10^{-11}$ m/Pa (from Blum et al. (2011))

VII - Conclusion

- Laser-based ultrasonic techniques can
  - excite and detect elastic waves at the surface
  - excite heterogeneities (fractures) inside optically clear materials
- Fracture size estimation (verified by direct observations)
- Future applications for earthquake dynamics
  - measure spatial variations in the fracture properties
  - delineate barriers and asperities (Scholz, 1990)
  - measurement of fracture response as a function of stress loads
  - local excitation of the fracture
  - measurement of fracture response as a function of fluid content
- For more details see Blum et al. (in press)

References

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