Photo-Simulated Luminescence Spectroscopy Stress Sensor for In Situ Stress Measurement

Yarom Polsky, Michael Lance, and Catherine Mattus – Oak Ridge National Laboratory
James Hemrick – Reno Refractories

Project Overview

The objective of this project is to develop a novel and robust technology and methodology for measuring the *in situ* stress state in the near borehole region. The proposed sensor technology is less mechanically complex and operationally simpler to implement than existing techniques for measuring in-situ stress such as overcoring and fracture sleeves.

Background

- Existing *in situ* stress measurement methods are either complex to implement or overly interpretive
  - Minifracs
  - Borehole imaging (breakouts)
  - Overcoring
  - Sleeve fracturing

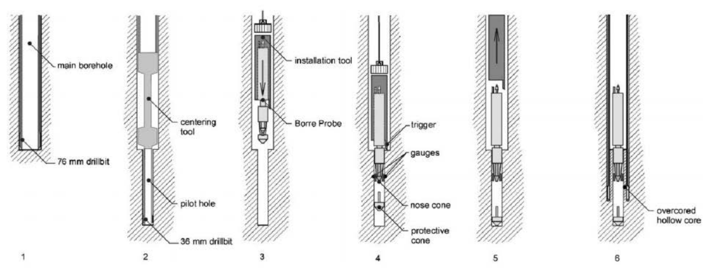
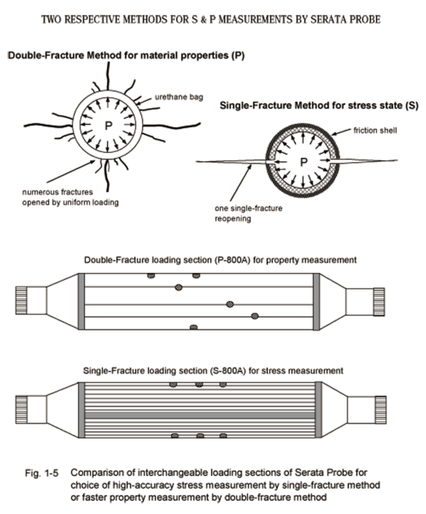


Figure 1: General steps in overcoring illustrated by the Borre probe (from Hakala et al., 2003).

Overcoring Method

Frac Sleeve



Picture from Serata Geomechanics

Proposed Solution

Develop a castable cementitious material with high concentration of stress responsive α-Alumina that can be installed in an overbalanced hydrostatic condition to characterize *in situ* stress magnitude and direction.

Advantages Over Existing Methods

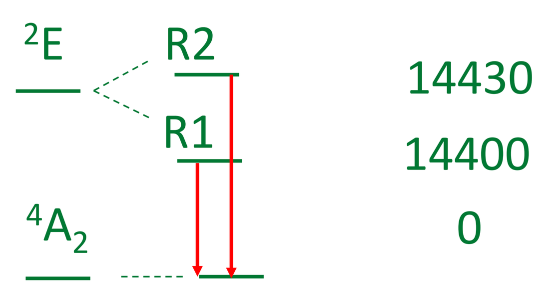
- Simpler implementation
- Better directional resolution

Basis for Photo-Stimulated Luminescence Stress Measurement

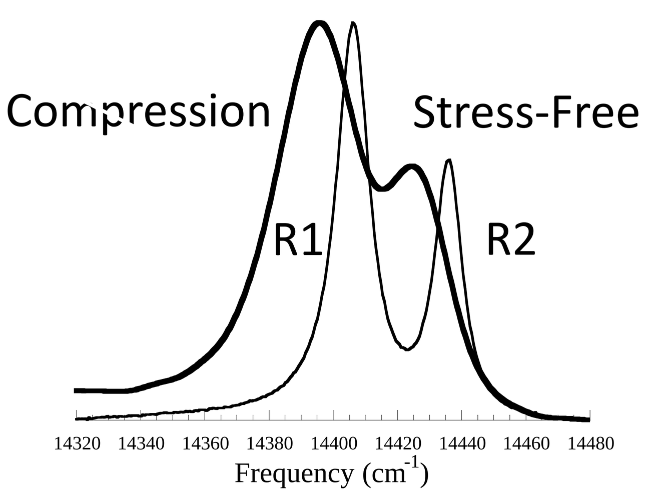
Luminescence of Cr^{3+} in Al_2O_3

The crystal field determines the energy levels:

Frequency (cm^{-1})



Stress Shift



Stress changes the distance between the ion and the surrounding crystal which causes the energy levels to shift:

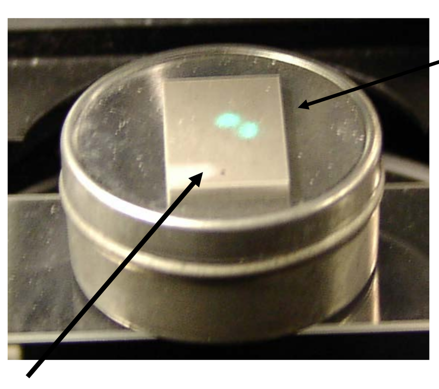
$$\Delta\nu = \Pi_{ij} a_{ik} a_{jl} \sigma_{kl}$$

The peak shift gives the mean hydrostatic stress in randomly-oriented alumina.

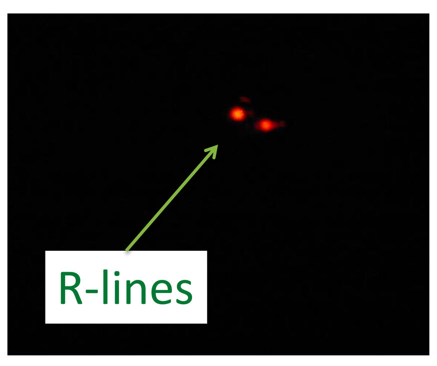
For isotropic polycrystalline α-Al_2O_3:

$$\Delta\nu = \tfrac{1}{3}(\Pi_{11}+\Pi_{22}+\Pi_{33})(\sigma_{11}+\sigma_{22}+\sigma_{33}) = \Pi_{ii}\sigma_h$$

Incident Laser Wavelength: 515 nm

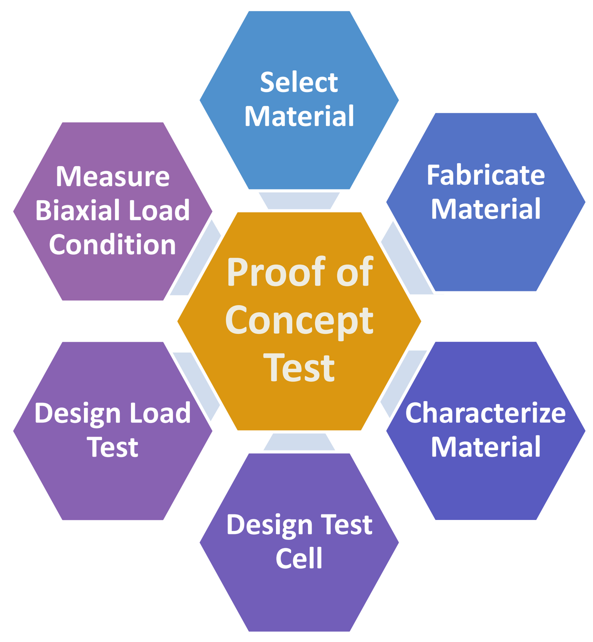


With Filter: Emission at ~690 nm



Technical Approach

1. Complete evaluation and selection of ceramic or cementitious materials with optimal alpha alumina concentrations needed for stress measurement
2. Complete design and fabrication of load frame, photo stimulated luminescence measurement system, and sample container.
3. Complete fabrication of test speciments and confirm that stress state can be measured using luminescence spectroscopy in uniaxial load tests.
4. Complete stress measurement using proposed sensor in laboratory simulation of in-situ conditions. Demonstrate ability of sensor to measure biaxial stress state orientation to within 10 degrees and within 25% of magnitude of applied stress values.

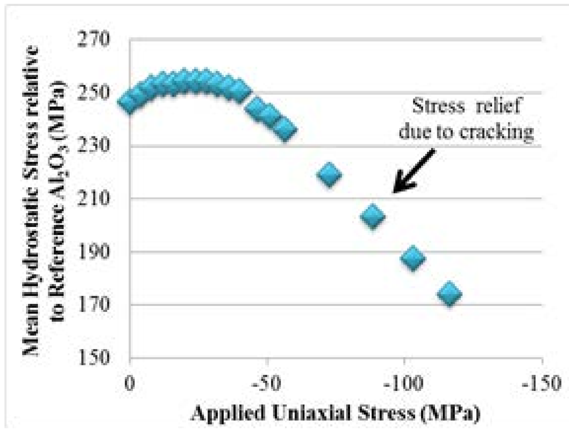


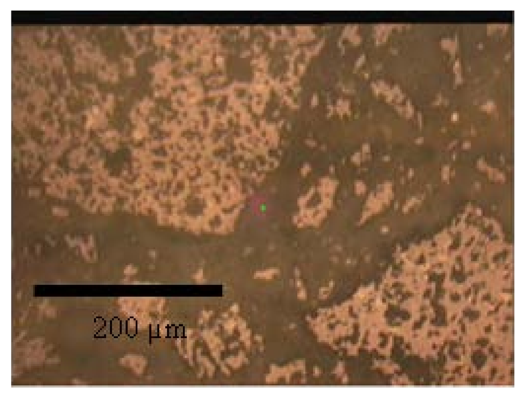
Progress to Date

Two rounds of material development

- 1st round characterization complete
- 2nd round characterization underway

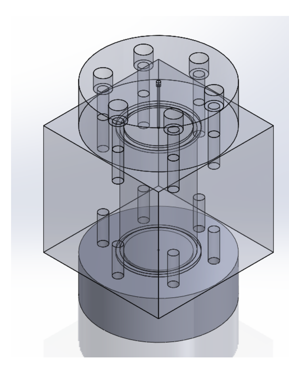
First round (left) and second round (right) samples



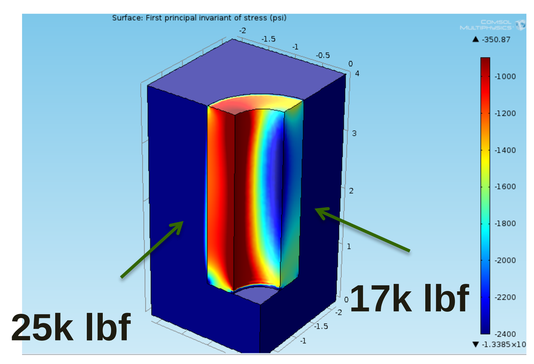


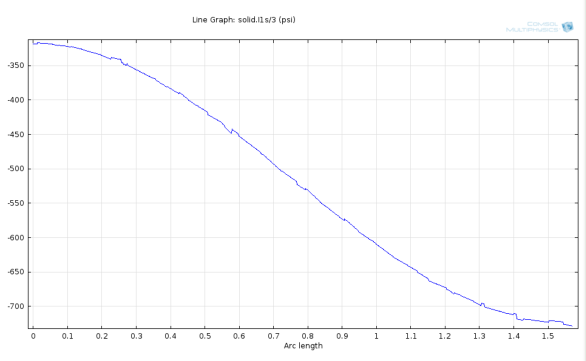
Hydrostatic stress vs applied uniaxial stress for 1st round sample (left) and microstructure of material (left)

Test setup concept design complete



Test cell





σ_{hyd} around circumference of plug

Future Plans

Year 1
- Formulate material PSLS material compositions suitable for field deployment
- Characterize materials against performance requirements
- Perform field deployment feasibility studies

Year 2
- Finalize development and testing of PSLS stress sensing material
- Complete design of pumping and cement casting system
- Completed design of field deployable fiber optic measurement system

Year 3
- Complete field trial of *in situ* stress measurement