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Thermal expansion, fluid flow, and thermal shock of cement and a cement/steel interface at elevated pressure and temperature

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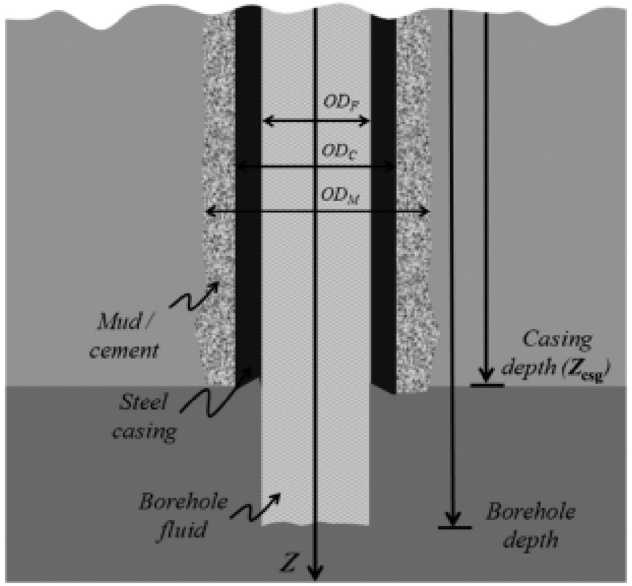
Outline

1. Motivations
2. Materials and methodology
3. Experimental results
4. Post-test analysis
5. Conclusions

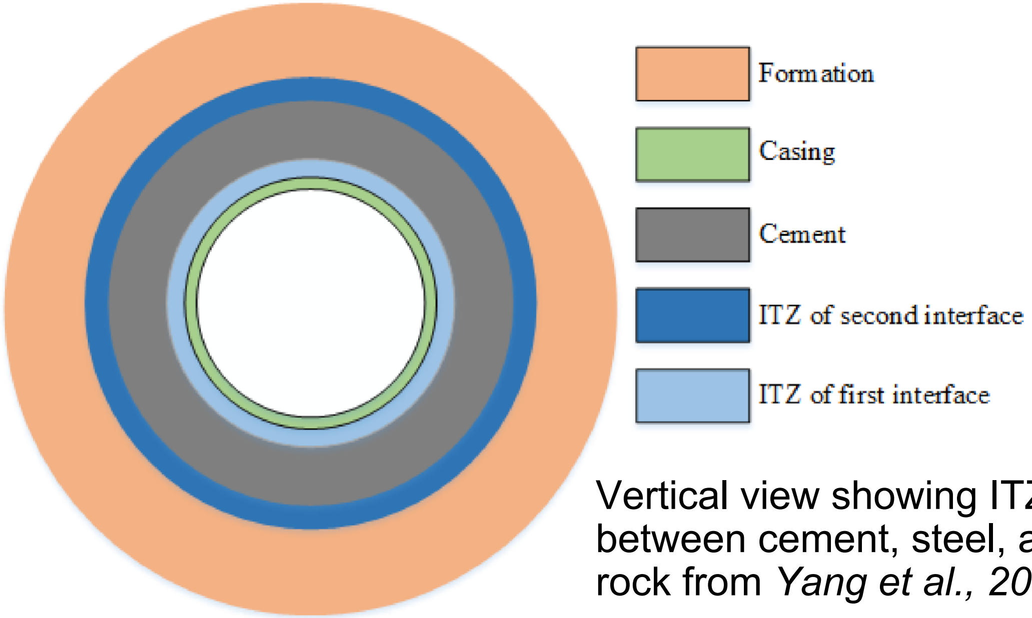
Motivations

Importance of Borehole Cement Interface

- Cement is a critical component of well stability
- Cement seals surrounding rock from wellbore, protects from casing corrosion, and supports steel casing



Borehole schematic from *Cuevas, 2021*

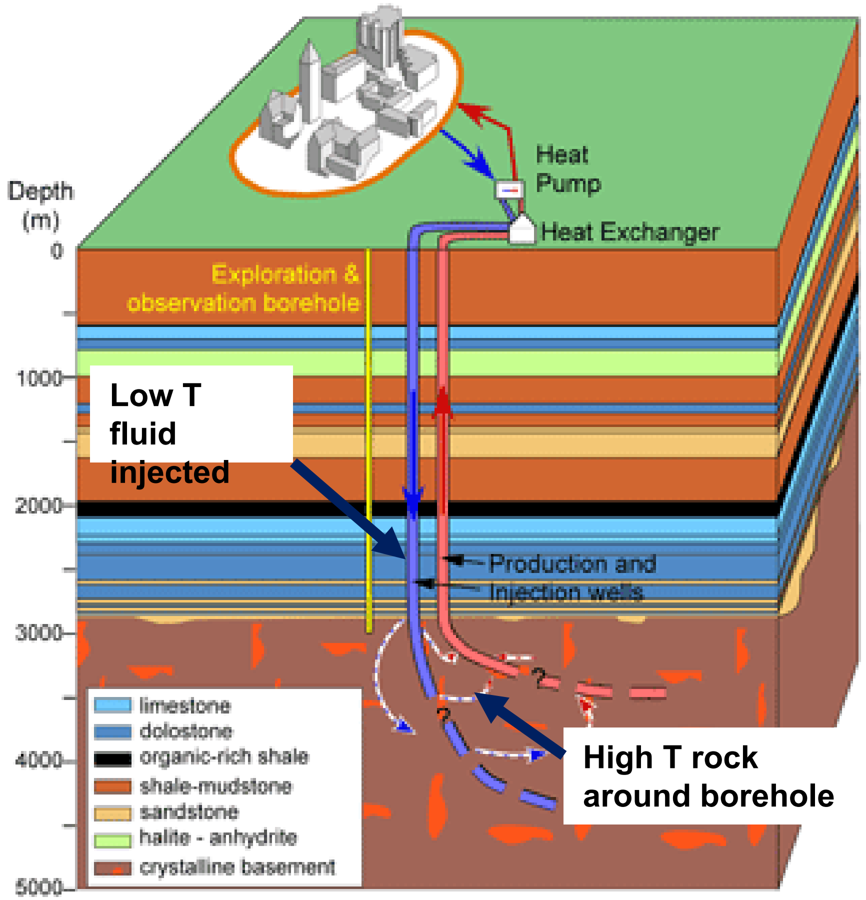


Vertical view showing ITZ between cement, steel, and rock from *Yang et al., 2022*

- Weakest point in cement between the cement-steel interface or interfacial transition zone (ITZ)
- ITZ strength depends upon material properties and borehole conditions (pressure, temperature, etc.)

Cement-Steel Interface in Geothermal Systems

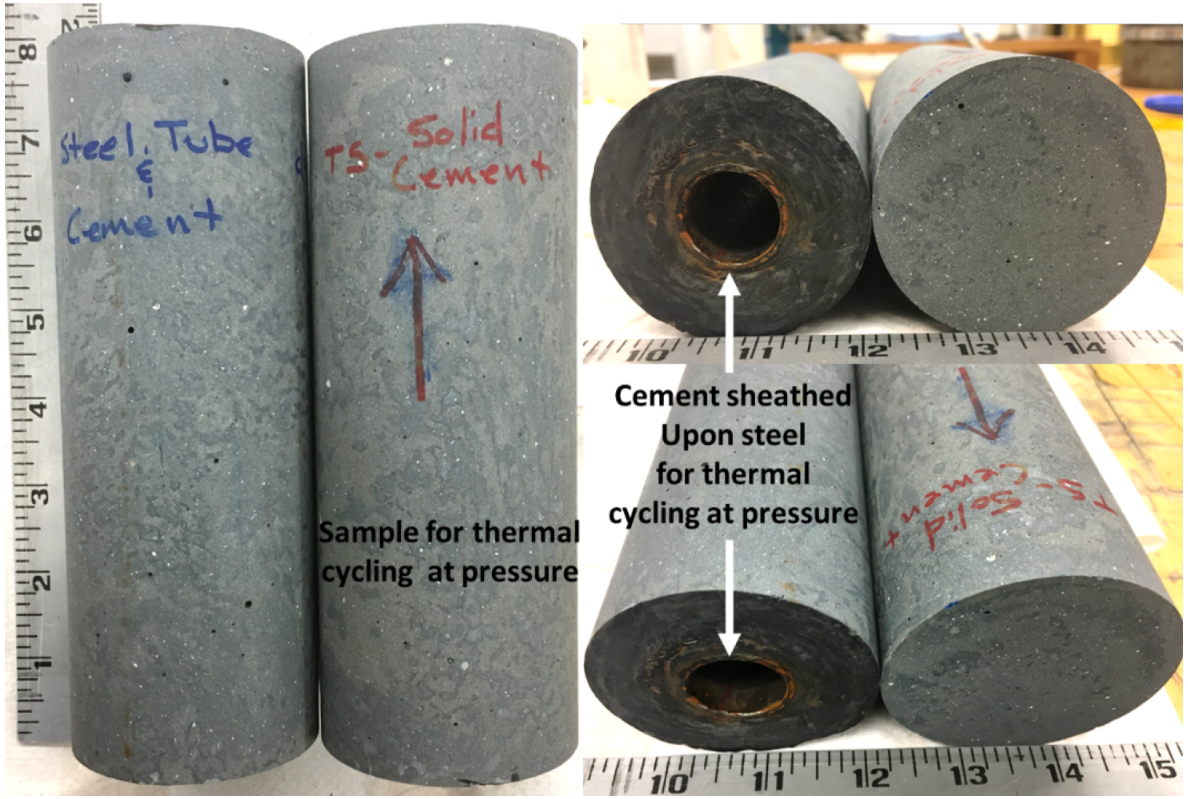
- Enhanced geothermal systems (EGS) typically inject cold water into hot formations (T > 150 ˚C)
- The 'thermal shock' from reducing temperature is expected to affect the cement-steel interface
    - Potentially weaken the bond and degrade the cement strength
- Thermomechanical behavior around borehole due to cold water injections remains largely uncharacterized

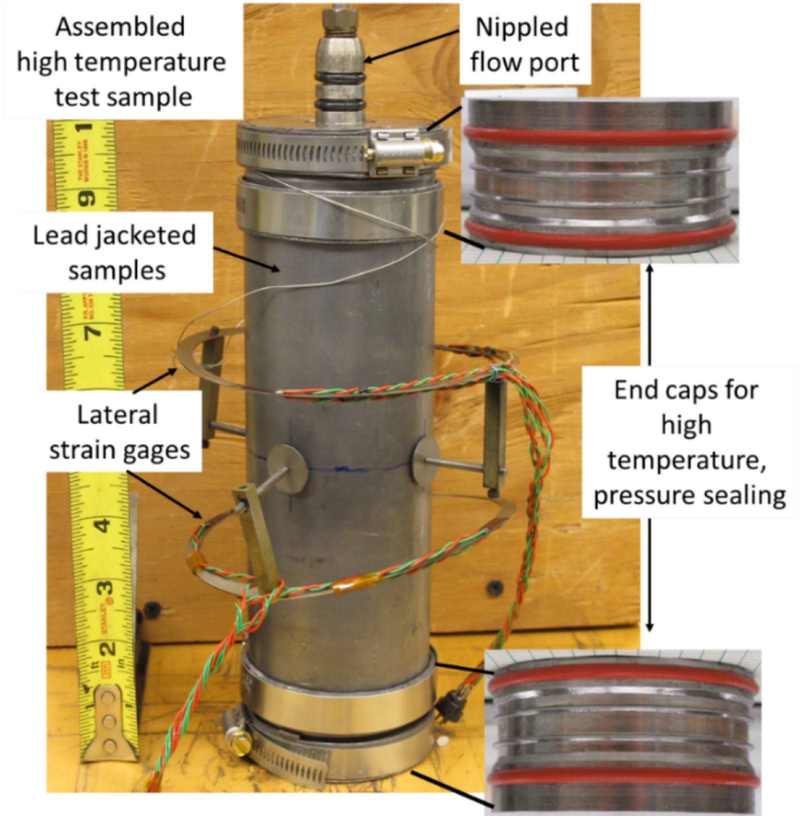


Geothermal system schematic modified from *Jordan et al, 2020*

Materials and Methodology

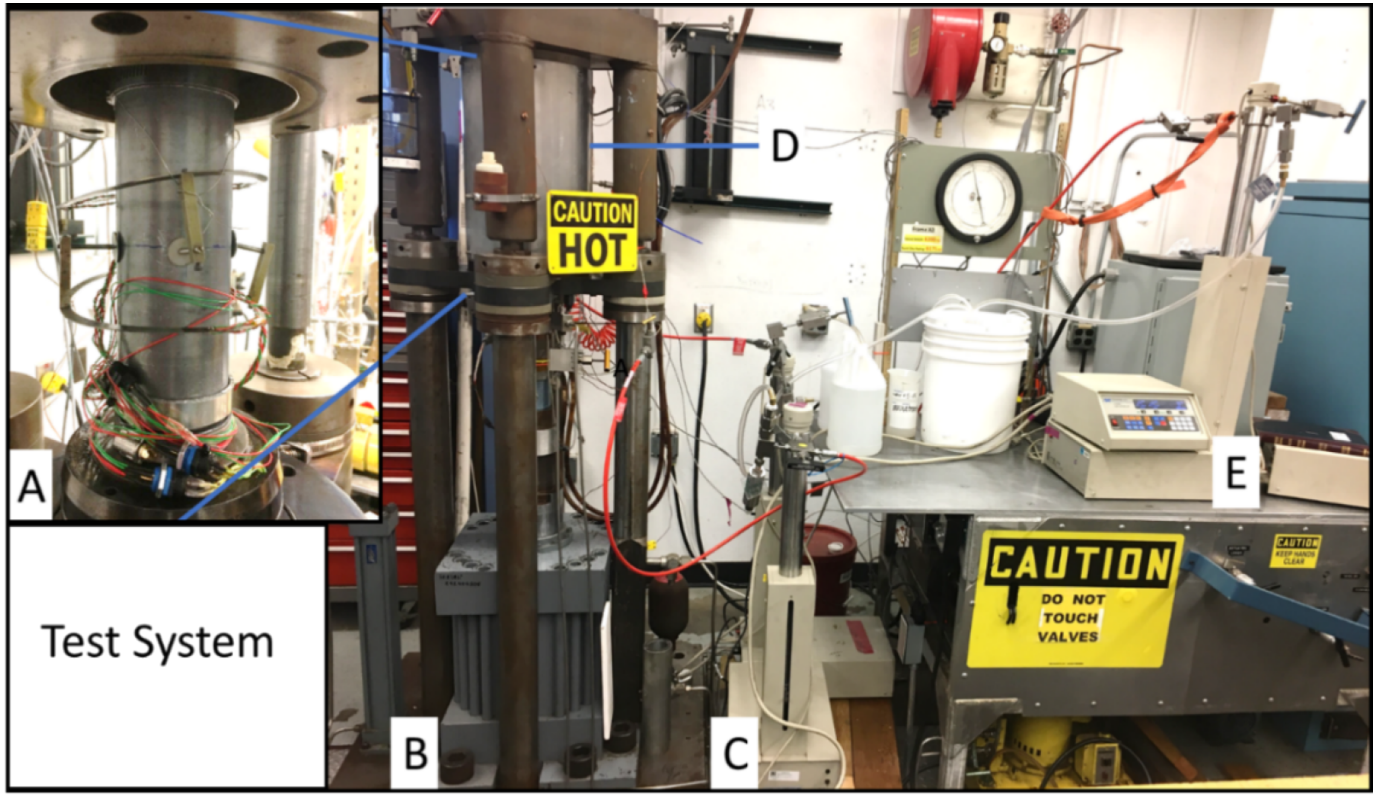
Borehole Cement Sample





- Thermally Insulating Lightweight Shock-Resistant Cement (TILRSC) developed by Brookhaven National Laboratory (for composition see *Sugama and Pyatina, 2021*)
- Cement sample tested is sheathed around steel tube simulating borehole ITZ

Test Plan



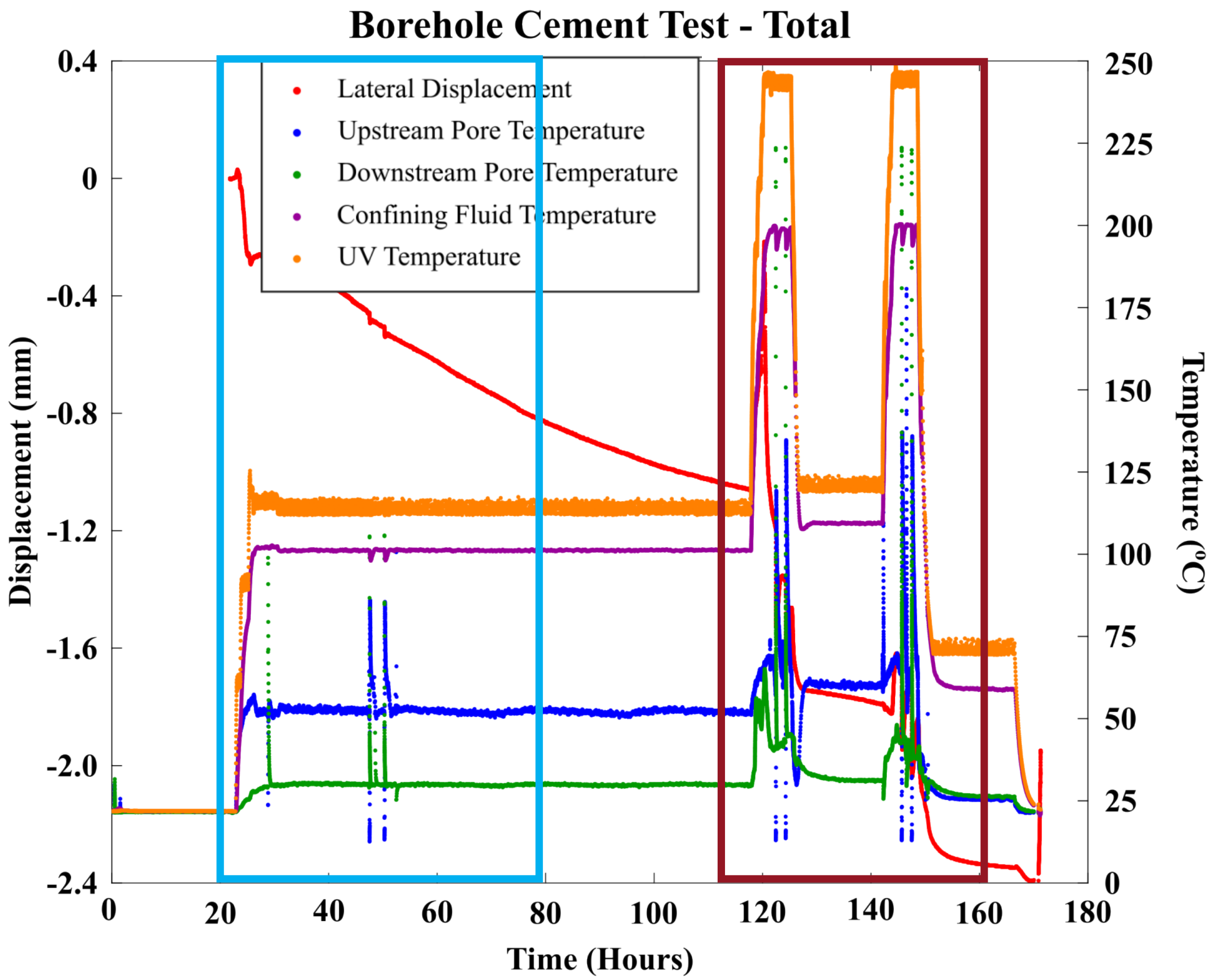
A – Assembled sample in test system
B – Loading frame
C – Pore pressure pumps

D – Pressure vessel with insulating furnace
E – Confining pressure pump

1. Sample confined at pressure of 20.7 MPa
2. Pore pressure applied at upstream and downstream ends to 17-17.3 MPa, upstream slightly higher to maintain fluid flow
3. Temperature increased to 100 ˚C and allowed to equilibrate
4. Cold water (T < 40 ˚C) injected with rapid flow rate at the upstream end to thermally shock sample for ~3 minutes
5. Temperature allowed to equilibrate with confining fluid
6. Repeat steps 3-5 at 200 ˚C
7. Unload pressures

Experimental Results

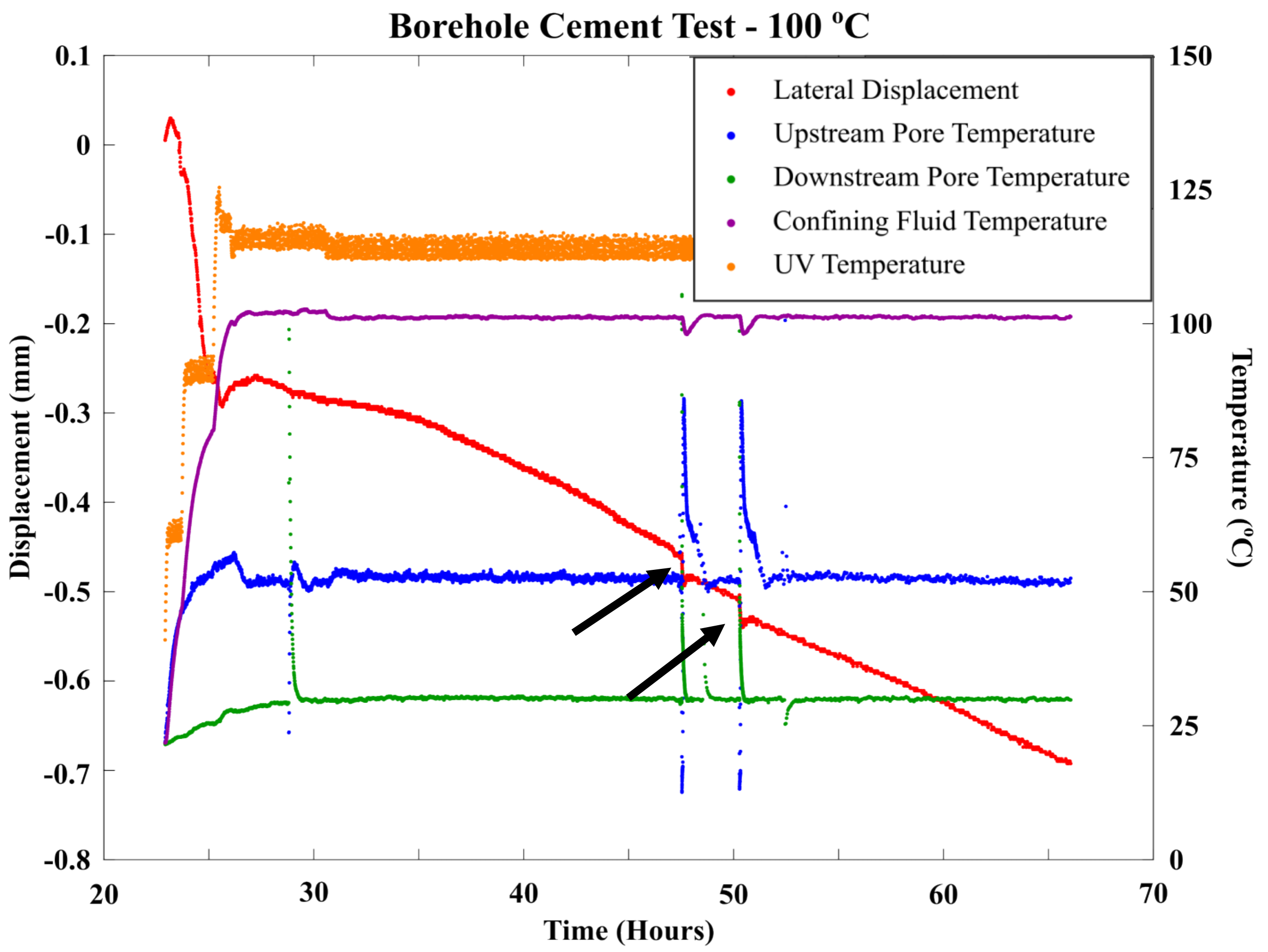
Cement Creep Test



- Full test approximately 170 hours
- Effect of temperature was characterized by lateral displacement (**red**)
- Thermal shocking occurred between **20-70 hours** (100 ˚C) and **110-160 hours** (200 ˚C)
- Negative displacement indicates contraction, positive displacement indicates expansion

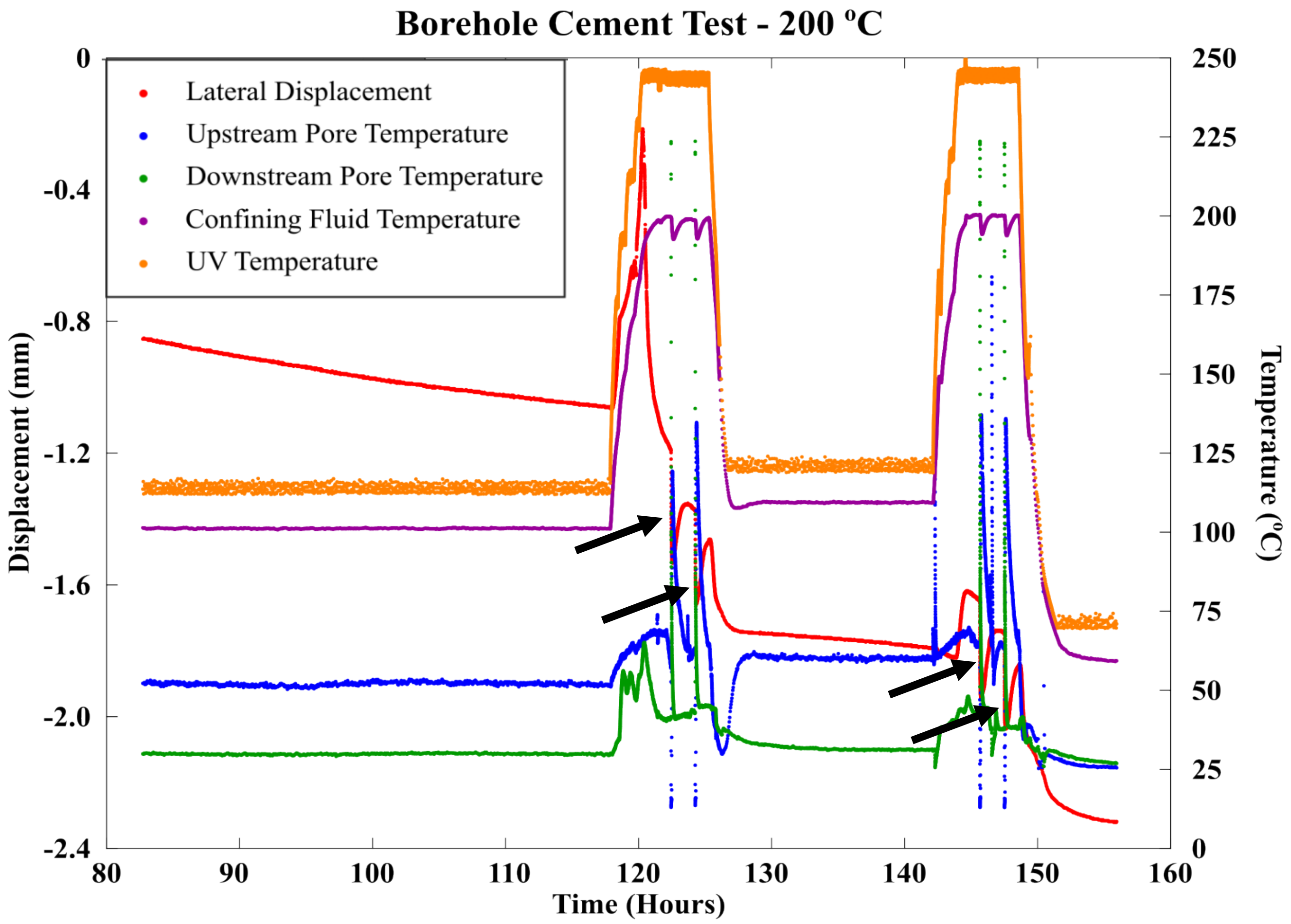
100 ˚C – Thermal Shock

- Temperature increase to 100 ˚C causes significant compaction
- Two thermal shock tests conducted on same day (**arrows**)
- Cold water injection caused rapid, minor contraction
- Thermal shocks increased compaction but did not change displacement rate after

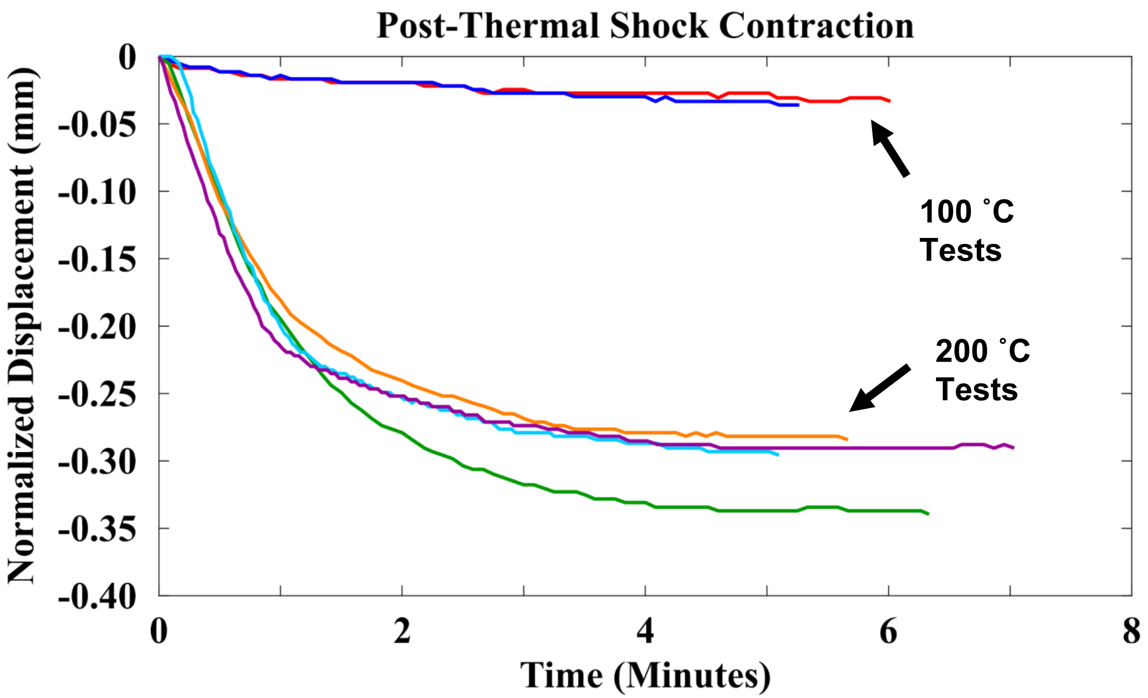


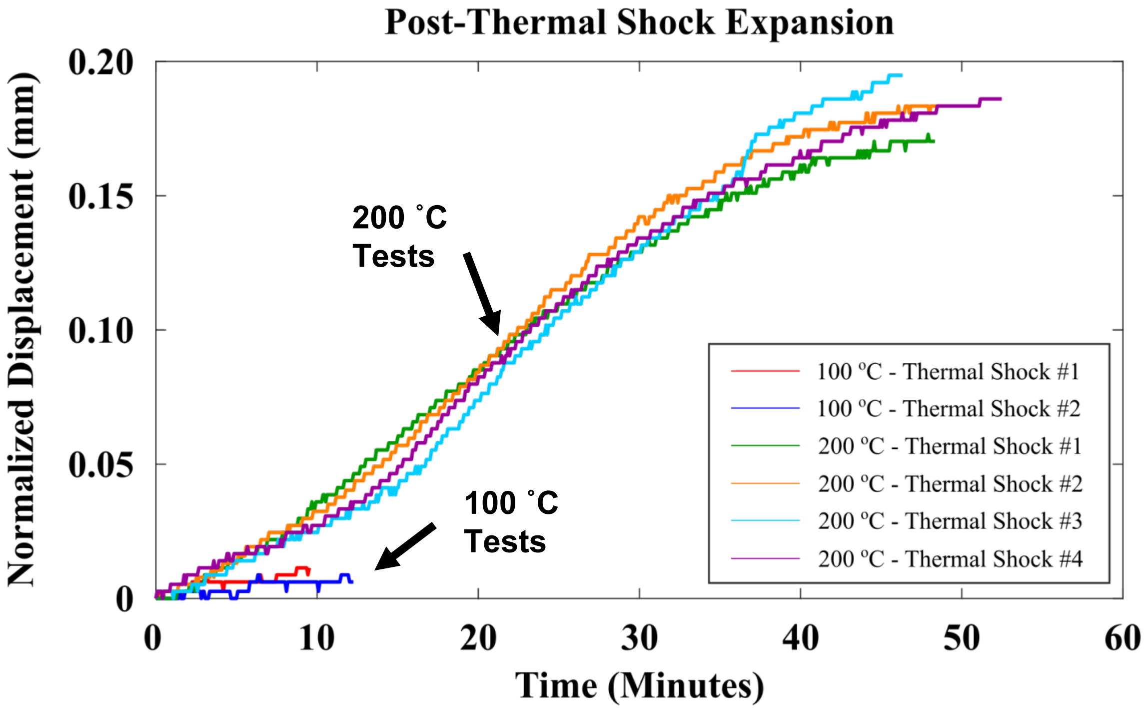
200 ˚C – Thermal Shock

- Temperature increase initially triggers significant expansion then contraction
- Four thermal shock tests, two each conducted on the same day (**arrows**)
- Cold water injection caused large rapid contraction then slow expansion as the cement-steel re-equilibrated to the surrounding temperature



Thermal Shock - Normalized Displacements

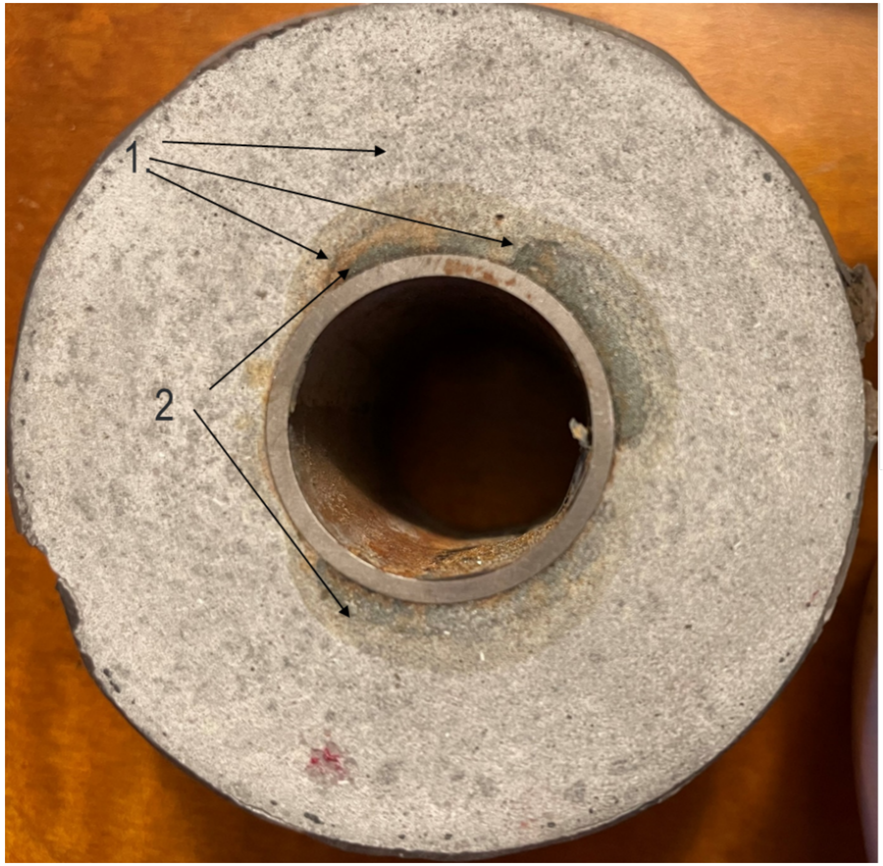




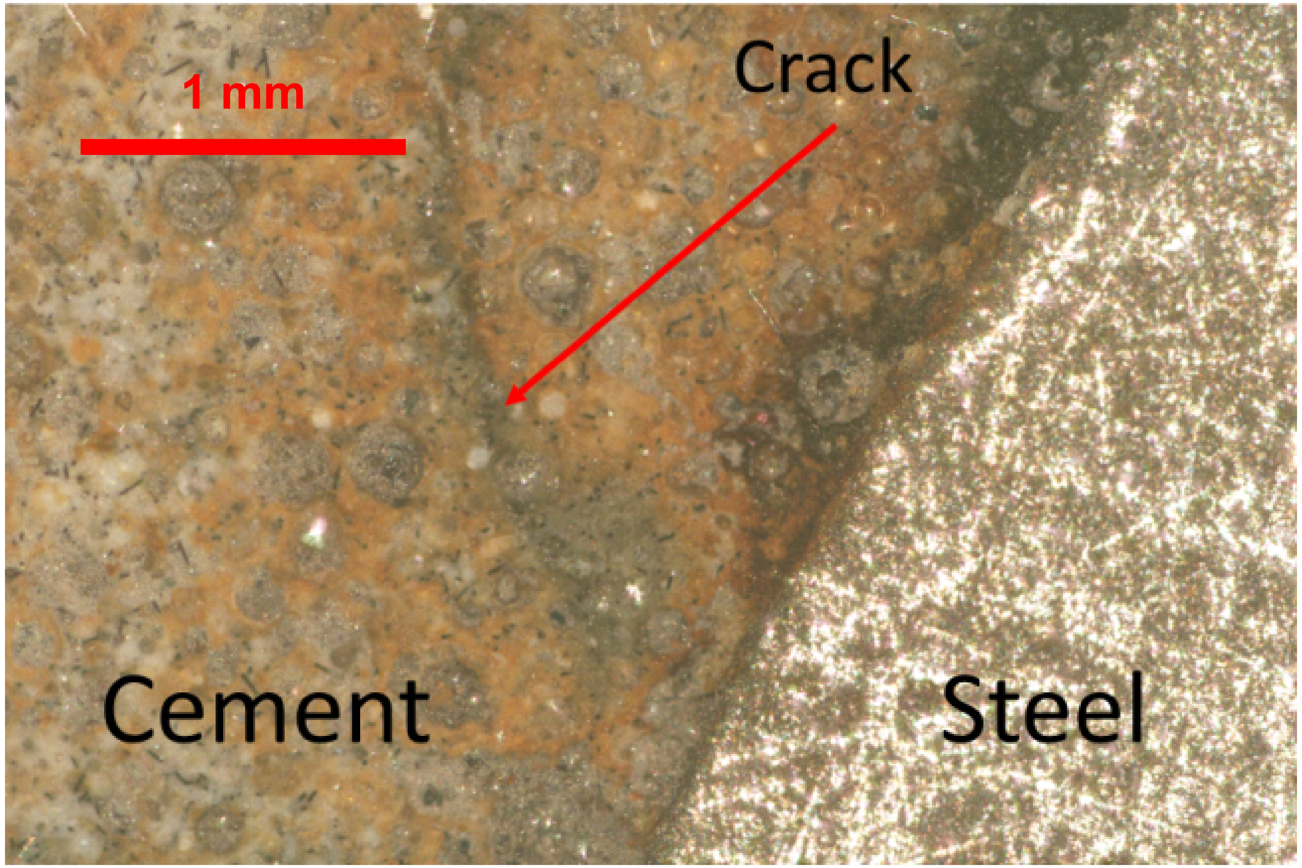
- Contraction is very rapid but stops after thermal shock test ends (~ 3 min)
- Expansion following contraction is smaller and occurs at a slower rate
- Larger thermal gradient produces greater contraction of the sample after each test

Post-Test Analysis

Post-Test Sample

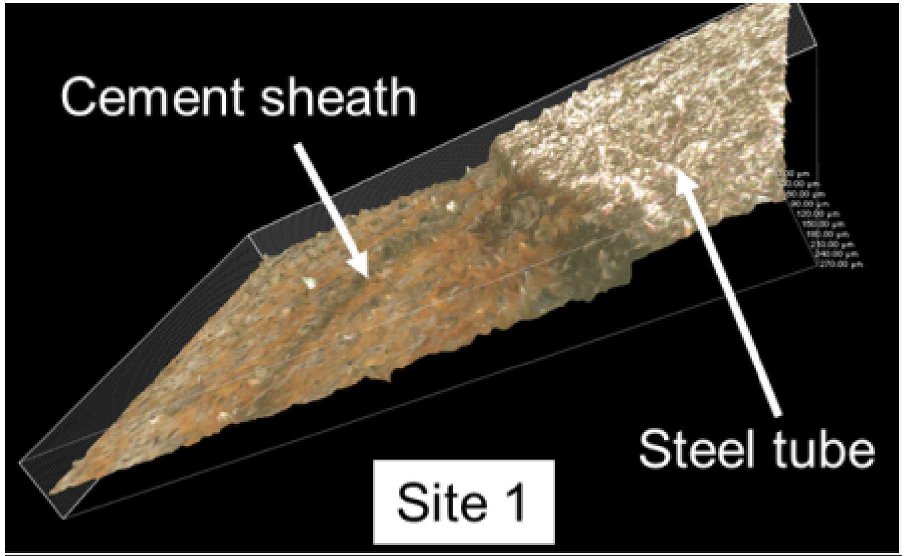


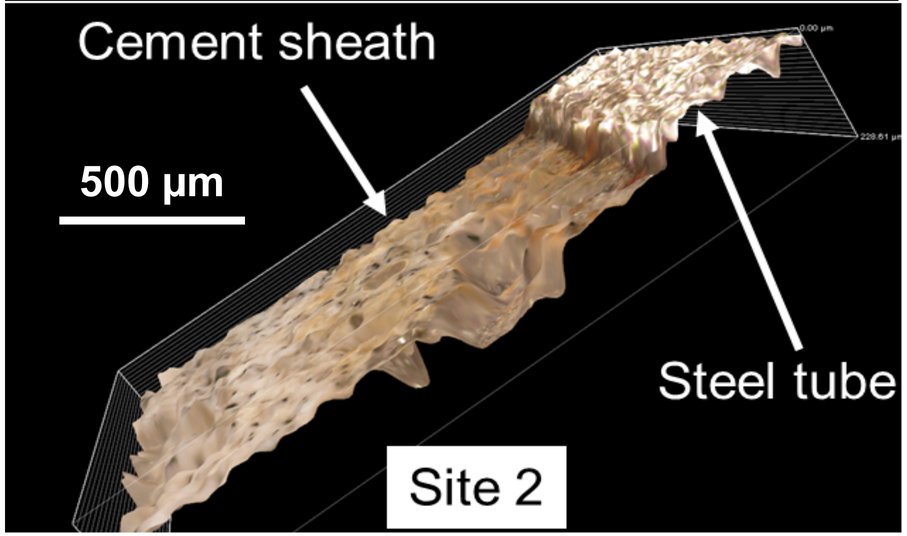
Cross-section of cement sample shows possible **fractures (1)** and **altered zone (2)** around the cement-steel interface

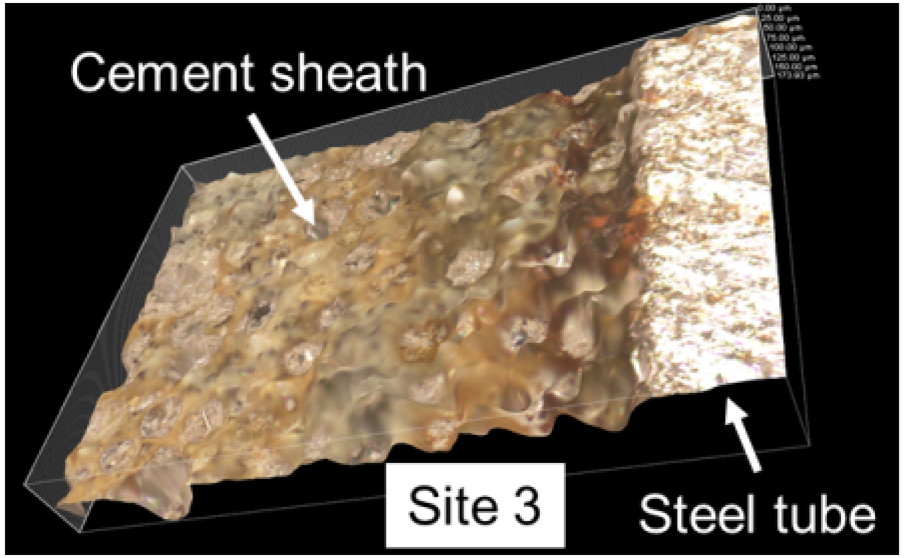


Microscope image of interface shows apparent cracking but **no separation at interface**

Cement-Steel Interface







- 3D images of cement-steel interface after testing
- Nikon Eclipse LV 150 3D microscope
- Cement-steel bond remains coherent post-test

Conclusions

Conclusions

- Cement compacts irreversibly during heating at pressure
- Cold water injection enhances cement contraction, depending on the temperature difference between the fluid and the cement-steel
- Observed fracturing and cement contraction/expansion during thermal shock tests suggest thermal shocks are major cause of material modification around interface
- Experimental results and post-test analysis indicate integrity of cement-steel interface is maintained throughout testing

References and Acknowledgements

References

Cuevas, N. H. (2021). An approximate inversion scheme for surface-borehole electromagnetic in the presence of steel casing: 1D implementation. *Geophysics*, 86(2), E111-E121.

Jordan, T., Fulton, P., Tester, J., Bruhn, D., Asanuma, H., Harms, U., & Smith, J. (2020). Borehole research in New York State can advance utilization of low-enthalpy geothermal energy, management of potential risks, and understanding of deep sedimentary and crystalline geologic systems. *Scientific Drilling*, 28, 75-91.

Sugama, T., & Pyatina, T. (2021). Hydrophobic Lightweight Cement with Thermal Shock Resistance and Thermal Insulating Properties for Energy-Storage Geothermal Well Systems. *Materials*, *14*(21), 6679.

Yang, Y., Li, L., Yu, W., Zhou, Y., Zhu, K., & Yuan, B. (2022). The Application of Breakthrough Pressure in the Evaluation of the Sealing Ability of Cement–Casing Interface and Cement Matrix in Underground Gas-Storage Wells. *Processes*, 10(4), 620.

Acknowledgements

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