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Sandia National Laboratories

A high-fidelity thermal-fluid-solid modeling approach to understand defect formation and residual stresses in additive manufacturing builds

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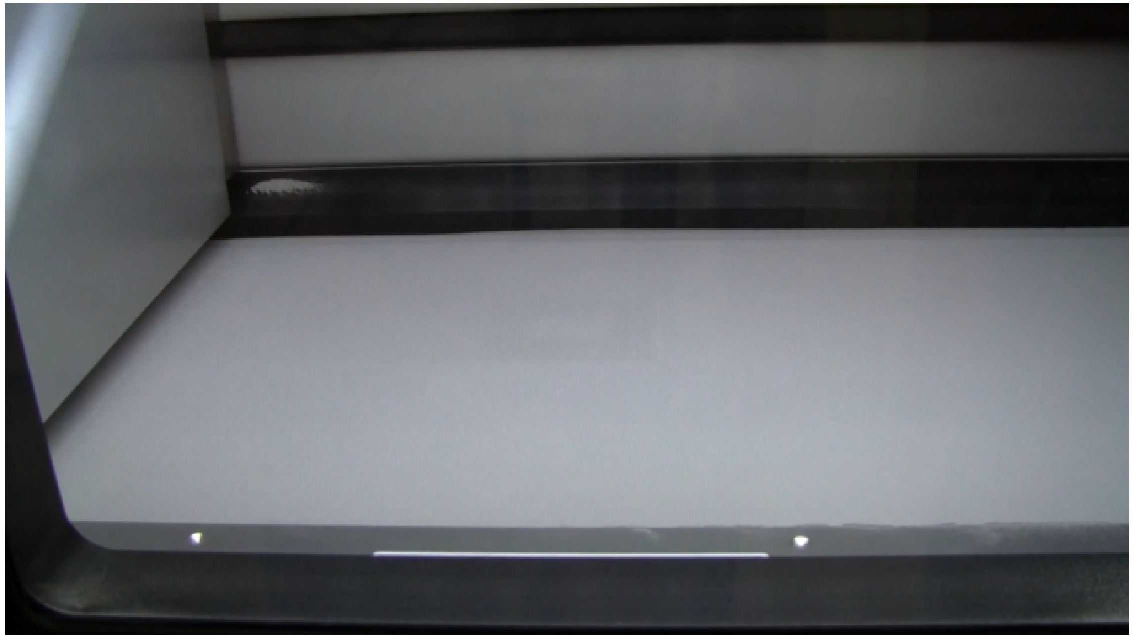
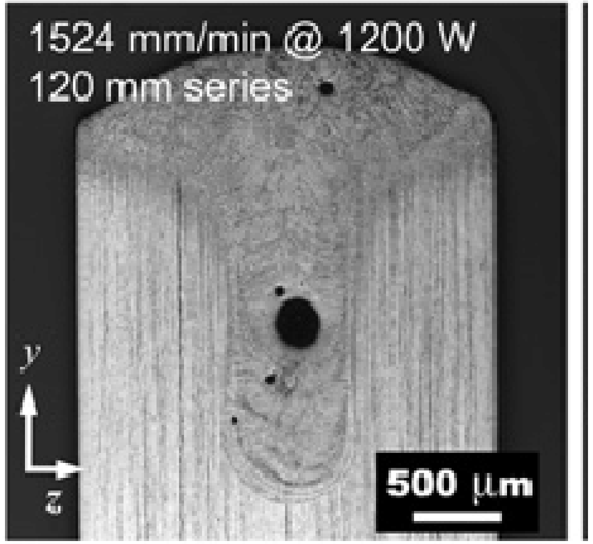
Defects are a concern in laser powder bed fusion (LPBF)



NIST

LPBF additive manufacturing

- Allows flexibility of design and rapid prototyping
- Ongoing research to have AM parts meet quality and standards
- Combining environments (irradiation, fluid, and solid mechanics) can be computationally challenging



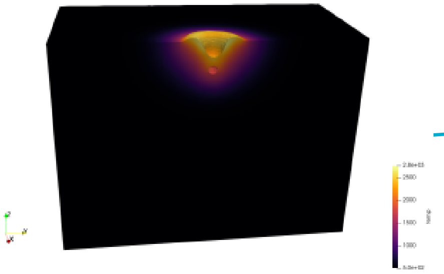
Example of a laser weld defect in 304L

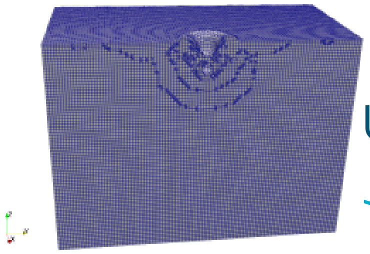
Madison & Aagensen, Scripta Materialia (2012)

- Keyholes, pores, surface roughness or thermal cracking are examples of concerning defects

Thermal-fluid-solid modeling approach

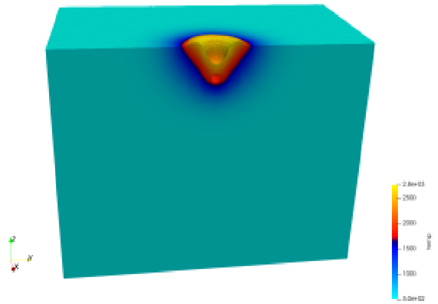
Thermo-fluid model Sierra/Aria
Run fluid model to get the temperature field for each timestep in simulation



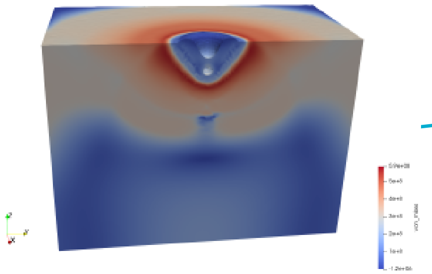


Make hex mesh
Using Cubit's sculpt algorithm, mesh the pore fluid-solid shape

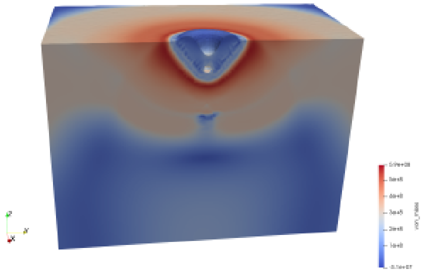
Time of 2ms split into 232 'iterations'



Solid Mechanics model 1 Sierra/SM
Map the thermal history onto new hex mesh for solid mechanics boundary conditions

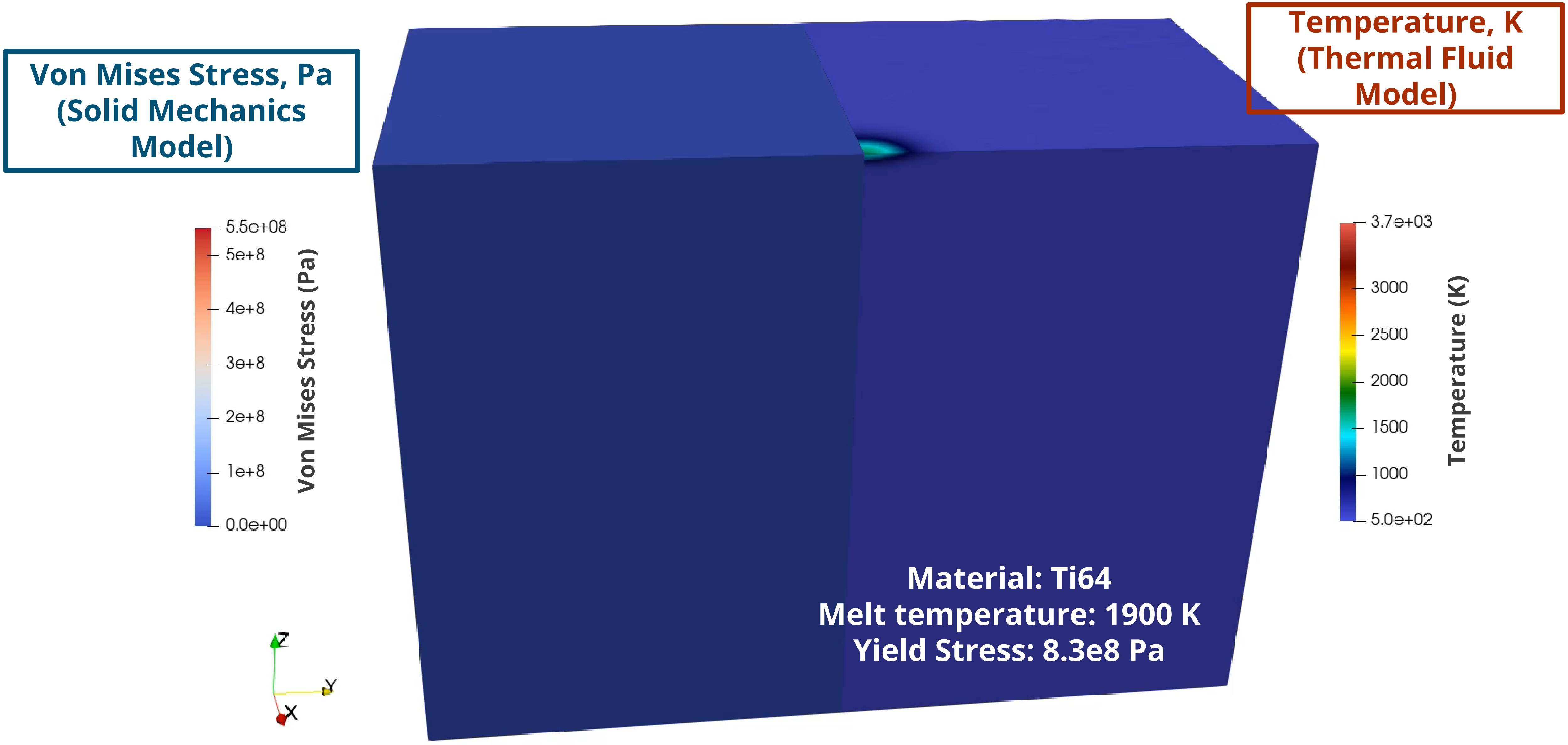


Solid Mechanics model 2 Sierra/SM
Map the previous iteration's state variables onto new hex mesh

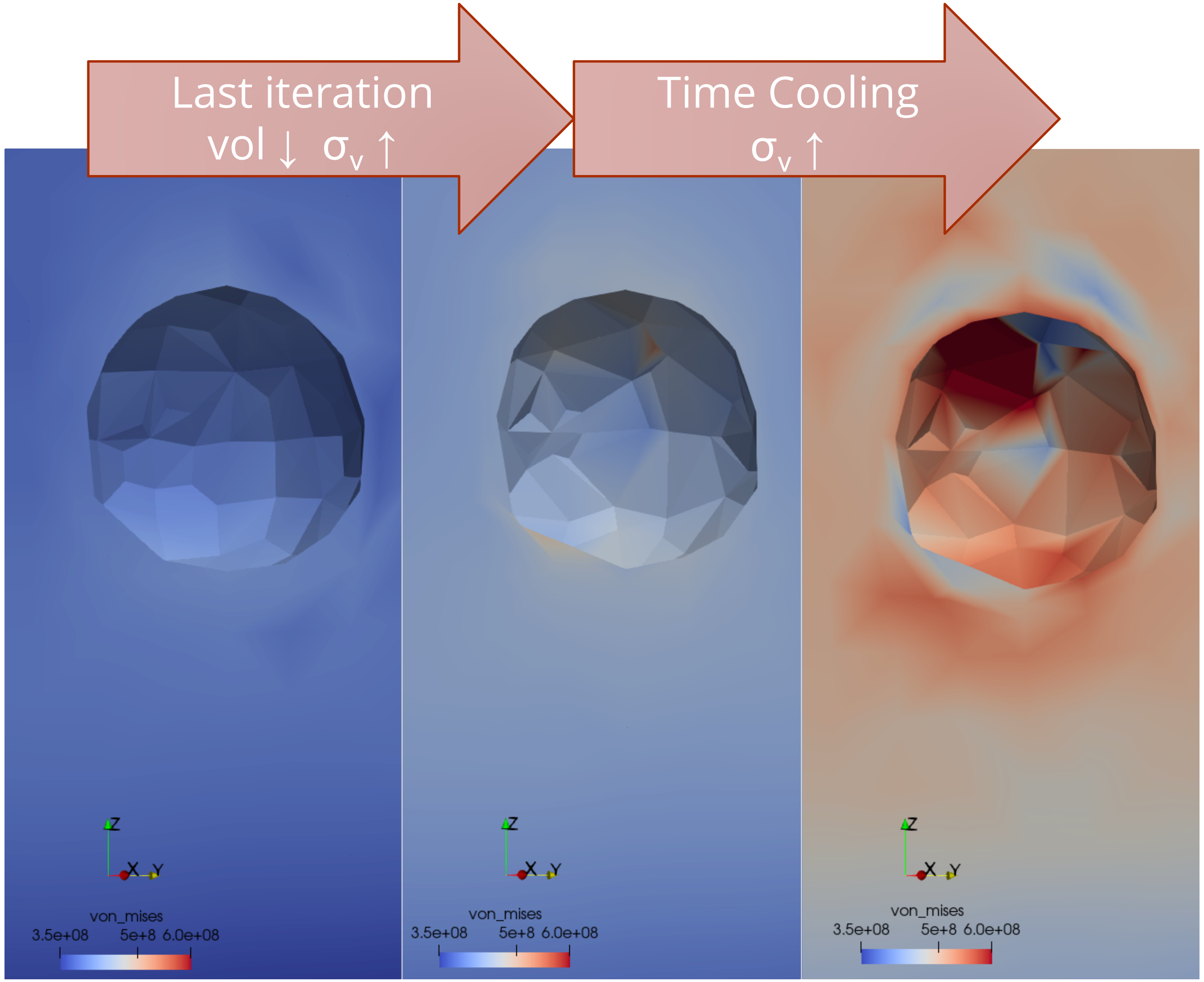


Solid Mechanics model 3 Sierra/SM
Compute new state variables and deformation using the thermal history and previous state variables

Stationary laser weld with melt pool pore defect

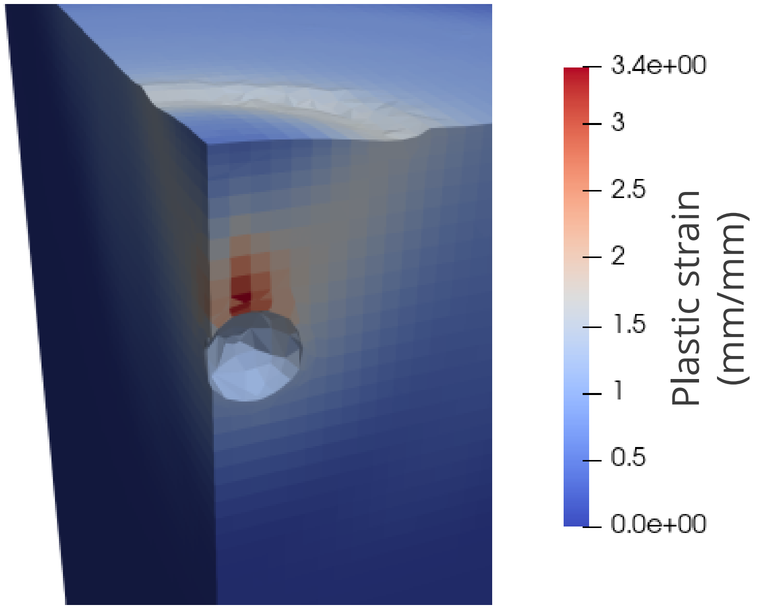


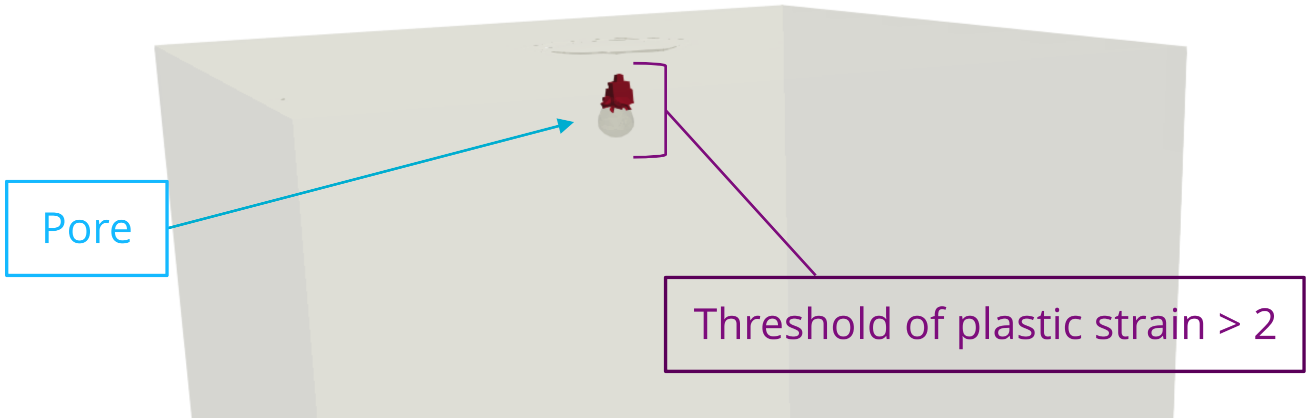
Stress in pore defect get higher as cools, pore collapses slightly

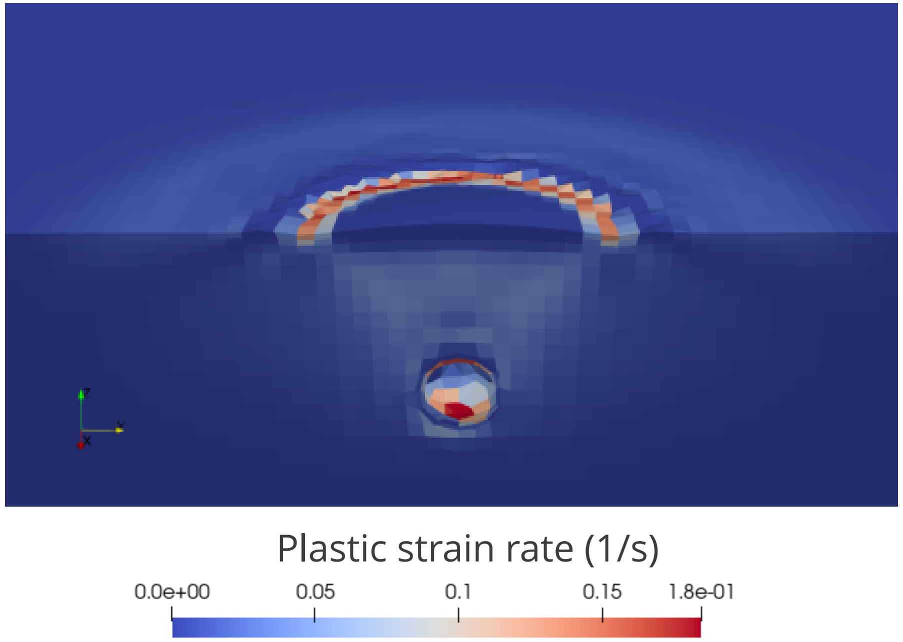


- As simulation calculates cooling, the pore volume decreases by 5.57 %
- Stress around the pore is effected
- Volume decreases in all x/y/z directions and is static through cooling

High magnitude plastic strain & rate of plastic strain near defect

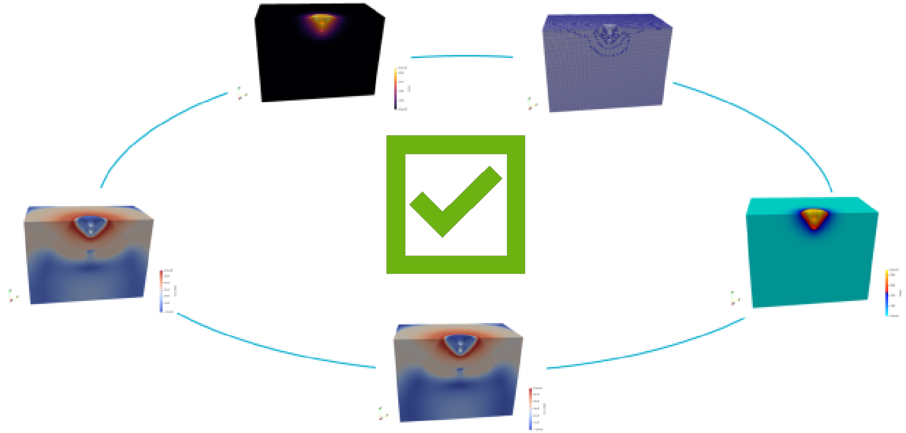






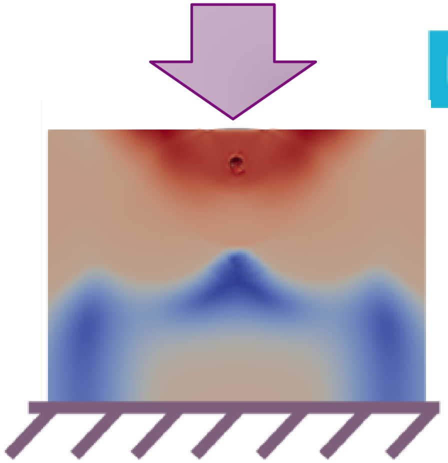
- Possible microstructural implications
- Higher dislocation densities which would impact local mechanical response
- May need higher complexity material model

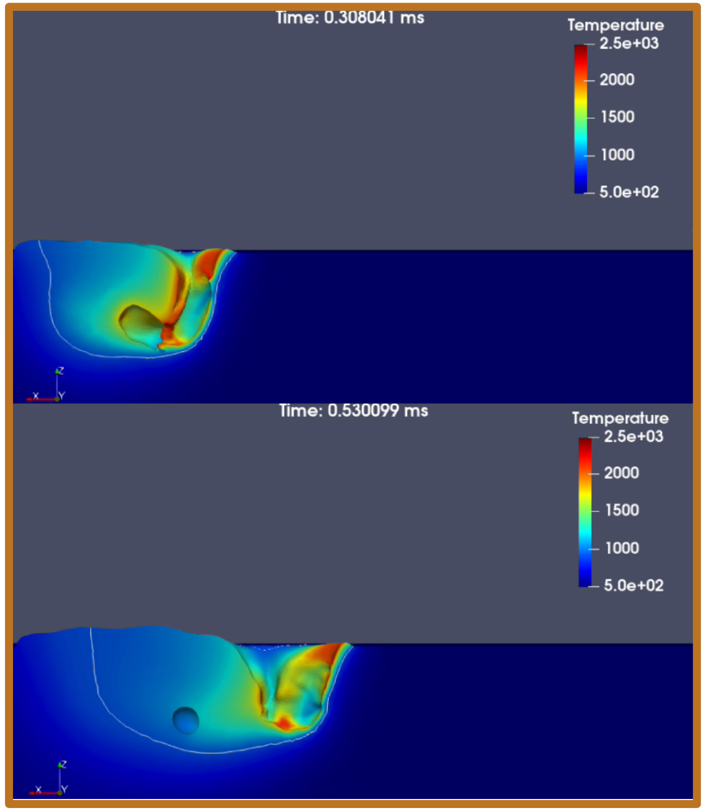
Main outcomes & future directions



Developed a workflow using a thermofluid model to predict residual stresses in presence of defects

Mechanical tests with defects and residual stresses





Application to dynamic environments and additive manufacturing

Thank you

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Citations

3D Printing with a Laser and Metal Powder. NIST. https://www.nist.gov/video/3d-printing-laser-and-metal-powder.

Madison, Jonathan & Aagesen, Larry. (2012). Quantitative characterization of porosity in laser welds of stainless steel. Scripta Materialia. 67. 783–786. 10.1016/j.scriptamat.2012.06.015.