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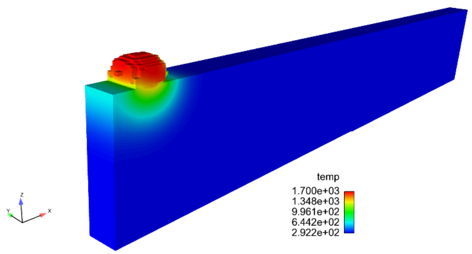

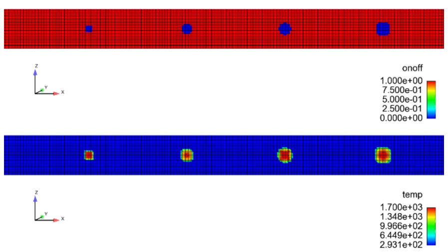

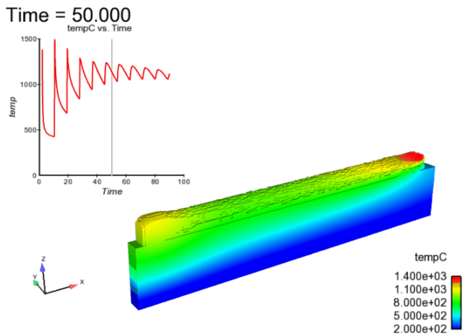

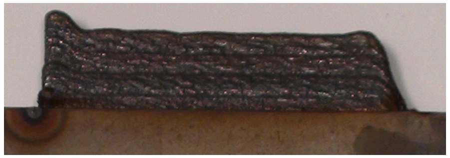

Process Modeling for Additive Manufacturing

Lauren L. Beghini, Arthur A. Brown, Samuel R. Subia, Michael E. Stender, Michael G. Veilleux, Joshua D. Sugar

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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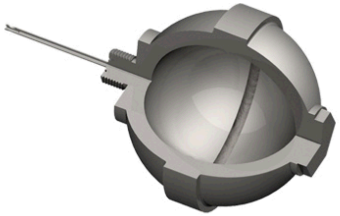
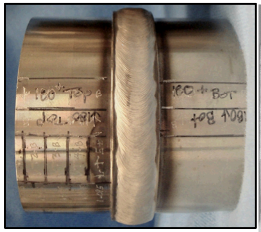
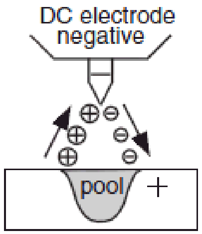
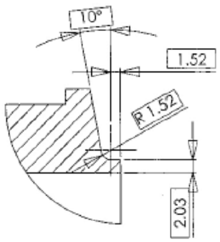
Objectives

Lisa Deibler, Joe Puskar

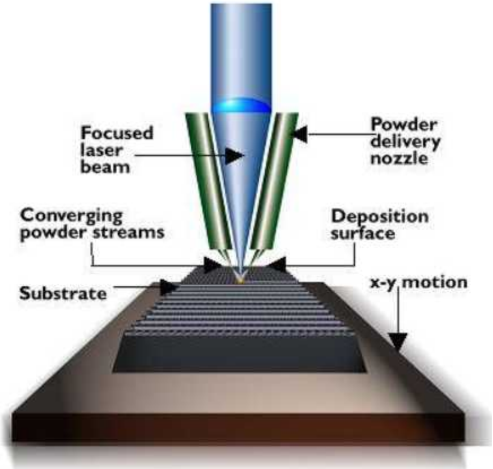
- Develop the capability to predict residual stresses in AM products
- Extend high-fidelity material models to capture material evolution during the formation process, leading to prediction of end-state material properties
- Provide basis to propose improvements to AM process variables, including those that minimize variation
- Apply to welding processes involving material deposition (future work):
  - Gas tungsten arc (GTA) weld
  - Electron beam
  - Laser welding





www.plasticslasermarking.com



UConn

How this fits in the AM community

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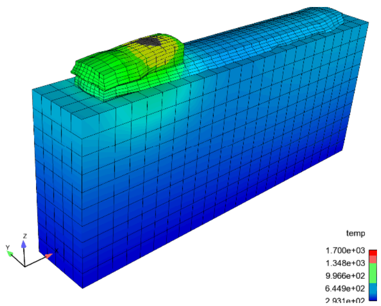
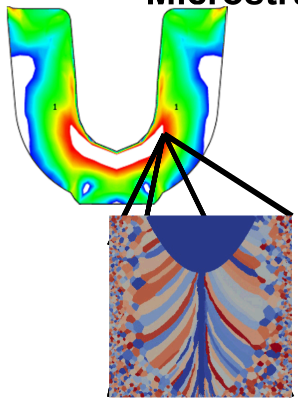
Lifecycle Analysis of Additively Manufactured Components

Process Design and Simulation

Advanced process controls and diagnostics enable simulation tools to "grow" near-net-shape structure

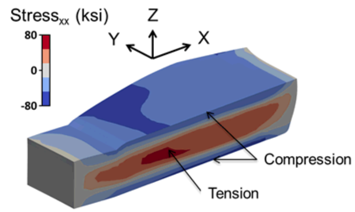


Microstructure and Properties



Internal state variable models account for microstructural evolution and distribution of properties (related to spatial variations of thermal history)

Residual Stresses

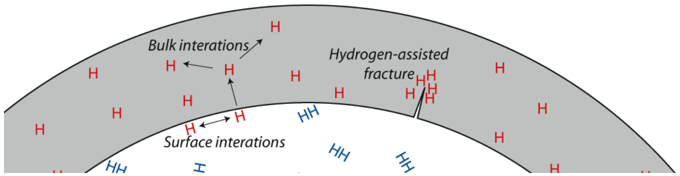


Solidification and thermal history result in strong residual stresses, which can impact performance

- Predictive uncertainties result in large safety factors, reduced lifetimes, and increased costs
- Our approach develops tools to reduce uncertainty, increase understanding, and enhance predictive capability.

Assembly and Service

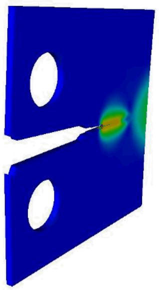
Multiphysics approaches for fully coupled simulation of chemical/thermal transport, mechanical loading, etc. to predict performance



(includes unique service environments, such as hydrogen embrittlement, corrosion, microstructural aging, etc)

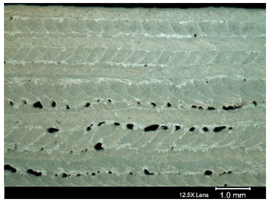
Crack Initiation, Growth and Failure

Transition from crack initiation to failure is not well characterized and depends on microstructure and defects



Margin/Uncertainty → Design Life

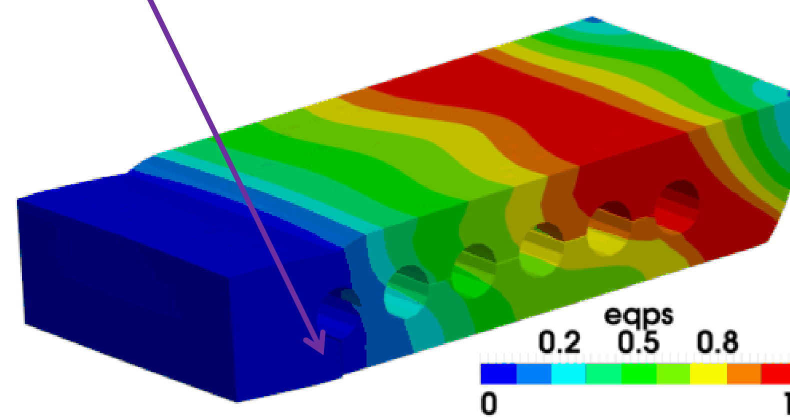
Service requirements may dictate design iteration to assure sufficient margin based on predictive uncertainties.
The lifecycle analysis provides a tool to enable design optimization to meet the requirements.

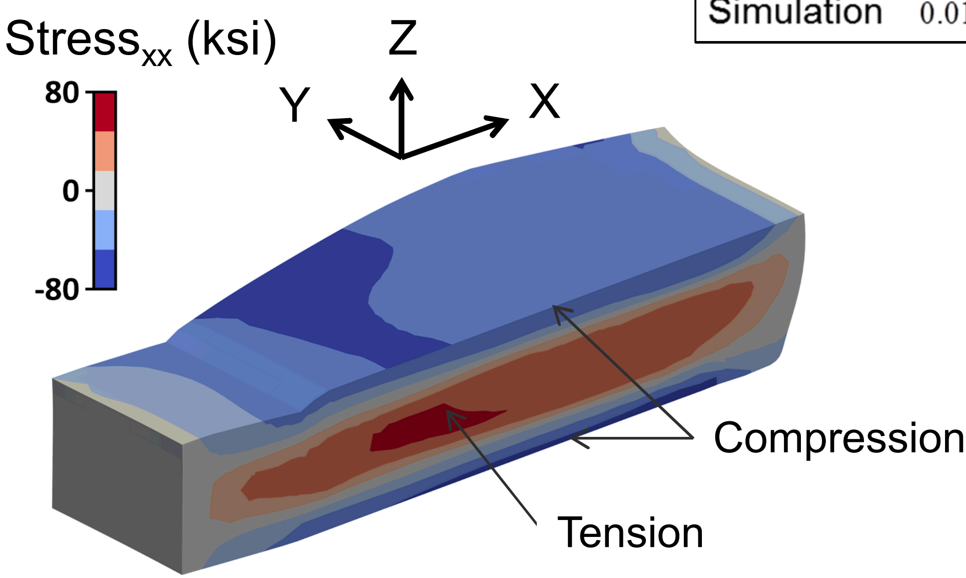


Motivation

- Residual stress can lead to undesirable distortion and cracking
- We have developed the ability to predict residual stress evolution
  - Part of the forged wedge is computationally machined away
  - The remaining material is then allowed to relax
  - Good comparison between experiment and simulation

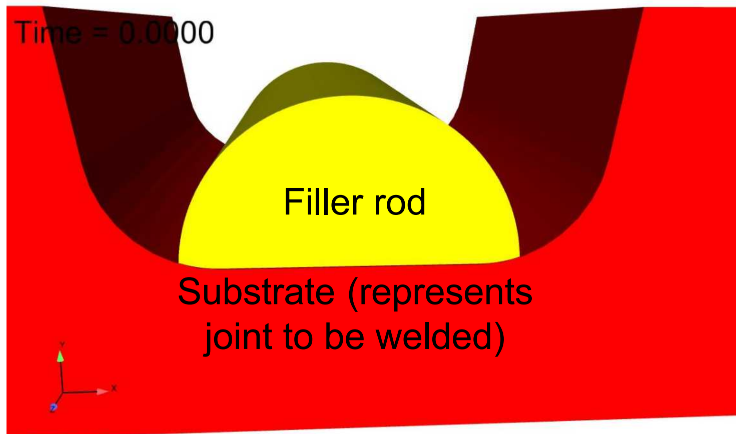
Step:	
Experiment	0.016 ± 0.001
Simulation	0.015 ± 0.002

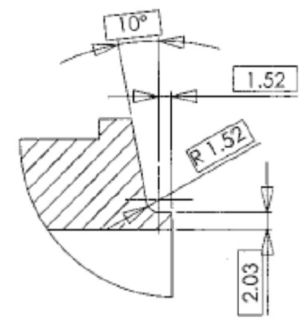




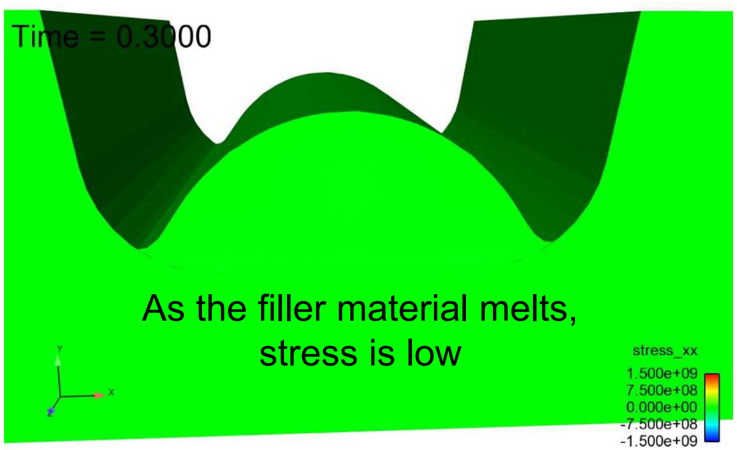
Simulation of GTA weld

- Filler rod is melted (and behaves as an isotropic, incompressible Newtonian fluid)
- Filler material then solidifies as it cools
  - Upon solidification, it becomes glued using a slide-to-tied contact algorithm

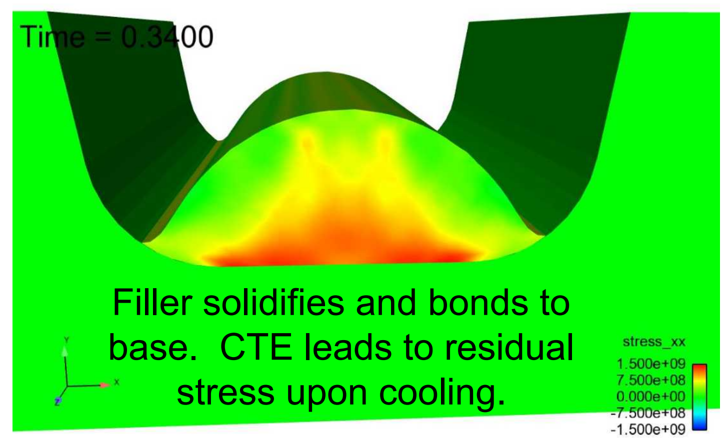




Filler rod is heated

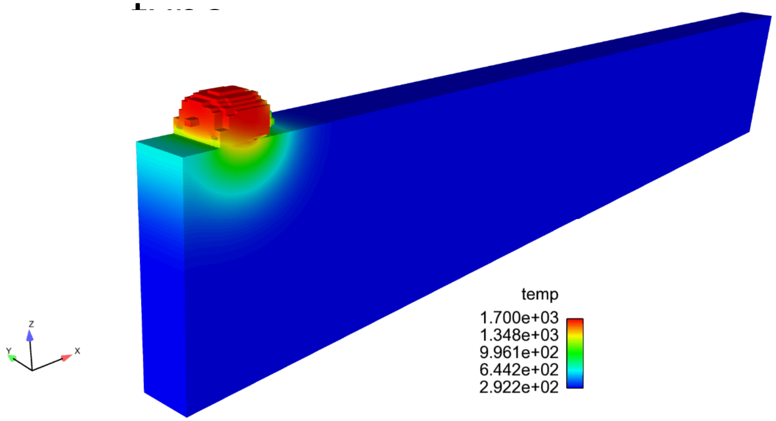


Filler rod is cooled



Spherical heat source

- Material is activated via a spherical, volumetric heat source
  - Inputs: raster path, melt temperature, diameter, efficiency, radius, spatial influence factor and distribution type



  - Activation user variable – toggles conductivity on/off within the sphere

- Activation and melt pool size based on variable input power

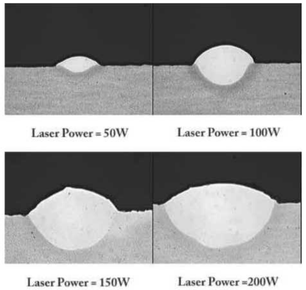
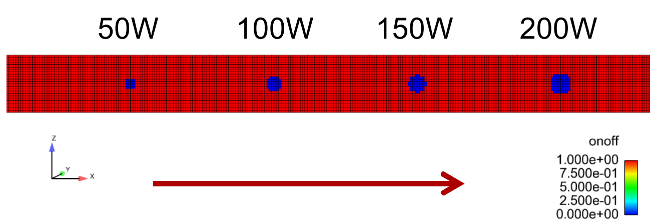
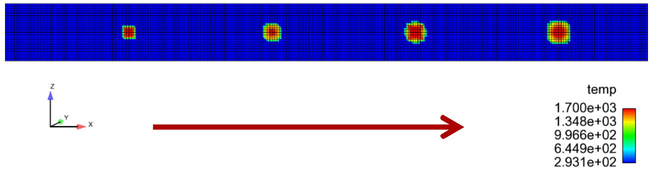


Figure 2: Cross-sectional photographs showing semi-circular type melt pool geometry over a range of laser powers. Travel speed = 5 mm/s, powder mass flow rate = 0.08 g/s.

http://www.lehigh.edu/~inemg/Framset/Research_Activities/JLP/LENS/LENS_4.htm



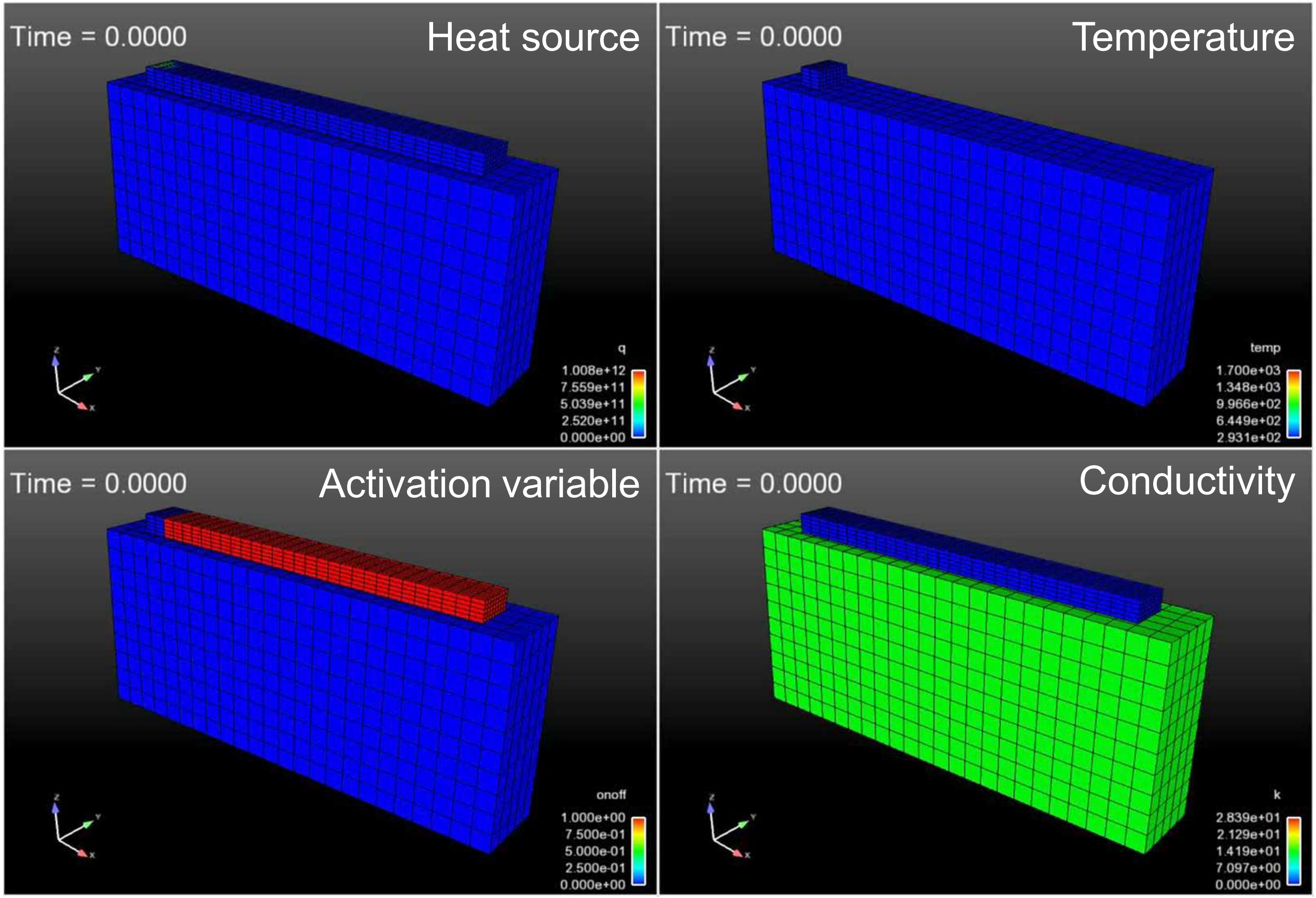
Number of activated elements increases with power



Melt pool size increases with power

Activation demonstration

- Coupled Aria/Presto code



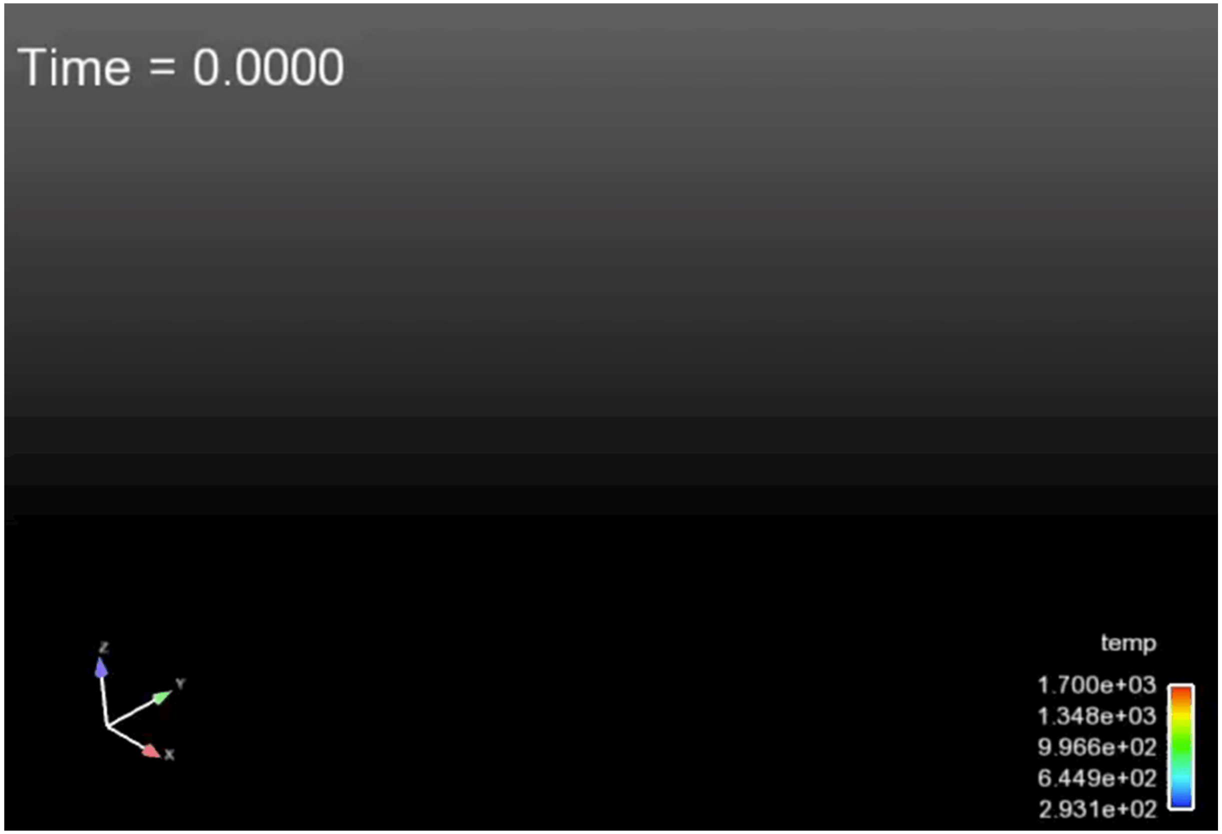
Implementation in SIERRA

- ARIA thermal code
  - New spherical, volumetric heat source based on raster path and variable power
  - Element birth via "inactive" elements – variable conductivity based on heat source
  - Activation and melt pool size based on variable input power

- Solid mechanics
  - Phase transformation at melt temperature
  - Contact transitions from Coulomb to glued (material melts then solidifies) to build up residual stresses
  - Work is underway to implement active/inactive material (compliant and weightless) on the solid mechanics side

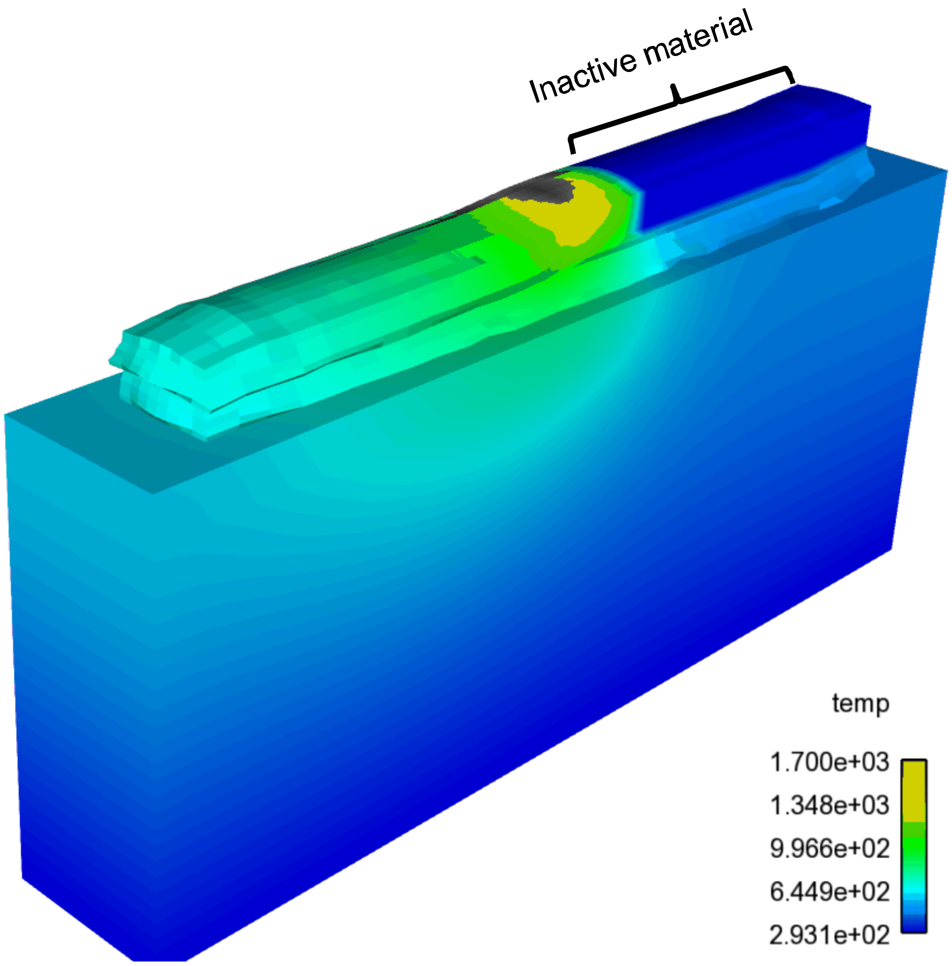
SIERRA demonstration

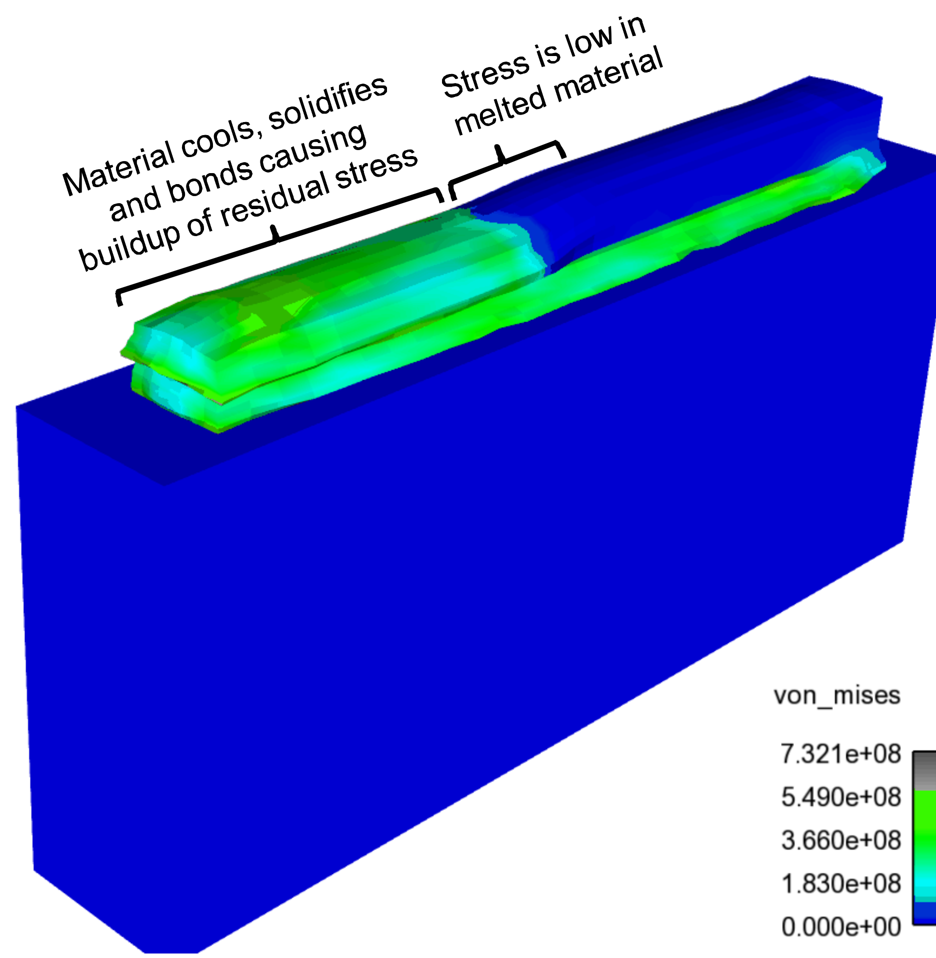
- Coupled simulation



- Work is underway to validate thermal profiles

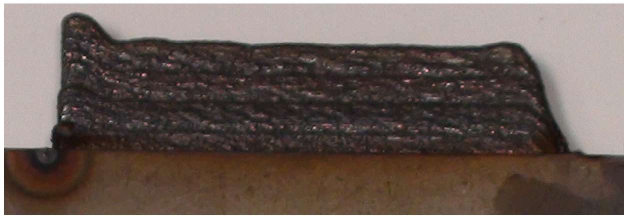
Buildup of residual stress



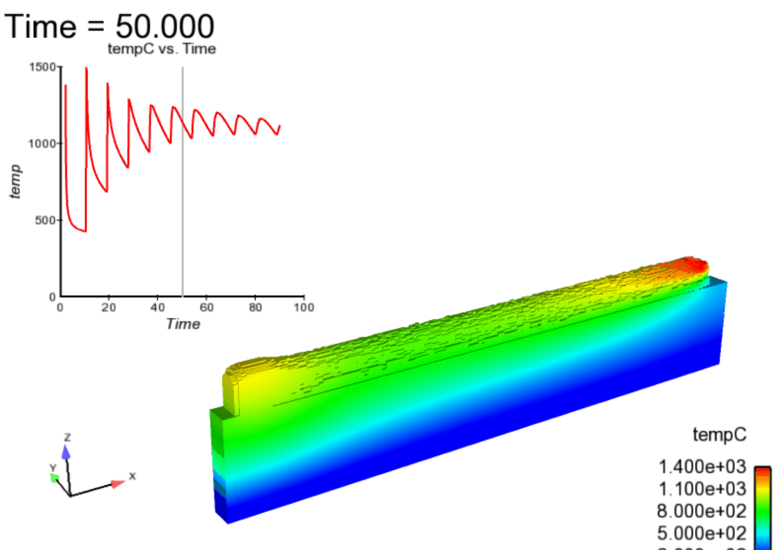


Leveraging our efforts…

- Validation activities

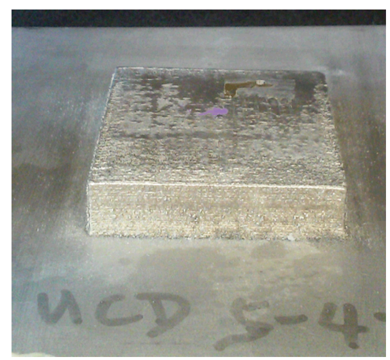


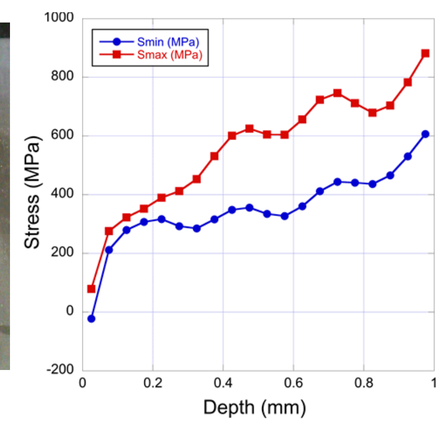
Experimental data provided by Josh Sugar's LDRD to validate the models



Modeling the thermal history of thin wall build

- Ongoing SNL activities
  - other LDRDs (Josh Sugar, Born Qualified, etc)
  - UC Davis Campus Executive Fellowship
  - GTS support for development of additive manufacturing
  - new AM machines





Residual stress measurements (Tom Reynolds)

Questions?