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Process Modeling for Additive Manufacturing

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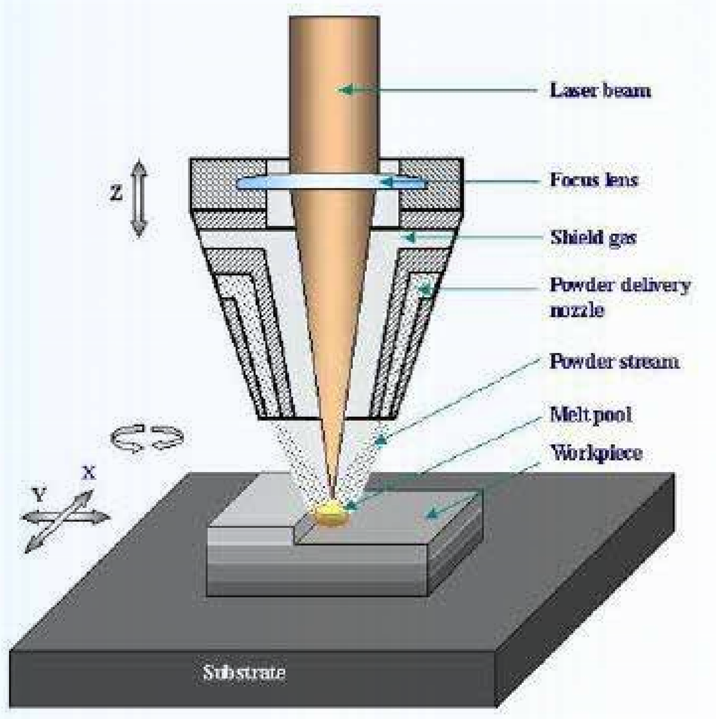
Research Objectives

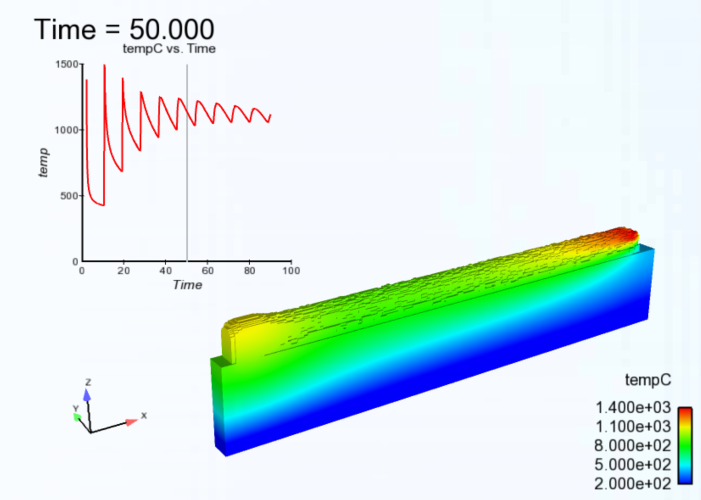


Reference: http://amrl.engr.ucdavis.edu/research/

- Extend high-fidelity material models to capture material evolution during the formation process, leading to prediction of end-state material properties
- Develop the capability to predict residual stresses in AM products
- Provide a basis for engineering tools to propose improvements to additive manufacturing process variables, including those that minimize variation and residual stresses

Problem Statement and Approach

- Develop computational simulation tools to model metal additive manufacturing process via integration with existing SNL software (SIERRA)
- Leverage our efforts with other SNL activities (including Josh Sugar's LDRD, UC Davis Campus Executive Fellowship, Gas Transfer Systems support for development of additive manufacturing, new AM machines, etc.)



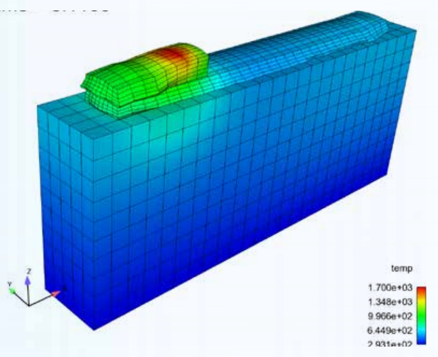
Experimental data provided by Josh Sugar's LDRD to validate the models

Introduction

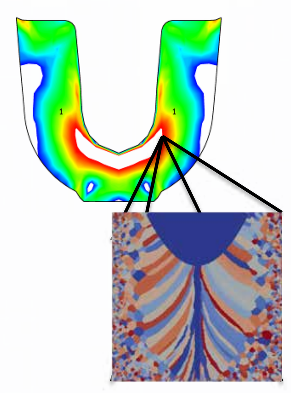
- Residual stresses lead to distortion and cracking
- Previous work has been done to develop the ability to predict residual stress evolution using rate and temperature-dependent plasticity model that has been validated for high temperature applications
- Better understanding of lifecycle of AM components is needed to reduce uncertainties

Process Design and Simulation

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

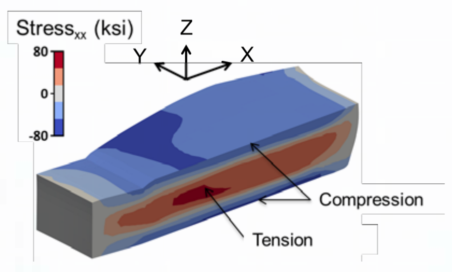


Microstructure and Properties



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

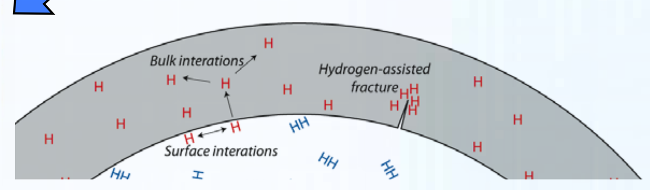
Residual Stresses



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

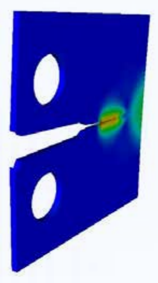
Assembly and Service

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.)

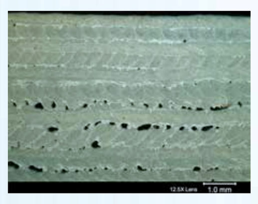
Crack Initiation, Growth and Failure



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

Margin/Uncertainty
⇨ Design Life

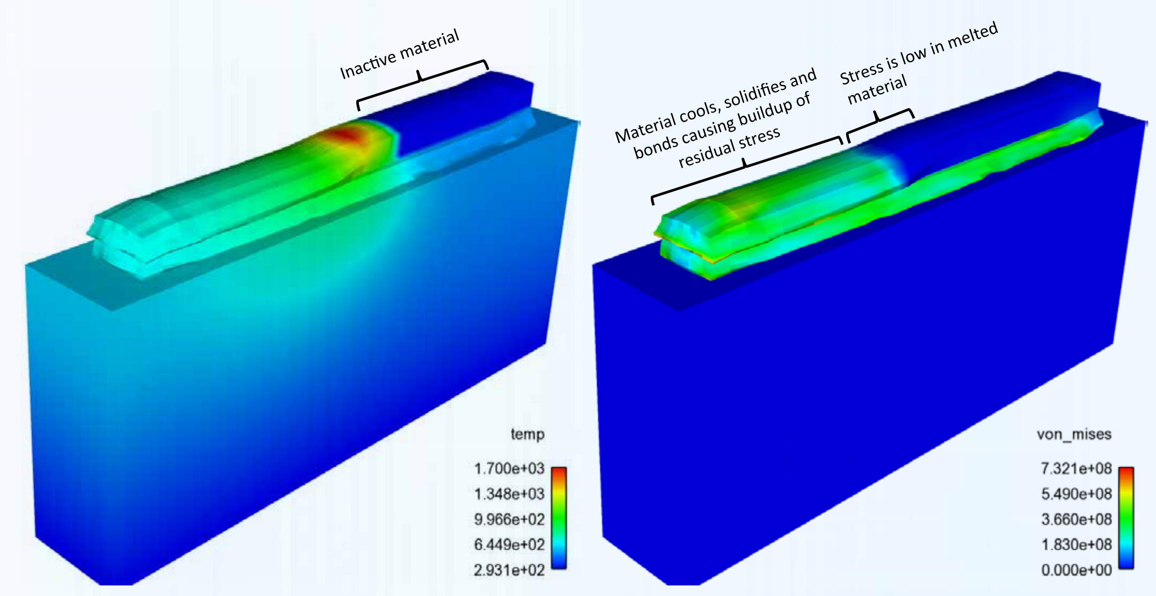
Service requirements may dictate design iteration to assure sufficient margin based on predictive uncertainties. The lifecycle analysis provides a tool to enable design optimization to meet the requirements.



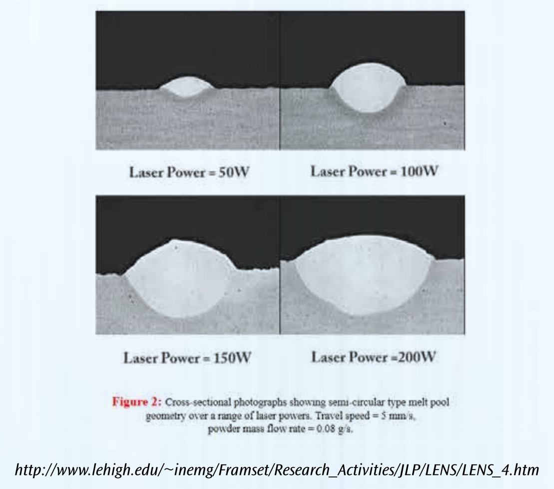
- Predictive uncertainties result in large safety factors, reduced lifetimes, and increased costs.
- Our approach develops tools to reduce uncertainty, increase understanding, and enhance predictive capability.

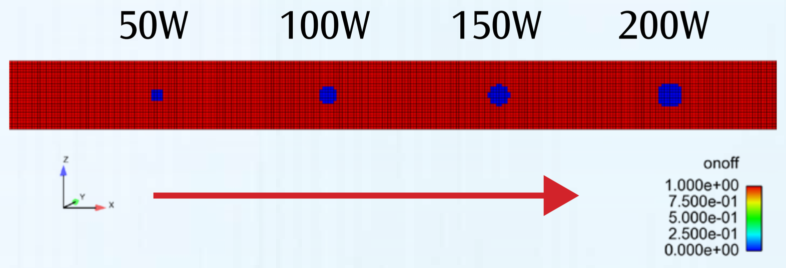
Results

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



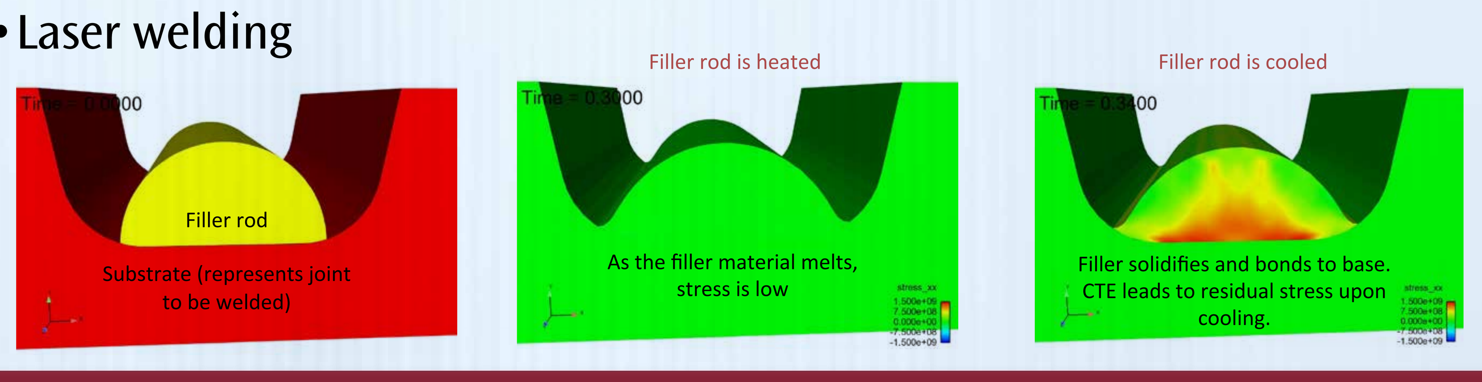


Number of activated elements increases with power

Melt pool size increases with power

Future Work

- Gas tungsten arc (GTA) weld
- Electron beam
- Laser welding



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