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Developing advanced manufacturing process models at the mesoscale to inform part scale models

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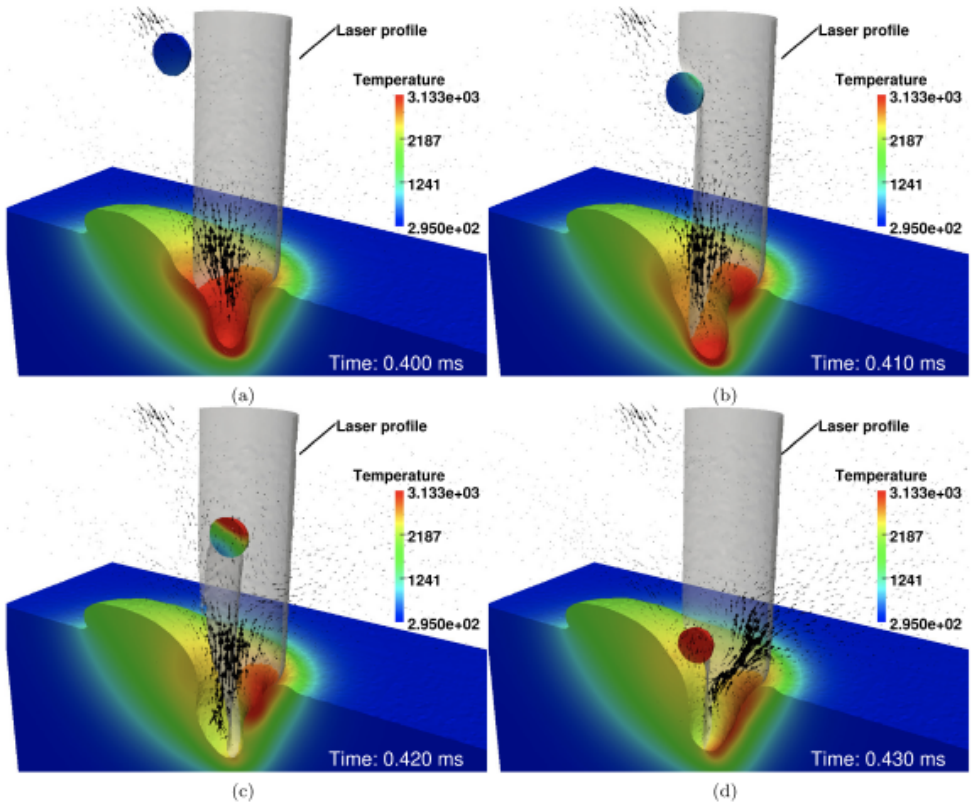
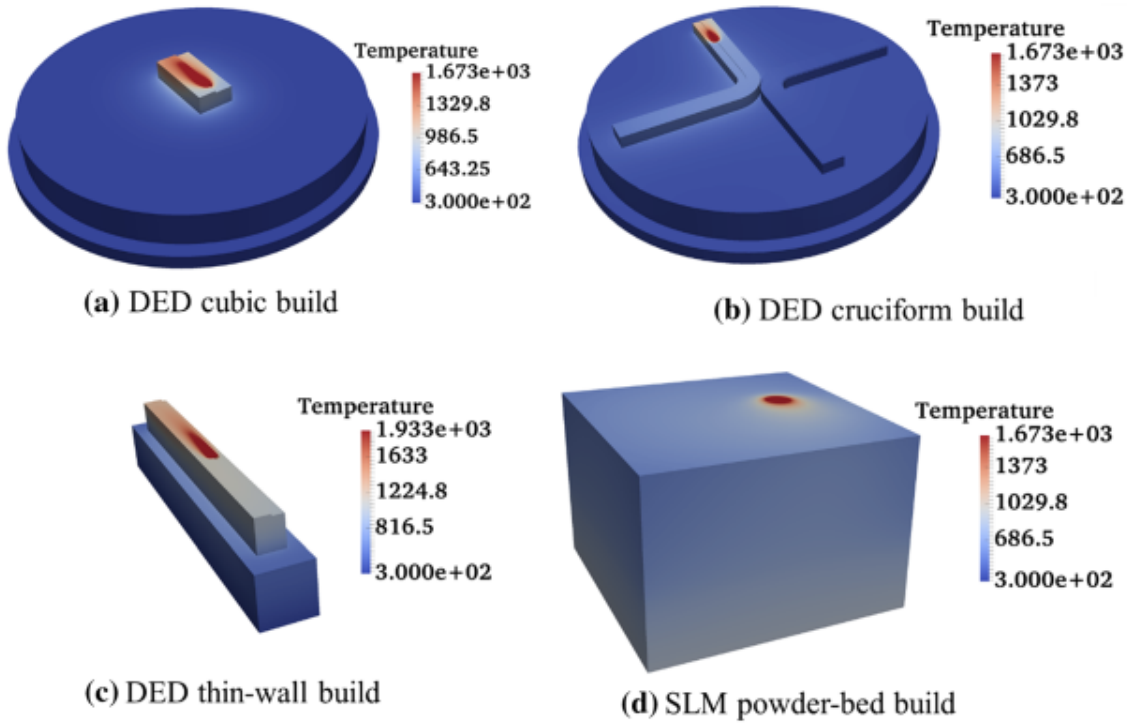
My background at Northwestern University and Sandia



Length: 1-10 mm

Time: ms - s

Lin, Stephen, et al. *Computer Methods in Applied Mechanics and Engineering* (2020)



Length: 10-100 mm

Time: min-hr

Mozaffar, Mojtaba, et al. *Computational Mechanics* (2019)

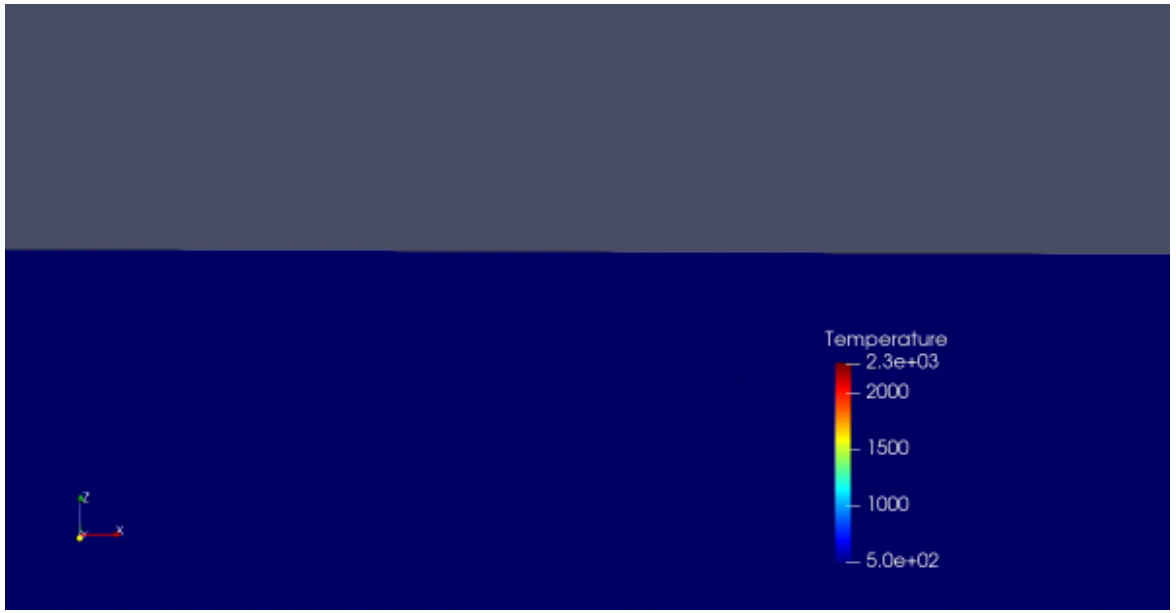
Mesoscale modeling of advanced manufacturing methods elucidate complex and localized phenomena

Mesoscale model account for:

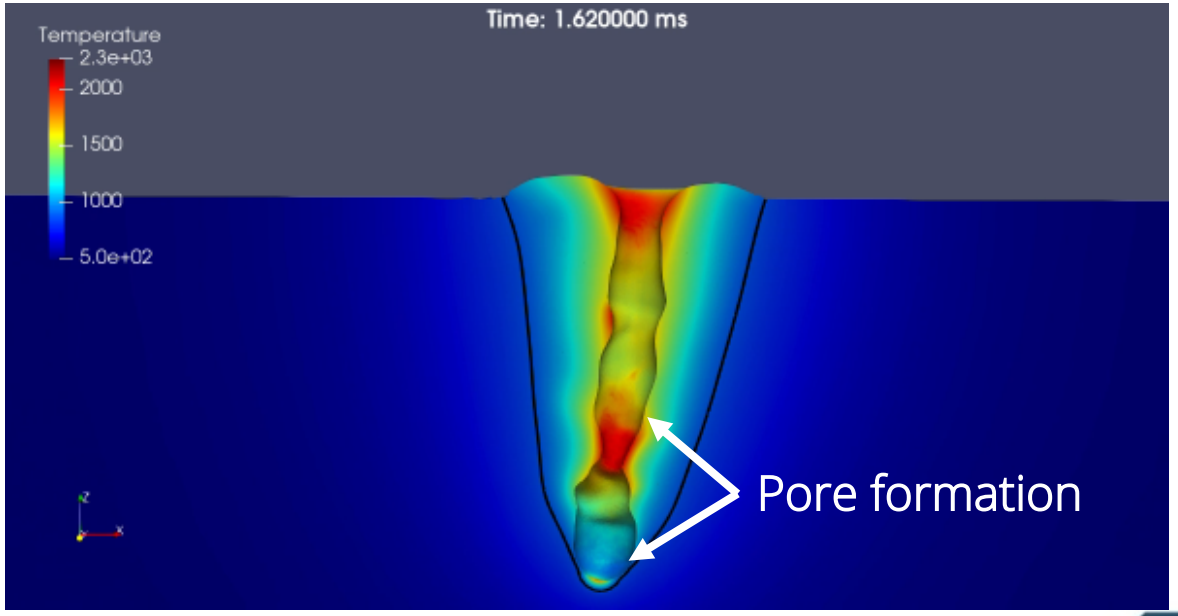
- Free surface evolution
- Marangoni/convective flow within molten pool
- Evaporation and subsequent keyhole formation
- Ray tracing, reflections within keyhole cavity
- Laser absorption within cavity

Mesoscale can explain:

- Track morphology
- Pore/defect formation
- Competing driving physics



Stationary spot weld of Al5182

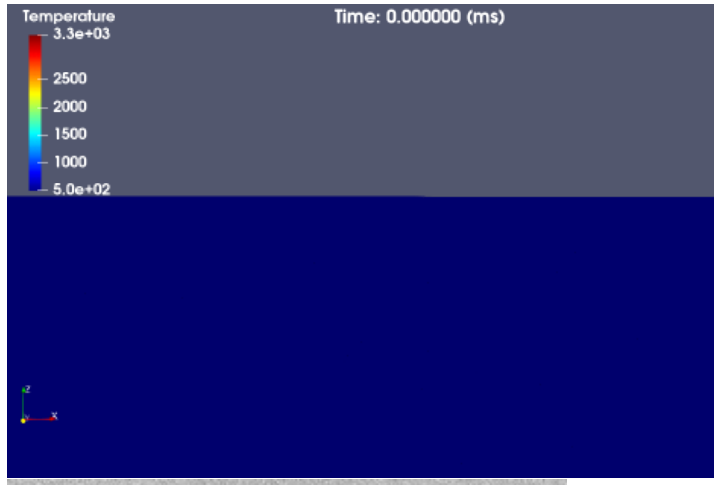


Cooling after laser turns off

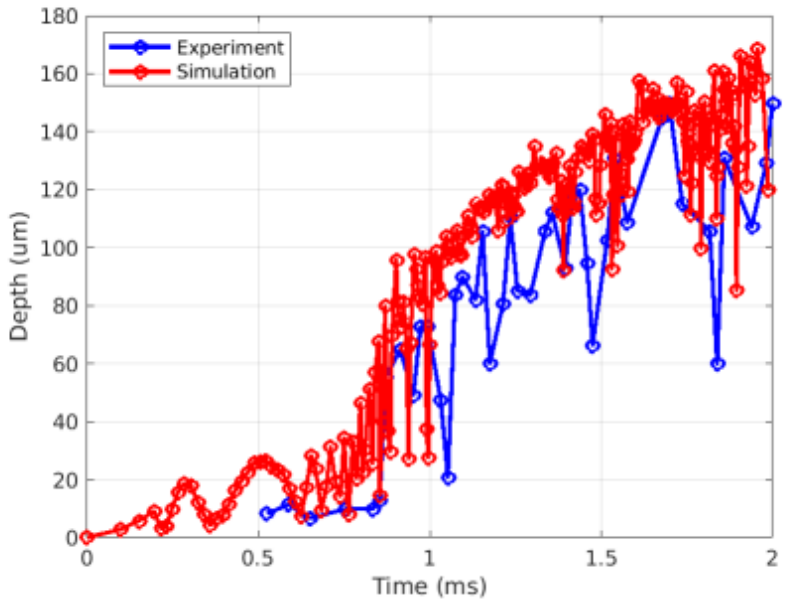
Mesoscale models require validation via experiments to ensure correctness

In-situ monitoring of experiments provide valuable insight

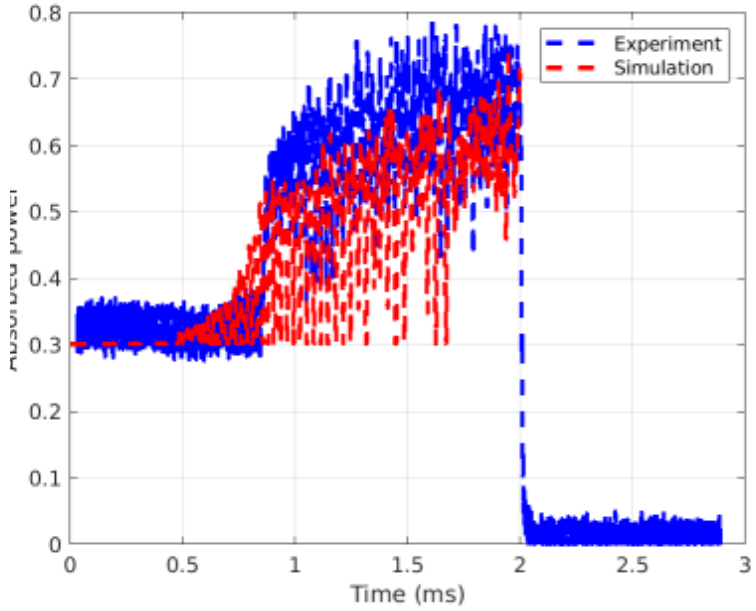
- Laser absorption, keyhole morphology, melt pool morphology over time are valuable for validating our models



Keyhole depth over time



Laser absorption over time

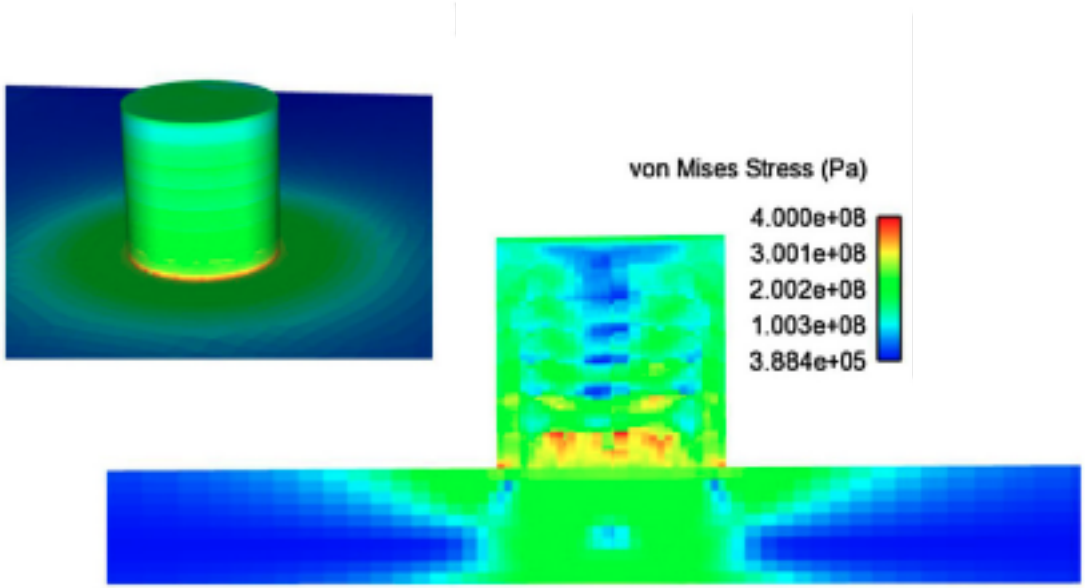


<u>Simulations are very expensive to run:</u>

- 5 equations to solve + multiple utilities to run
- Very nonlinear physics restricting time step (~ 10-100ns)
- Model up to 2 ms of physical time
- Runtime on order of days – weeks on 1000s of cores

Spot weld of Ti64 Alloy, Simonds, Brian J., et al. *Applied Materials Today* (2021):

Part scale modeling of advanced manufacturing methods can model final products dimensions



Stender, Michael E., et al. *Additive Manufacturing* (2018)

Part scale model account for:

- Thermal evolution
- Distortion
- Full build geometry

Simulations are more tractable:

- Physics reduction to simplify nonlinearities
  - Artificial beam enlargement
- Larger time steps step (~ 0.05s)
- Model up to 2 min of physical time
- Runtime on order of days – weeks on 64 of cores

These models leave out complex physics

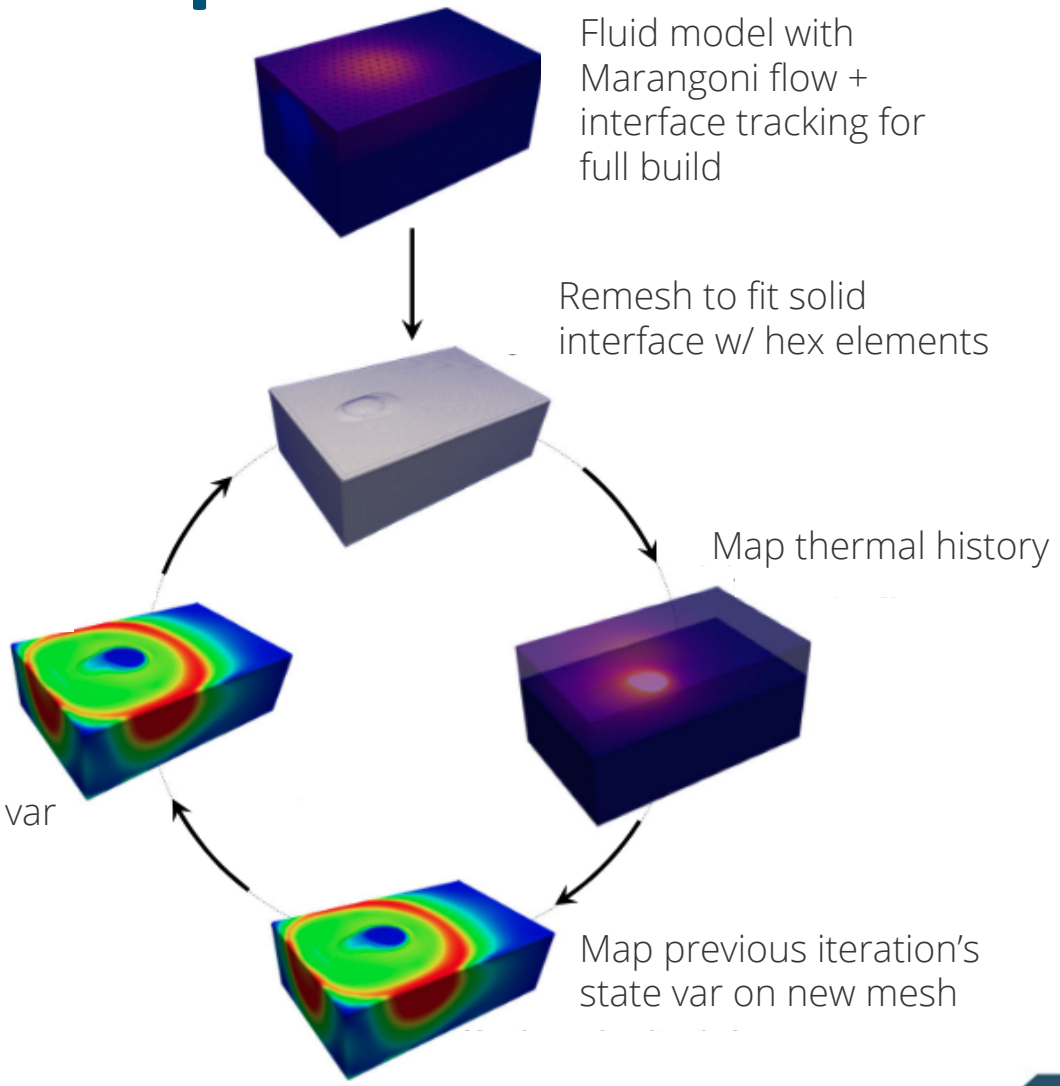
- Drive physics for weld pool formation
- Marangoni, recoil force, ray trace etc.

Coupling mesoscale models to the part scale is an ongoing and complicated path forward

Complex physics
- Evaporation physics
- Fluid flow
- Pore formation

Part scale model
- 10-100 mm
- min - hrs

Mesoscale model
- 1-10 mm
- ms



Beghini, Lauren L., et al. *Computational mechanics* (2021):

Opportunities for collaboration and paths forward

- Experimental data for validation of numerical models
  - In-situ measurements of weld pool dimensions, laser absorption, keyhole formation
  - Other applications include wire arc welding, powder bed and LENS processes
- Coupling strategies to bridge mesoscale and part scale
  - Incorporate key physics into part scale model
  - Recoiling forces, weld pool morphology, fluid flow

Questions?