SAND2019-10656PE

Computational Modeling of MHD Liquid Metal 3D Printing

Daniel Moser (Sandia National Laboratories)

In collaboration with Xerox (formerly Vader Systems)

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Metal Additive Manufacturing Technologies

- Powder-Bed fusion
  - Focused heat source (ie. laser or electron beam) used to selectively melt sections of a metal powder bed layer-by-layer to build up a part
- Binder jetting
  - Adhesive selectively deposited onto metal powder bed layer-by-layer to build a part which is heated in post-processing to melt the metal and burn off adhesive
- Material extrusion
  - Metal powder particles in adhesive binder extruded onto base plate to build up part which is heated to melt the metal and burn off adhesive

Challenges of Current Technologies

- Powder-Bed fusion
  - Requires expensive powder feedstock
  - Some powders pose safety risk
  - Heat treatment (to reduce residual stresses) is often necessary
  - Support structures and connections to base plate difficult to remove
- Binder jetting and Material extrusion
  - Requires expensive powder feedstock
  - Print process produces green part which requires additional processing
  - Full material density challenging to achieve

Magnet-o-Jet™ Liquid Metal 3D Printing

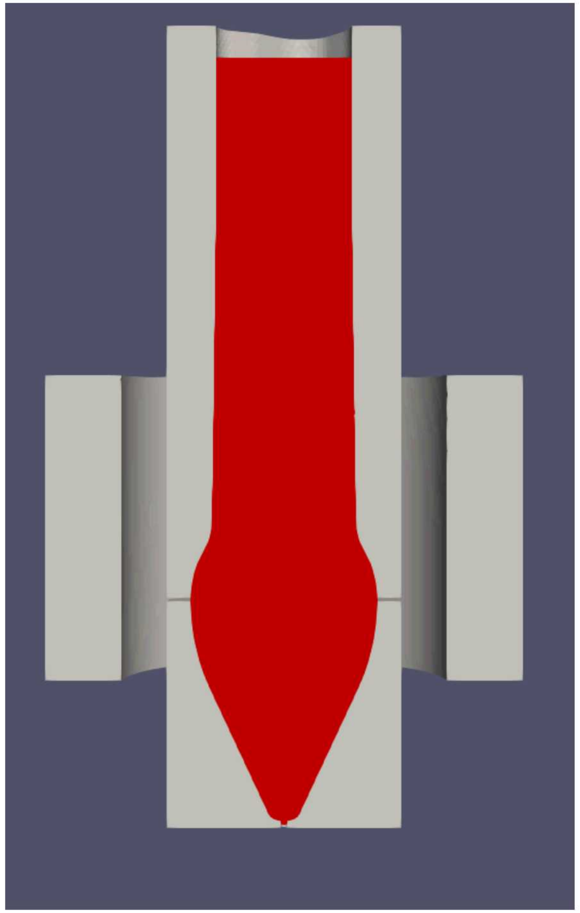
- Developed by Vader Systems, later acquired by Xerox
- Uses novel magnetically-driven pump to jet liquid metal droplets onto a build plate
- Can print materials traditionally challenging for other processes (ie. reactive or high reflective)
- Applied to print wide variety of traditional parts as well as specialty applications such as conductive traces, lattices, part repairs, and printing on existing structures

Advantages of the Magnet-o-Jet™ Technology

- Wire feedstock
  - Less expensive and safer to handle than powder
  - Simpler setup/teardown and extensive cleaning not required when changing materials
- Direct deposition of metal droplets
  - No post-print processing required
  - Full density parts easy to achieve
  - No heat treatment needed to relieve thermal stresses
  - Parts can be released from baseplate without machining or special tools
  - Faster build rates

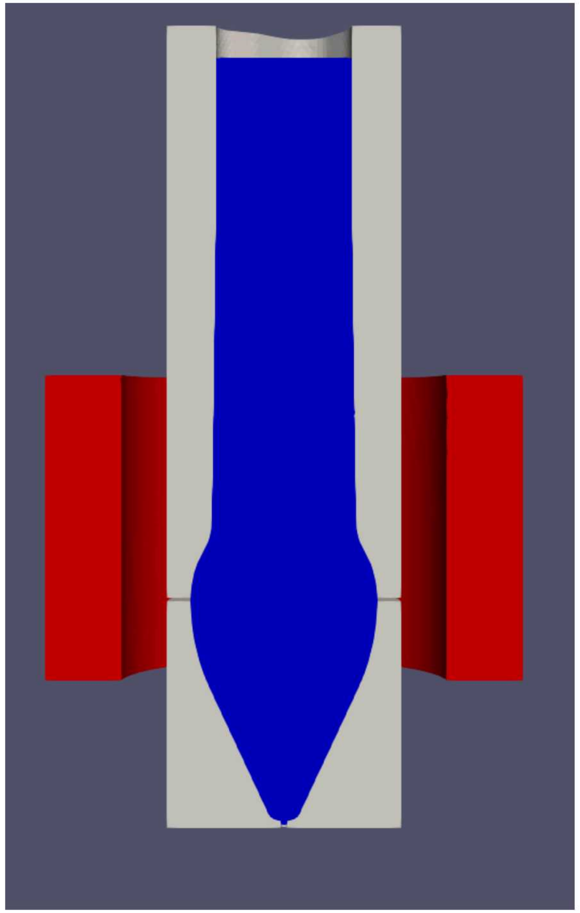
The Magnet-o-Jet™ Process

- Wire feedstock is melted in print nozzle to produce reservoir of liquid metal



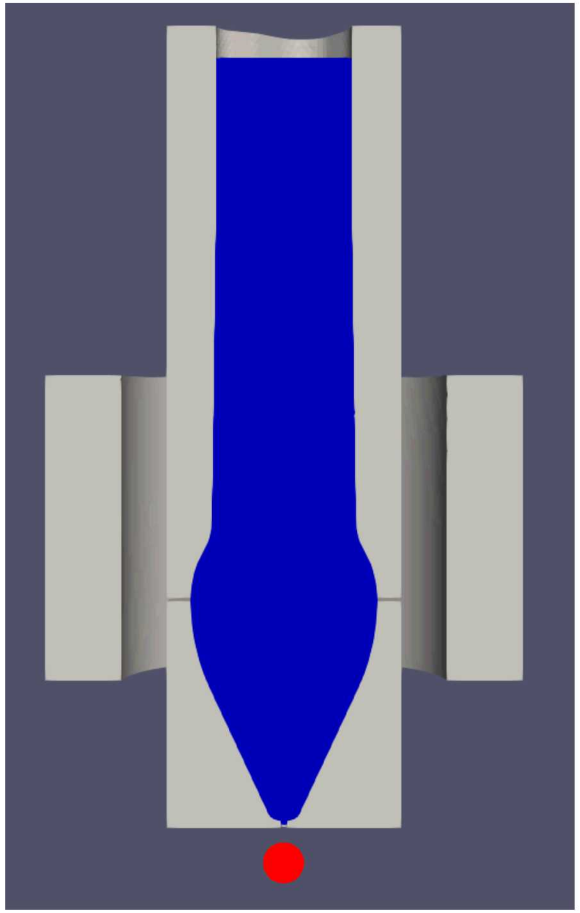
The Magnet-o-Jet™ Process

- Wire feedstock is melted in print nozzle to produce reservoir of liquid metal
- Coil surrounding nozzle is energized to produce magnetic field



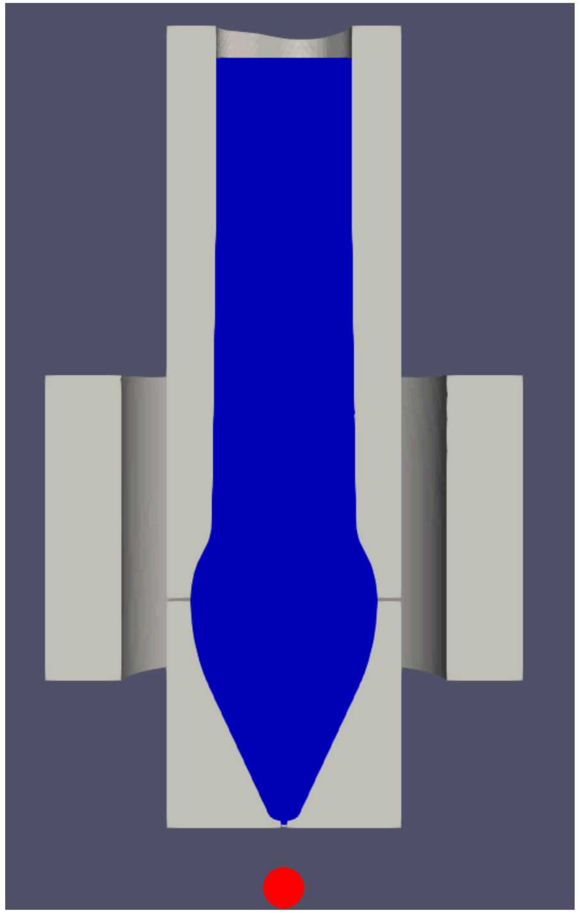
The Magnet-o-Jet™ Process

- Wire feedstock is melted in print nozzle to produce reservoir of liquid metal
- Coil surrounding nozzle is energized to produce magnetic field
- Lorentz force induced in liquid metal forces droplet ejection



The Magnet-o-Jet™ Process

- Wire feedstock is melted in print nozzle to produce reservoir of liquid metal
- Coil surrounding nozzle is energized to produce magnetic field
- Lorentz force induced in liquid metal forces droplet ejection
- Droplet falls under gravity to deposit on baseplate/existing part
- Droplet cools and fuses to baseplate/existing part

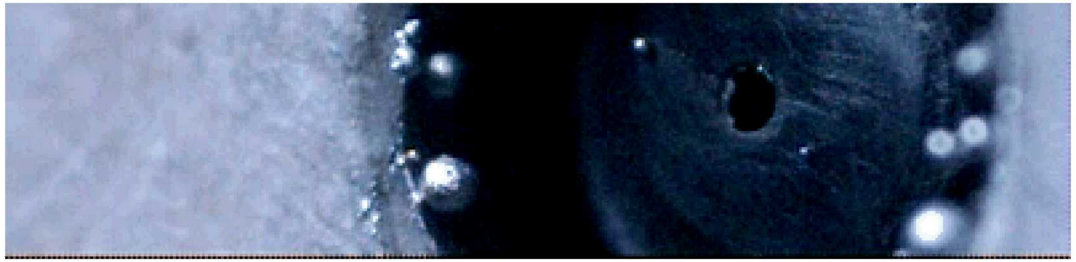


Magnet-o-Jet™ Potential and Challenges

- Currently prints in Aluminum 4043, 4047, 1100. Can be expanded to other materials (ie. other aluminum alloys, bronze, copper)
- Faster droplet ejection rates possible
  - Faster build rates
- Smaller droplet sizes possible
  - Finer resolution
  - Better surface finish
- Multiple print heads possible
  - Multi-material printing
- All these enhancements require good process controls

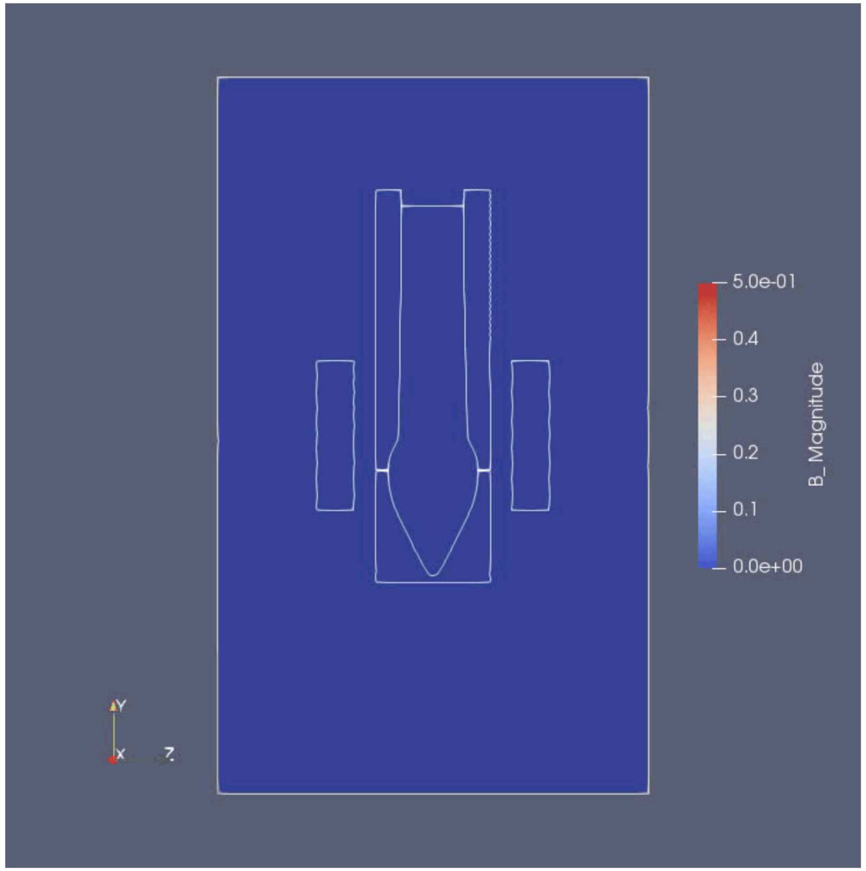
Magnet-o-Jet™ Process Control

- Droplet ejection depends on variety of process inputs
  - Current pulse in coil
  - Nozzle geometry
  - Fluid properties
  - Material wetting parameters
- Process relies on control of droplet ejection
  - Single, regularly shaped droplets (no breakup)
  - Predictable droplet trajectory (determines deposition location on baseplate)
- Strong understanding of which inputs have biggest impact on droplet ejection required



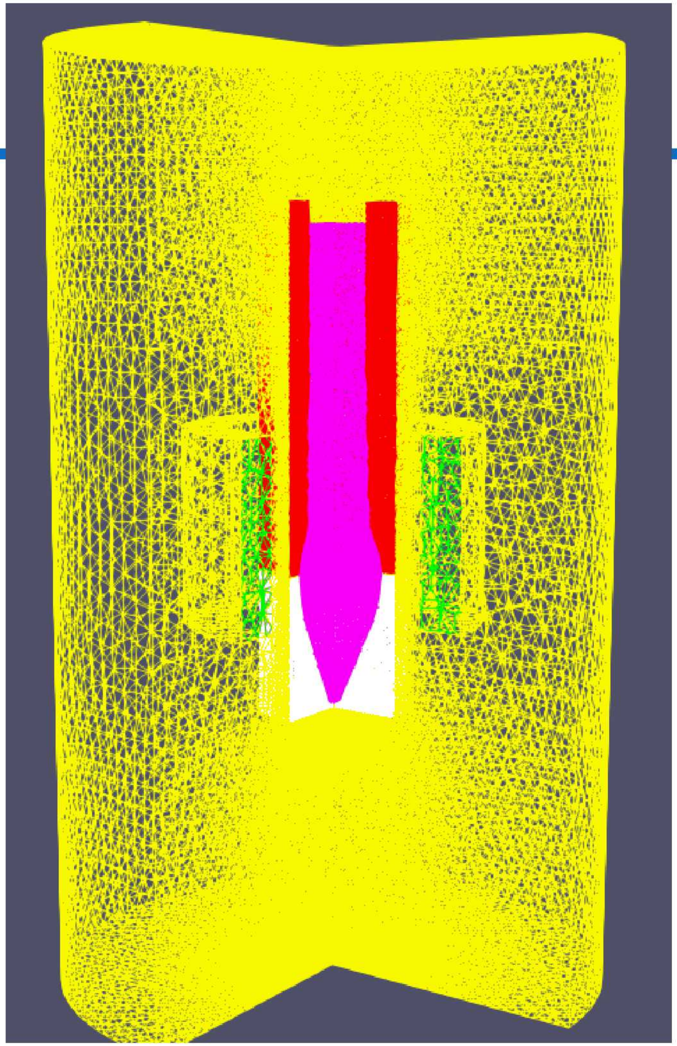
Modeling the Magnet-o-Jet™ Process

- Implemented model in Sandia-developed Sierra engineering mechanics simulation suite
- Fully coupled magneto-hydrodynamic formulation
- Newly developed magnetic flux modeling module calculates induced magnetic field due to imposed current
- Couples to existing multi-phase flow capability
  - Interface-resolving level set technique with adaptive meshing
- FEM framework with scalable matrix solvers through Trilinos solver library



HPC for the Magnet-o-Jet™ Process

- Massively-parallel high-fidelity 3D modeling of the print nozzle
  - Capable of modeling current pulse on 10M+ element mesh in 2-3 hours on ~800 processors
  - HPC resources allow for long run times to model multiple consecutive pulses
- Multiple model evaluations can be conducted in parallel to explore impacts of input process parameters
  - Parameter sweeps
  - Reduced order model generation
  - Model-based design



Conclusions

- Model validation currently being performed
- Validated model will be used to investigate droplet instabilities in order to allow:
  - Faster ejection rates
  - New materials
  - Smaller droplet sizes
- Future collaboration?