

Metal Additive Manufacturing Optimized, via Simulation Solution

ESI solutions can model the micro, meso and macroscopic scale of 3D printing

Phenomena

- Laser Direct Metal Deposition 3D Printer

Applications

- Automotive
- Aerospace
- Biomedical
- Marine
- Transportation
- Manufacturing

Main Simulation Focus

- Melt pool
- Residual stresses & Distortion
- Material properties

Models/Physics

- Powder particle flow & Radiation (Control Angle Discrete Ordinate)
- Surface tension (Marangoni forces)
- Heat transfer
- Phase change
- Residual stresses

Analysis Type

- CFD
- FEA

Computing Power

- 4 – 32 CPUs per run
- Runtime: overnight

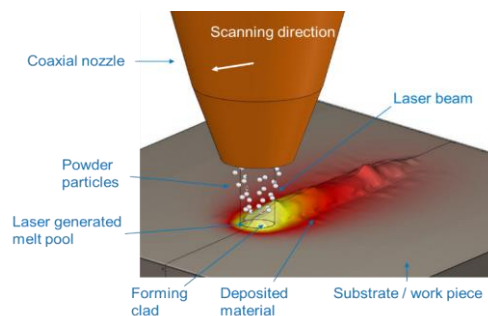
Findings

- Model micro, meso & macroscale separately to model phenomena
- Thermal distribution & powder flight correlate to reality

mesoscopic and macroscopic scales.

Challenges of Simulating Additive Manufacturing Equipment

The growth of additive manufacturing (3D printing) in industry is due, in part, to its ability to produce increasingly complex customized products.



Laser direct metal deposition additive manufacturing model. Courtesy of ESI and University of Manchester.

With a single piece of equipment, powder and a Computer Aided Design (CAD) file, companies can decentralize their production and prototyping. Additionally, 3D printers have the ability to build products that cannot be made with traditional manufacturing processes.

"However, the lack of standardization, design rules, repeatability, production speed and quality control significantly hinders the expansion of 3D printing", notes Mustafa Megahed, Manager of CFD & Multiphysics Center of Excellence at ESI Group.

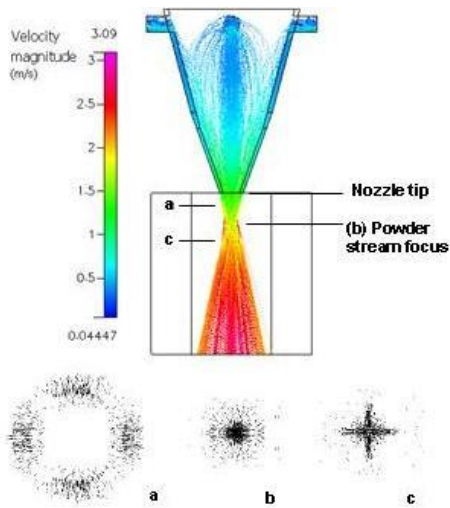
Simulating additive manufacturing mechanisms can go a long way to help bring 3D printing to the next level. Additive manufacturing technologies like laser direct metal deposition (LDMD or Blown Powder Additive Manufacturing) involves the modelling of microscopic,

"When simulating LDMD, you are dealing with particles in the order of 10 microns in diameter, a laser beam diameter of 1-2 mm, a work piece several centimeters long, and a laser path that could be as long as a kilometer", stressed Megahed.

"If you were to simulate that all at once", he added, "It would take more computing power than current high performance computing (HPC) could handle."

This multi-scale problem can be a challenge to simulate. Fortunately, ESI Group has developed a multi-scale, multiphysics solution to characterize the physics associated with additive manufacturing processes.

Multiphysics of a LDMD 3D Printer



Powder stream simulation & deposition patterns based on nozzle substrate distances ("a" close, "b" focused, "c" far). Courtesy of ESI and University of Manchester.

LDMD printers have a nozzle with two functionalities: dispersing the particles and adhering them to the substrate with heat.

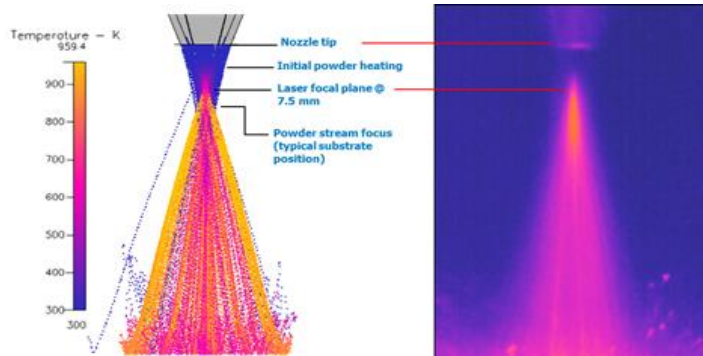
A laser focused through the central hull of the nozzle acts as the heat source. It melts the metal substrate and particles so they combine into a melt pool. The melt pool beads onto the substrate due to the surface tension forces.

The particles are dispersed from the outer ring of the nozzle. A carrier gas blows out of the ring and releases the metal powder onto the substrate. Particles that do not get hot enough to join the melt pool will impinge and bounce off of the substrate surface as material and energy losses.

Simulations are needed to optimize:

- Nozzle to substrate distance, to control particle deposition pattern
- Laser speeds, to control the melt pool
- Material properties of the final product

Simulating a Multi-Scale Problem like a LDMD 3D Printer



Comparison of thermal distribution & powder in-flight. Simulation has good correlation to reality. Courtesy of ESI and University of Manchester.

Commented [MM1]: This seems to be wrong??

"The micro scale models of the LDMD simulation deal with the powder trajectory and the thermal cycle of the melt pool", explained Megahed.

The particle flow is modelled using Lagrangian tracking and the laser is simulated by the Control Angle Discrete Ordinate model. The

model was extended to account for laser interaction with the particles (scattering and absorption).

To simplify the computation, interaction between particles is ignored in-flight. The research teams at ESI and The University of Manchester found a middle ground between experimentally measured powder particle temperatures and numerical predictions.

"The micro scale simulation is used to optimize the nozzle and process parameters to influence the melt pool shape avoiding porosities or build defects. The thermal cycle is obtained as a by-product and is utilized in macro-models to determine the corresponding residual stresses", explained Megahed.

The results of the micro scale model will feed into the macro scale model. This simulation will determine the residual stresses and distortions created as the melt pool cools and solidifies.

"The distortion is certainly not wanted because the final shape might not match the original design", said Megahed. "Also the residual stresses represent an internal load, leading to reduced load capacity of the material. These imperfections will also accumulate as the model builds and sections are heated and cooled multiple times."

The mesoscale model looks into the overall metallurgical properties of the build. The results will be dependent on the alloy composition, temperature distribution, deposition patterns, and residuals. Therefore, the micro and macro simulations interact with the mesoscale model. Today, ESI's CFD & Multiphysics Center of Excellence uses metallurgical tools and data bases from their established metal based manufacturing tools, such as ESI's casting simulation suite ProCAST, to generate these results.

ESI's 3D Printer Simulation Solutions

Megahed has demonstrated that solvers, databases, and capabilities of ESI's End-to-End solutions can be used to simulate additive manufacturing processes. The ongoing research effort will lead to a suite of tools dedicated to additive manufacturing and its unique modelling needs.

But within Megahed's words there might be a hint to the future of the ESI Group and 3D Printing. ESI Group has a tendency to package their technologies together into industry-specific design tools that

enable end-to-end virtual prototyping. Examples of this includes [HVAC](#), [metal stamping](#), and even [aircraft seats](#).

Given this knowledge and Megahed's mention of a workflow construction, it would not be surprising to see an additive manufacturing equipment design tool sometime in the near future. In the meantime, ESI Group does offer customer assistance to use their currently available tools to simulate additive manufacturing.

To learn more about simulating other additive manufacturing technologies, follow these links on powder bed and wire fed 3D Printers.

*ESI Group has sponsored this post. They have no editorial input to this post - all opinions are mine.
Shawn Wasserman*