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Modeling Microstructure Evolution During Metal Additive Manufacturing

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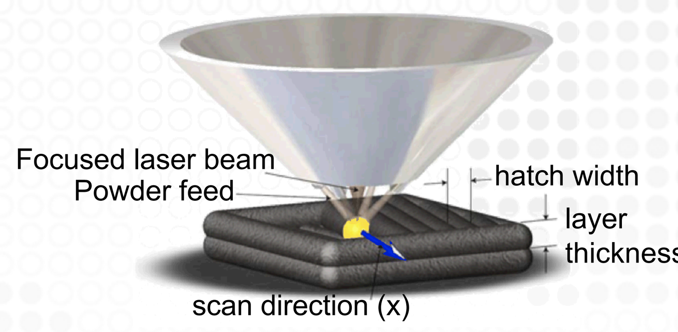
Introduction

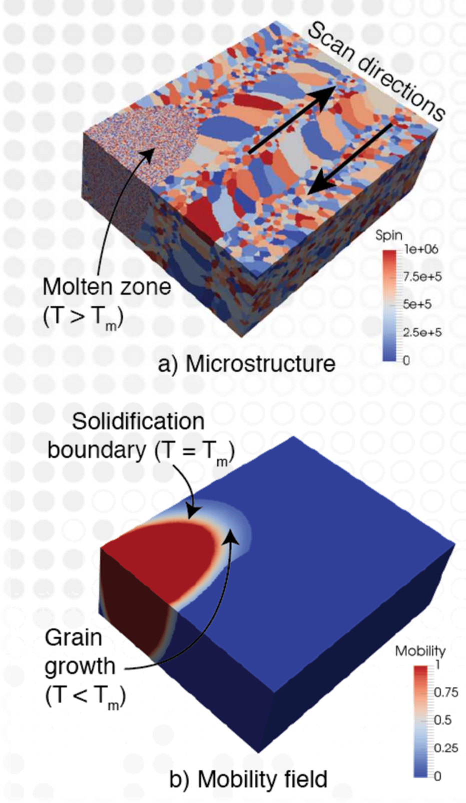
Additive manufacturing processes offer the ability to create metallic parts with complex shapes without the expense and time commitment required with traditional approaches. However, the complex, non-uniform temperature histories of these processes result in materials with complex, anisotropic microstructures. Here, a Monte Carlo-based Method[1,2] is introduced to model microstructure evolution during additive manufacturing processes along with approaches to quantify the results.



Schematic of LENS AM process

Model description

A user defined melt pool is scanned through the simulation domain on a specified trajectory. The material is represented as a cubic lattice of sites with "spins" that represent specific grains. When the melt pool travels through a lattice site, the spins are randomized and any existing grain assignment is lost. At the solidification new grains nucleate or existing grains grow epitaxially. Further grain evolution occurs in the temperature gradient surrounding the melt pool.



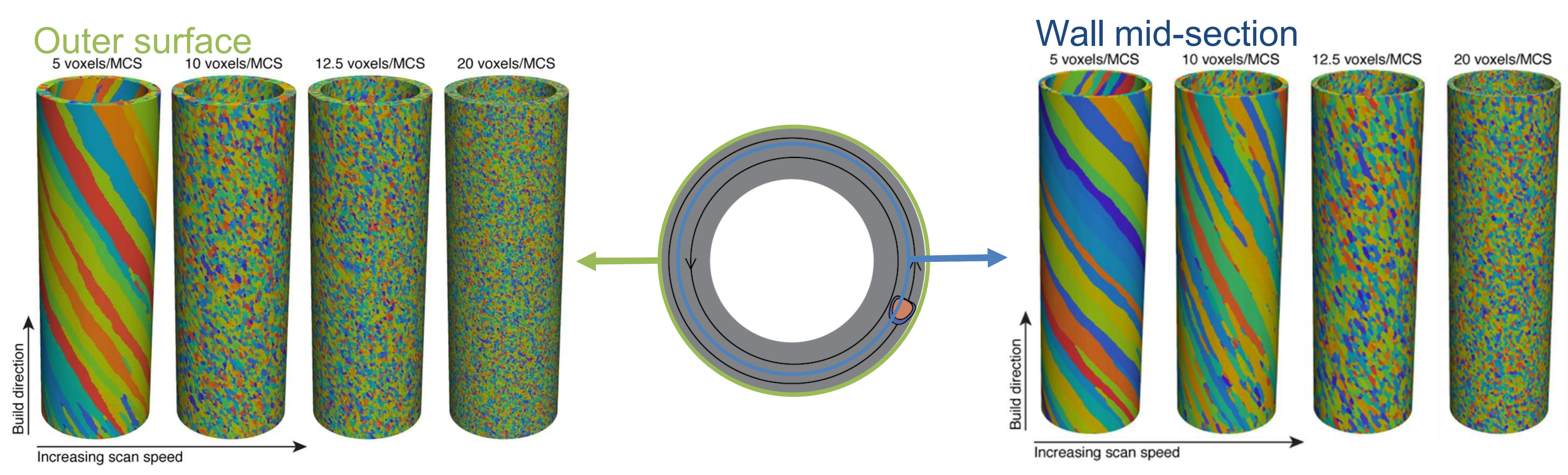
Using synthetic AM microstructures in mechanics simulations[3]

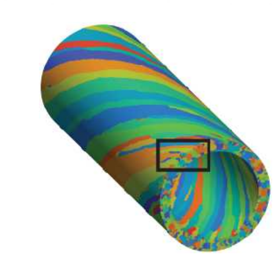
Synthetic microstructures were generated for a powder fed-like AM process within a tubular domain. The resulting microstructures were remeshed and used in Direct Numerical Simulations (DNS) of mechanical response in the elastic regime.

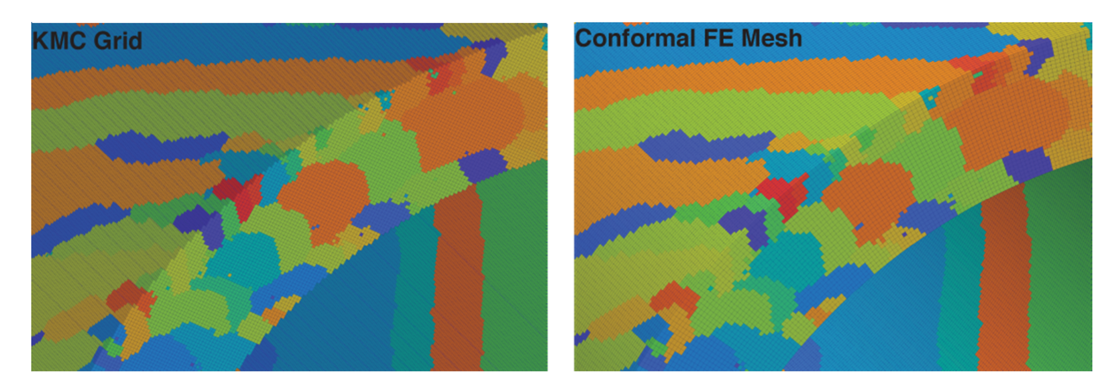
Microstructure simulation

Simulations were performed at four scan velocities. Each tube was simulated using a scan pattern of two concentric circular scans per layer.

Resulting microstructures showed a transition between columnar and equiaxed grains as scan velocity increased.



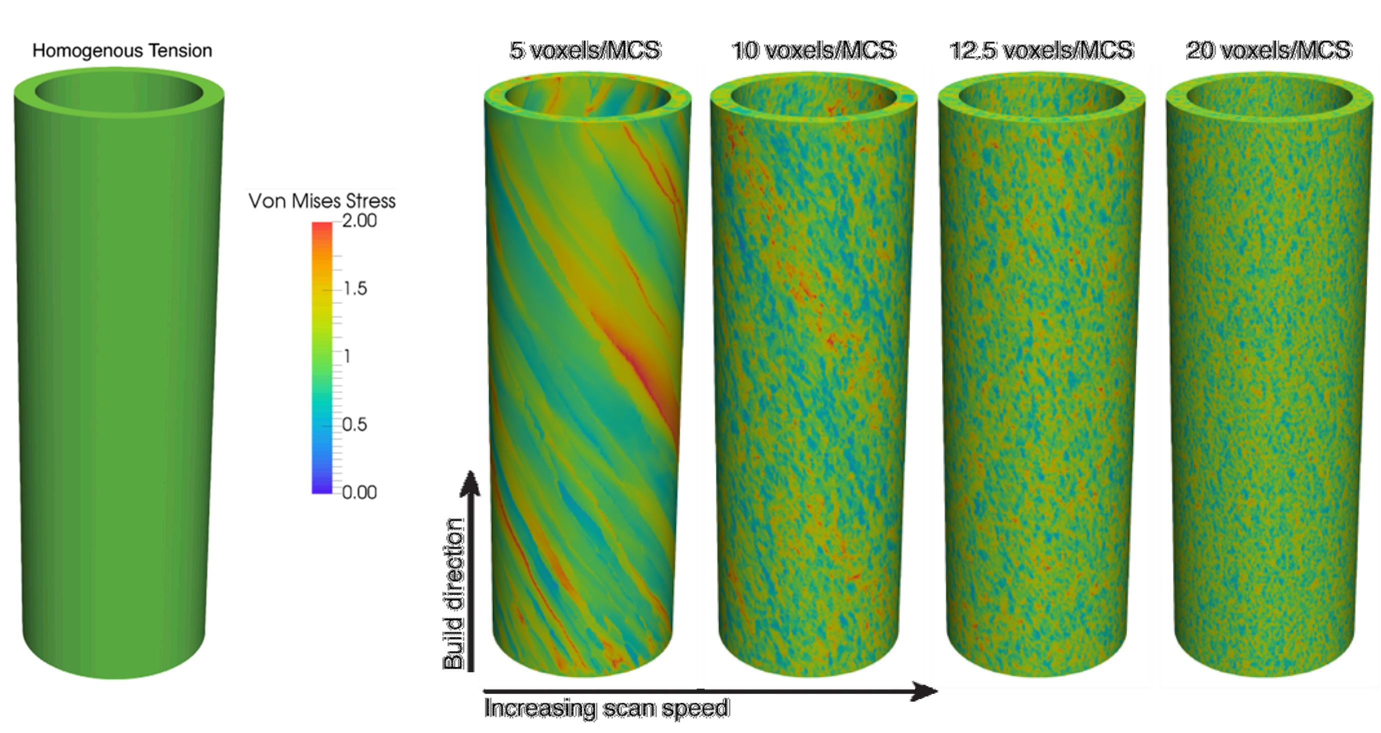




Voxelized Monte Carlo microstructures were remeshed to a conformal finite element mesh of ~ 55,000,000 elements.

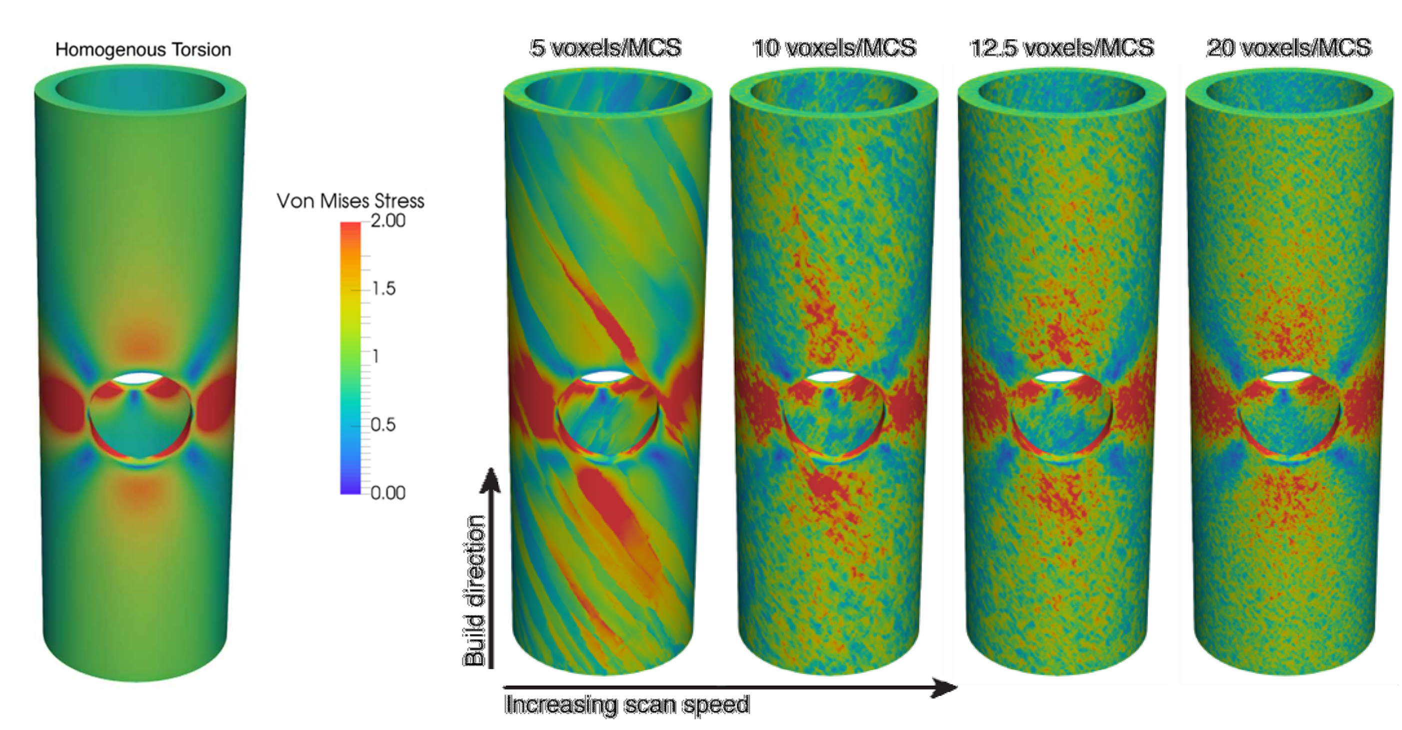
Pure tension loading

The introduction of a synthetic microstructure resulted in significant deviation from the uniform response of a homogenous tube. The helical pattern of columnar grains decreased with increasing scan velocity, resulting in more isotropic variation.



Pure torsion loading

A side hole was "machined" from the tube before the application of torsional loading. For each scan velocity, the synthetic microstructure resulted in substantial variation from the homogenous response.

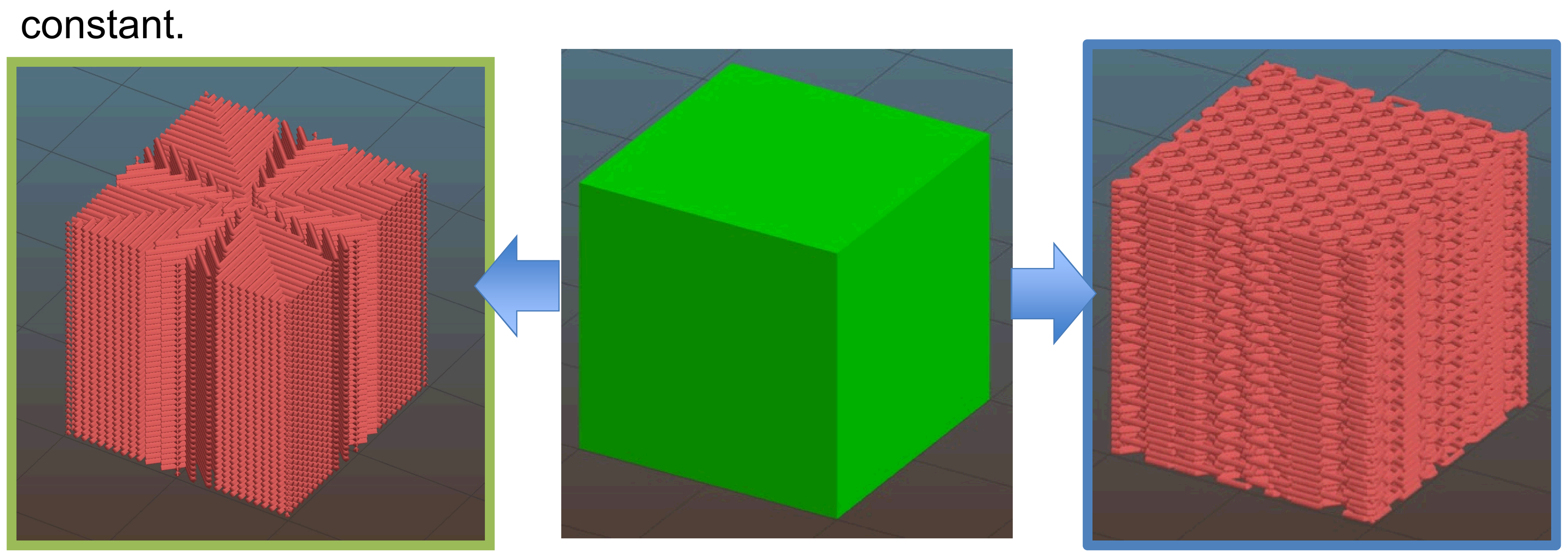


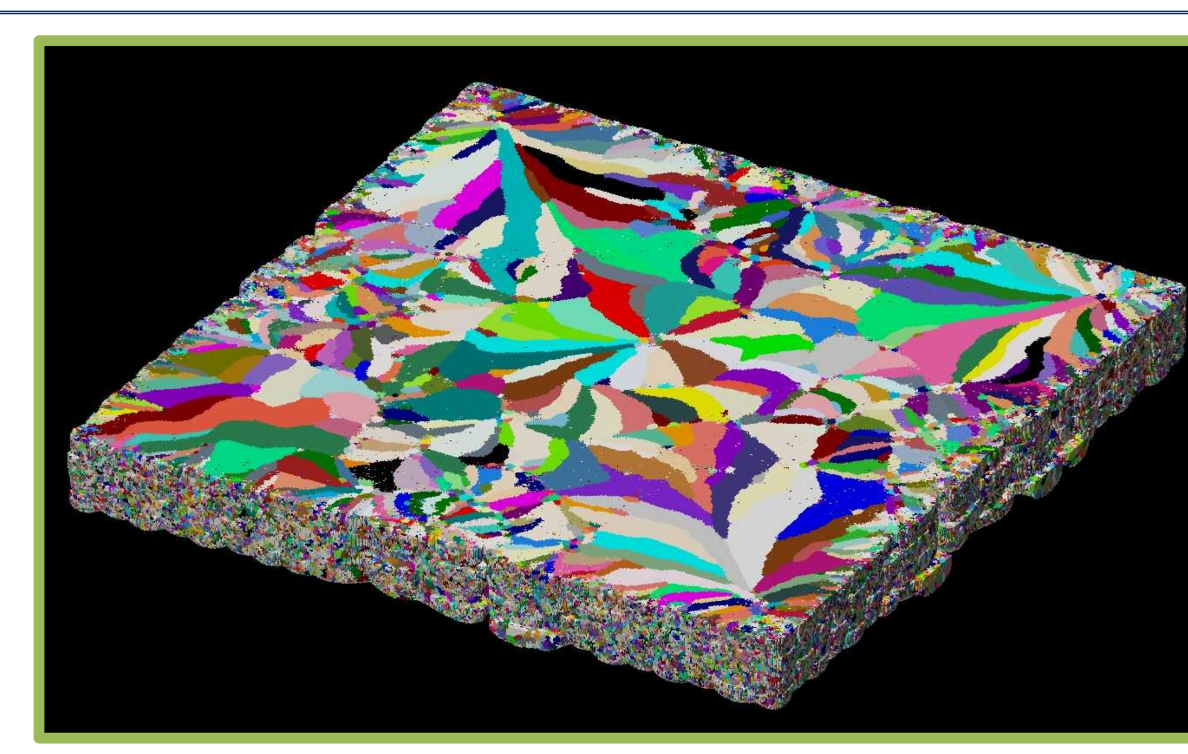
Coupling with thermal diffusion solver

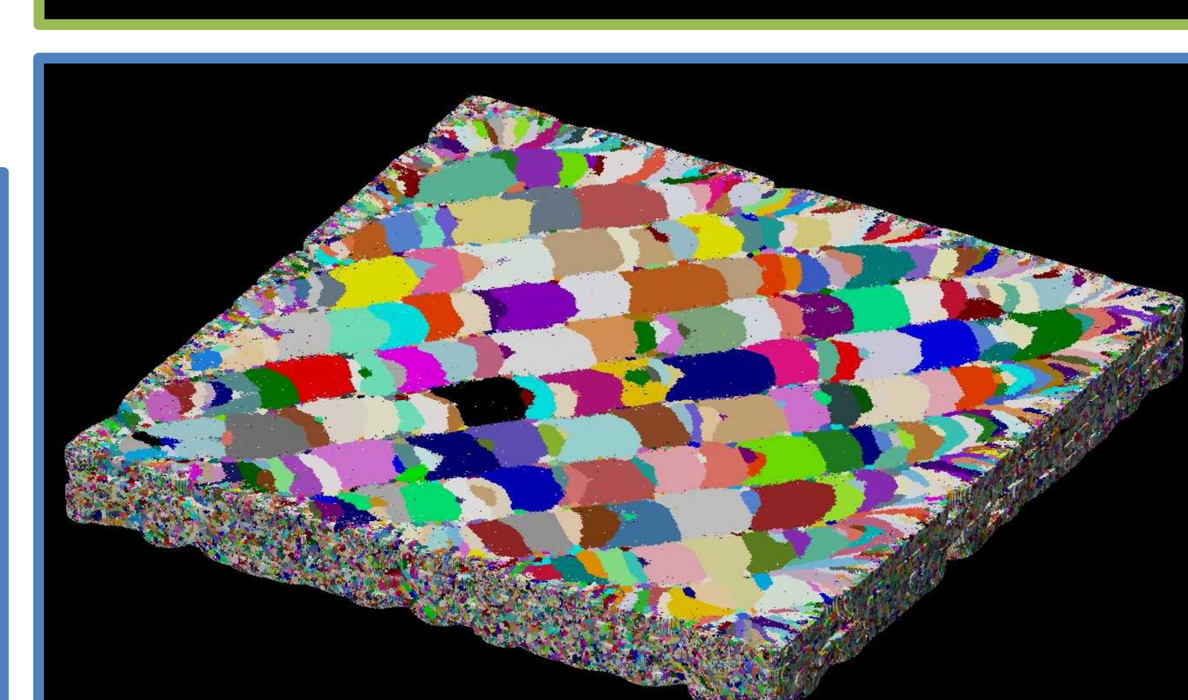
A finite difference thermal diffusion solver has been directly coupled with the microstructure simulation. A 3D Gaussian heat source is used to model laser energy input. The model also implements convection/radiation boundary conditions, latent heat, and temperature-dependent element activation.

The thermal solver also allows for the use of externally-specified scan patterns through the use of a G-code interpreter. An example of microstructural variation with scan pattern is shown.

A cube was sliced into two unique scan patterns in Slic3r (below), which were then used to drive microstructural simulations (right). All other parameters were held constant.







1.Rodgers, T.M., et al. JOM, 2016. **68**(5): p. 1419-1426.
2. Rodgers, T.M., et. al. Computational Materials Science, 2017.
3. Rodgers, T.M., Bishop, J.E., Madison, J.D. *In preparation*
4. Rodgers, T.M., Abdeljawad, F., Madison, J.D. *In preparation*

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