IITM-UofL Research Symposium April 2022

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Materials Innovation Guild
Guide – Dr. Sundar V Atre

Affiliation

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Research Area:

Metal Additive Manufacturing

Lab Website - http://scipivision.scipitutors.com/

Key Focus Areas for Researcher presentation

Title

Evaluation of Process Simulation for Laser-Powder Bed Fusion

Technologies

Laser-powder based Additive manufacturing, CAD modelling, STL Conversion, MSc Hexagon Software (Simufact Software) for AM Simulations, Mechanical and Thermal based AM Simulations, Additive Manufacturing (3D Printing) for process validation and application support, and AM integrated (process and performance) simulation.

Abstract

Laser-powder bed fusion, as an additive manufacturing process, is defined by intense thermal cycles, with cooling rates as high as 10^7 K/s and cycle times as small as 25 μs. This results in the as-printed parts being characterized by distortion and internal stresses. With the primary value addition of process-centered in the fabrication of complex geometries with tight tolerances in fields such as aerospace, medical industries the penalties for part failures incurred in the form of safety and cost are high. 'Simufact', is an L-PBF process simulation suite developed by MSC Hexagon software company which, for a given set of process parameters, provides the distortion, internal stresses developed in the printed parts as output. The present study sought to evaluate the process simulation, by comparing the experimental observations in terms of part distortion obtained in a stainless-steel cube fabricated through L-PBF, with the process simulation obtained with the same set of process parameters. In terms, of setting up the process simulation, mesh optimization was carried out by comparing the results over a range of voxel sizes, and picking the largest among them after a steady-state has been achieved. By comparing the experimental observations with the simulation, we saw that overall length observed from the computational simulation and experiment are nearly the same and some slight deviation in results have been seen due to the considerable amount of shrinkage occurred in the printing process due to the phase change leading to changes in dimensions. It was also evident that decreased element size results in more computation time and increase voxel meshes element size results in a decrease in total distortion/surface deviation.

Keywords: Additive manufacturing, Simufact, voxel, L-PBF, mesh optimization, thermo-mechanical simulation

Key Focus Areas for Researcher presentation

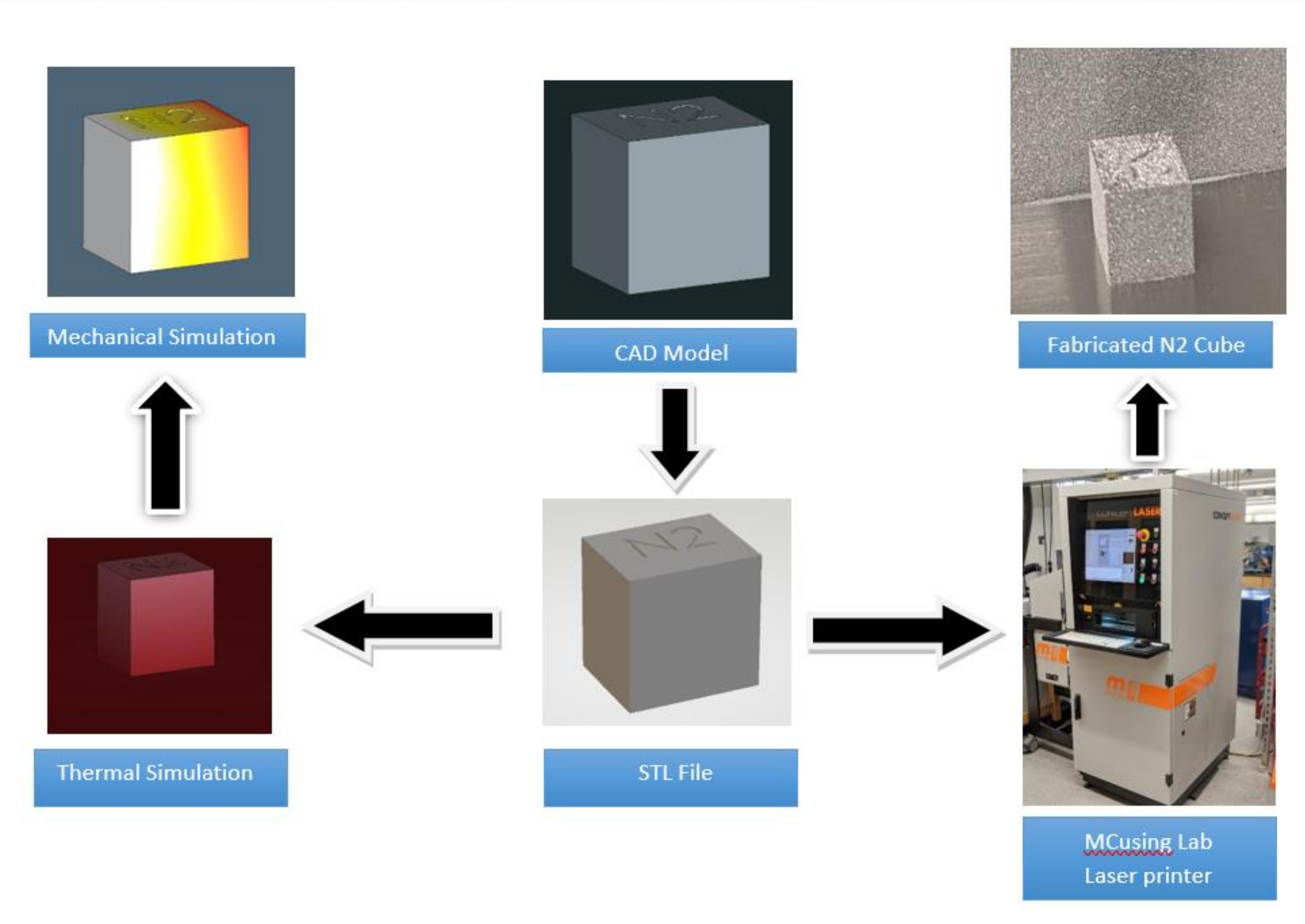
Industry Application

Additive Manufacturing (AM) research on material-process-geometry interrelationship investigations, Design for AM (DfAM), Generative design, AM process simulation (Simufact), Integrated structural/ performance simulation of 3D printed parts (Simufact-Ansys).

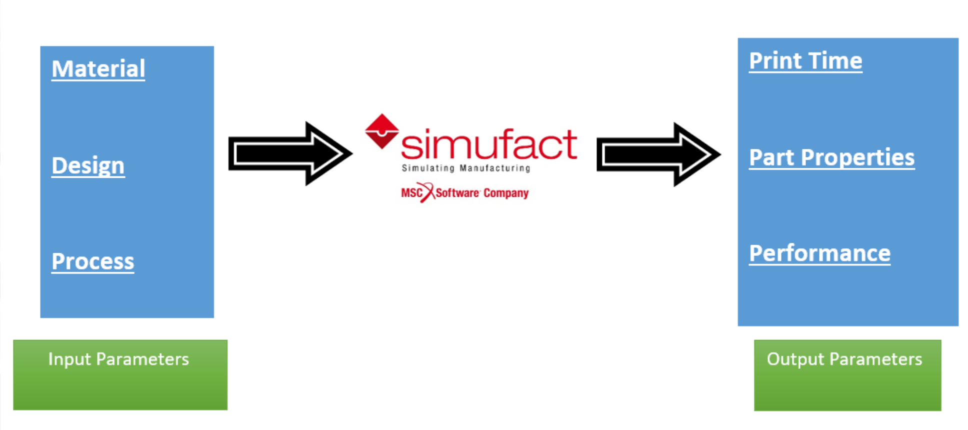
Economic Analysis:

- ❑ Methodology of predictive simulation and experimental verification of LPBF printed sample
- ❑ Governing Mechanical and Thermal Equations
- ❑ Printing parameters

Methodology



Methodology of predictive simulation and experimental verification of L-PBF printed part



Overall approach predicting simulation results

Thermo-Mechanical Simulation model

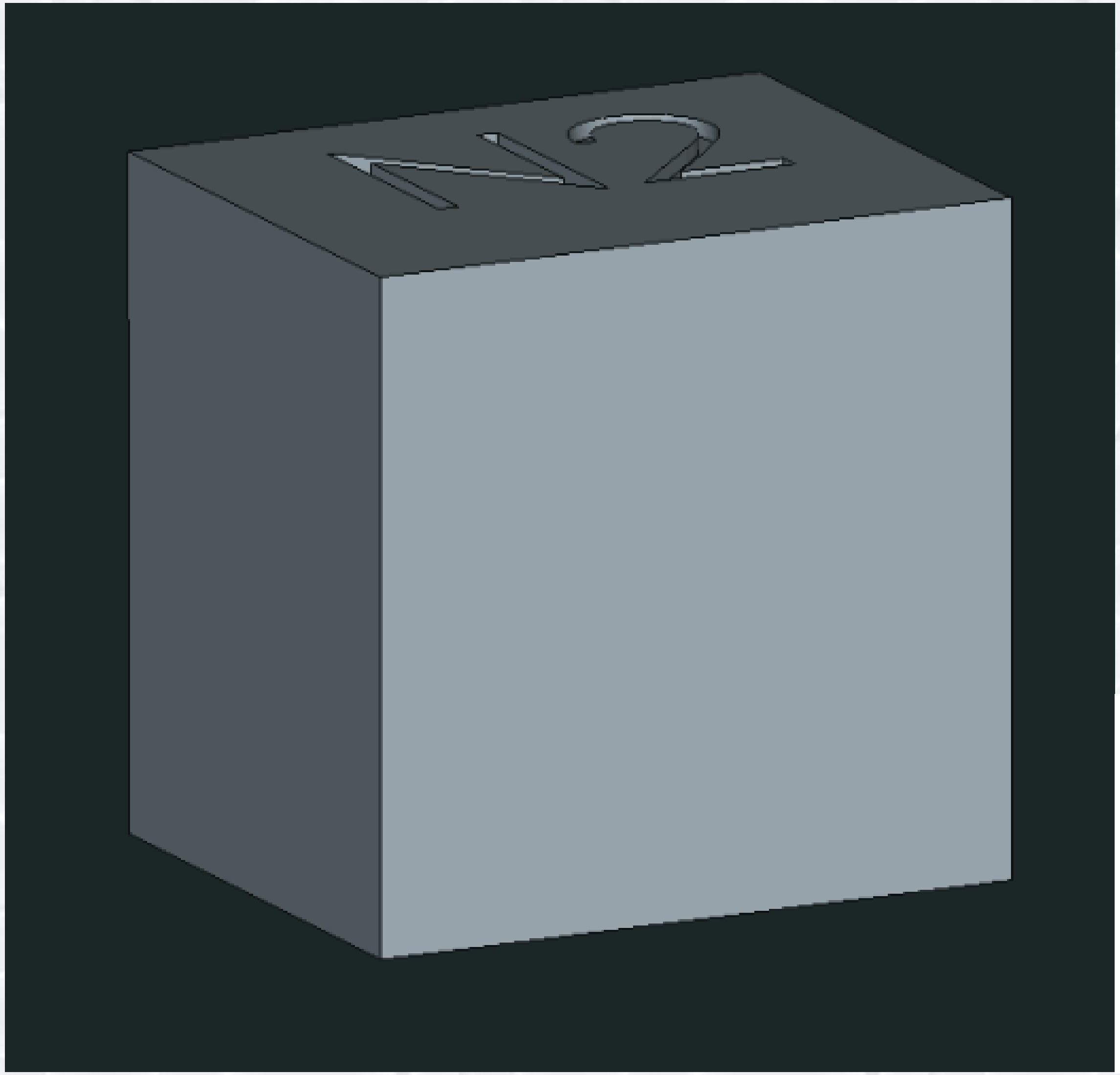
The mechanical and thermal solver models are predicting the stress and thermal contours over the structures. The layer-by-layer process simulation provides evaluation and observation of the stress, deformations and temperature results over the significant amount of time for the desired sample. The temperature distribution over the printed part, fabricated through LPBF process is predictable through continuum heat diffusion equation:

$$\rho Cp \ \frac{\partial T(x,y,z,t)}{\partial t} - k\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right) T\ (x,y,z,t) = E_v$$

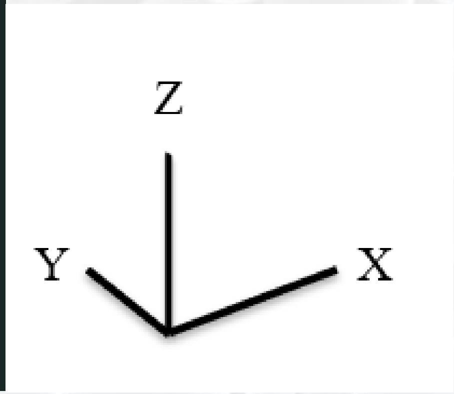
ρ *is the material density,* Cp *is specific heat,* k *is thermal conductivity, and* E_v *is Energy density*

T (x, y, z, t) is the instantaneous temperature at location (x, y,z) at time t and second derivative term (continuous Laplacian) in the heat equation captures the effect of shape on the temperature distribution. Energy density is defined as the amount of energy supplied by the laser to melt a unit volume of powder. The volumetric energy density is a function of laser power (P), laser scanning speed (v), spacing between two consecutive laser tracks (h), and layer thickness (t). $\mathrm{E} = \frac{\mathrm{P}}{\mathrm{v\,x\,h\,x\,t}}$

Fabricated Cube : CAD Model



- Simple
- Three dimensional
- Solid section (core vs surface)



<u>Length – 10</u>
<u>Width – 8</u>
<u>Height - 10</u>

<u>All dimensions are in mm</u>

Material Properties & Printing parameters

Material properties for Wrought 25Cr7Ni stainless steel

S.No	Material Properties	Value
1	Density	7.7 g/cc
2	Yield Strength	650 MPa
3	Ultimate Tensile Strength	870 MPa

Experimentally observed values

Printing Parameters

S.No	Simulation Parameter	Value
1	Machine Type	Mlab Cusing
2	Maximum laser (W)	90
3	Maximum laser speed (mm/s)	600
4	Laser thickness (mm)	0.02
5	Scan width (mm)	0.12
6	Build space dimension (mm)	100 X 100 X 100

Temperature Distribution & Thermal History

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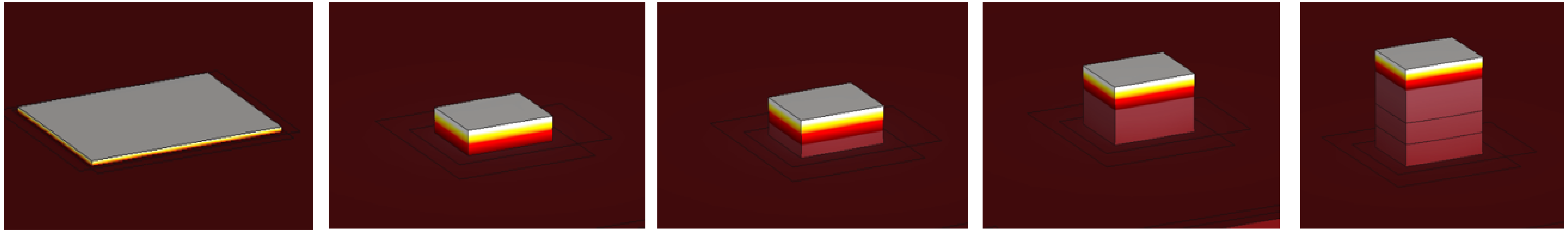
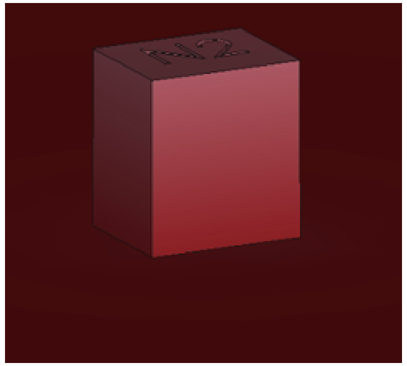
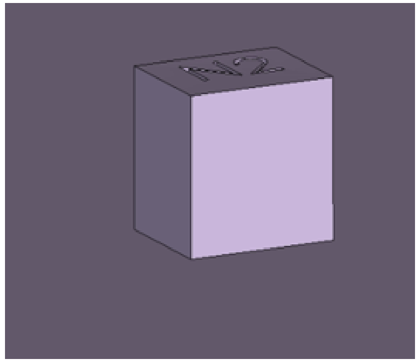
Layer by Layer Formation



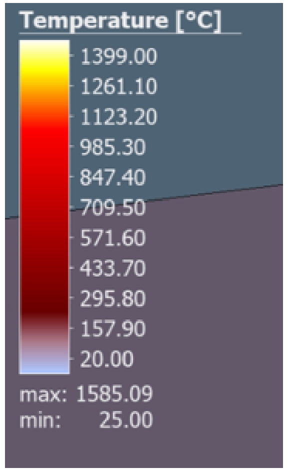
Layer 1 | Layer 2 | Layer 3 | Layer 5 | Layer 9

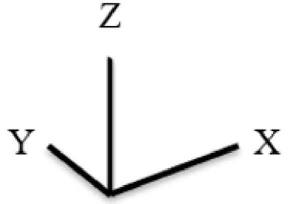


Precooling



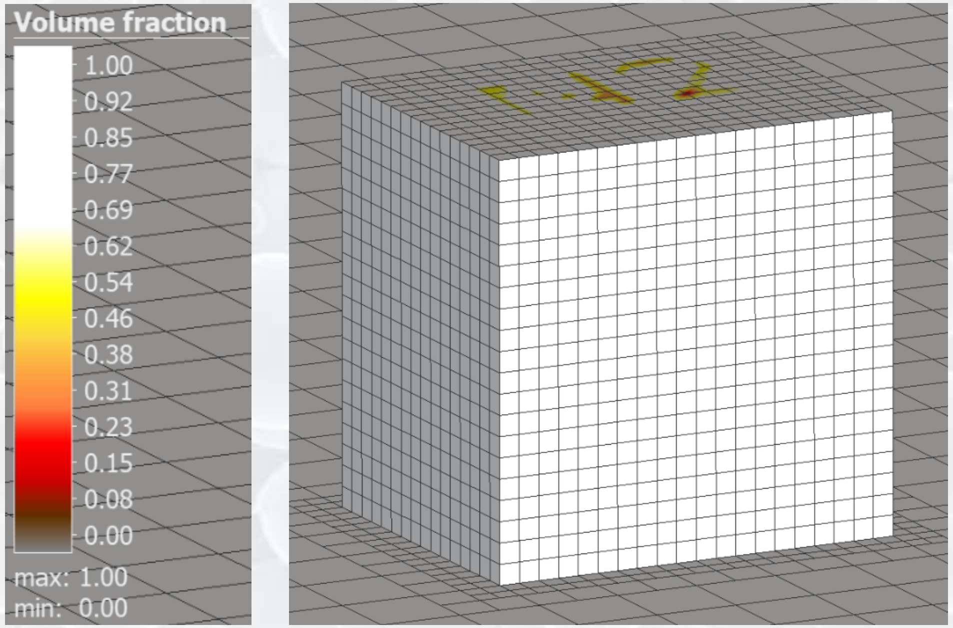
After-cooling





Voxel Mesh Optimization

Voxel mesh optimization is obtained using Volume fraction. The ‘Volume fraction’ describes how much volume of the voxel element is actually filled by the geometry



Voxel mesh results for 0.5 mm mesh size

Voxel Size (in mm)	0.5	0.8	1	2	4
Yield Stress (in MPa)	397.49	434.78	437.72	586	585

Distortion & Dimensional Variation

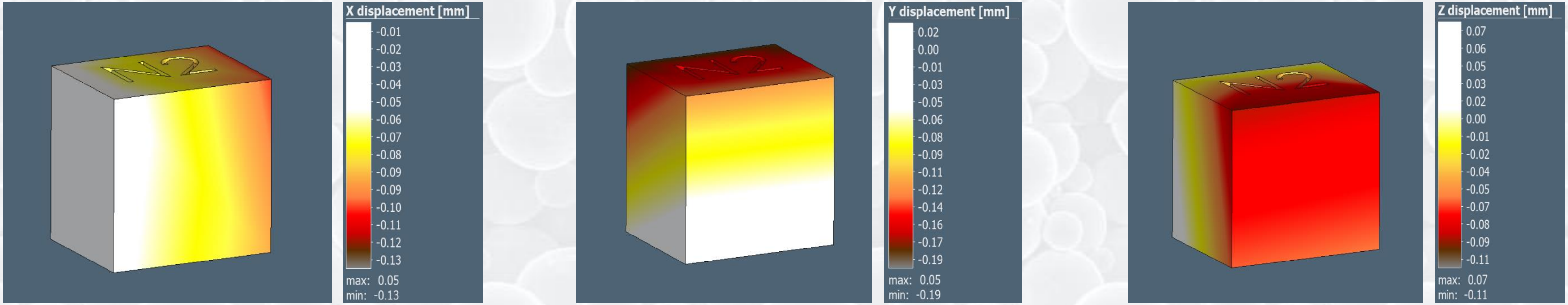
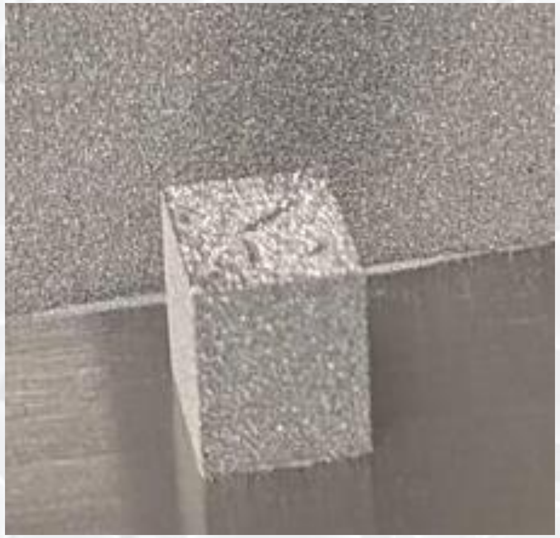


Figure shows the displacements results for 0.5mm voxel size in X, Y & Z direction respectively

Voxel Size	0.5 mm	0.8 mm	1 mm
Overall Length – X (Before Cutting)	10.10	10.07	10.08
Overall Length – X (After Cutting)	10.06	10.06	10.04
Overall Length – Y (Before Cutting)	8.06	8.02	8.06
Overall Length – Y (After Cutting)	8.07	8.05	8.06
Overall Length – Z (Before Cutting)	9.8	10.03	10.05
Overall Length – Z (After Cutting)	9.8	10.04	10.06

Fabrication & Experimental Results



Developed Cube Sample

Displacement	Before Cutting - Experimental	After Cutting – Experimental
Overall Length – X	10.13	10.095
Overall Length – Y	8.07	8.145
Overall Length – Z	9.815	9.7975

Overall Length	Before Cutting (Simulation)	Before Cutting (Experimental)
X Direction	10.10	10.13
Y Direction	8.06	8.07
Z Direction	9.8	9.815

Overall Length	After Cutting (Simulation)	After Cutting (Experimental)
X Direction	10.06	10.095
Y Direction	8.07	8.145
Z Direction	9.8	9.7975

Learning & Conclusion

Simulation results vs Experiment

- ❑ Dimension prediction (X,Y,Z) (before & after cutting) vs experiment
- ❑ Warpage pattern (before cutting) vs experiment
- ❑ Reverse warpage (before & after cutting)
- ❑ Thermal history
- ❑ Residual stresses (before & after cutting)

- The evaluated L-PBF AM based simulation results is giving optimal results because of the optimal selection of process parameters to evaluate the behavior of the sample cube before it’s being developed using SLM based printers. The software framework shows the sample, mechanical and thermal behavior for each and every fabricated layer using Laser powder-based fusion, (L-PBF) process.
- Fabrication was done with a maximum error percentage of 0.9% from the results those obtained from the computational simulation and No difference was observed in the simulation results when the cutting direction is changed from +X (front to back) to +Y (right to left).

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Authored by:

Arulselvan Arumugham Akilan; Swapnil Kumar; Mohammad Qasim Shaikh; Ravi K. Enneti; Sundar V. Atre

Published in:

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