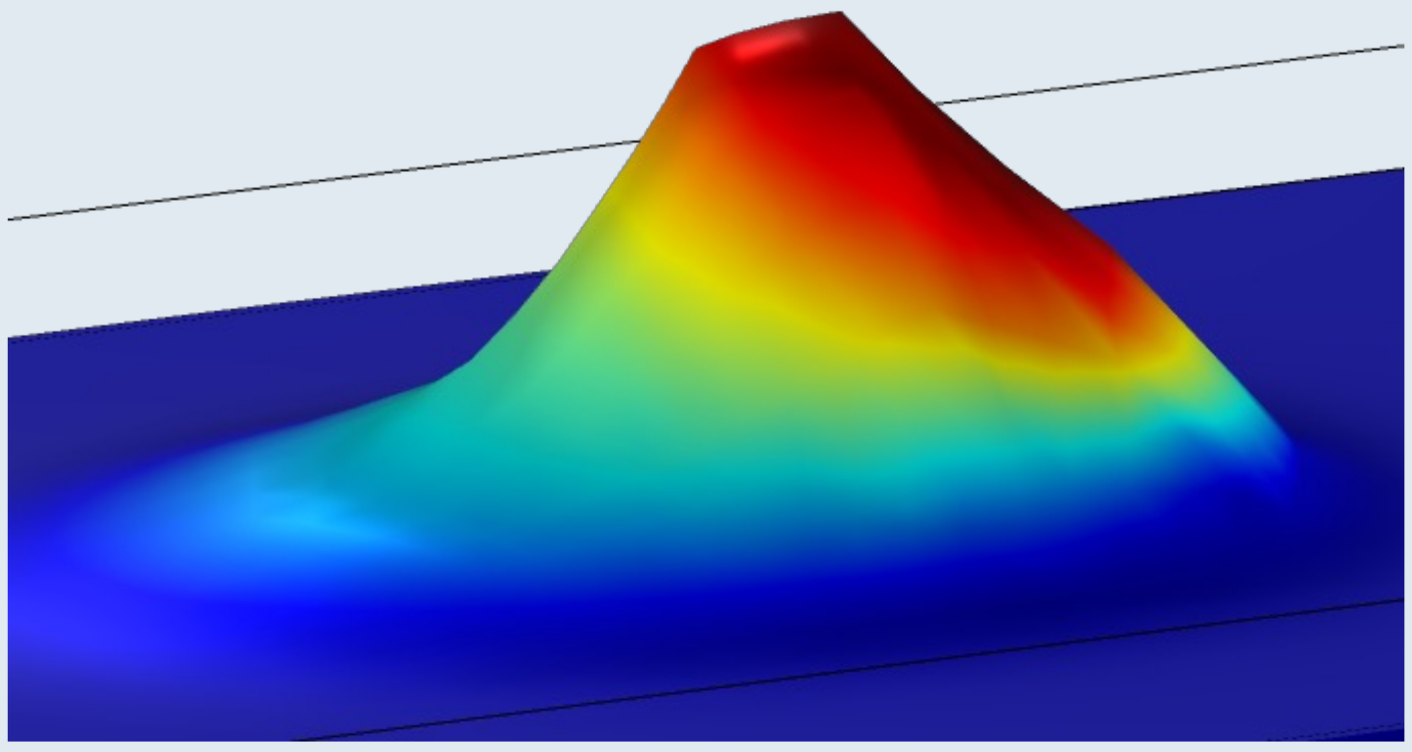

# Thermomechanical Model of Laser Powder Bed Fusion

A study on residual stress and impact of laser process parameters including laser velocity and laser power, using volumetric heat source.

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## Abstract

Laser Powder Bed Fusion (LPBF) is a precise manufacturing process well-suited for creating complex geometries, but it generates high thermal gradients, leading to residual stress that can damage parts. Ti-6Al-4V requires precise control to ensure proper dimensions. This study developed a finite element method (FEM) simulation in COMSOL Multiphysics® to examine how laser power and scanning velocity affect melt pool geometry and residual stress. Temperature-dependent properties and phase changes were included to improve model accuracy.

The results showed that higher laser power and lower scanning velocity increased peak temperature and melt pool size. However, the effect on residual stress was more complex: increasing laser power raised stress levels, while scanning velocity initially reduced stress before increasing it again at higher speeds. These findings underline the importance of optimizing LPBF parameters to minimize residual stress. The simulation was validated against experimental data, providing insights for improving LPBF processes.

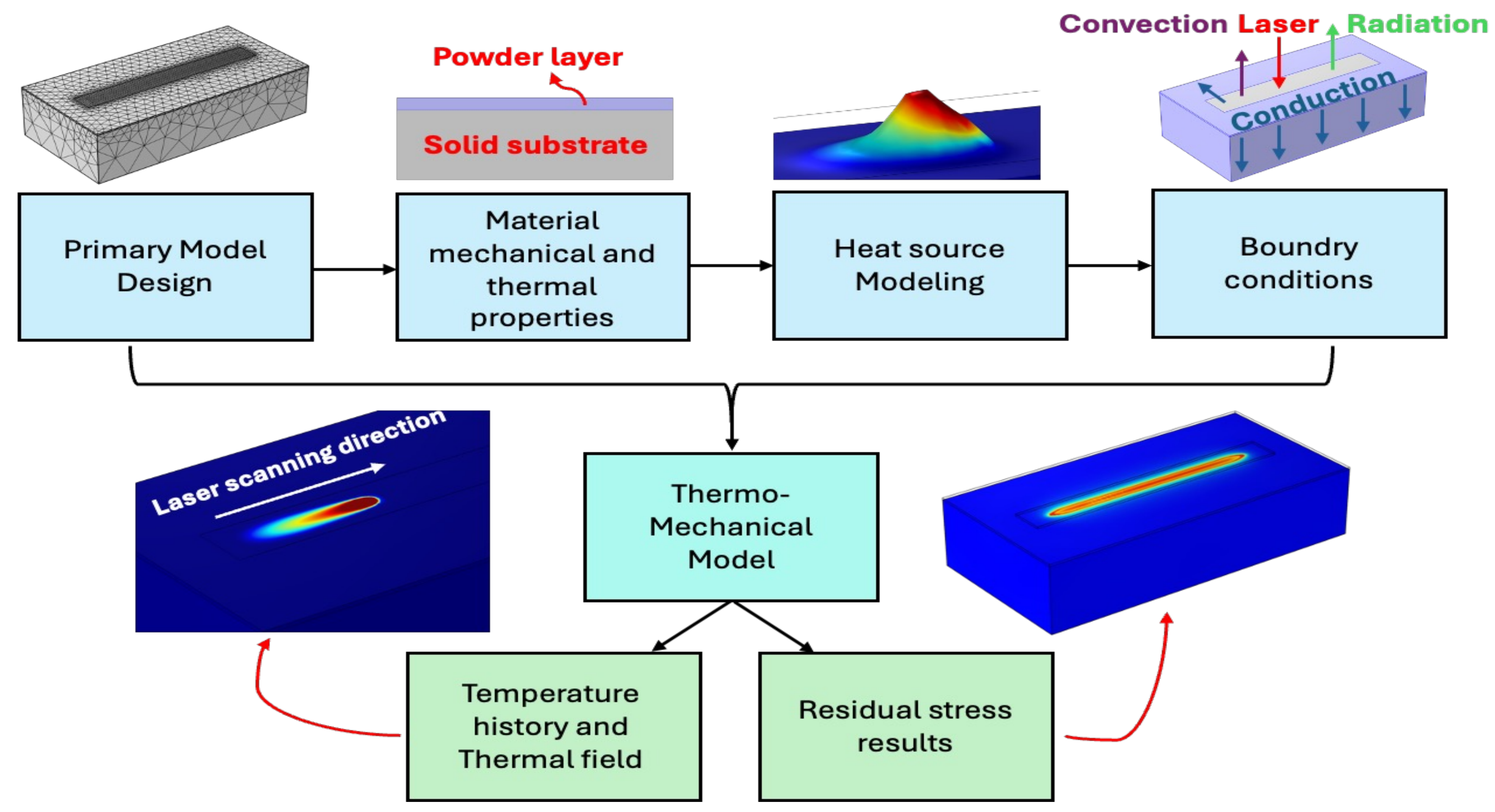


Figure 1. Framework of developed thermomechanical model for LPBF.

## Methodology

In this study, Ti-6Al-4V was used for both the substrate and powder layer, with an average particle size of 30 µm, matching the powder layer thickness in the simulation. A rectangular model with dimensions of 4000×2000×1000 µm was developed in COMSOL Multiphysics, where the powder and solid substrate were distinguished by different thermal properties. The mesh was refined to 40 µm in the melting zone and coarser further out to balance accuracy and computation time. The heat source was modeled using both a 2D Gaussian distribution and a 3D volumetric model, incorporating a temperature-dependent absorptivity profile. All forms of heat transfer—conduction, convection, and radiation—were accounted for, considering temperature-dependent properties like thermal conductivity and density. Time steps of 1 µs for heating and 155 µs for cooling were used to optimize computation time. The simulation was validated by comparing melt pool dimensions to experimental results from the literature.

## Results

The results demonstrate that laser scanning velocity and power significantly influence residual stress during LPBF of Ti-6Al-4V. As laser velocity increases, residual stress generally decreases due to reduced heat input and smaller melt pools. However, beyond a critical velocity (around 900 mm/s), residual stress increases again due to faster cooling rates and steeper thermal gradients. In contrast, increasing laser power consistently raises residual stress, as higher energy input results in larger melt pools and greater temperature gradients, leading to more pronounced thermal expansion and contraction during solidification. These findings highlight the importance of optimizing laser parameters to control residual stress and enhance the quality of LPBF parts.

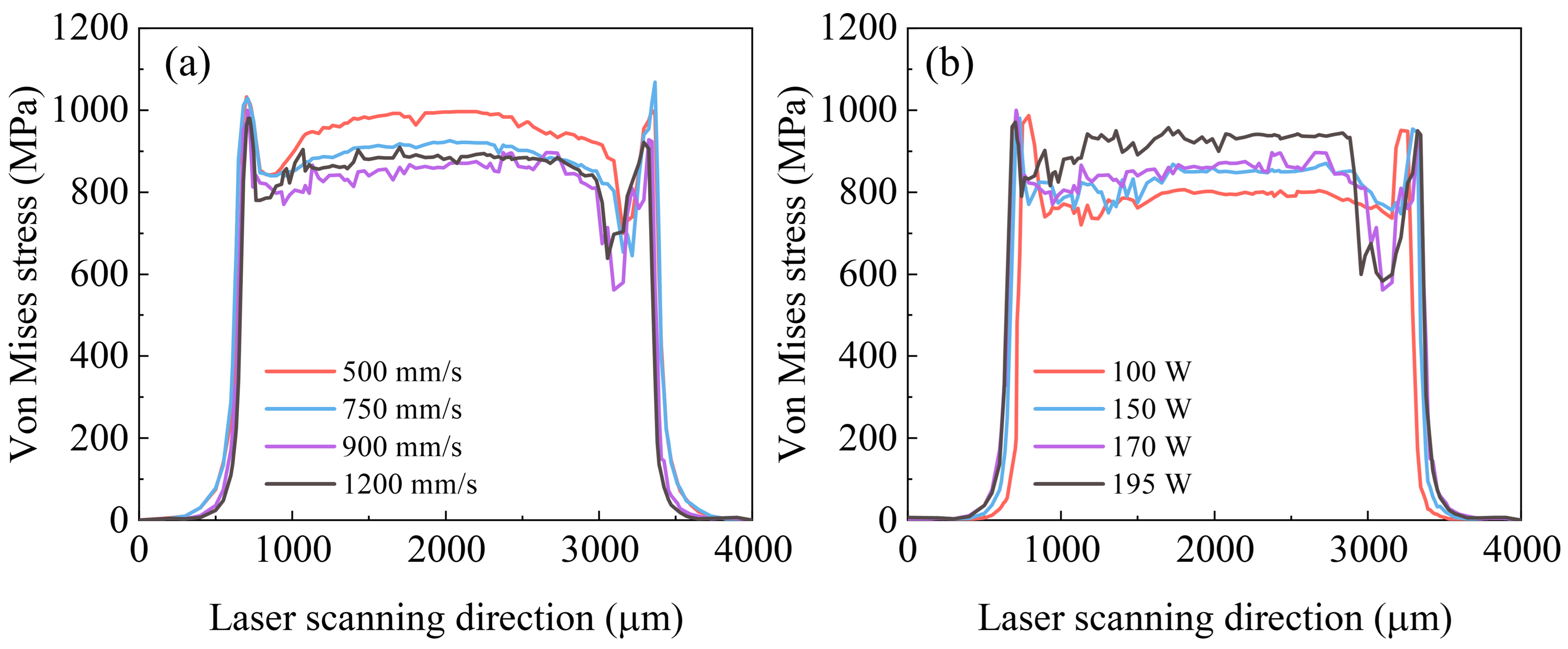


Figure 2. Thermal residual stress curves, under a) laser power 170W, and b) laser velocity 900 mm/s.

## REFERENCES

1. J. J. S. Dilip *et al.*, "Influence of processing parameters on the evolution of melt pool, porosity, and microstructures in Ti-6Al-4V alloy parts fabricated by selective laser melting," *Progress in Additive Manufacturing*, vol. 2, no. 3, pp. 157–167, Sep. 2017.
2. H. Mohammadkamal and F. Caiazzo, "Thermomechanical simulation of laser powder bed fusion for Ti-6Al-4V: A study on residual stress and impact of laser process parameters using volumetric heat source," *Proceedings of the 2024 11th International Workshop on Metrology for AeroSpace (MetroAeroSpace),* vol. 2024, pp. 1-6, June 2024.

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