HR/PhD

Popular science summary of the PhD thesis

PhD student	Alberto Santi
Title of the PhD thesis	Thermo-metallurgical-mechanical Modeling of Metal Additive Manufacturing Processes
PhD school/Department	DTU Construct

Science summary

Metal 3D printing, also known as Metal Additive Manufacturing (MAM), is revolutionizing the production of complex metal parts. Unlike traditional subtractive methods, where material is cut away from a block, MAM builds components layer-by-layer using a focused energy source, such as a laser, to melt and print metallic materials. This approach enables the creation of lighter and intricate designs, reduces waste, and shortens production time. However, the process remains difficult to control: even slight changes in laser power, speed, or alloy properties can lead to unwanted defects, such as porosities, cracks, or distortions.

To understand and predict such effects, researchers increasingly rely on computer simulations that reproduce the manufacturing process virtually. These models enable the exploration of how process parameters affect temperature, stresses, and microstructure without requiring hundreds of costly experiments. Yet, building accurate models is challenging because metal 3D printing involves many interacting physical phenomena (heat transfer, melting, solidification, and mechanical deformation) spanning from micrometers to full part scales.

This PhD thesis develops and tests a hierarchy of models to describe these processes efficiently and reliably. The work combines thermal, mechanical, and microstructural simulations for the two main laser-based technologies: Powder Bed Fusion and Directed Energy Deposition. A key outcome is the envision of a multiscale framework that links small-scale models, which describe melt pool and grain growth, with large-scale ones that predict residual stresses and distortions. The thesis also outlines systematic procedures for verifying, validating, and calibrating models to ensure their predictive accuracy and credibility.

Altogether, the research contributes to the development of faster and more reliable virtual tools for designing and optimizing metal 3D printing processes. Such models can support the development of new materials and component designs, reduce trial-and-error experiments, and accelerate the industrial adoption of additive manufacturing within an Integrated Computational Materials Engineering (ICME) approach.