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Sim2AM computational methods for optimizing the SLM additive manufacturing process

Numerical analysis of single-tracks produced by laser powder bed fusion

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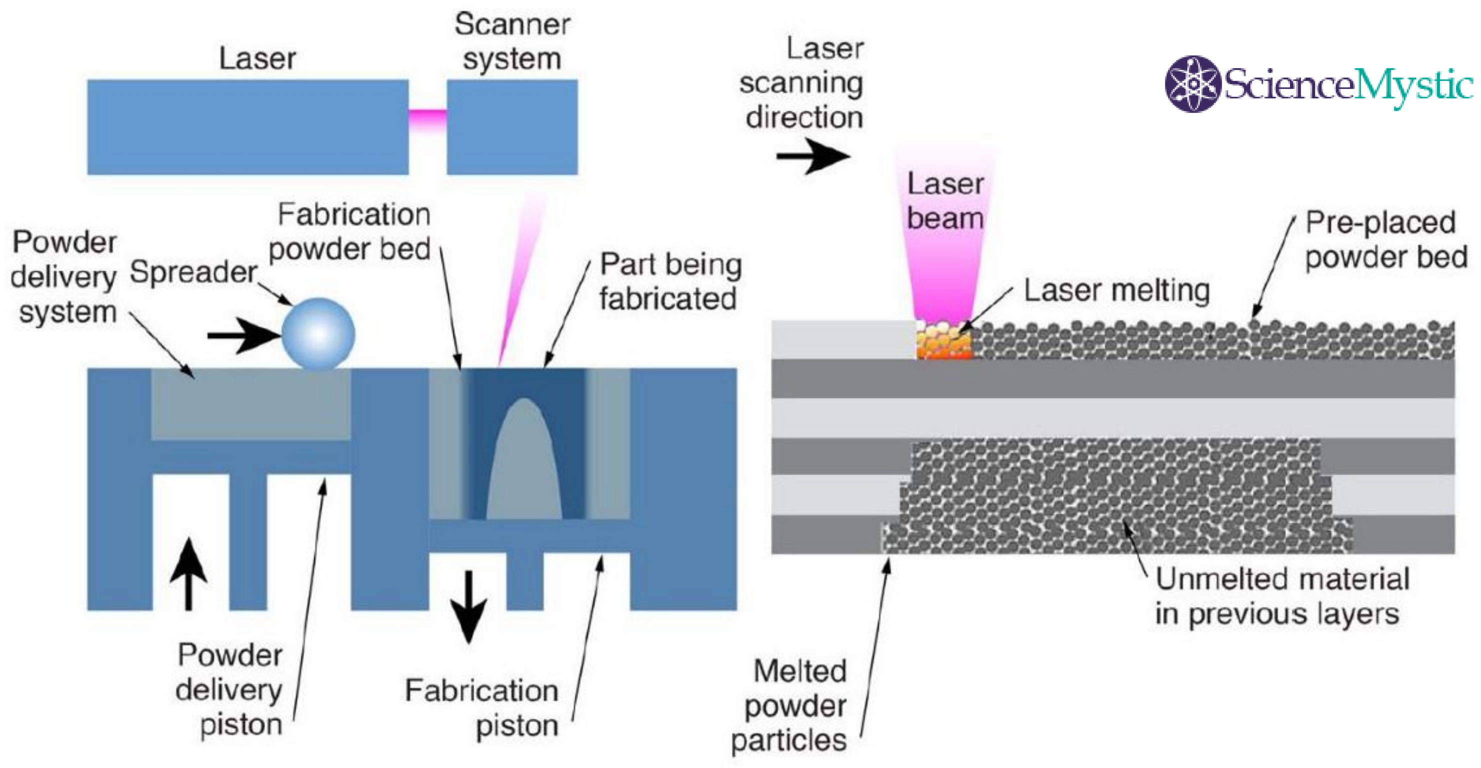
Introduction

Additive manufacturing processes for **metallic parts** are growing due to the:

- Potential for producing high-value, complex, individually customized parts;
- Short development time;
- Efficient use of raw materials (minimum waste).

Laser-Powder Bed Fusion (L-PBF) is a metal powder-based technology, where a high power-density laser is used to melt and fuse metallic powders, creating a melt-pool.



However, the cyclic melting and solidification processes generate complex heat transport and physical mechanisms, leading to **defects**, such as porosity, rough surfaces, residual stresses, part distortions and cracking.

Objectives

Expensive and time-consuming **experimental trial-and-error tests** are required to determine the process parameters to produce components without defects.

Numerical simulation of the L-PBF process can provide an **improved understanding of the physics** behind the manufacturing process.

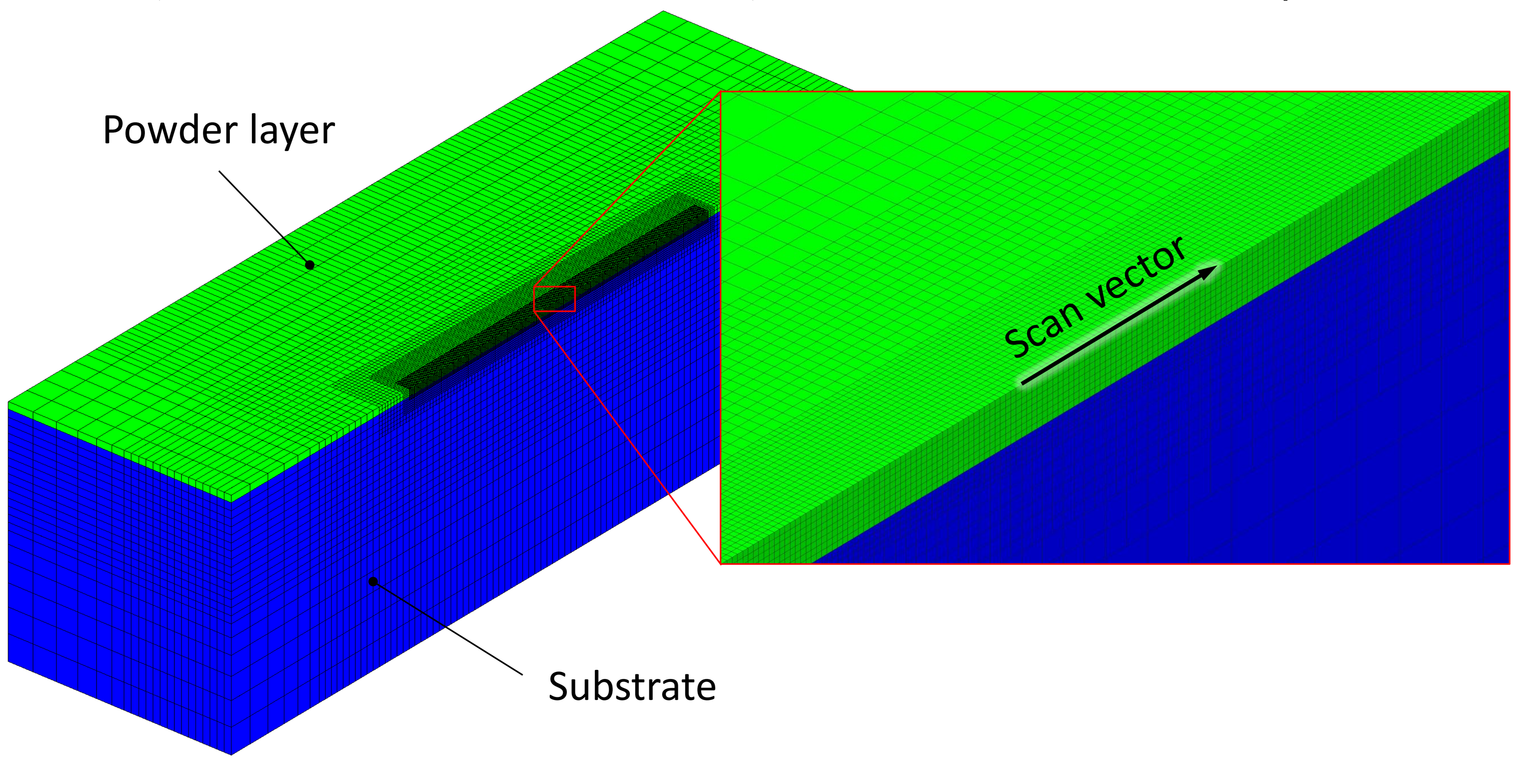
In this study, a meso-scale finite element model of single-tracks produced by L-PBF process was built to evaluate the effect of the process parameters on melt-pool geometry and size, for AlSi10Mg powder.

The **design of experiments** considers different combinations of laser power and scanning speed, comparing the continuous wave and the modulated pulsed wave.

Numerical Model

The **transient thermal analysis** of single-tracks deposition was carried out using the in-house finite element code **DD3IMP**. The model considers:

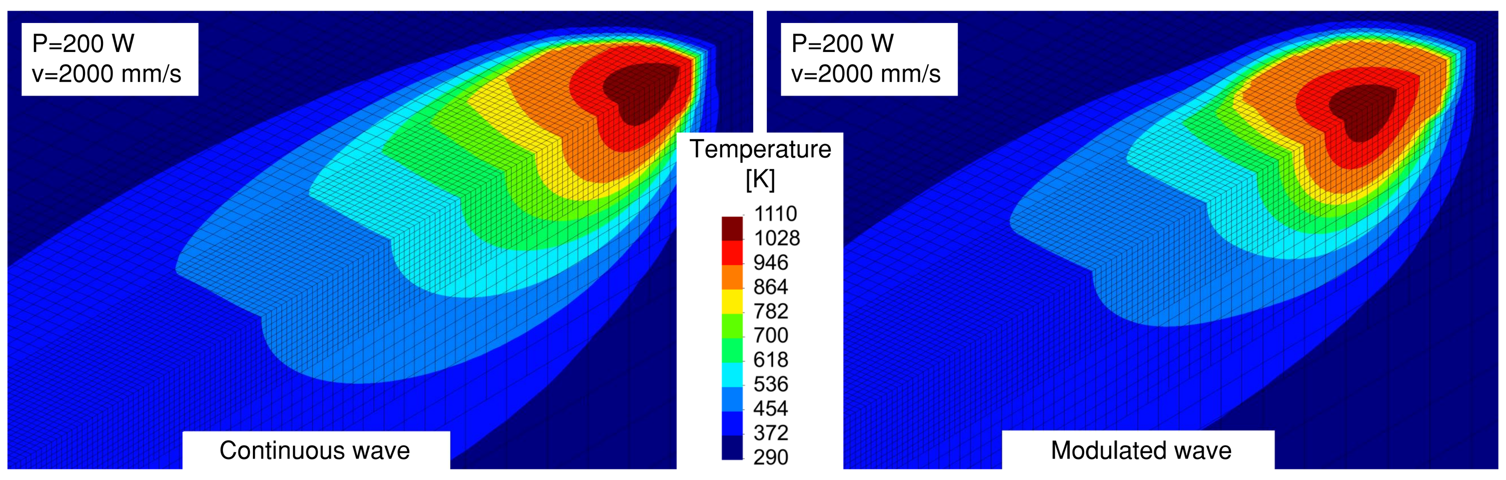
- A volumetric Gaussian heat source (80 μm of spot size);
- Heat losses by convection and radiation at the top surface;
- The thickness of the powder layer was 30 μm, considering half-width of the substrate (1×1×3.5 mm^3) due to symmetry conditions;
- The non-conforming mesh of the substrate+powder layer is composed by 158,340 linear hexahedral elements, minimum element size of 4 μm.



Results

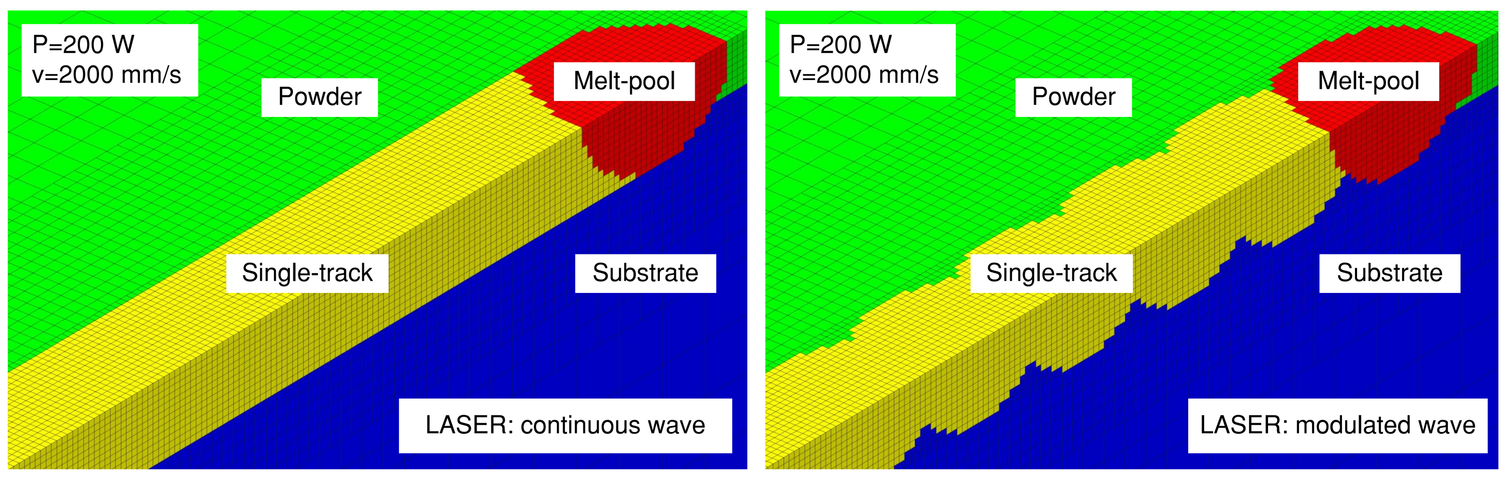
The predicted temperature field around the laser beam for 200 W of laser power and 2000 mm/s of scanning speed is compared for the **continuous** and the **modulated pulsed wave**. The peak temperature (around 1110 K in both cases) is a singularity inside the melt pool region.

The use of the modulated pulsed wave (exposure time: 20 μs and point distance: 40 μm), led to a significantly **smaller temperature gradient** ahead the laser beam.



The material phase of each finite element (powder, solid and liquid) is defined through the thermal history, using the melting temperature as bound (840 K). It is updated at the beginning of each time increment, defining the thermo-physical proprieties of the current increment.

The material phase predicted is compared for the same process parameters. The modulated pulsed wave leads to a **non-uniform width of the scanned track** due to the large point distance value adopted. Moreover, the **bonding interface is discontinuous**. On the other hand, the track obtained with the continuous wave is always continuous and homogenous.

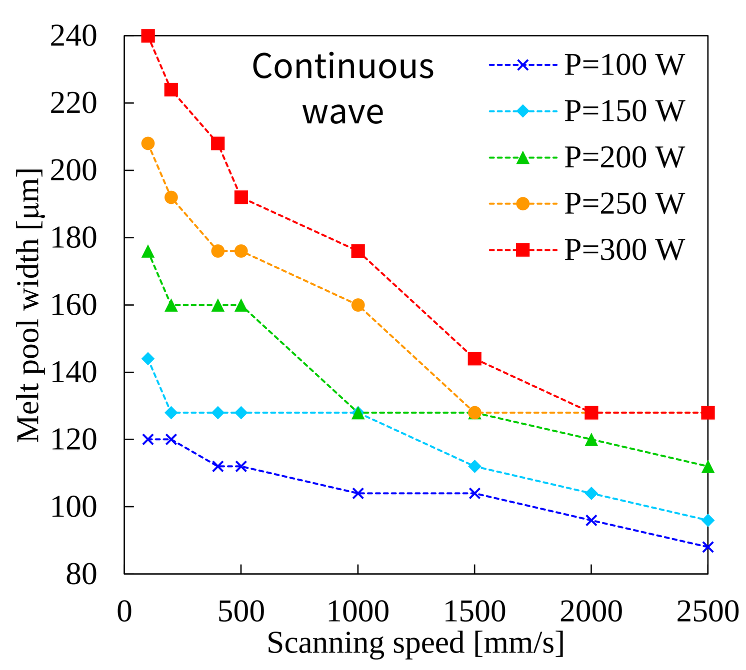


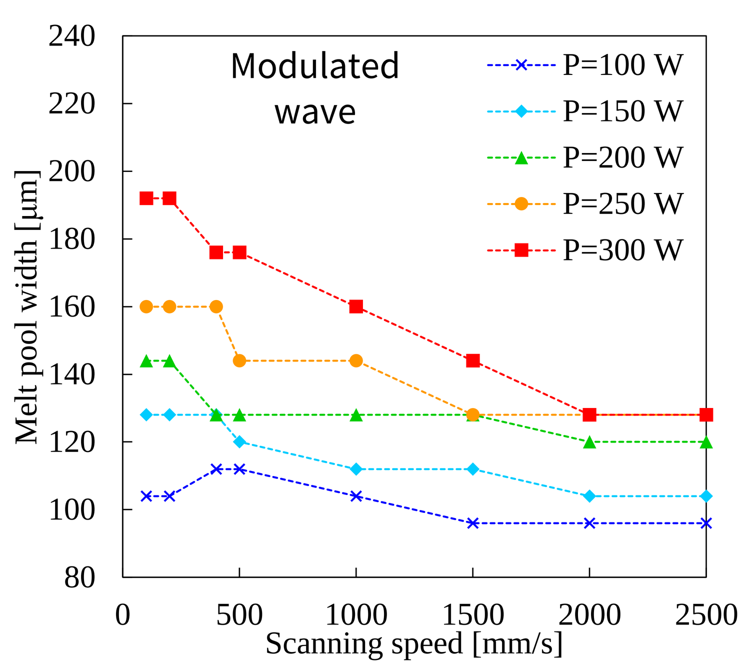
The melt-pool width was predicted for different combinations of laser power and scanning speed. The **melt-pool width increases** with:

- The increase of **the laser beam power**;
- The reduction of **the scanning speed**.

In both cases, there is an increase of input energy for the same time interval.

The effect of the scanning speed on the melt-pool width is less evident for the modulated pulsed wave, particularly for low values of scanning speed. Considering the continuous wave for the laser, the melt-pool width ranges between 88 μm (minimum power and maximum scanning speed) and 240 μm (maximum power and minimum scanning speed).





The results show that the numerical simulation of the L-PBF process can provide a basis for the process optimization, allowing to define the **suitable process window**.

Acknowledgements

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