Fast macroscopic thermal analysis for Laser Metal Deposition

D. Weisz-Patrault*

* Solid Mechanics Laboratory (LMS), École Polytechnique, CNRS
Université Paris-Saclay, F-91128 Palaiseau, France
e-mail: daniel.weisz-patrault@polytechnique.edu

ABSTRACT

Laser Metal Deposition (LMD) consists in injecting a stream of metallic powder that is molten by a laser beam in order to deposit material layer-by-layer on a substrate. This technology enables the users to produce complex thin wall structures such as meta-materials, auxetics etc. LMD process is an emerging technology, whose development is still in progress and offers high improvement potential. Process control constitutes a major industrial challenge. Thus, the main objective of many studies [1, 2] is to link the process parameters of the machine to the final metallic microstructure and residual stresses, as the ambition is to optimize the mechanical properties of the manufactured parts. This link is a complex interweaving of coupled physical processes: heat transfer, microstructural evolutions (e.g., phase transitions), plasticity etc.

The LMD process induces very specific temperature history including very high temperature gradients (near the fusion bed) and thermal cycling. Both the microstructure formation/evolution (solidification, solid state phase transitions, grain mobility etc.) and the formation of residual stresses are driven by thermal conditions during the process. Therefore, significant efforts have been made to simulate accurately, at the macroscopic scale, both temperature evolutions and solidification kinetics. However, macroscopic modeling of such processes is computationally costly (usually based on Finite Element models with element activation techniques) [3–6]. This hinders the development of efficient numerical optimization of process parameters in order to reach microstructure and material properties requirements.

In this contribution, a novel simplified semi-analytic thermal analysis of the LMD process is presented to obtain computationally efficient simulations of the entire process. The proposed approach enables to compute in the produced part: temperature, solidification and solid-state phase transitions kinetics (based on Avrami equation), taking into account the process parameters, substrate characteristics and heat sources due to the enthalpy change during phase transitions. The proposed simulation strategy applies to arbitrary shapes in the horizontal plane, the only geometrical restriction being that the part is a superposition of identical layers. In addition, the proposed approach applies to arbitrary nozzle paths (continuous, back and forth etc.). Powder melting is not simulated, as molten metal is directly deposited on top of the already existing layers. However a fraction of the laser power is transmitted to the top layer, which is taken into account in the computation.

The proposed work provides a simple tool to study the influence of process parameters, to design in-situ experiments and in term to develop an optimization loop to reach material requirements.

REFERENCES

[1] William E Frazier. Metal additive manufacturing: a review. *Journal of Materials Engineering and Performance*, 23(6):1917–1928, 2014.

[2] Tarasankar DebRoy, HL Wei, JS Zuback, T Mukherjee, JW Elmer, JO Milewski, Allison Michelle Beese, A Wilson-Heid, A De, and W Zhang. Additive manufacturing of metallic components–process, structure and properties. *Progress in Materials Science*, 92:112–224, 2018.

[3] Guillaume Marion, Georges Cailletaud, Christophe Colin, and Matthieu Mazière. A finite element model for the simulation of direct metal deposition. In *International Congress on Applications of Lasers & Electro-Optics*, volume 1, pages 834–841. LIA, 2014.

[4] Jacob Smith, Wei Xiong, Jian Cao, and Wing Kam Liu. Thermodynamically consistent microstructure prediction of additively manufactured materials. *Computational mechanics*, 57(3):359–370, 2016.

[5] Trevor Keller, Greta Lindwall, Supriyo Ghosh, Li Ma, Brandon M Lane, Fan Zhang, Ursula R Kattner, Eric A Lass, Jarred C Heigel, Yaakov Idell, et al. Application of finite element, phase-field, and calphad-based methods to additive manufacturing of ni-based superalloys. *Acta materialia*, 139:244–253, 2017.

[6] M Biegler, B Graf, and Michael Rethmeier. In-situ distortions in lmd additive manufacturing walls can be measured with digital image correlation and predicted using numerical simulations. *Additive Manufacturing*, 20:101–110, 2018.