TITLE

Characterization of GraIn Structure generated by L-PBF process at Track scale through Experiment And thermo-Metallurgical-Mechanical Modelling

Project acronym

GISTEAMMM

Global objective of work

The objective of **GISTEAMMM** is to characterize the grain structure generated by laser powder bed fusion (L-PBF) process at track scale: one track or single wall with several tracks, in which the grain structures will be obtained by both experiment and thermo-metallurgical-mechanical modelling. The anisotropic elastic-viscoplastic material laws at grain levels are expected to be extracted by considering the influence of inherent residual stress generated during printing process.

Context

The proposed project is selected under the frame of GIS (Scientific Interest Group) "HEAD - High energies in additive manufacturing", which is a new scientific interest group for additive manufacturing. Its aim is to increase the diffusion of the uses of additive manufacturing by removing the barriers faced by industry. The project is financed by two doctoral schools from both Centre for Material Forming (CEMEF), MINES Paris, and Solid Mechanics Laboratory (LMS), Ecole Polytechnique.

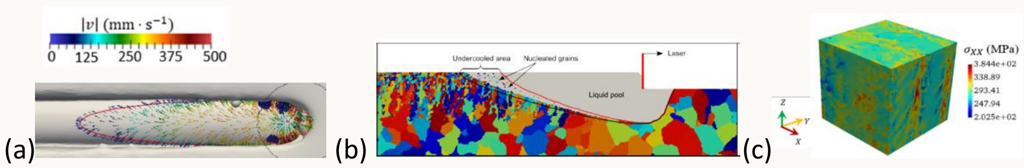
Regarding the numerical simulation, most of the mechanical behavior laws used for additive manufacturing (AM) process simulation are elastic-plastic, and the input parameters come from traction tests on samples that are not produced by AM [1]. Even the as-built additive manufactured (AMed) specimens are characterized, the inherent residual stress is usually ignored [2] and its effect on mechanical behavior is also difficult to be extracted. Moreover, when predicting AMed grain structure, the role of the as-build thermomechanical deformation on the microstructure evolution is ignored.

Detailed presentation with figure(s)

The proposed research tasks related to numerical and experimental sides are summarized as below:

Numerical simulations:

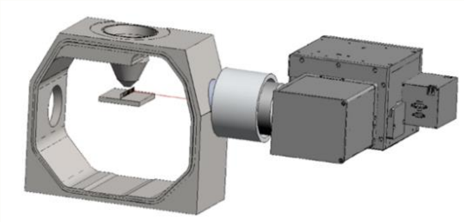
- Thermo-metallurgical-mechanical modelling of L-PBF deposition at track scale (CEMEF) → grain structure with inherent residual stress.
- Study the influence of local deformations on the intragranular texture→ distribution of different crystal orientation within one grain.
- Study the effect of grain structure on hot cracking.
- Representative volume element (RVE) traction relaxation simulations with anisotropic elastic-visco-plastic mechanical behavior laws by both crystal plasticity [3] and Hill48 anisotropic plasticity [4] (LMS, CEMEF) → average RVE behavior for part scale modelling.
- Understand the generated residual stress at grain level and its influence on traction tests at part scale.



Thermohydraulics and metallurgical simulations, and following RVE mechanical response (Chen, 2018[5], Camus et al, 2022[6], Zhang et al. 2022[7])

Experiments:

- Track printing by L-PBF (a third partner)
- Characterization of residual stress and crystal orientation distribution within the grains (LMS, CEMEF)
- Traction relaxation tests of AMed specimen (CEMEF or LMS): RVE level or standard specimen



EBSD and HR-DIC using novel laser-SEM setup (LMS, Ecole Polytechnique)

Expected results:

- Novel coupling work between the growth of grain structure and anisotropic mechanical behavior during solidification at melt pool level.
- Explain the reason of intragranular texture.
- Understand the effect of grain structure on hot cracking during LPBF process
- Study the inherent residual stress by both experiment and numerical simulations at grain level.
- Propose an anisotropic material law for part scale modelling by considering the effect of residual stress for L-PBF process simulation.

With the method of level-set, CEMEF has developed the meso-scale model for ceramics [5] and for metals [8], in which the powder bed may be assumed as a continuum. The melt pool development and resulting track shape can consequently be simulated by several deposited tracks. Furthermore, a thermomechanical analysis at the scale of the track during solidification was also demonstrated [5]. The prediction of the grain structure is also coupled with the prediction of the heat flow deduced from the meso-scale model [9, 10], which is now applied to L-PBF at part scale showing relevant trends for morphology and crystallographic textures of the grain structure [6].

GISTEAMMM is a twin project with the ANR-JCJC GRAMME at CEMEF, which is coordinated by Dr. Zhang. GRAMME aims to develop an efficient and relevant coupling strategy in LPBF process modelling between microstructure development and anisotropic mechanical behavior at part scale during and after construction. The collaborator in LMS, Ecole Polytechnique, is Dr. Upadhyay. He has recently obtained a project GAMME financed by ERC Starting Grant.

References:

[1] P. Promoppatum, V. Uthaisangsuk. Part scale estimation of residual stress development in laser powder bed fusion additive manufacturing of Inconel 718. Finite Elements in Analysis and Design 189 (2021) 103528.
[2] F. Gao, B. Macquaire, Y. Zhang, M. Bellet. A new localized inverse identification method for high temperature testing under resistive heating: application to the elastic-viscoplastic behavior of L-PBF processed In718. Strain (2022) e12409. https://doi.org/10.1111/str.12409.
[3] M. V. Upadhyay, L. Capolungo, V. Taupin, C. Fressengeas and R. A. Lebensohn. A higher order elasto-viscoplastic model using fast Fourier transforms: effects of lattice curvatures on

mechanical response of nanocrystalline metals. International Journal of Plasticity 83 (2016) 126 – 152.
[4] Z. Li, J. Xiong, Q. Xu, J. Li, B. Liu. Deformation and recrystallization of single crystal nickel-basedsuperalloys during investment casting. Journal of Materials Processing Technology 217 (2015) 1–12.
[5] Q. Chen, G. Guillemot, C.-A. Gandin, M. Bellet. Three-dimensional finite element thermomechanical modeling of additive manufacturing by selective laser melting for ceramic materials. Additive Manufacturing. 16 (2017): 124–137.
[6] T. Camus, D. Maisonnette, O. Boulin, O. Senninger, G. Guillemot, Ch.-A. Gandin. 3D Cellular Automaton modelling of grains structures generated by L-PBF. in preparation (2022).
[7] Y.Zhang, Ch.-A. Gandin, M. Bellet. A simple anisotropic elasto-visco-plastic model for predicting mechanical behaviour of grains structures generated by laser powder bed fusion (L-PBF) process simulation. in preparation (2022).
[8] A. Queva, G. Guillemot, C. Moriconi, C. Metton, M. Bellet. Numerical study of the impact of vaporisation on melt pool dynamics in Laser Powder Bed Fusion - Application to IN718 and Ti–6Al–4V. Additive Manufacturing 35 (2020) 101249.
[9] S. Chen, G. Guillemot, C.-A. Gandin. Three-dimensional cellular automaton-finite element modeling of solidification grain structures for arc-welding processes. Acta Materialia 115 (2016) 448–467.
[10] C. Xue, N. Blanc, F. Soulié, C. Bordreuil, F. Deschaux-Beaume, G. Guillemot, M. Bellet, C.-A. Gandin. Structure and texture simulations in fusion welding processes – comparison with experimental data. Materialia 21 (2022) 101305.

Tools	Numerical development is based on the parallel finite element library CimLib® at CEMEF and home software at LMS; Characterization of additive manufactured specimens will be performed by LMS and CEMEF.
Key-words	Grain structure, Anisotropic plasticity, Thermo-metallurgical-mechanical modelling, Laser powder bed fusion.
Project type/ cooperation	The research works are collaborated between Laboratoire de Mécanique des Solides (LMS) of Ecole Polytechnique and Centre de Mise En Forme des Matériaux (CEMEF) of MINES Paris.
Skills, abilities requested	Engineer/Master student in the field of computational mechanics, or applied mathematics. Strong knowledge of finite element method, solid mechanics and programming (C++) skills, and good English level. Basic knowledge of metallurgy is also required.
Location	CEMEF (Sophia Antipolis), MINES Paris, PSL Research University.
CEMEF team(s)	2MS
Expected starting date	September or October 2022 (3 years)
Supervisor(s)	Yancheng ZHANG, Manas Upadhyay, Michel BELLET, Charles-André GANDIN
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