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Computational Platform for Additive Manufacturing by Multiscale Method and Model Reduction Technique (AM_MULTI)

Context and objective of the Ph.D. work:

The project aims at developing an efficient computational platform for additive manufacturing by multi-scale approach and model reduction technique under the framework of finite element and level-set formulation. The additive manufacturing process that will be considered is the SLM process (Selective Laser Melting) for metals.

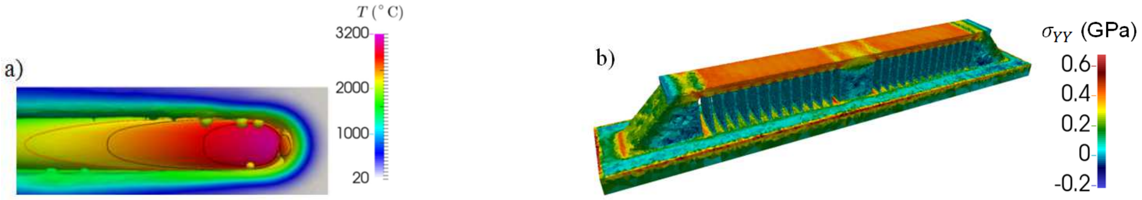
In the team TMP (Thermo-Mechanics Plasticity) at CEMEF, both meso- and macro-scale numerical models for SLM process have been originally developed within the framework of finite element (FE) method and level-set formulation: see figure hereunder.

The first model has been originally developed during the PhD of Qiang Chen [1] at meso-scale to capture track formation and associated local stress during the laser process. Contrary to particle-scale method, the powder bed is considered as a porous continuum being transformed in a dense melt, and further solidified. The formation of the melt pool, the hydrodynamics, the resulting shape of the deposited tracks and the surrounding stresses can be simulated. The same FE level-set method was adapted during the Tenue Track period of Yancheng Zhang to macro-scale simulations without considering the melt pool and its hydrodynamics [2]. The macro-scale approach aims at providing a description of heat flow and mechanical response at the scale of the whole part. In order to keep sustainable computational time, the powder bed melting and the energy input are simplified by considering the scale of a single layer or a set of fractions of layer. The distortions and the residual stresses resulting from the heating and thermal cycling of the built part can be simulated [3].

Based on that robust background, the objective is to evolve towards an efficient computational platform by multi-scale modelling and model reduction techniques.

The PhD project detailed hereafter will be developed in CEMEF laboratory (MINES ParisTech). For the task of model reduction, the research will be in collaboration with Prof. David Ryckelynck from CDM laboratory (Centre des Matériaux - MINES ParisTech) and Dr. Thomas Toulorge in the team of MSM of CEMEF. The corresponding experimental works – for validation purpose – will be performed at CDM by the team of Dr. Christophe Colin, in the framework of the ADDITIVE3D project with the spin-off company Transvalor (Sophia Antipolis).

This PhD opportunity is financially supported in the frame of the “Contrats Doctoraux Ecole” of MINES ParisTech.



Two-scale models developed at CEMEF [1, 2] for SLM simulation. a) Meso-scale model: temperature distribution (alumina, top view), b) Macro-scale model: residual stress in horizontal direction (IN718 - Ni-based superalloy)

The CEMEF laboratory has developed two approaches for the simulation of SLM additive manufacturing processes during the past years. A meso- approach dedicated to the simulation of elementary track formation and a macro- approach at the part scale (see Figure). The two methods are part of the C++ library CimLib developed in the laboratory. The numerical developments done in the AM_MULTI project will extend the capacity of this library and specifically its application to AM simulation.
Three main tasks will be included in this project:
1) Multiscale model coupling meso- and macro- scale models. The useful information extracted from the developed meso-scale model can be considered as an input of the macro-scale model. Conversely, during the construction process, the thermal and mechanical boundary conditions to be applied in the meso-scale model can be extracted from the macro-scale model to get more accurate local simulation results.
2) Extension of the macro-scale model capacities: inherent strain technique [4]. In the macro-scale model, the deposition of material and laser energy by fractions of layer, layer by layer and by “super layer” (several layers at a time) is now available. However, the non-linear mechanical resolution is still too costly for parts having very complex shape. The inherent strain method is proposed as a candidate for an efficient macro-scale model, as it could be run through linear resolutions only: calculation time could be reduced by a factor 5 or more.
3) Full-order/reduced-order model for parametric studies. If the simulated system is huge, the above proposed strategies are still costly for parametric studies to define optimized process windows in industry. Based on the authors’ expertise [5], the hybrid full-order/reduced-order model [6] is proposed for modelling the selective laser melting process in the macro-scale in the frame of level

set and mesh adaptation.

The ambition of the present project is to increase the visibility of CEMEF and MINES ParisTech in the field, and take leadership with respect to potential competitors, by extending our software capacities.

The PhD student will also benefit from advanced teaching and expertise of different advisors in scientific computing, and programming in C++ language. In addition, he will have access to lectures and team experiences in fluid and solid mechanics, material science and digital metallurgy. These capacities will provide opportunities to develop future activities in various R&D sectors in industry. An alternative perspective could be to start an academic scientific career.

References:
[1] Q. Chen, G. Guillemot, C.-A. Gandin, M. Bellet, Additive Manufacturing 16 (2017) 124–137.
[2] Y. Zhang, G. Guillemot, M. Bernacki, M. Bellet, Computer Methods in Applied Mechanics and Engineering 331 (2018) 514–535.
[3] Y. Zhang, Q. Chen, G. Guillemot, C.-A. Gandin, M. Bellet, Comptes Rendus à l'Académie des Sciences (2018, accepted, to be published).
[4] P. Alvarez, J. Ecenarro, I. Setien, M.S. Sebastian, A. Echeverria, L. Eciolaza, International Journal of Naval Architecture and Ocean Engineering 2 (2016) 39–46.
[5] Y. Zhang, A. Combescure, A. Gravouil, International Journal for Numerical Methods in Engineering 111 (2017) 176–200.
[6] J. Baiges, R. Codina and S. Idelsohn. Computer Methods in Applied Mechanics and Engineering 267 (2013) 23-42.

Candidate profile:	Engineer / Master student in the field of computational mechanics, or applied mathematics. Student attracted by problematic linked with the modelling and simulation of physical phenomena.
Keywords:	Additive manufacturing, selective laser melting process, thermo-mechanical evolution, multi-scale coupling, finite-element method, inherent strain method, model reduction
Location:	CEMEF MINES ParisTech, Sophia Antipolis
Supervisors:	Yancheng ZHANG, David RYCKELYNCK and Michel BELLET
Salary:	~1650 € /month net (after income tax).
Starting date:	01/10/18
Project type / cooperation	“Contrats Doctoraux Ecole” of MINES ParisTech
Tools	C++ library CimLib in CEMEF

For more details, you may contact:	Yancheng ZHANG (yancheng.zhang@mines-paristech.fr), Equipe TMP, CEMEF David RYCKELYNCK (david.ryckelynck@mines-paristech.fr), SIMS, CDM (Evry) Michel BELLET (michel.bellet@mines-paristech.fr), Equipe TMP, CEMEF
Application on line:	http://www.cemef.mines-paristech.fr/sections/formations/doctorats/pour-postuler

CEMEF is a research laboratory of MINES ParisTech, PSL University, associated with CNRS (UMR 7635) the French National Foundation for Scientific Reseach. It has 115 people including 31 scientists and 50 Ph.D. students, from 15 different nationalities. It is located at Sophia Antipolis, Technopark between Nice and Cannes. It is organized in 10 research teams. It mainly conduct research linked to experimental study, modelling and numerical simulation of materials flow during processing.

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