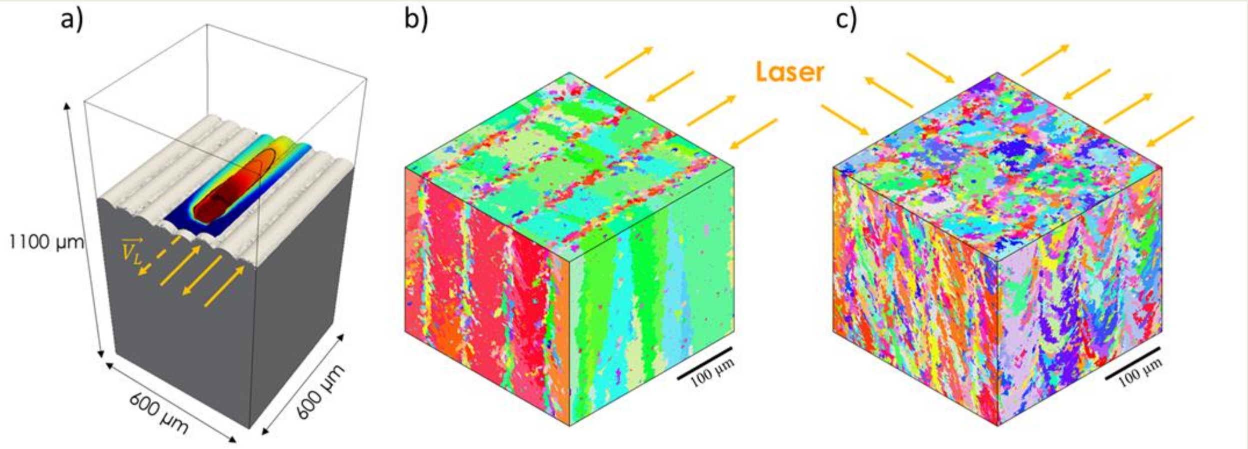
Phd position 2024- CEMEF

Title	***Modelling of additive manufacturing processes*** ***– Application to low-loss magnetic alloys produced by 3D lamination***
Acronym	FALSTAFF
Framework	Research project carried out within the 2MS team (Metallurgy, Mechanics, Structures & Solidification) of the CEMEF (Center for Material Forming, Mines Paris, PSL University). The PhD student will be supervised by permanent researchers from the 2MS team, and will benefit from CEMEF resources, as well as from the associated training.
Global objective of work	Thermohydraulic and microstructural modeling of powder additive manufacturing processes applied to magnetic alloys (Iron-Silicon and Iron-Cobalt-Vanadium), as part of the ANR project FALSTAFF gathering academic partners, Roberval (laboratory of the University of Technology of Compiègne), ICB-LERMPS (laboratory of the University of Technology of Belfort Montbéliard) and LITEN (CEA laboratory), as well as industrial partners, APERAM and ALSTOM.
Context	Additive manufacturing (AM) has led to a revolution in mechanical design by allowing the production of parts with complex shapes and original geometries. However, in the field of electrical machines, AM remains underdeveloped. The studies are driven by the demand for mechanical-electrical energy conversion machines, particularly in the context of electric vehicles, with the desire to have a high specific power, associated with low losses. Thus, an electrical machine is composed of different subsystems on which AM technologies would bring decisive innovations. The magnetic circuit is a component of interest, in particular the stator (fixed part) composed of ferromagnetic elements, currently designed through a stack of insulated laminated sheets. The ANR FALSTAFF project aims to explore new ways of producing these elements, freeing themselves from the constraints of current geometries, while preserving components properties, particularly in terms of magnetic efficiency. The FALSTAFF project aims to explore new innovative ways of producing ferromagnetic alloys, in the form of 3D laminated components, combining magnetic and insulating structures. Two methods will be proposed, by the development of internal porosity or by the combination of two materials, and through the exploitation, respectively, of the L-PBF (Laser Powder Bed Fusion) and DMD (Direct Metal Deposition) processes. Similarly, two materials must be investigated in the context of the part construction, iron-silicon and iron-cobalt-vanadium alloys. Laminated test pieces will be produced, exploring different parameters and manufacturing strategies also integrating the required heat treatments. The parts produced will then be characterized, in order to analyze the link between process parameter and microstructural, chemical and mechanical properties, with the aim of finding the optimal process conditions. Ultimately, the project aims to demonstrate the industrial interest of producing ferromagnetic components by FA process. The subject proposed by CEMEF aims to develop a thermo-hydraulic modeling of the investigated FA production processes, at the scales of interest, coupled with a Cellular Automata – Finite Elements (CAFE) approach allowing, in the long term, the study of the grain structures development being built, and resulting textures.

Detailed presentation

CEMEF has developed, in recent years, various tools dedicated to the numerical modeling of additive manufacturing processes. It has thus proposed relevant models allowing to follow the deposition of isolated material bead, at the mesoscopic scale, as well as the production of large-sized parts at the macroscopic scale [1,2]. As part of this work, thermomechanical and microstructural modeling tools are available, allowing a prediction of grain structures at relevant scales to explore the influence of manufacturing parameters (power, speed of heat sources, etc.) or scanning conditions (trajectory, etc.) as illustrated in figure as part of the L-PBF method. These methods are based on the coupling between two resolution. One, based on the finite element method solving the heat conservation equation (thermal evolution) in the entire system and momentum in the liquid pool (flow prediction). The other, based on the cellular automaton approach, using a regular grid of cells, mimics microstructure development (nucleation, growth and grain capture). The activity carried out in FALSTAFF will benefit from these numerical tools and methods and, more generally, from all the knowledge and skills acquired by CEMEF in this field.

More specifically, the proposed PhD project aims to develop a reliable modeling of microstructural evolutions in the L-PBF and DMD processes, in connection with the targeted construction strategies on the magnetic alloys. Complex multilayer deposition strategies, comparable to experiments, will be investigated, with the introduction of insulating layers (L-PBF – Strategy 1) or by use of bi-material laminations (DMD – Strategy 2). The effects of laser power, speed and trajectory on the orientation and morphology of microstructures will be analyzed, after experimental validation of the simulation tools. In addition, the composition effects and the metallurgical transformations during cooling will be investigated with the PhysalurgY tool [3] coupled with the ThermoCalc software. Constructions of increasing complexity (single bead, layer, etc.) will be produced by ICB-LERMPS and LITEN and characterized in terms of grain size and orientation, by Roberval laboratory. These experimental data will be directly used by CEMEF to validate the numerical developments carried out. This modeling will determine the texture and orientations of the grain, the nature of the phases and will ultimately aim to estimate the magnetic and mechanical in-use properties. The optimal elaboration strategies will then be defined at various scales: mesoscopic, to investigate the stability of the melted zone to limit the defects and macroscopic to follow the structural evolutions at the part scale. Based on the reliable digital tools developed, we will thereafter analyze the influence of materials properties and process parameters on the part properties and the occurrence of manufacturing defects [5].



Simulation of the L-PBF additive manufacturing process by a) a stationary thermal field translation strategy and associated solidification structures with b) an alternating trajectory without modification of

	the travel directions and c) trajectory with 90° rotation of the travel directions between consecutive layers [4]. All of the digital developments carried out will enrich CEMEF's collaborative computing library, Cimlib (C++). The PhD student will thus benefit, in return, from the developments made in this tool by other users (re-meshing method, numerical resolution, parallelized approach, etc.). He\she will receive training and develop skills in the field of materials science, computational mechanics and transfers of energy and momentum. In addition, he\she will receive extensive training in the field of scientific computing and programming, in particular to master CEMEF's computing tools.
Bibliography references	[1] A. Queva, Simulation numérique multiphysique du procédé de fusion laser de lit de poudre - Application aux alliages métalliques d'intérêt aéronautique, Doctorat MINES ParisTech, CEMEF, 2021 [2] Y. Zhang, G. Guillemot, M. Bernacki, M. Bellet, Macroscopic thermal finite element modeling of additive metal manufacturing by selective laser melting process, Computer Methods in Applied Mechanics and Engineering 331 (2018), 514-535 [3] PhysalurgY, bibliothèque de calcul CEMEF, https://physalurgy.cemef.mines-paristech.fr/ [4] T. Camus, D. Maisonnette, O. Baulin, O. Senninger, G. Guillemot, Ch.-A. Gandin, Three-Dimensional Modeling of Solidification Grain Structures Generated by Laser Powder Bed Fusion, Acta Materialia, *submitted* [5] C. Xue, N. Blanc, F. Soulié, C. Bordreuil, F. Deschaux-Beaume, G. Guillemot, M. Bellet, Ch.-A. Gandin, Structure and texture simulations in fusion welding processes – comparison with experimental data, Materialia (2021), 101305
Diffusion	Communication in national and international congresses. Publication in scientific journals linked to AM processes.
Tools	CIMLIB finite element libraries, cellular automaton, monitoring of metallurgical transformations (PY library), clusters and associated training
Key-words	Additive Manufacturing, Solidification, Microstructure, Thermohydraulic modelling and CAFE
Skills, abilities requested	Engineer or Master 2 in the fields of materials, mechanics or applied mathematics. Student attracted by topics related to modelling and numerical simulation of physical phenomena and engineering science.
Gross annual salary	28,5k€
Location	CEMEF, Sophia Antipolis (Site de Mines Paris - PSL)
CEMEF team	Metallurgy, Mechanics, Structures & Solidification – 2MS
Supervisor(s)	Charles-André GANDIN (charles-andre.gandin@minesparis.psl.eu) Gildas GUILLEMOT (gildas.guillemot@minesparis.psl.eu)

To apply: You can only apply online by filling in the CEMEF online form on :

https://applyfor.cemef.mines-paristech.fr/phd/