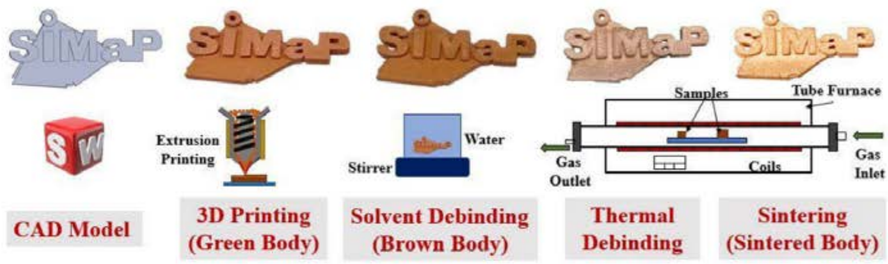
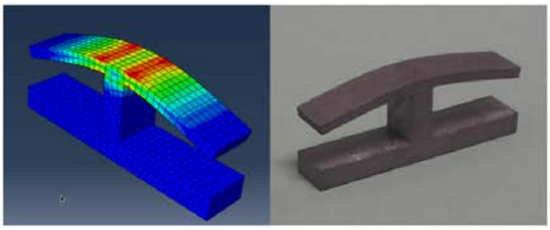
PhD offer – SIMaP laboratory

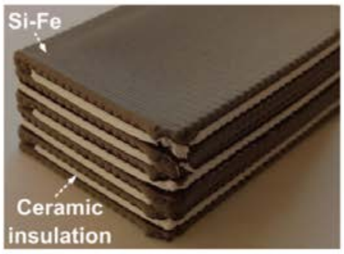
Multi-material additive manufacturing by 3D extrusion printing and sintering: experimental and numerical studies



Copper 3D Extrusion printing and sintering (SIMaP)



FEM modeling of sintering stage (SIMaP)



Multimaterial application in the field of magnetic materials from ref. [3].

Context

Additive manufacturing by 3D extrusion printing of a powder loaded paste followed by sintering has the potential to produce complex multi-material geometries interesting for several applications (e.g. embedded heating elements, reduction of losses in a ferromagnetic alloy by insertion of insulating layers) [1-3]. The process is versatile, cost effective and based on commercial ceramic or metal feedstock developed for powder injection molding, an industrially established process. Feedstock pellets, that consist in a polymeric binder system loaded with a ceramic or metal powder, are feeded in a screw-based extruder and deposited layer-by-layer in the form of a filament by a heated nozzle. A complex 3D part can be obtained and subsequently debinded and sintered. A challenging part in this process is the control of the sintering stage in order to obtain defect-free and net-shape parts. Indeed, inhomogeneous densities, anisotropic shrinkage or creep under gravity are difficult to avoid. In the case of co-sintering of multi-material parts, additional challenges arise from mechanical stresses that build up due to differential sintering rates and/or thermal shrinkage during cooling down. For these reasons, the demonstration of multi-material parts obtained by 3D extrusion followed by sintering is very scarce in the literature [1-3].

Objectives and work program

In this context, the objectives of the PhD work are:
- develop the process for several ceramic and metallic materials using commercial feedstock: optimization of printing and sintering parameters, microstructural and mechanical characterization of final parts.
- investigate both printing and sintering stages for one or several bi-material systems.
- develop and calibrate 3D finite element modeling of the sintering stage first to predict the deformation of mono-material parts and then to predict differential shrinkage effects in multi-material systems.

- demonstrate the relevance of the approach by the realization of a complex industrially inspired part.
A classical experimental material science approach (elaboration- characterization) will be implemented and coupled with in-situ characterization (optical dilatometry, X-ray tomography) and finite element modeling of the sintering step.

Scientific environment

The SIMaP laboratory has already developed and investigated the 3D extrusion and sintering of several metallic alloys (copper [4], steel [5], Ti alloy) during the last few years for applications like heat sinks or medical implants. The PhD student will work on the AIM3D Exam 255 equipment available at SIMaP laboratory, which include two printing heads. He will also benefit from the large experience and know-how of the SIMaP laboratory on the study of sintering, which includes the use of advanced tools and techniques like optical dilatometry [6], in-situ synchrotron X-ray tomography [7], finite element [8] and discrete [9] modeling. Additionally, SIMaP participates in a European program on a related topic creating an international dynamic work environment for the PhD student.

Candidate skills and background

The candidate must be graduated from an engineering school and/or with a Master degree whose training focuses primarily on materials science or related field.
We are looking for a student with a strong interest in experimental materials science, mechanics of material and also willing to work on numerical simulation.

Start:

Oct. 2023

PhD advisors:

David Jauffrès, Jean-Michel Missiaen

Salary:

2044€/month, gross

Contact and application (ASAP and before 01/05/2023):

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References:

[1] Gonzalez-Gutierrez J, Cano S, Schuschnigg S, Kukla C, Sapkota J, Holzer C. Additive manufacturing of metallic and ceramic components by the material extrusion of highly-filled polymers: A review and future perspectives. Materials. 2018;11(5). doi:10.3390/ma11050840
[2] Schroffenegger M, Penner D. Multi-material ceramic material extrusion 3D printing with granulated injection molding feedstocks. 2023;49:6361-6367. doi:10.1016/j.ceramint.2022.10.170
[3] Selema A, Beretta M, Van Coppenolle M, et al. Evaluation of 3D-Printed Magnetic Materials For Additively-Manufactured Electrical Machines. Journal of Magnetism and Magnetic Materials. 2023;569:170426. doi:10.1016/j.jmmm.2023.170426
[4] Singh G, Missiaen JM, Bouvard D, Chaix JM. Copper extrusion 3D printing using metal injection moulding feedstock: Analysis of process parameters for green density and surface roughness optimization. Additive Manufacturing. 2021;38:101778. doi:10.1016/j.addma.2020.101778
[6] Singh G, Missiaen JM, Bouvard D, Chaix JM. Additive manufacturing of 17–4 PH steel using metal injection molding feedstock: Analysis of 3D extrusion printing, debinding and sintering. Additive Manufacturing. 2021;47:102287. doi:10.1016/j.addma.2021.102287
[6] Lichtner A, Roussel D, Röhrens D, Jauffres D, et al. Anisotropic sintering behavior of freeze-cast ceramics by optical dilatometry and discrete-element simulations. Acta Materialia. 2018;155:343-349. doi:10.1016/j.actamat.2018.06.001
[7] Venkatesh AM, Bouvard D, Lhuissier P, Villanova J. 3D Analysis of Ceramic Powder Sintering by Synchrotron X-ray Nano-tomography. Journal of the European Ceramic Society. December 2022:132949. doi:10.1016/j.jeurceramsoc.2022.12.065
[8] Largiller G, Dong L, Bouvard D, Carry CP, Gabriel A. Deformation and cracking during sintering of bimaterial components processed from ceramic and metal powder mixes. Part II: Numerical simulation. Mechanics of Materials. 2012;53:132-141. doi:10.1016/j.mechmat.2012.05.012
[7] Paredes-Goyes B, Jauffres D, Missiaen J-M, Martin CL. Grain growth in sintering: A discrete element model on large packings. Acta Materialia. 2021;218:117182. doi:10.1016/j.actamat.2021.117182