Synchotron nano-Imaging informed Tailoring of Additive Manufacturing Microsctructures Against strain Localization.

Context of the project

The as-built microstructures of newly designed Al alloys for laser powder bed fusion (L-PBF) additive manufacturing are often complex with heterogeneities developing across all scales from the grain scale with regions with submicron equiaxed (FG) and regions consisting of coarser columnar grains (CG) down to the atomic with variations in solid solution composition in the different regions. The microstructure inherited from L-PBF can be considered as composite since FG and CG regions are spatially organized in complex patterns. The macroscopic mechanical behaviour is governed by this complex organization. The heterogeneity of the microstructure together with its spatial organization promotes or inhibits strain localization during plastic deformation and thus affects the damage evolution. Percolation of the regions made of FG or CG is of primary importance to delay strain localization and early necking during straining. The first objective of the project is to achieve a better understanding of the relationship between the microstructure of a new Al alloy designed specifically for L-PBF and the macroscopic mechanical behavior. The second objective of the project is to be able to tailor the microstructure to control the macroscopic mechanical behavior by altering the building strategies. To do so, we will develop advanced imaging tools to enable the in situ 3D characterization of such multi-scale heterogeneous microstructures. The project thus requires the ability to tailor the microstructure distribution, characterize those distributions, and evaluate their mechanical behaviour. Obviously, the ability to finely characterize the strain field during the tests and relate them to the microstructure distribution is required to conduct an informed optimization.

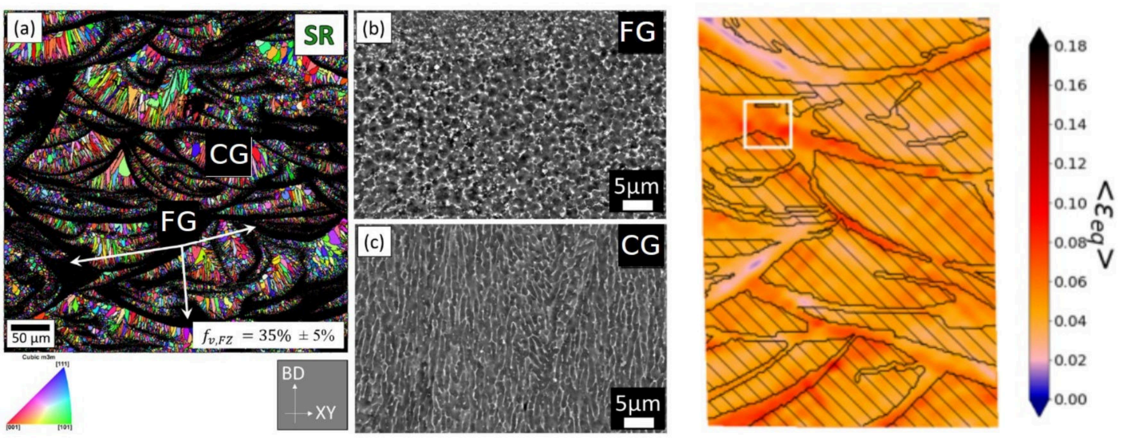

Figure 1: Overview of the microstructure in the stress relieved conditions. (a) EBSD-IPF map of the Al FCC-phase revealing the bimodal character of the microstructure with fine grained zones (FG, mostly in black) and zones consisting of coarser columnar grains (CG). Typical examples of BSE images taken respectively in the (b) FG, and (c) CG. Intermetallic particles appear in bright. (d) Example of microscale strain distribution in the FG (hatched region is CG).

PhD program

The PhD candidate will be in charge of the experimental part of the project: from the definition of the additive manufacturing building strategies up to the analysis of the in situ mechanical tests and the assessment of the chosen strategies.

State of the art: The student will first conduct a literature review on microstructure tailoring by manipulating scanning strategies in L-PBF (Laser Powder Bed Fusion) with a specific emphasis on Al alloys. This work will also include a summary of the main studies focused on the understanding of the microstructure-mechanical properties relationships (from the macro-scale down to micro-scale)

Tailoring the microstructure: The student will design building strategies based on the variation of the selected processing parameters. A large processing parameters screening and a quick characterization using optical microscopy will be employed to identify the most promising microstructures, which will be deeply characterized by SEM/EBSD/EDS. The purpose will be to define the key microstructural characteristics that can be tuned on demand: (i) At the fine scale i.e. the scale of the microstructure, the one representative of a single homogeneous region and (ii) At the mesoscale i.e. the scale of several melt pools. For(i), the microstructure will be described in term of grain size, grain shape, texture, misorientation, secondary phases, solid solution composition. Instrumented nano-hardness maps will be collected on the various types of regions in the as-build state and in a few samples subjected to post-fabrication heat treatments to determine the local mechanical properties. For (ii), the architecture of the microstructure will be characterized (type of regions, 3D arrangement of the different regions). X-ray nano-tomography over a large field of view will help to identify the most promising topologies. A multi-resolution AI based acquisition strategy, relying on already existing algorithms, will be developed and validated.

Effect of the local morphology: Samples will be selected based on : the similarity and the simplicity of topology of the regions ; the similarity of types of local microstructure ; and the differences in meso-scale morphology. The selected configurations will be in depth analyzed by in situ X-ray nano-tomographic tensile tests on small samples. Digital volume correlation will be used to determine microscale strain distribution. Spatial correlations between the type of phases, the strain localization and the damage evolution will be established. The multi-resolution acquisition strategy will be tested on small samples to quantify the ability to obtain the strain fields with this method.

Effect of the large scale topology: Built parts will be selected based on the similarity of local microstructures but with varied topology of the regions. The selected configurations will be in depth analyzed by in situ X-ray nano-tomographic tensile tests on large samples. Spatial correlations between the topology, the strain localization and the damage evolution will be obtained.

Synthesis and dissemination: The PhD candidate will write a Ph.D. manuscript and the most interesting results will be published in scientific journals. Intermediate results will be presented in conferences.

PhD applications requirements

Considering the ambition of the project, only high level of excellence applications will be considered with the following profile:

- Masters-level degree or graduate of Engineering school in Mechanics, Materials or Physics with good knowledge in solid mechanics;
- Strong motivation for experimental based advanced approaches;
- Strong analytical skills, including general coding abilities (python/matlab);
- Knowledge in image analysis would be a plus;
- Ability to work/interact with scientific and technical people
- The PhD student is expected to be self-motivated, creative, and capable of critical thinking.

PhD conditions

- PhD allocation co-funded by UGA and ESRF in the framework of the project GATES Excellences UGA
- Starting date: October 2024 or earlier
- Duration: 3 years
- Research laboratory and Location : Laboratory of Science and Engineering of Materials and Processes (SIMAP), Grenoble, France. European Synchrotron Radiation Facility (ESRF), Grenoble, France.
- Supervision: Julie VILLANOVA (ESRF/ID16B), Pierre LHUISSIER and Luc SALVO (SIMaP - CNRS - Univ. Grenoble Alpes)
- Interested? Please send your application to pierre.lhuissier@simap.grenoble-inp.fr

(a)

(b)

Figure 2: (a) ESRF by night. (b) Grenoble campus.