PhD position

GPM (Groupe de Physique des Matériaux), CNRS UMR 6634, Rouen, France

Measurement of multiaxial residual stresses at the local scale of a polycrystal by FIB-DIC-FEM coupling. Application to additive manufacturing of 316L Additive manufacturing and austenitic-ferritic steel.

Supervisory team:
Ronan Henry, Fabrice Barbe, Benoit Vieille

Background and general objectives:

A solid can be in a state of zero stress at the macroscopic scale, and have non-zero stresses at the local scale. Metallic materials can be affected by these states, particularly if phase transformations are involved in the elaboration process. The interactions between heat, metallurgy and mechanics are indeed the source of the development of these stresses, as is well known in the fields of welding, casting or additive manufacturing. Since these internal stresses are intrinsic to the process, and are neither desired nor well controlled, they are referred to as residual stresses. They are added to those due to external mechanical loading, and can therefore contribute to premature damage to a material: reduced fatigue life, acceleration of stress-dependent physical mechanisms (diffusion of chemical species, phase transformation, oxidation).

Various techniques have therefore been developed to monitor these residual stress states. On the macroscopic scale of a part, these involve removing material locally, for example by drilling, and measuring the deformations caused by stress relaxation. This measurement can be carried out using Digital Image Correlation (DIC), providing deformation fields and opening up the possibility of characterizing a multiaxial field. In this multi-axial context, the transition from the state of measured deformations to the state of residual stresses is made using Finite Element analysis (FEM) , reproducing the material removal operation.
This method can be transposed to the micrometric scale of the part: the integration of a focused ion probe (Focus Ion Beam, FIB) into a Scanning Electron Microscope (SEM) enables material to be ablated to a scale of a few micrometres, while capturing the image of the material as it is machined. As the material has been previously marked on its surface by ~10 nm markers, the Digital Image Correlation (DIC) method is used to measure the displacements of these markers and deduce a deformation field. Given the characteristic dimensions (plot, trench, markers), the stresses involved (~100 MPa) and the high stiffnesses, the accuracy required for a usable displacement measurement is of the order of 1 nm.

Ensuring the conditions for sufficiently accurate field measurements is the first challenge of this thesis. The first objective is therefore to develop the SEM-FIB-DIC analysis protocol based on samples with simple, known residual stress conditions: uniaxial stress of approximately known value (XRD method), grain size large enough to guarantee homogeneous mechanical fields. The second objective is to extend the method to a context of heterogeneous (intrinsically multiaxial) microstructure and mechanical fields. This implies explicitly considering the microstructure of the immediate vicinity of the treated pillar in finite element analyses, whether this be other grains or another phase. The context is that of steels produced by additive manufacturing, or of an austenitic-ferritic steel. Both are highly heterogeneous, with characteristic grain-to-grain or phase-to-phase lengths of the order of a few µm; both can involve stress states of the order of 300-400 MPa, and for both a detailed knowledge of these states represents a strong industrial challenge given the cutting-edge applications targeted.

GPM resources and skills:

This project relies on the complementary skills, expertise and resources brought together at GPM and in the consortium of researchers involved in the project:

1. SEM/FIB analysis facilities, operated by R. Henry, expert in FIB microscopy and SEM in situ micromechanical testing [1]. Two complementary FIB devices are available: FIB Helios G5 UX with advanced automation methods, paving the way for a large number of analyses statistical representativeness; FIB Helios G5 CXe, using a plasma source to perform source for faster machining, opening up the method's applicability on a mesoscopic scale (~100 µm).

2. DIC analysis tools, commonly used in the materials mechanics team, in particular for monitoring crack propagation during bending tests [2]. Figure 1 illustrates the results of SEM-FIB-DIC analyses carried out as part of [3].
3. Expertise in the analysis of the mechanical behaviour of metal alloys as a function of their microstructure, in particular of materials derived from additive manufacturing [2,4].
4. Expertise and resources for full-field FE analysis of polycrystalline systems with high microstructure resolution, coupled with microstructural analysis and mechanical testing mechanical testing, particularly in crystalline plasticity [5-7].

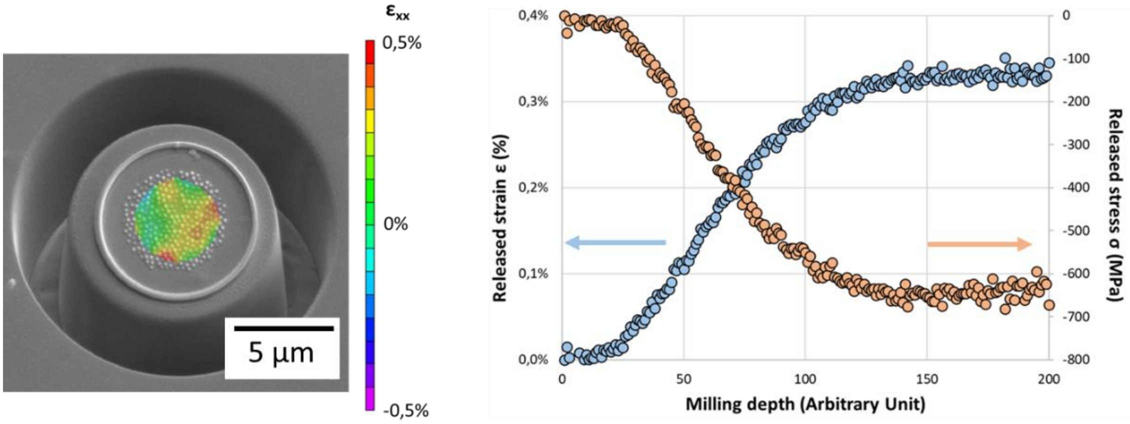

Figure 1 : DIC measurements of the strain field on each image, strain ε and stress σ measured for each machining step. This test demonstrates the presence of tensile stresses in one phase of a two-phase austeno-ferritic steel. According to [3].

Candidate profile:

The person recruited must have an engineering or master degree in mechanics or materials science, with skills in the mechanics of materials in relation to their microstructure, and in finite element analysis. Experience in microscopy would be a plus. The candidate must have a taste for experimental analysis (SEM-FIB) and data processing in connection with modeling (DIC-FEM). Applications should include a CV + covering letter + transcripts of the last 2 years of study, and if possible a letter of recommendation or the names of people to contact for recommendations.

Location: Laboratory GPM, Rouen, France
Start: oct. 2024

References:

[1] Ronan Henry et al, Fracture properties of an irradiated PWR UO2 fuel evaluated by micro cantilever bending tests,Journal of Nuclear Materials, 538, 2020, 152209, doi : 10.1016/j.jnucmat.2020.152209

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[5] E. Paccou, Y. Carpier, R. Henry, C. Keller, F. Barbe, B. Vieille. Local residual stress measurements by FEA coupling:application to inconel alloys produced by powder bed fusion, Journées annuelles SF2M, Caen, 2628 october 2021 (poster)

[6] C. Keller, M. Calvat, B. Flipon, F. Barbe, Experimental and numerical investigations of plastic strain mechanisms of AISI 316L alloys with bimodal grain size distribution, International Journal of Plasticity, 153, 2022, 103246, doi : 10.1016/j.ijplas.2022.103246.

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