Use of nano-gauges for determination of mechanical behaviours of metallic materials used in additive manufacturing

Work environment for the PhD student:

The University of Technology of Troyes (UTT)

UTT is a French institution of higher education established in 1994. It is today one of the largest engineering schools in France. Over 2,500 students are registered at the University, enrolled on undergraduate, postgraduate and doctoral study programs. In the renowned yearly ranking of French magazines, UTT takes enviable positions. Information that is more detailed is available on http://www.utt.fr/en/about-utt.html.

A) The LASMIS research team

The LASMIS team has a significant experience in the field of shot-peening, of residual stresses modelling, of residual stresses measurements, of nano-indentation and of advanced modeling of the behavior of materials. Our team cooperates with industrial partners such as Renault, Peugeot SA, SNECMA or Turbomeca (Safran Group) and academic partners such as University Paris VI, University of Reims, ENSAM or INSA de Lyon, in the field of process modeling together with experimental characterization and understanding of physical phenomena.
For more details, see: http://www.utt.fr/en/education/phd-studies/mechanical-systems-and-materials.html (in English) and http://lasmis.utt.fr/fr/projets_de_recherche.html (in French).
Moreover, this research project is part of the global research policy on risk management of the joint research laboratory of CNRS (French National Research Council) and UTT established in January 2010. LASMIS team includes also researchers of EPF in Mechanics and Materials axis (see below)

B) The L2n research team

The Light, nanomaterials, nanotechnologies (L2n) research team has an international recognition in the field of nano-optics as attested by the organization of the Near-Field Optics 15 (NFO15) conference in 2018. This international recognition is demonstrated by the extended international network of the lab. During the thesis, you will have the unique opportunity to work in a 760m2 clean room where 10 millions € of facilities are dedicated to nanofabrication and nanocharacterization. Besides, you will evolve in the context of the INSOMNIA project which is a national project recently labelled by the National Research agency to create a new research axis on mechanoplasmonics.

EPF Established in 2007 at the EPF, graduating school of engineering, the **MECHANICS & MATERIALS** research axis develops methods and tools for the design of sustainable materials and mechanical structures.

The MECHANICS & MATERIALS research axis deals with:

- The analysis of materials and structures in the presence of geometrical singularities, and additive manufacturing;
- Rapid tooling for the factory of the future;
- Design For Additive Manufacturing (DFAM);
- Biomechanics.

Since 2015, the EPF of Troyes developed an Additive Manufacturing platform to work on smart material, advanced materials [1] and post-treatments in partnership with the UTT.

Main participants and supervisors

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Available equipment's

- Finite Element codes (ABAQUS, Z-Set for which source code is available).
- High level computing facilities.
- 3D Printing and Additive Manufacturing machines (UTT/EPF);
- Every PhD student shares an office with other PhD students. A personal desk is offered to each PhD student along with a personal computer and full personal access to the internet and bibliographic databases.

Background and environment of the project

At University of Technology of Troyes (UTT), the research axes in mechanics within the Charles Delaunay Institute (ICD) / Laboratory of Mechanical Systems (LASMIS) has acquired a recognized expertise for the modelling of materials behavior. The LASMIS is indeed at the origin of several models that, applied to the simulation of manufacturing processes, enable to consider a complete virtualization of the line production/manufacturing. One of the essential points of this work is based on a multiphysical approach including thermodynamics to describe any real complex motion of the matter. These models have proved their efficiency to simulate and to optimize various manufacturing processes such as forming, shot peening, machining....

Nowadays, new method of manufacturing are available for creating structure and microstructure. It is possible to design any geometry only limited by the accuracy of 3D printers. This opportunity enables also to test easily new behaviours. For example, (new) materials with gradients of properties, non-linearities, anisotropies can now be developed and tested with these new manufacturing processes.

At the opposite, the description of complex behaviours of complex materials is possible only with numerical simulations. Besides, description of such behaviours depends strongly on the scale of description. For example, when considering atomic scale, it is practically impossible to simulate macroscopic samples, i.e. superior to $1 \mu m^3$. When considering grain scale, scale transition methods are still time-consuming. This is dramatically accentuated with elasto-plasticity and damage behaviours.

In order to test durability in service of the structure parts or to simulate the forming of complex parts, it is also spilled today in different industries (aeronautics, cars…) to use numeric simulators. Such an approach is useful and did not stop improving during the last 20 years. The target of these modellings is always to value the resistance of a piece or a structure, resistance to the failure or to fatigue in a context of performance optimization and costs reduction. Nevertheless, the precision wished to account for the physical phenomena depends mainly on two factors limiting:

- The calculation time bounded to the complexity of such model, to the chosen algorithmic scheme and to the power of calculators.

- The physical content itself, bound on the one hand to the diversity of the phenomena occurring and on the other hand to the considered scales of resolution, as previously illustrated.

Some fundamental and applied works are in progress in many laboratories, academic but also industrial ones, to push away these limits. For example, taking into account of finite transformations for continuous media became a necessity. The correct description of these finite distortions constitutes thus an essential point to hang realistic kinematics behavior. The correct description of the kinematics behavior constitutes yet an open problem mainly to choose correct quantities used in the behavior models that must describe the mechanical behavior undergone by matter.

Within the research axes in mechanics of the Charles Delaunay Institute (ICD) / Laboratory of Mechanical Systems (LASMIS) of University of Technology of Troyes (UTT), these problems are also investigated. Indeed, the LASMIS has developed calculation models bound notably to finite element analysis software ABAQUS and ZéBuLoN, permitting to simulate efficiently virtual forming processes in the case of elastoplastic materials. The originality of such works is to take into account of the strong multiphysical couplings between the thermal aspects, the elasto-visco-plastic aspects and the damage aspects. As previously said, these coupled models, once computed, showed their efficiency to simulate and to optimize various manufacturing processes. The relevance of such an approach has already been demonstrated through lots of phD thesis achieved at the laboratory [1-4]. The problem of objectivity of the chosen quantities in behavior models and the description of the kinematics also arises in the setting of the micromechanical approach developed at LASMIS. A thesis [5] has been achieved to test those elastoplastic models in finite distortions with ductile damage while considering a scale transition method, as well as to validate experimentally on particular material (Copper). Another thesis [6] has validated these experimental and numeric approaches on duplex stainless steels. Even based on the principles of thermodynamics of continuous media, the existing models are today eventually more mathematical than physical. For example, one of the limits of this inductive approach comes from the anisotropy taken into account through a phenomenological formulation [7]. The scale transition approach remains thus to be developed to include all effects of anisotropy [8-9].

Description of the PhD proposal

In addition, the team has developed specific manufacturing technologies using the NanoMat platform, in particular nanoscopic objects for monitoring mechanical quantities [10,11], thanks to strong collaboration with L2N laboratory. The technological purpose is indeed the development of a new generation of optical sensors of deformations from materials that change color when they undergo deformations. This color change can come either from the displacement of the metal nanoparticles (NPs) and thus from the variation of their optical coupling, or from the deformation of the NPs themselves. To optimize the operation of these sensors of the future, we need to obtain advances in fundamental research concerning the mechanical deformation of NPs and the modification of their optical properties. By relying on these techniques, we can then follow the properties of the materials. This has already been proven on traditional materials (austenitic steels, duplex steels, titanium alloys). It should be possible to extend this especially to architectural materials (advanced materials) that are obtained by innovative processes such as additive manufacturing [12-14]. Indeed these materials have special properties due to the structure that we want to give them but especially in connection with the manufacturing process that shapes them and whose parameters are often very special / extreme (fusion laser ...). In addition, this additive manufacturing technique will necessarily evolve to even smaller spatial resolutions to ensure even more finely the properties of the materials thus architected. The condition for this evolution is a knowledge / measurement of the properties of these materials, such as displacement, deformation, distortions..., at microscopic or nanoscopic scales. The knowledge of these kinematic fields can then be related to the behavior models of the materials and to the "physical" quantities: the stress, the energy... by a cross-checking of the data. This is one of the goals that we are aiming for in this project through small-scale measures, as well as mechanical modelling and numerical simulations of the material behaviors.

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