

On the effect of anisotropy on the mechanical behavior of microstructure and structure obtained with 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>.

The LASMIS research team

The ICD/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.

Background 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 behaviors. 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 behaviors of complex materials is possible only with numerical simulations. Besides, description of such behaviors 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 $1\mu\text{m}^3$. When considering grain scale, scale transition methods are still time-consuming. This is dramatically accentuated with elasto-plasticity and damage behaviors.

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:

The main objective of this PhD proposal is to study the propagation of anisotropy's effect in mechanical behavior from the microscopic scale until the scale of the structure. In this research, the work can be planned in three main phases:

- As a first step, anisotropy will be considered in mechanical behavior at different scales (microstructure and/or structure). Elasticity and elasto-plasticity will be addressed as material behaviors. Specific geometries will be designed to obtain a significant influence of the anisotropy of constituent shapes and orientations. To simulate the influence of those anisotropies on the behavior, it will be necessary to develop specific numerical scheme. The latter will be based on existing micromechanical models that will be improved with specific

developments. The idea is to obtain general methods to address the simultaneous problem of anisotropy and heterogeneity, whatever the considered scale [10-12].

- As a second step, the correlation between both aspects (anisotropy and heterogeneity) and the transition toward scale (until the scale structure) will be considered. The assumption of the existence of some damping effect due the transition from the scale of microstructure to the scale of the structure will be addressed. Here, using specific mathematical tools related to the demonstration of the Saint Venant's Principle (concept of characteristic decay length [13]) could be investigated.
- As a third step, an experimental confrontation could be considered, using some facilities of LASMIS. Additive manufacturing processes [14],[15] could be used to produce some structure for which we could control anisotropy and heterogeneity at a micro/meso scale. Then using tensile and/or torsion test machine, the effect of anisotropy and heterogeneity at the scale of structure could be evaluated and compare with the result of the model previously proposed.

The PhD advisors:

Pr. **Benoît Panicaud**, 39, obtained a Master of Engineering from Engineering School of La Rochelle in 2001 and a Master of Physics and Mechanics of Materials from University of Poitiers in 2001. He defended his PhD in University of La Rochelle in 2004, on the coupling between chemical and mechanical effects during high temperature oxidation. After a postdoctoral position in University of Marseille on the mechanical effects on semi-conductors, he became assistant professor in UTT in 2006 and has published 68 papers among which 47 in rank A international journals. He is actually responsible for the Physics and Mechanics engineering department, constituted of two labs (L2N and LASMIS). He is also fully involved in different teams of LASMIS due to its modeling skills.

Pr. **Pascal Lafon**, 52, obtained a Master of Mechanical Engineering from Toulouse university in 1989, and defended his PhD in the Engineering School on applied science of Toulouse in 1994 on the subject "Optimal design of mechanical system : optimization in mixed variables". He was involved in the creation of University of Technology of Troyes in 1994 and became full professor in 2009 in the Physics and Mechanics engineering department. He was the head of the LASMIS team from 2012 to 2016. His research activities are related to optimisation of mechanical system and processes. He supervised 12 PhD students (8 defended) and published 93 papers among which 26 in international journals. He is actually responsible of the programme "Mechanics, Materials and Optics and Nanotechnology" of PhD doctoral school and also responsible of the Master in "Mechanics, Materials and Advanced Processes".

Available equipments

- Finite Element codes (ABAQUS, Z-Set for which source code is available).
- High level computing facilities.

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.

References

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