Determination of the local mechanical behavior of metals with optical methods: from instability to fracture

PhD at University of Technology of Troyes, supervised by
Prof. Manuel FRANCOIS and Dr. Léa Le Joncour

1. Aim of the PhD work

The manufacturing of industrial components with complex shapes requires very advanced numerical models which, in turn, rely on accurate descriptions of the constitutive behavior of the materials. In the case of metal sheet forming by stamping, the formability of the material is limited by an instability phenomenon called necking which leads to the appearance of defects (wrinkles) and, eventually to fracture. Although the onset of the instability is well documented in the scientific literature, from both the experimental and theoretical point of view, much less is known about what happens between this onset and fracture. In our research group, a method using Laser Speckle Pattern Interferometry was developed to investigate the development of necking. In particular, it was shown that the intrinsic dynamics of necking can be studied independently from the geometry of the specimen and that a "master curve" can be found for each material. From this starting point, many questions can be investigated. For instance, what is the origin of this master curve? What is the link between damage development and necking evolution? What is the influence of the deformation rate on necking evolution? A particularly nagging question is: what governs the width of the necking zone and how is it linked to the famous "internal length" of the material that appears in non-local constitutive behavior of materials? A new set-up, based on high speed holographic microscopy and a comparison with non-local modelling of necking will certainly help answering these questions.

Figure 1: necking band in a copper sheet. One can note how straight and regular the band is.
In parallel some colleagues in our group are developing non-local modelling constitutive behavior (micromorphic) in a thermodynamic based theoretical framework in order to simulate numerically various forming processes, taking into account the softening of the material due to ductile damage. During the PhD project, interaction with these colleagues will enable to compare modelling and experiments.

Figure 2: Interference fringes observed at various stages of the localization process. Left: symmetric hourglass shape at the beginning during diffuse necking, middle: asymmetric X shape at the onset of localized necking, right: slash shape just before fracture. Each fringe represents a displacement of 600 nm (the resolution is about 20 nm). The color picture is the strain rate field deduced from fringe pictures.

2. Detailed description of the research project

The PhD work will take place through two stages, one mostly experimental and the other one will be modelling.

Experimental work: previous experiments were performed with ESPI at macroscopic scale only. In the proposed work, the ESPI measurements will be completed by in-depth local characterization of the material with X-ray diffraction, SEM observations, instrumental nano-indentation or EBSD. Concerning optical measurements, the existing set-up will be improved to investigate the influence of strain rate on the necking development. The use of Digital Holography will also allow a better resolution and thus get much closer to the fracture than in previous studies. Analysis of the local rotation rate will provide a better understanding of the kinematics and the plastic flow inside the necking bands.

Numerical modelling: As the behavior of the material becomes unstable (loss of ellipsicity), the modelling of necking requires the use of a non-local formulation to regularize the solution. The chosen approach is based on a micromorphic scheme developed in our laboratory (the micromorphic parameters describe both plasticity and damage) or developed by S. Forest in Ecole des Mines de Paris (the micromorphic parameters describe plasticity only). The model will be used to analyze the ESPI measurements and identify the parameters of the constitutive model and retrieve one or two internal length of the material. Once the
internal length is known, a stage of interpretation (and additional experiments) will be necessary to understand its physical meaning. The unicity and the stability of the solution will also be investigated.

Several publications are expected from this work and, at least:

- One the local characterization
- One on the use of Digital Holography, as applied to this problem
- One or two on the modelling and identification of the internal length(s) and damage parameters

The project will be performed through a cooperation with partner laboratories such as AGH University of Science and Technology of Krakow (Poland) or Ecole des Mines de Paris (France).

3. Work environment

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 2,700 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. More detailed information is available on http://www.utt.fr/en/about-utt.html.

The LASMIS research team:

The LASMIS research team (about 60 researchers) is part of Charles Delaunay Institute which is associated to CNRS (the French National Center for Scientific Research, equivalent to the Chinese Academy of Science).

The LASMIS team has a significant experience in the field of photomechanics (the use of optical techniques to measure mechanical quantities such as displacement, velocity or strain fields), damage mechanics, numerical modelling of material forming processes and experimental characterization of post-necking behavior of materials. It possesses a recognized know-how in the field of damage mechanics and Electronic Speckle Pattern Interferometry (ESPI/DSPI) (see Tables 1 and 2). Our team cooperates regularly with industrial partners such as Renault, Peugeot SA, Renault SA, AREVA, Arcelor-Mittal, SNECMA or Turbomeca (Safran Group) and academic partners such as University Paris 6, Ecole des Mines ParisTech, Shanghai JiaoTong University, Dortmund Technical University or AGH University of Krakow (Poland).

The international recognition of UTT in the field of damage mechanics and material forming can be seen through the organization by UTT of the 2nd International Congress on Damage

Table 1: number of papers published between 2000 and 2016 according to ISI Web of Science with the keyword “ductile damage”. UTT ranks at #2 with 60 papers among other prestigious institutions. The total number of published papers in this period and indexed in ISI Web of Science is 671. It should be noted that CNRS (rank 1) is not really a laboratories but a group of laboratories (like Chinese Academy of Science).

Table 2: number of papers published between 2000 and 2016 according to ISI Web of Science with the keyword “ESPI”. UTT ranks at #9 with only 16 papers among other prestigious institutions. The total number of published papers in this period and indexed in ISI Web of Science is 990. It should be noted that CNRS (rank 8) is not really a laboratories but a group of laboratories (like Chinese Academy of Science).

Available equipment:

- Several optical set-ups for Laser Speckle Pattern Interferometry, including one which is mounted in-situ on a mechanical testing system
- High speed digital holographic microscope
- Instrumented nano-indentation system
- Two X-ray diffractometers
- Numerical microscope
- Finite Element codes (ABAQUS, Z-Set).
Every PhD student shares an office with other PhD students. A personal desk is proposed to each PhD student along with a personal computer and full personal access to the internet and bibliographic databases.

**PhD supervisors**

The PhD work will be supervised jointly by Professor Manuel François and Dr Léa Le Joncour. They have co-supervised one PhD work together: Dr Chengheri Bao (defense in 2016), sponsored by a CSC grant.

Prof. Manuel François, 54, obtained a Master of Engineering from Arts et Métiers ParisTech in 1985, a Master of Science in Metallurgy from University Paris 6 in 1987. He defended his PhD in Arts et Métiers ParisTech in June 1991. After being Associate Professor in University of Nantes from 1993 to 2000, he became full Professor in UTT in 2000 (promoted exceptional class in 2011). He lived one year in China to teach French language in 1985-1986. He has supervised 18 PhD students and has been involved in 11 others PhD theses. He has published about 235 papers among which 80 in rank A international journals. He has been Dean of the Mechanical Engineering Department of UTT, Development Manager of UTT, member of the Executive Board of UTT and director of the LASMIS research laboratory (51 people, including 21 faculty).

Dr. Léa Le Joncour, 31, obtained a Master of Structure Calculation from Paris-Saclay University in 2007. She defended her PhD in University of Technology of Troyes in 2011. She became an Assistant professor in UTT in September 2012. She already co-directed 2 PhD thesis, and has been involved in 2 others. In less than 8 years she has performed 6 significant experimental campaigns on Large European Instruments (neutron sources and synchrotron radiation) such as the Center of Accelerators and Nuclear Analytical Method (near Praha), the ISIS research center (near Oxford), ESRF (near Grenoble).

**4. Contact and application**

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The applicant should send his/her detailed CV, a motivation letter, a list of references, a copy of grades sheets and two recommendation letters. Before the final decision, some of the applicants will be interviewed through Skype (or equivalent system).
5. Publications in the last ten years

Our publications restricted to the field of ESPI, necking, localization, damage, constitutive behavior and instrumented indentation.


