RESEARCH TOPIC FOR THE CSC PHD PROGRAM

Topic title: Efficient and accurate prediction of plastic instabilities in thin metal sheets using Fast Fourier transform (FFT) method

Keywords: Sheet metal forming, Ductility limits, FTT approach, Microstructural parameters, Material design.

Topic short description: The prediction of plastic instability, such as localized necking or plastic buckling, in sheet metals during forming processes represents a significant challenge. It is well known that the occurrence of such instability phenomena mainly depends on the mechanical and microstructural characteristics of the metal sheets, such as grain morphology and orientation and the crystallographic structure. To accurately account for these characteristics in instability predictions, several computational strategies based on multiscale schemes have been developed by the host research team. These strategies predict the onset of plastic instability by considering a polycrystalline aggregate as representative of the studied sheet (see, Fig. 1). The mechanical constitutive equations are formulated at the single crystal (microscopic) scale, and a multiscale transition scheme is employed to determine the overall behavior of the polycrystalline aggregate from that of the single crystal constituents. An instability criterion, such as the Rice bifurcation theory or the initial imperfection approach, is coupled with the overall polycrystalline behavior to predict the incipience of localized necking at the macroscopic level. To ensure the transition between the single crystal and polycrystalline scales, the host research team initially used the self-consistent approach [1, 2]. More recently, the periodic homogenization approach has been used as an alternative to the self-consistent scheme. This evolution in multiscale modeling has been motivated by the enhanced accuracy of the periodic homogenization scheme in modeling polycrystalline behavior [3–5]. Despite these significant improvements, the application of the periodic homogenization scheme in predicting the onset of localized instabilities poses some technical difficulties, such as the very high CPU requirements needed for running the computation strategy, especially for polycrystalline aggregates with complex microstructures, and numerical convergence problems that may arise particularly in the large deformation range. The objective of this thesis project is to develop a new computational strategy that circumvents the technical problems related to the use of the periodic homogenization scheme. This new approach, based on the Fast Fourier Transform (FFT) method, will enable a more detailed description of thin metal sheets with complex microstructures (incorporating realistic morphology of grains, grain boundaries, size effects, ...) with a reduced CPU time [6]. The adoption of this new computational strategy is expected to significantly enhance the capabilities of our numerical tools used to predict the onset of localized necking. The single crystal constitutive models used in previous work by the host team will be integrated into this new computational strategy. These models will be improved to better describe the microscopic behavior by considering some key challenging effects not sufficiently investigated so far, such as non-associated plasticity, thermomechanical coupling, phase transformation effects, and more. The resulting computation strategy, based on the FFT method, will be coupled with the Rice bifurcation criterion by developing the suitable software tools.

The algorithmic schemes and associated computational tools developed in this project will be validated by comparing the numerical predictions to several experimental results. Once fully validated, the developed computational strategy will be used in both academic and industrial contexts to provide guidelines and assistance in the design of new generations of metallic alloys with improved ductility.

References

[1] Franz, G., Abed-Meraim, F., Berveiller, M., 2013. Strain localization analysis for single crystals and polycrystals: Towards microstructure-ductility linkage, *International Journal of Plasticity*, Vol. 48, pp 1–33.

[2] Akpama, H.K., Ben Bettaieb, M., Abed-Meraim, F., 2017. Localized necking predictions based on rate–independent self–consistent polycrystal plasticity: Bifurcation analysis versus imperfection approach, *International Journal of Plasticity*, Vol. 91, pp 205–237.

[3] Zhu, J., Ben Bettaieb, M., Abed-Meraim, F., 2020. Investigation of the competition between void coalescence and macroscopic strain localization using the periodic homogenization multiscale scheme, *Journal of the Mechanics and Physics of Solids*. Vol. 143, 104042.

[4] Zhu, J., Ben Bettaieb, M., Zhou, S., Abed-Meraim, F., 2023. Ductility limit prediction for polycrystalline aggregates using a CPFEM-based multiscale framework, *International Journal of Plasticity*. Vol. 167, 103671.

[5] Zhou, S., Ben Bettaieb, M., Abed-Meraim, F., 2024. A physically-based mixed hardening model for the prediction of the ductility limits of thin metal sheets using a CPFE approach, *International Journal of Plasticity*. Vol. 176, 103946.

[6] Gélébart, L., 2020. A modified FFT-based solver for the mechanical simulation of heterogeneous materials with Dirichlet boundary conditions, *Comptes Rendus Mécanique*. Vol. 348, N° 8–9, pp 693–704.

Required background:

- Solid background in non-linear solid mechanics and numerical methods;
- Good analytical and programming skills (e.g., Matlab, Mathematica, C/C++, Fortran);
- Good understanding of the physics of localized necking and associated modeling.
- Previous experience with numerical schemes and their implementations in software environments would be an asset.

ParisTech school: Arts et Métiers
Research laboratory: LEM3
Lab location: Metz
Lab website: https://lem3.univ-lorraine.fr/
Research team: Numerical Methods, Instabilities and Vibrations
PhD delivered by: Arts et Métiers
Doctoral School: Ecole doctorale SMI 432
Advisors: Farid Abed-Meraim, Mohamed Ben Bettaieb

Contact point for this topic : Mohamed Ben Bettaieb (Mohamed.BenBettaieb@ensam.eu)

Research field: Material science, Mechanics and Fluids

Research subfield: Mechanical Engineering

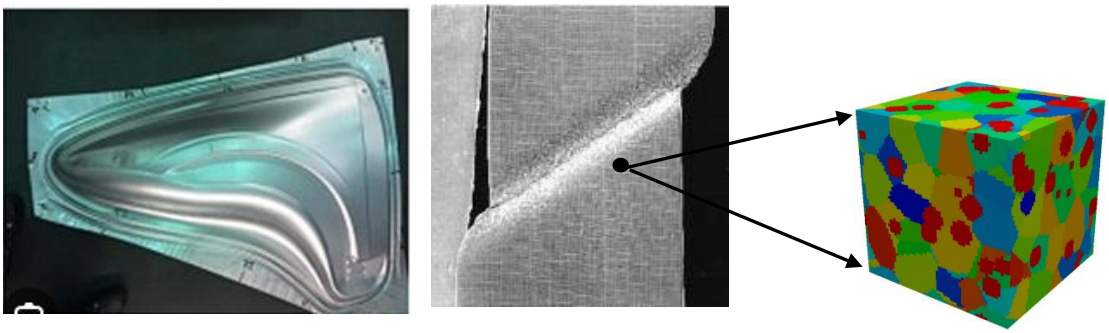

Fig. 1