Post-doctoral project: Multiscale investigation of the complexity of plastic flow and phase transformation in a duplex medium manganese steel

Objectives

The project aims at studying a duplex medium Mn steel containing an austenite phase retained in a ferrite matrix. Such alloys belong to a new family of advanced high-strength steels which attract a great interest, in particular, because of a high potential for automotive applications [Lee2015, Arlazarov2012]. Their excellent mechanical properties are due to the transformation-induced plasticity (TRIP) effect caused by a gradual transformation of the austenite into martensite during straining. The TRIP gives rise to a high work-hardening rate and provides a remarkable combination of high strength and ductility. Moreover, this object of study presents a multifaceted interest for the fundamental understanding of plasticity. Investigations of the last two decades have proven that the plastic flow of solids is associated with complex collective dynamics resulting from the interaction and self-organization of dislocations. The studied steel presents an outstanding example of such phenomena [Callahan2019], namely, a jerky flow known as the Portevin-Le Chatelier (PLC) effect [Lebyodkin2022]. To understand the interactions between the PLC and TRIP effects is a real challenge for the current research. Recent studies by members of our team with the aid of the in situ high-energy x-ray diffraction (HEXRD) on synchrotron beamline allowed to determine the 3D stress states for each phase evolving in the steel during tensile tests. It was found that different phases do not equally contribute to the PLC effect [Lamari 2022]. The objective of the project is to decrypt this behavior with the aid of both experiments aimed at assessing local deformation processes, notably, using digital image correlation (DIC) and acoustic emission, and mathematical analysis of the complexity of plastic flow, using methods of the theory of nonlinear systems [Lebyodkin2022].

Project implementation

The objective of this study will be achieved thanks to a combination of various experimental techniques allowing for an access to the hierarchy of scales involved in the collective deformation processes, and also due to application of various kinds of theoretical methods for the analysis of the recorded characteristics. The work on the project will be organized as follows.

- The team has already accumulated data on the evolution of both stress partitioning between different phases (HEXRD) and surface strains (DIC) during tension of a duplex steel containing 4% of Mn and prepared model microstructures with specific heat treatments. These data will allow to the post-doctoral fellow to tame theoretical methods described below.
- A new series of experiments aimed at relating the above-described characteristics to the deformation processes taking place at much finer scales will be implemented by combining DIC with the acoustic emission technique and high-frequency local extensometry.
- The so-obtained various responses of the material to the mechanical loading (fluctuations of the applied stress and internal stresses, evolution of local strain-rate field, acoustic activity) will be analyzed using complementary statistically-based methods including multifractal and rescale-range formalisms, refined composite multiscale entropy analysis, distribution functions, wavelet analysis, and so on.
- These investigations will be supported by the microstructure characterization using electron microscopy. It is also envisaged to propose an appropriate modeling, thanks to collaboration with researchers of LEM3 developing multi-scale plasticity models.

NB: Please note that both LEM3 and IJL are ZRR (Zone à Régime Restrictif). The access to the laboratories is subjected to the approval of the French security and defense authorities. The instruction of the agreement takes about 2 months and the success of the procedure is not guaranteed.

Bibliography

[Arlazarov2012] Arlazarov, A., Gouné, M., Bouaziz, O., Hazotte, A., Petitgand, G., & Barges, P. (2012). Evolution of microstructure and mechanical properties of medium Mn steels during double annealing. Materials Science and Engineering: A, 542, 31-39.

[Lee2015] Lee, Y. K., & Han, J. (2015). Current opinion in medium manganese steel. Materials Science and Technology, 31(7), 843-856.

[Callahan2019] Callahan, M., Perlade, A., & Schmitt, J. H. (2019). Interactions of negative strain rate sensitivity, martensite transformation, and dynamic strain aging in 3rd generation advanced high-strength steels. Materials Science and Engineering: A, 754, 140-151.

[Lamari2020] Lamari, M., Allain, S. Y., Geandier, G., Hell, J. C., Perlade, A., & Zhu, K. (2020). In situ determination of phase stress states in an unstable medium manganese duplex steel studied by high-energy X-ray diffraction. Metals, 10(10), 1335.

[Lebyodkin2021] M.A. Lebyodkin, T.A. Lebedkina, J. Brechtl, P.K. Liaw, Serrated Flow in Alloy Systems, in: J. Brechtl, P.K. Liaw (Eds.), High-Entropy Materials: Theory, Experiments, and Applications, Springer International Publishing, Cham, 2021: pp. 523–644.

Required skills

Ph.D. in Materials Science or Mechanics. Excellent knowledge in materials science, mechanics, and physics of plasticity. Experience in characterization of microstructures by scanning electron microscopy. Good knowledge in programming languages, especially Matlab. Basics in the nonlinear dynamics of complex systems. Inspiration for scientific research. Good capacity of a team work. A good level in English.

Work context

This project is supported by the laboratory of excellence DAMAS (Design od Alloy Metals for low-Mass Structures, https://labex-damas.univ-lorraine.fr) founded by the LEM3 (Laboratoire d'Etude des Microstructure et de Mécanique des Matériaux, UMR7239, Metz, http://www.lem3.univ-lorraine.fr) and IJL (Institut Jean Lamour, UMR7198 CNRS, Nancy, https://ijl.univ-lorraine.fr). The research team is composed of permanent researchers, post-doctoral fellows and PhD students of the LEM3 and IJL. The post-doctoral scientist will be located in LEM3 where a part of experiments and the entirety of data processing will be carried out. A part of the experimental work, notably concerning TEM or complimentary HEXRD experiments, will be realized with IJL. Collaborations are envisaged both on the national and international levels, notably with Mines ParisTech, with partners of DIAMS project (PEPR DIADEM France 2030) and DYNAUSTAB RFCS project (Horizon Europe), in which IJL and LEM3 are involved.

Duration: 1 Year

Remuneration: 2773 € per month (gross wage)

Contacts

Dr Mikhail Lebedkin email : mikhail.lebedkin@univ-lorraine.fr
Pr Sébastien Allain email : sebastien.allain@univ-lorraine.fr

Application

The candidate has to provide a detailed CV, a cover letter, and PhD thesis reports. It would be useful to add letters of recommendation or a contact information for references. The application can be sent to the two contact e-mails.