Institut de Recherche Dupuy de Lôme

IRDL – UMR CNRS 6027
Université Bretagne Sud
Rue de Saint Maudé – BP92116
56321 Lorient Cedex – FRANCE
https://www.irdl.fr/

Calibration of strain rate and temperature dependent models up to rupture of high strength steels

PhD at IRDL
European project VForm-xSteels (http://www.vform-xsteels.eu)

Supervisor: Pr Sandrine THUILLIER

Starting date: September 2021
Duration: 3 years position
To apply to the position: send a CV and a motivation letter to S. Thuillier, email address: **sandrine.thuillier@univ-ubs.fr**

VForm-xSteels is a European project (Research Fund for Coal and Steel, grant number 888153) dedicated to the calibration of elasto-visco-plastic models for steel sheets, entitled "Toward virtual forming and design: thermomechanical characterization of advanced high strength steels through full-field measurements and a single designed test". The main goal of the project is to develop an efficient and accurate methodology for material characterization and determining the material parameters of thermomechanical models, from a dedicated single test that involve non-homogeneous temperature and strain fields. High strength steels are very attractive materials, for their high mechanical properties that lead to significant weight decrease and their high recycling potential. This vast project has been subdivided into different work packages and this PhD is mostly dedicated to the one related to the design of a novel test using an integrated topology-shape optimization methodology and a thermomechanical indicator. Such a test should be able to give the necessary information to calibrate an elasto-visco-plastic model. The team from the University of Aveiro is in charge of proposing a shape and boundary conditions for such a test, based on an optimization procedure. However, from a previous study [1], it comes that calibrating the viscous part of the mechanical behavior can be rather challenging and specific tests are also needed to bring complementary information about the strain rate and temperature dependence.

Generally speaking, steel sheets exhibit a mechanical behavior that is (mostly) slightly anisotropic, with positive hardening under monotonic loading, Bauschinger effect with a strain-rate dependence, which magnitude depends on the temperature range [1,2]. A huge number of studies have been dedicated to the three first features and more specifically to the calibration of anisotropic elasto-plastic models with mixed hardening to represent them; the calibration of visco-plastic models, able to represent the strain-rate and temperature dependence, has also been investigated, e.g. [3], but it still represents a challenge when several orders of magnitude of the strain rate are considered. For example, strain localisation effects involve a strain rate distribution for a given sample, e.g. [1], and the same test performed at several macroscopic strain rates add more information, and having both contributions in an experimental database is still a challenge for parameter identification. Johnson-Cook constitutive equation, with some modifications, is often used, though it presents strong limitations [1]. A recent alternative, based on machine learning algorithms, such as artificial neuronal networks [6], has highlighted an interesting trend, that may provide hints to formulate further modifications.

The aim of this PhD is to develop a calibration procedure for visco-plastic models dedicated to high strength steels, as well as the necessary experimental database, using different set-ups at IRDL, like bulge test on Hopkinson bars [4] and Gleeble tests at high temperature, e.g. up to 500°C [1]. The experimental database should also include tests for calibrating hardening and initial anisotropy. Moreover, calibration of a rupture criterion should also be included [5], as rupture prediction is an essential aspect in the mechanical design of a test. Strain distribution would be measured by digital image correlation (DIC) and as a hybrid experimental approach is necessary, a DIC-to-FE (finite element) procedure would be used with the software MatchID[1]. A dedicated constitutive equation should be chosen and/or developed, to reproduce the strain rate and temperature dependent features of the mechanical behavior of high strength steels.

Such an experimental database is rather large but necessary at the same time to derive a consistent set of material parameters. A classical approach based on finite element model updating (FEMU) would be developed, based on the numerical modeling of each test, coupled to an inverse identification procedure, to determine the best set of parameters. Moreover, a comparison with heterogeneous tests, to be designed during the VForm-xSteels project by the partners, should be performed as well as to carry out some of the experiments. Finally, the idea of a single heterogeneous test, as opposed to several (even many) tests with controlled strain states, should be also compared to other alternatives arising with the development of machine-learning [7].

The PhD work will take place at IRDL (Lorient), with regular meetings with the European partners. As English is the common language for all the presentations/written reports, a good level (B2-C1) of English is necessary.

Skills: mechanics of materials, finite element simulation (Abaqus), framework of elasto-visco-plasticity, metallic materials, experimental mechanics, Python as programing language

8 partners from academy and industry, in Europe

VForm-xSteels

Universidade de Aveiro, Portugal

Université de Bretagne Sud, France

Katholieke Universiteit Leuven, Belgium

Università Politecnica Delle Marche, Italy

MatchId, Belgium

OCAS (OnderzoeksCentrum voor de Aanwending van Staal) NV, Belgium

DAF Trucks NV, The Nederlands

University of Southampton, with Professor Fabrice Pierron as associate partner

References

[1] https://www.matchid.eu/

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[3] B. Erice and C.C. Roth and D. Mohr. Stress-state and strain-rate dependent duc- tile fracture of dual and complex phase steel. Mech Mater 116 (2018) 11–32. DOI:10.1016/j.mechmat.2017.07.020
[4] V. Lafilé, B. Galpin, L. Mahéo, C. Roth, V. Grolleau, Toward the use of small size bulge tests: Numerical and experimental study at small bulge diameter to sheet thickness ratios, Journal of Materials Processing Technology 291 (2021) 117019. DOI:10.1016/j.jmatprotec.2020.117019.48535
[5] A. Kacem, H. Laurent, S. Thuillier, Influence of experimental boundary conditions on the calibration of a ductile fracture criterion, Engineering Fracture Mechanics 248 (2021) 107686. DOI: 10.1016/j.engfracmech.2021.107686
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