PhD position

Context and goals of the PhD

Mean-field modeling of microstructure evolutions

Numerical metallurgy is expected to become a key component of the metallic materials industry for either helping to develop and/or optimize processing routes or for monitoring in real-time microstructure evolutions during production. The need of predictive, robust and fast numerical models which are able to describe microstructure evolutions of different kinds of alloys and under a wide range of thermomechanical conditions is constantly increasing. The development and extension of these models, by reducing the number trial and error procedures and by process optimization, are expected to help reduce carbon emissions in order to meet European Union's objectives in climate change. Monitoring microstructure evolutions during complex thermomechanical processes will also help ensuring targetted in-use properties of metallic materials since the latter are strongly linked to their microstructures.

Several numerical frameworks exist in order to track microstructure evolutions during thermomechanical treatments. The full-field approach relies on an explicit description of the microstructure: each grain of the polycrystal is represented and will evolve with respect to its neighborhood. Topology is intrinsically taken into account and equations for microstructure evolutions can be postulated at a local scale along grain boundaries. While being faithful to an experimental microstructure, explicitely tracking each grain remains costly in terms of computation time which limits the use of full-field models to studies at the mesoscopic (polycrystal) scale. To circumvent this limitation, mean-field models have been developed and are used since the 1950's to statistically predict microstructure evolutions. These models rely on an implicit/simplified description of the microstructure often based on the use of grain classes. Grains of similar properties are grouped into classes and mean-field models predict the evolution of grain distributions. First only able to account for the grain growth mechanism [1], mean-field models have been extended in the past two decades in order to account for more complex microstructure evolution mechanisms such as dynamic recrystallization [2], post-dynamic recrystallization and Smith-Zener pinning. While already providing good results on single-phase alloys and under conventional thermomechanical conditions, the model developed at CEMEF needs to be extended and validated to a wider range of applications. This project takes place in the context of the DIGIMU consortium which is dedicated to the development of robust numerical models for microstructure evolutions prediction at the service of major industrial companies.

The present project aims at extending a physically-based mean-field model for the prediction of recrystallization and grain growth kinetics. In order to broaden the range of validity of the current model several actions are considered. (i) Better account for microstructural heterogeneities on hardening using crystal plasticity. These developments will rely on homogenization techniques at the polycrystal scale and the use of the self-consistent approach. (ii) Better account for the effect of solute drag and grain boundary pinning on the grain boundary migration mechanism. A more refined description of second-phase particles and their evolution with respect to thermomechanical conditions is envisaged. (iii) Validate and extend the model to high strain rate conditions for Ni-based superalloys.

These numerical developments will be integrated in an extension of the FORGE® software dedicated to mean-field modeling of microstructure evolutions. These numerical developments will also benefit to other students of the team/laboratory and could be implemented in the DIGIMU® software.

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Partners

Keywords

Mean-field model - Dynamic and post-dynamic recrystallization - Computational Metallurgy - Crystal plasticity - Homogenization - Self-consistent model

Candidate profile and skills

Degree: MSc or MTech in Metallurgy or Applied Mathematics, with excellent academic record. Skills: Numerical Modeling, Metallurgy, programming, proficiency in English, ability to work within a multi-disciplinary team.

Offer

The 3-year PhD will take place in CEMEF, an internationally-recognized research laboratory of MINES Paris located in Sophia-Antipolis, on the French Riviera. It offers a dynamic research environment, exhaustive training opportunities and a strong link with the industry. Annual gross salary: 29.7k€ plus additional benefits. She/He will join the Metallurgy μStructure Rheology (MSR) research team.

[1] M. Roth, B. Flipon, N. Bozzolo and M. Bernacki. Comparison of Grain-Growth Mean-Field Models Regarding Predicted Grain Size Distributions, Materials 16 (20), pp.6761, 2023. 10.3390/ma16206761 .

[2] L. Maire, J. Fausty, M. Bernacki, N. Bozzolo, P. de Micheli, C. Moussa. A new topological approach for the mean field modeling of dynamic recrystallization. Materials & Design 146, pp.194-207, 2018. 10.1016/j.matdes.2018.03.011 .