RECYCAL ANR Project

PhD Offer

3D multiscale modelling of damage mechanisms in Recycled Aluminum alloys

Context of the project

In terms of sustainability, aluminum alloys are known to be materials of choice. They allow lightweighting and thus fuel consumption reduction due to their low density. However, producing aluminum from bauxite ore is very energy intensive and today's aluminum industry represents 2% of the global greenhouse gas (GHG) emissions. Recycling aluminum allows both energy savings and a drastic reduction of GHG emissions, because only 5% of the energy required for primary synthesis (ore reduction) is needed to remelt aluminum scrap. However, reaching high levels of recycled content leads to contamination by tramp elements, the main one being iron. As these elements typically have a low solubility in aluminum, they are integrated in intermetallic phases, negatively impacting product properties such as formability and in-service ductility. The current challenge lies in finding solutions to mitigate this detrimental effect, in order to meet demanding properties in spite of higher impurities contents.

The PhD is part of a very ambitious project (ANR RecycAl with 3 PhDs) involving complementary expert teams in the field: Constellium for the material supply, material formulation and industrial application, CMAT Mines Paris PSL for the in-situ synchrotron observations of ductile failure mechanisms, SIMAP INP Grenoble for plane strain bending experiments and CEMEF Mines Paris PSL for advanced 3D modeling of ductile damage mechanisms of heterogeneous microstructures.

This PhD hiring is devoted to the 3D finite element (FE) full-field modeling of heterogeneous microstructures, application of boundary conditions coming from X-Ray laminography experiments, high-fidelity modeling of ductile fracture at the microscale based on FE simulations and use of neural network based approaches to define and calibrate a macroscopic low-order damage model that can be used at the macroscopic scale.

PhD program

This PhD program will handle the numerical tasks of the RecycAl project (Work Packages WP4, WP5 and WP6 presented in the RecycAl diagram in Figure 1) with close interactions with the 2 other experimental PhD positions. The following tasks are expected:

- **Step1: Digital twin initialization**
  - Segmentation and meshing of 3D microstructures based on X-Ray laminography observations;
  - Definition of the Representative Volume Element (RVE) size and definition of RVE boundary conditions based on Digital Volume Correlation (DVC) from in-situ X-Ray images.
- **Step 2: Digital twin development and validation**
  - 3D modeling of nucleation, growth and coalescence of microvoids at the microscale with an homogeneous matrix;
  - Coupling of crystal plasticity approaches with previous microscale ductile fracture mechanisms;

- Validation of the digital twin on configurations (loading conditions and microstructure configurations) tested experimentally.

- **Step 3: Machine Learning based homogenization and upscaling for industrial applications**
  - Once validated with experimental observations, the microscale full-field model will be used for loading conditions and microstructure configurations different from the one studied experimentally so as to generate reliable additional input data;
  - Integration by data fusion of both experimental data and predictions from the full-field model in order to train a reliable and efficient machine learning-based model for the prediction of the homogenized ductile damage onset and evolution. The use of recurrent neural network (RNN) and/or multilayer perceptron (MLP) will be investigated for this objective.
  - Upscaling by development and validation of an Hosford-Coulomb mean-field model that would account from the microstructure.

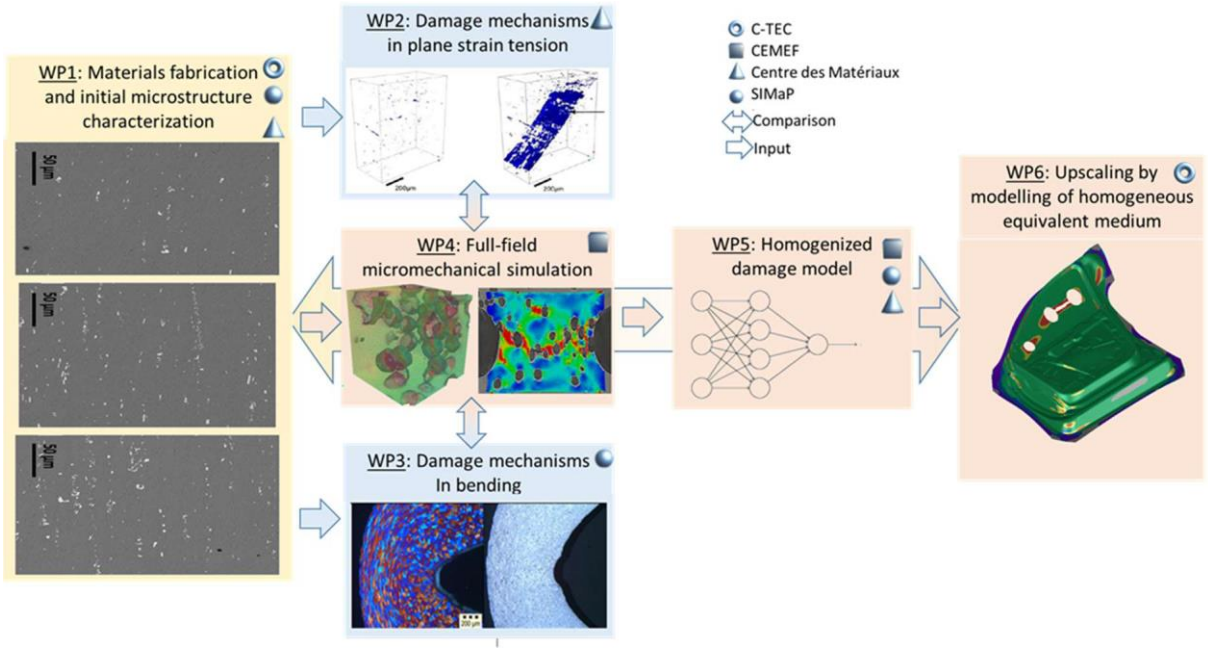

Figure 1. ANR RECYCAL Work Packages and Organization

• PhD program benefits and PhD applications requirements

This PhD offers a unique opportunity to develop cutting-edge numerical methods to address multi-scale ductile damage and fracture of recycled aluminum alloys. Thanks to the international renowned expertise and complementarity of the 3 research teams, the project should lead to many important scientific publications. The major role of Constellium in the Aluminum industry is also a guarantee of industrial-oriented research and applications in various fields (aeronautics, automotive, packaging).

Considering the ambition of the project, only high level of excellence applications will be considered with the following profile:

- Masters-level degree or graduate of Engineering school (Mines, Centrale, INSA, INPs, UTC...) in Computational Mechanics or Computational Engineering with good knowledge in nonlinear solid mechanics;
- Strong motivation for finite element numerical development and Machine Learning based approaches;
- Strong analytical skills;
- Knowledge in non linear solid mechanics, including plasticity and damage would be a plus;

- Ability to work/interact with both academic and industrial teams;
- The PhD student is expected to be self-motivated, creative, and capable of critical thinking.

PhD conditions

- Starting date: October 2024 or earlier
- Duration: 3 years
- Research laboratory and Location : Centre de Mise en forme des Matériaux (CEMEF) Mines Paris PSL – Sophia Antipolis. Close collaboration and interactions with CONSTELLIUM
- Academic supervision: Pierre-Olivier BOUCHARD, Daniel PINO MUNOZ, Marc BERNACKI (CEMEF, Mines Paris - PSL)
- Industrial supervision within the ANR RECYCAL Project: Fanny MAS
- Interested? Please send your application to pierre-olivier.bouchard@minesparis.psl.eu