FATIGUE DAMAGE MODELLING OF ALUMINIUM ALLOY POLYCRYSTALS CONTAINING INTERMETALLIC PHASES

Manon Lenglet[1,2]*, Anna Ask[1], and Samuel Forest[2]

[1]Office National d'Etudes et de Recherches Aérospatiales (ONERA), Châtillon, France, [2]MINES Paris, PSL University, Centre des matériaux (CMAT), CNRS, Evry, France
** Presenting Author email: manon.lenglet@onera.fr*

Abstract
The objective of this work is to model fatigue damage of the aluminium alloy AA2139 at the microscopic scale. It combines an experimental campaign and numerical simulations for a complete modelling of the alloy. Special attention is given to the reproduction of the alloy grain morphology and crystallography. Moreover, intermetallic phases are preferred sites for fatigue crack initiation in this alloy. Therefore, a method for taking into account the alloy microstructural complexity including the presence of intermetallic phases is presented. Finally, a fatigue damage model using a fatigue indicator parameter (FIP) is considered for the introduction of a crack and its propagation in simulations.

1. Introduction
In polycrystalline alloys, fatigue damage is strongly influenced by the microstructure. Nowadays crystal plasticity models can be used in order to take into account the crystallography and microstructural mechanisms but there is no consensus on how to predict accurately crack initiation sites and their most significant mechanisms. The present work focuses on numerical aspects to understand and predict the physical mechanisms that lead to crack formation and its propagation in high cycle fatigue in high-strength aluminium alloys for aerospace applications. Numerical results are then compared to experimental results.

2. Methodology
The first challenge is the realistic modelling of the complex microstructure of the AA2139 alloy. Dream3D [1] is used to carry out a statistical analysis on orthogonal EBSD (2D), and statistically representative 3D data are deduced [2]. Finally, each EBSD is used as an imposed surface finite element mesh and is extruded with respect to 3D aspect ratio and crystallography. Once microstructures are generated, numerical simulations are performed with the finite element method software Z-set [3]. The Méric-Cailletaud crystal plasticity model [4] is used and material parameters are calibrated from an experimental campaign performed at ONERA.

Crack initiation in this alloy is known to take place on ruptured intermetallic phases [5]. We propose an approach where we consider these intermetallic phases by submodelling illustrated in Fig. 1. This approach consists in a first global simulation of the polycrystal without any intermetallic phase, and a second local simulation on a subdomain including an intermetallic phase. The strain field at the common interface that is calculated in the global simulation serves as boundary condition in the second, local simulation.

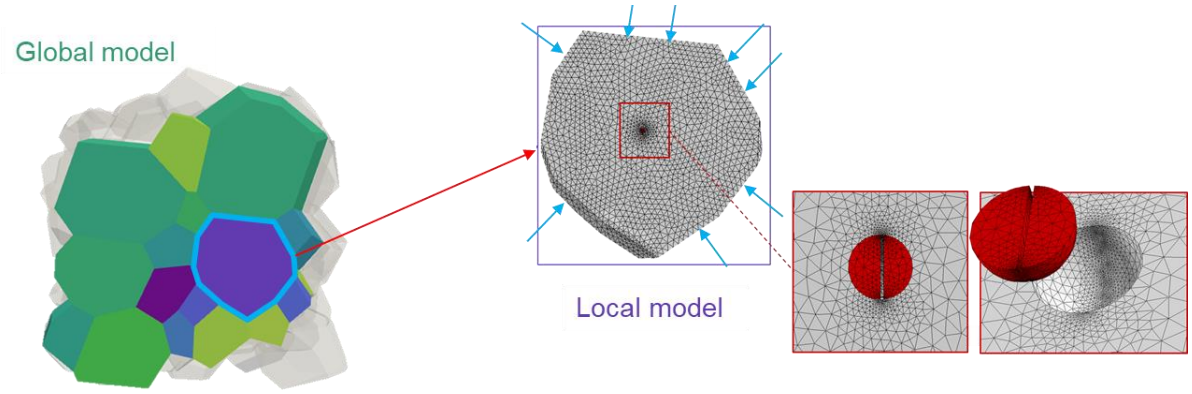

Figure 1 - Submodelling of a ruptured intermetallic phase in a polycrystal generated with Neper [6]

The fatigue damage is then accounted for by Fatigue Indicator Parameters (FIP), computed at the end of each simulation, both local and global. Several FIPs are considered to take into account various phenomena that may contribute to fatigue damage, such as surface roughness, local ratchetting or stress concentration around the intermetallic phase. Some of them are implemented in Z-set, in addition to a microstructure-sensitive Fatemi-Socie criterion [7].

The last step is the insertion of a crack and its propagation, and is managed with the adaptive meshing features developed in the dedicated Z-set module, called Z-cracks. When the chosen FIP reaches a certain yield, a crack is inserted in the geometry, logically at the cracking of the intermetallic phase as seen Fig. 2. Then the propagation process also relies on an FIP: by computing the adapted Fatemi-Socie criterion after a given loading sequence, along experimental results, local crack direction and growth rate are estimated along the crack path. Remeshing routines allow the crack to propagate and the iterative process can continue with the updated crack geometry [8].

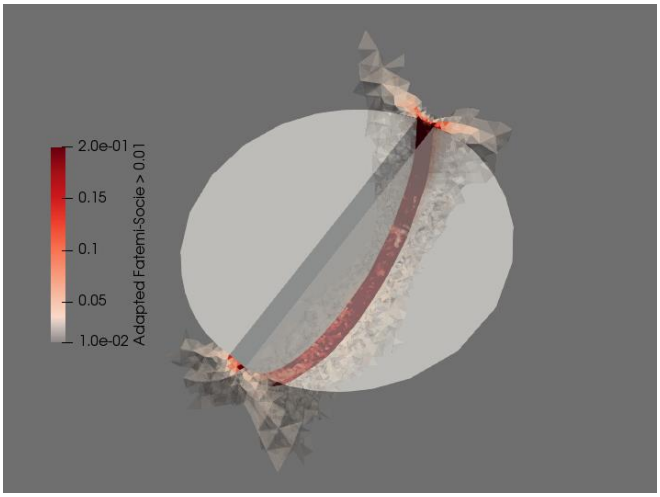

Figure 2 - Adapted Fatemi-Socie around the ruptured intermetallic phase before the crack initiation

In parallel to simulations, an experimental campaign is designed to provide information on the early fatigue damage behavior at the grain scale. Optical and electronic microscopy is used to study the role of the intermetallic phases but also other defaults, including the grain boundaries, on early crack initiation and propagation.

3. Conclusions

The microstructure of the AA2139 aluminium alloy is successfully represented for a better accuracy in the simulations. Moreover, the simulation scheme implemented in this work allows an efficient modelling of the alloy both with respect to variations in microstructure and configurations of intermetallic phases (like their shape, number, and location). Finally, an innovative way of modelling fatigue damage and then crack propagation at intermetallic phases is introduced.
The combined micro- and macromechanical experimental campaign allows for a fine calibration of the fatigue damage model parameters.

Acknowledgements
The financial support of the Clean Sky 2 project within the European Union's Horizon 2020 under the number 945583, GAM-2020LPA is gratefully acknowledged. More specifically, the LPA IADP program (Large Passenger Aircraft Innovative Aircraft Demonstrator Platform) and the ADEC project. We also acknowledge the material support of Airbus SAS Operations and Constellium.

References

[1] http ://dream3d.bluequartz.net, version 6.5.141, 2020

[2] Saylor, D.M., Fridy, J., El-Dasher, B.S. et al. *Statistically representative three-dimensional microstructures based on orthogonal observation sections*. Metall Mater Trans A 2004, 35: 1969–1979

[3] http://www.zset-software.com, version 9.1.3, 2021

[4] Méric, L., Poubanne, P., and Cailletaud, G. *Single Crystal Modeling for Structural Calculations: Part 1—Model Presentation*. ASME. J. Eng. Mater. Technol. 1991, 113(1): 162–170

[5] Nizery, E., et al. *Influence of Particles on Short Fatigue Crack Initiation in 2050-T8 and 7050-T74*. Materials Science Forum. Trans Tech Publications 2014, 794–796: 296–301

[6] https://neper.info/index.html, version 3.3.2, 2020

[7] Wang, W., et al., *Effects of microstructure on rolling contact fatigue of a wind turbine gear based on crystal plasticity modeling*, International Journal of Fatigue 2019, 120: 73-86

[8] Proudhon, H., et al. *3D simulation of short fatigue crack propagation by finite element crystal plasticity and remeshing.* International Journal of Fatigue 2016, 82(2): 238-246