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THE FRENCH AEROSPACE LAB

POST-DOCTORATE PROPOSAL

Title: Development of a high performance simulation methodology to evaluate the dispersion of fatigue lifetime of polycrystals across several load levels.

Reference : **PDOC-DMAS-2022-06**
(to be recalled in all correspondence)

Start of contract: 01/01/2023	**Application deadline:**

Duration: 12 months, possibly extendable to 24 months - Net yearly salary: about 25 k€ (medical insurance included)

Keywords

High performance simulation, Fatigue, Microstructure

Profile and skills required

Non-linear material behavior, Numerical simulation (finite element and or FFT-based solvers), good programming skills. Experience with crystal plasticity and C++ and/or modern Fortran would be valued.

Presentation of the post-doctoral project, context and objective

Reducing the margins of overly conservative structural integrity criteria is an essential avenue for weight reduction in aircraft design. The difficulty of quantifying the intrinsic dispersion of the fatigue life of metallic parts is one of the main obstacles. To address it, a trend is to apply stochastic models that may intrinsically reproduce fatigue life dispersion [1]. Once fitted to a Wohler curve with a limited number of points, they can provide an estimation of the fatigue life distribution at any load level. To deliver accurate predictions, these models should properly capture the degree of correlation that exists between the fatigue lives of a specific specimen under different stress levels. Indeed, it is shown in [1], that two models relying respectively on the hypothesis of uncorrelated or fully correlated lives at different stress levels can yield a difference up to 45% in the fatigue reliability estimates.

The complex interplay of plasticity and fracture at the microstructure scale accounts for a large part of fatigue life variability, and is thought to be one of the major sources of internal correlation of a statistical Wohler curve. Yet, microstructure induced variability is hard to measure as fatigue tests are not repeatable at different loads on the same material sample. On the other hand, numerical simulation allows modeling of the same digital microstructure under virtually any fatigue loading.

ONERA has opened this post-doctoral position to progress towards the development of a numerical framework to investigate those correlations through intensive numerical simulation of the fatigue life of polycrystalline microstructures. Ideally, the industrially relevant outcome should be a simulated fatigue life database of Ni-based superalloys for the training of the stochastic fatigue models developed at ONERA. The candidate will have to engage in both numerical and physical improvements of ONERA's fatigue modeling tools. To achieve these goals, the candidate may explore different directions according to his/her skills and tastes.

The main part of the work will consist in designing a computationally efficient approach mapping a stochastic model of microstructures and material properties to a fatigue life prediction. The candidate will ground the procedure on a review of state-of-the-art methods to produce microstructure sensitive fatigue simulations [2, 3]. A particular focus of the approach should target the implementation of numerical schemes to accelerate the simulation of thousands of plasticity

cycles, such as the WATMUS algorithm [4]. The choice of a microstructure and material properties generation tool, able to span the relevant space to capture fatigue life correlations, is also a subject of high interest for the project goals. The proposed implementation of this framework should rely on the numerical tools developed at ONERA, which are well fitted for high performance computing: the finite element suite Zset and/or the FFT-based solver AMITEX_FFTP.

In parallel, the candidate may also have to propose a sufficiently refined modeling strategy to study the role of the competition between different failure mechanisms in the lifetime correlations between stress levels. For the project, this investigation will focus on the competition between surface and bulk crack initiation within Ni based superalloys. Paths to explore may include:

- going beyond classically used fatigue indicator parameters with the choice of a relevant crack initiation criteria
- pragmatic strategies to model fracture precursors such as plastic slip localization [5]
- multiscale methodologies to couple local high fidelity modeling of crack initiation to the microstructure wise fatigue simulation detailed in the previous paragraph [6].

Candidates should have solid skills in programming and numerical mechanics, experience with the use and development of a finite element or an FFT-based solver, and a good knowledge of non-linear material mechanics. Experience with crystal plasticity and polycrystalline materials modeling would be strongly appreciated.

[1] Liu, Y., & Mahadevan, S. (2007). Stochastic fatigue damage modeling under variable amplitude loading. *International Journal of Fatigue*, *29*(6), 1149-1161

[2] McDowell, D. L., & Dunne, F. P. E. (2010). Microstructure-sensitive computational modeling of fatigue crack formation. *International journal of fatigue*, *32*(9), 1521-1542.

[3] Yaghoobi, M., Stopka, K. S., Lakshmanan, A., Sundararaghavan, V., Allison, J. E., & McDowell, D. L. (2021). PRISMS-Fatigue computational framework for fatigue analysis in polycrystalline metals and alloys. *npj Computational Materials*, *7*(1), 1-12

[4] Joseph, D. S., Chakraborty, P., & Ghosh, S*. (2010). Wavelet transformation based multi-time scaling method for crystal plasticity FE simulations under cyclic loading. Computer methods in applied mechanics and engineering, 199(33-36), 2177-2194*

[5] Marano, A., & Gélébart, L. (2020). Non-linear composite voxels for FFT-based explicit modeling of slip bands: application to basal channeling in irradiated Zr alloys. *International Journal of Solids and Structures*, *198*, 110-125.

[6] Ozturk, D., Kotha, S., Pilchak, A. L., & Ghosh, S. (2019). Two-way multi-scaling for predicting fatigue crack nucleation in titanium alloys using parametrically homogenized constitutive models**.** *Journal of the Mechanics and Physics of Solids*, 128, 181-207

Host laboratory at ONERA

Department : Intitulé in extenso

Location (ONERA centre): Châtillon

Contact: Aldo Marano, Pascale Kanoute

Phone: +33 1 46 73 46 09 Email : aldo.marano@onera.fr pascale.kanoute@onera.fr