# Fatigue crack propagation modeling using a local approach to fracture

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## ABSTRACT

In the aeronautical field, fatigue crack propagation analysis is commonly performed at the macroscopic level through a global energetic approach that considers the material in its elastic domain. Within this framework, the plastic zone is assumed to be confined at the crack tip, in the singularity area. However, recent observations on specimens made of Nickel-based superalloys at 550°C [1] tend to highlight nonlinear phenomena occurring in the process zone, ahead of the crack tip. This plasticity leads to deterioration mechanisms, and to a disturbed crack front, with flat to slant fracture in mode I loading or "tunneling effect" under holding-times. To deal with such complex fracture problems, elastic fracture mechanics is not anymore adapted.

To model fatigue crack propagation in a Ni-based superalloy used in the high-pressure stages of aero-engines [2], the present study proposes to use a local approach to fracture. It consists in estimating more accurately the stress and strain fields in the crack tip area where plasticity occurs. The knowledge of these mechanical fields offers the possibility to characterize the fracture processes by the use of either a damage criterion in post-processing or a fully coupled damage model. This last one can be phenomenological and established within the Thermodynamics of Irreversible Processes and the Continuum Damage Theory frameworks [3, 4], by fully coupling the elasto-viscoplastic behavior and damage. This damage is the combination of different deterioration mechanisms. The most relevant one is fatigue damage which represents persistent slip bands that appear after several reversal loadings. In addition, creep damage also needs to be taken into account, representing holding-period degradation processes at the grain boundaries. Finally, ductile damage can have a contribution for the highly loaded plastic zone in the vicinity of the crack tip.

Fatigue damage is, most of the time, cyclically estimated by the use of a damage law written in terms of loading parameters such as the loading ratio or the stress amplitude. The innovative aspect of the present study is to model fatigue damage in an incremental manner to avoid using cycle-counting algorithms. The main issue with incremental fatigue damage is to describe properly the mean-stress effect. As part of the solution, this study proposes to take into account, in the constitutive equations, the microcracks' closure effect [3].

Another issue is associated with the fact that there is a full coupling between damage and the elasto-viscoplastic behavior. In this case, the structure will progressively exhibit a softening behavior. Then, the well-posedness of the equilibrium problem is not verified anymore and the constitutive equations lose their ellipticity. When performing Finite Element calculations, this leads to spurious localization problems. To obtain mesh-independent results, non-local methods [4, 5] are thus considered.

**REFERENCES**


[1] E. Fessler. Fatigue-creep-environment effect on the crack growth behavior under hold-time conditions in DA Inconel718, PhD thesis, Toulouse INP, 2017.

[2] A. Devaux, B. Picqué, M.F. Gervais, E. Georges, P. Héritier. AD730™ - A new Nickel-based superalloy for high temperature engine rotative parts, *Superalloys 2012: 12$^{th}$ International Symposium on Superalloys*, 2012, 911-919.

[3] J. Lemaitre, R. Desmorat. Engineering Damage Mechanics: Ductile, Creep, Fatigue and Brittle Failures *Springer-Verlag*, Berlin, 2005.

[4] K. Saanouni. Damage Mechanics In Metal Forming: Advanced Modeling and Numerical Simulation *John Wiley* & *Sons, Inc*, Hoboken, 2013.

[5] S. Feld-Payet. Crack initiation and propagation in nonlocal ductile media, PhD thesis, École Normale Supérieure des Mines de Paris, 2010.