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Numerical modeling of fatigue testing for small crack propagation from artificial defect

PhD : Propagation of small cracks in interaction with the microstructure

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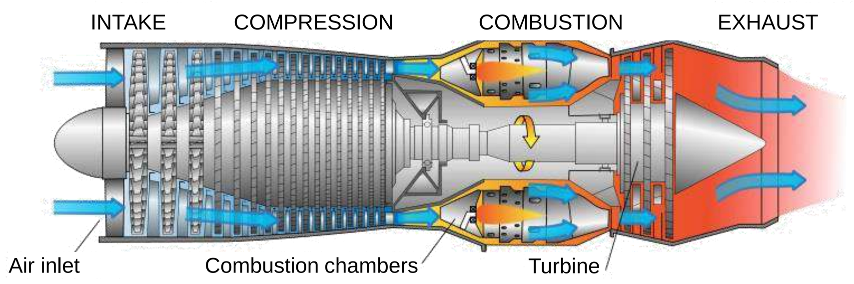
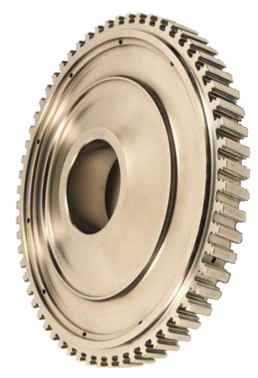
Industrial context



Part :
INCONEL 718 DA
high pressure
turbine disk



Global issues :

- Understanding the small cracks regime initiated by an artificially generated surface micro-defect
- Investigating the influence of the material microstructure on the propagation of those micro-cracks fatigue [1,2]

Numerical goals

Carry out numerical simulation of experimental fatigue testings with tailored surface defect

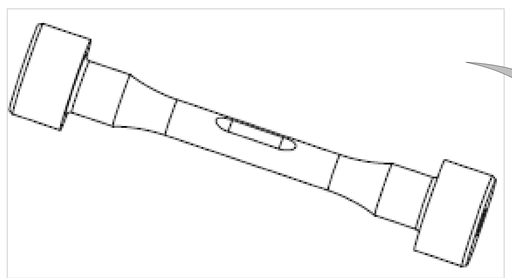
Implement a multiscale modeling approach based on adaptive mesh refinement

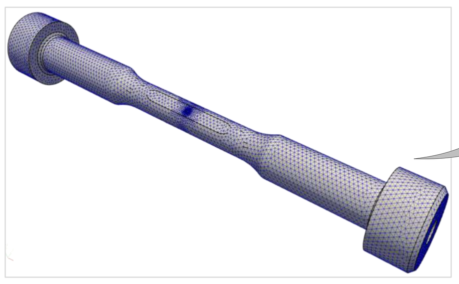
Study the influence of grain orientations and grain size, varying from tens of microns to a few hundred

Numerical strategy

Z-cracks

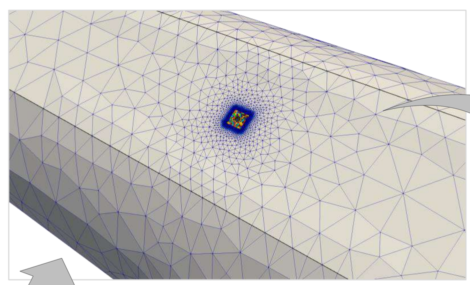
FreeCAD modelization



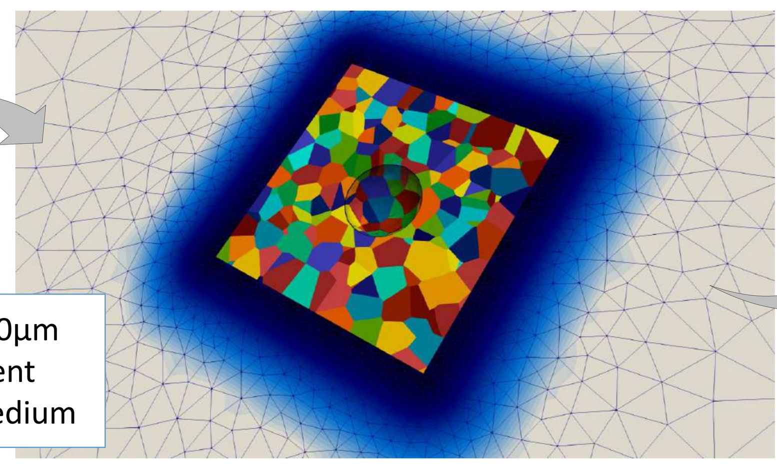


GMSH 3D meshing

Patch approach [3]

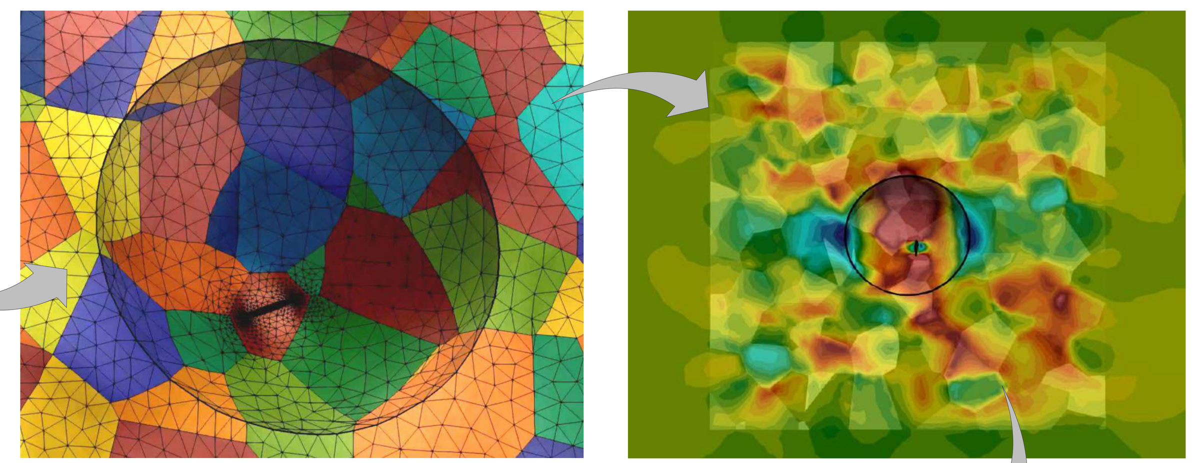


Neper (Voronoi) microstructure



1600 grains Ø=10µm within equivalent homogeneous medium

Defect, adaptative remeshing, loading, crack growth

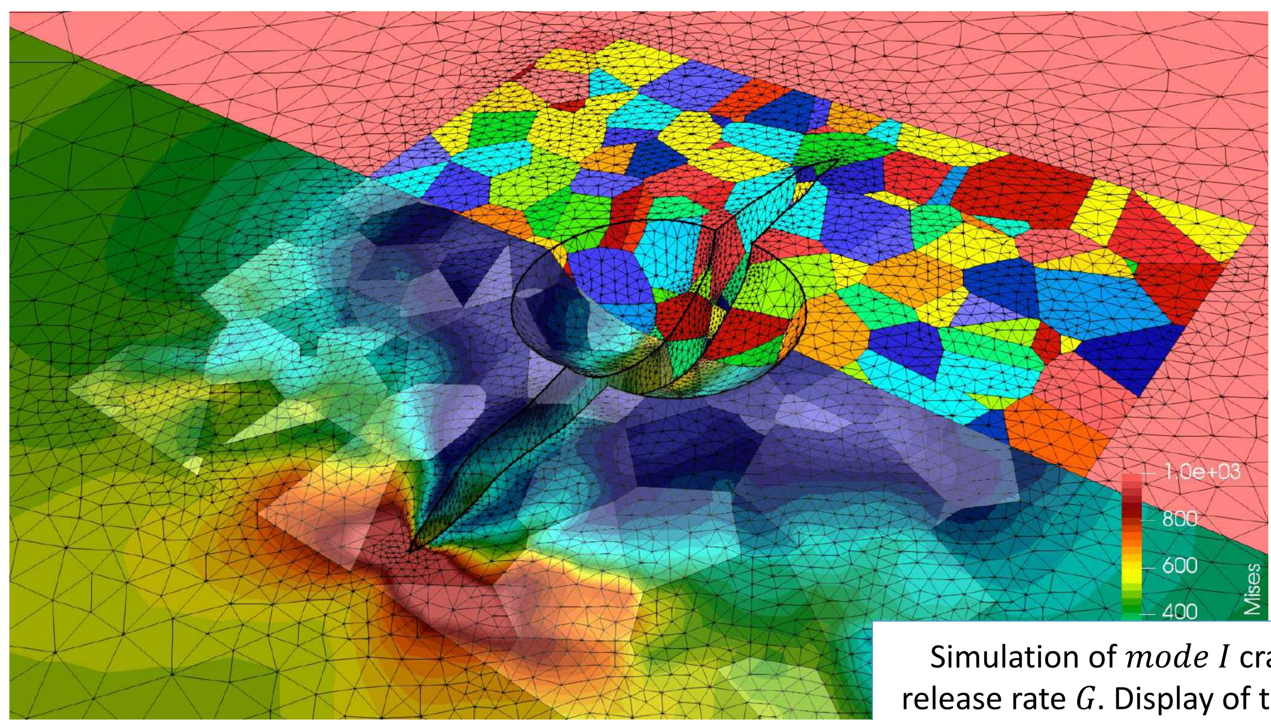


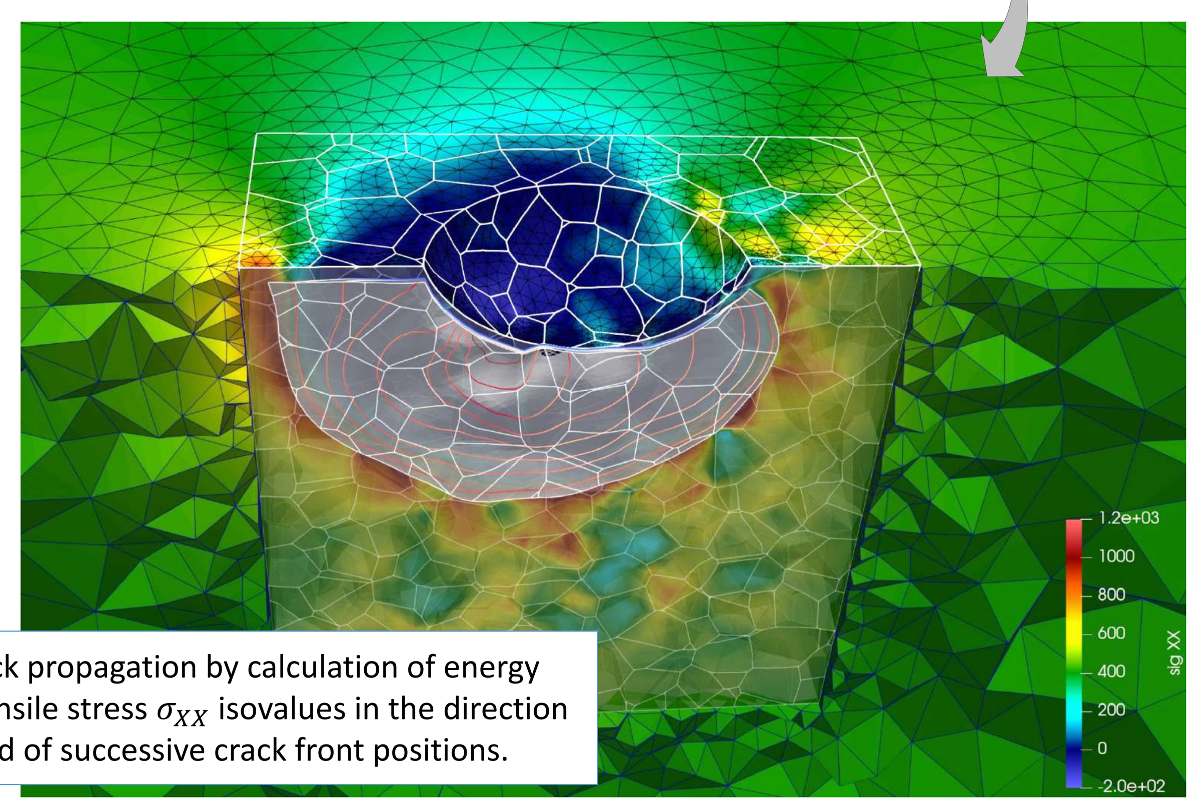
Preliminary results with Paris law

$$G\text{-}\theta \ method \quad \& \quad \frac{da}{dN} = C.\Delta G^m$$

Crack path and velocity influenced by :

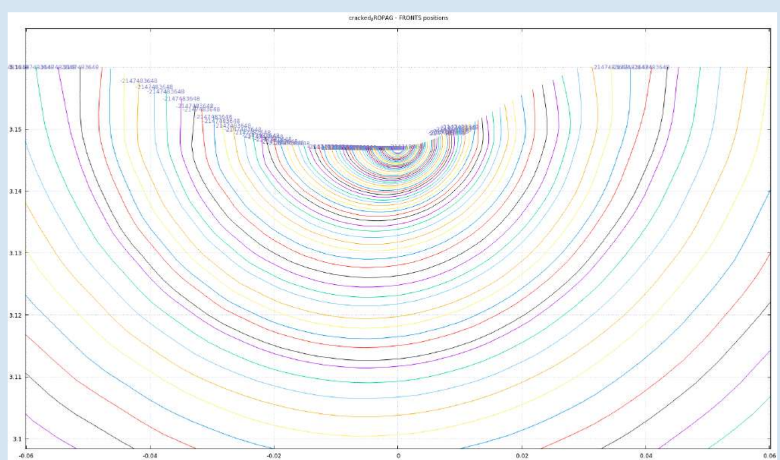
- microstructure presence
- cubic elasticity anisotropy (Zener ratio) in crystal aggregate (grains mismatch)
- crystallographic orientation distribution (preferred direction)



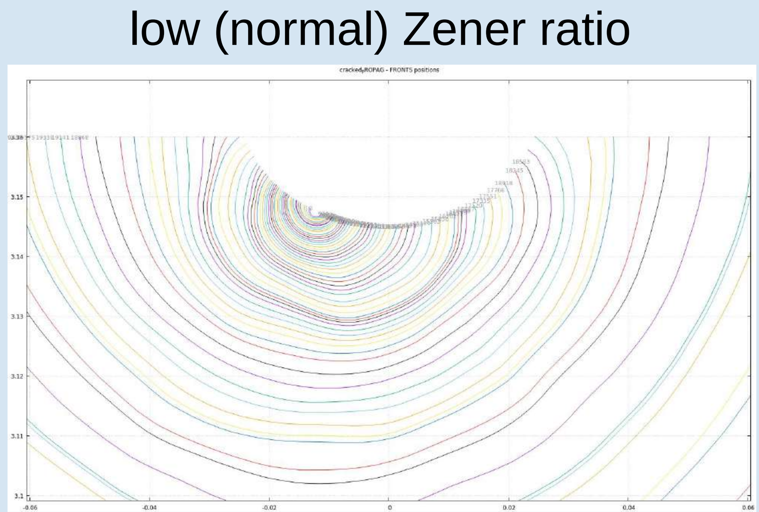


Simulation of *mode I* crack propagation by calculation of energy release rate G. Display of tensile stress σ_{XX} isovalues in the direction of the opening crack and of successive crack front positions.

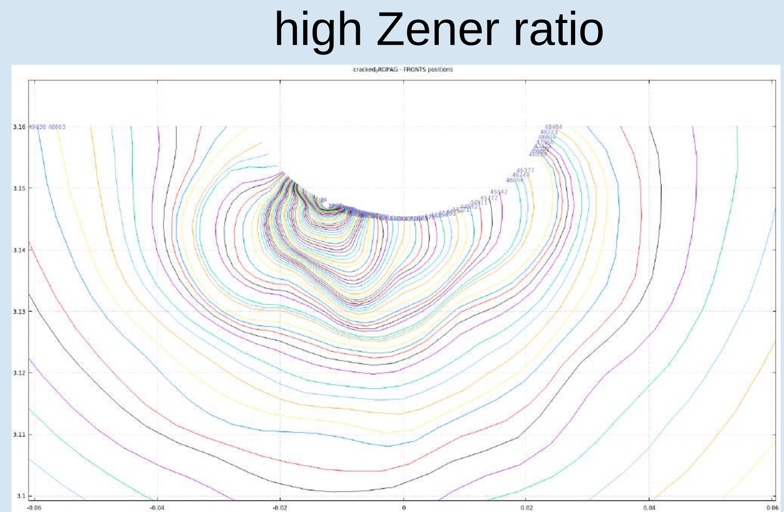
no microstructure



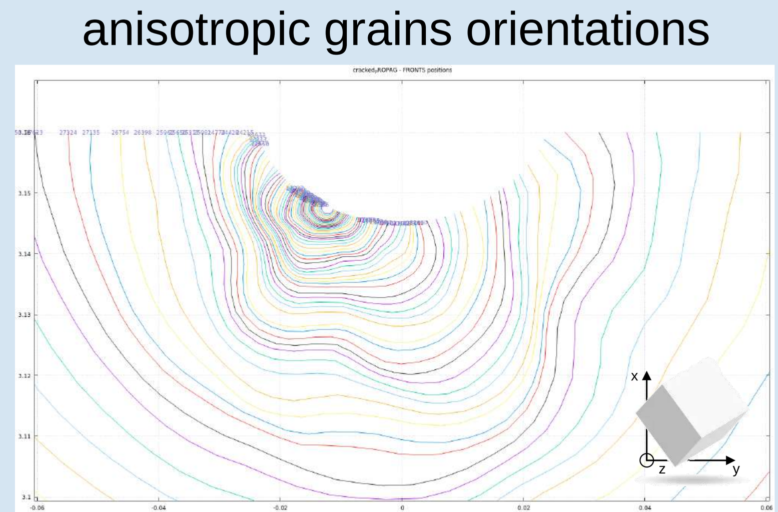
low (normal) Zener ratio



high Zener ratio

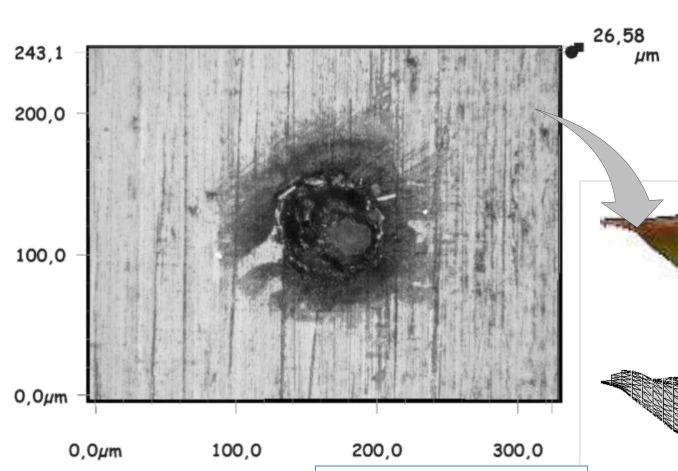


anisotropic grains orientations

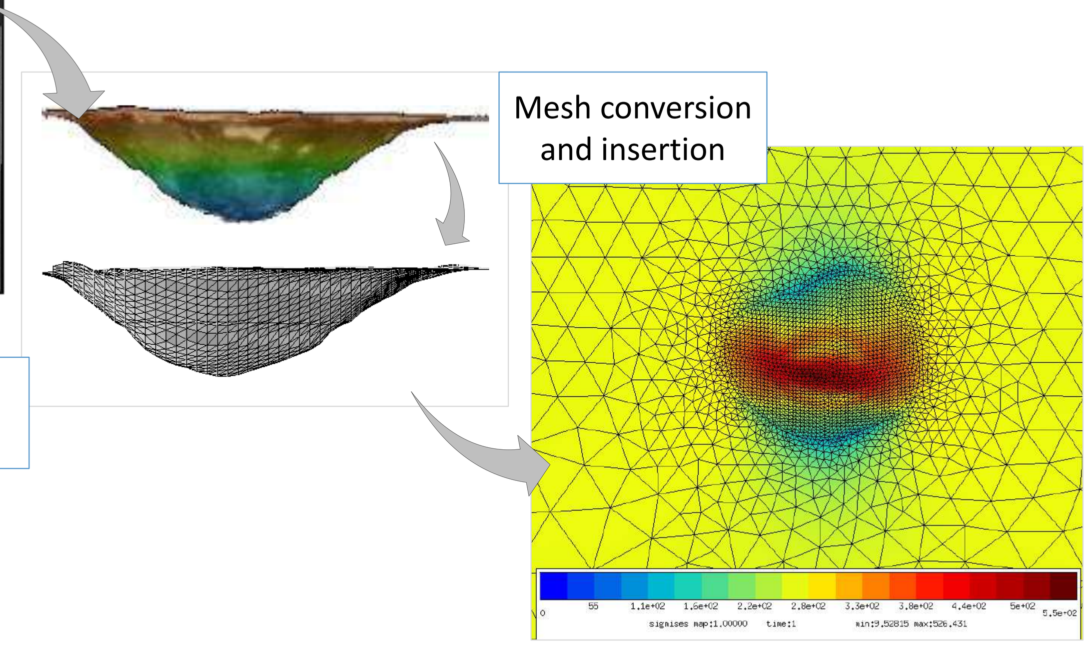


Perspectives for realistic modelization

Take into account the real morphology of the defect with a numerical twin :

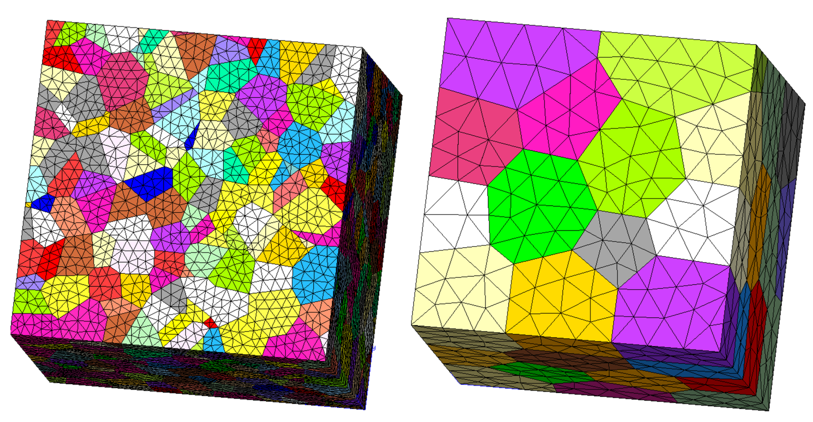


3D microscope observations



Mesh conversion and insertion

Introduce the authentic microstructure of the material surface with EBSD analysis :



Microstructure examples :
N_{g1}=1600 and $Ø_1$=10µm N_{g2}=50 and $Ø_2$=34µm

Study the connection between crystal plasticity and crack propagation characteristics [4,5] by considering :

- the propagation law (Paris or other) at the aggregate scale
- the material behavior (grain boundaries interaction, dislocation based plastic slip)

10th fatigue design International Conference 29 & 30 November 2023 • France

[1] Chowdhury, P., & Sehitoglu, H. (2016). *Mechanisms of fatigue crack growth – a critical digest of theoretical developments*. Fatigue & Fracture of Engineering Materials & Structures, 39(6), 652-674.
[2] ASTM, E647, *Standard Test Method for Measurement of Fatigue Crack Growth Rates.*
[3] Chiaruttini, V., & Vattré, A. (2022). *Approche Standard Test Method for Measurement of Fatigue Crack Growth Rates monolithique globale/locale à interface diffuse par intersection de maillage*. 15ème colloque national en calcul des structures.
[4] Wilson, D., & Dunne, F.P.E. (2019). *A mechanistic modelling methodology for microstructure-sensitive fatigue crack growth.* Journal of the Mechanics and Physics of Solids, 124, 827-848.
[5] Zhang, X., Dunne, F.P.E. (2022). *3D CP-XFEM modelling of short crack propagation interacting with twist/tilt nickel grain boundaries*. Journal of the Mechanics and Physics of Solids 168, 105028.