Cyclic behavior of a Ni-based superalloy: effects of annealing twins and grain size

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Abstract

The macroscopic behavior of metallic parts is largely determined by the properties of the constitutive material, which in turn is widely influenced by the microstructure created during the forming process. It is well established that the fatigue lifetime inversely increases with grain size, while the resistance to creep is reduced. Furthermore, for turbine disks, two distinct mechanisms determine the fatigue lifetime:

- Crack initiation at the surface for large load amplitudes.
- Crack initiation in the bulk for low to mid load amplitudes, usually at large grains or inclusions.

The transition between these regions represents a crucial point in the fatigue lifetime of turbine disks, as it corresponds to the loading of critical zones.

Given the incomplete understanding of the interplay between microstructure and macroscopic fatigue behavior, the design rules employed in the aircraft industry frequently fail to consider the influence of microstructure. This leads to the use of excessive design margins, which ultimately results in the production of aeronautical parts with higher mass than necessary. Consequently, it is imperative to explicitly incorporate microstructure into numerical simulations in order to minimize the mass of turbine disks and fuel consumption.

However, due to the size of the problem, it is impossible to directly simulate the behavior of structures at the macroscopic scale based on a detailed representation of microstructural heterogeneities at the microscopic scale. To address this issue, the field of mechanics of heterogeneous materials (a.k.a micromechanics) aims at determining relationships between the microstructure and the macroscopic response of the material, based on volume averages over a sample that is statistically representative.
Based on these premises, Safran Tech aims at developing a fatigue model that accounts for the microstructural features of the material. To this end, full-field simulations are performed on polycrystalline aggregates. Crystal plasticity laws that include other contributions, such as the distance to the grain boundary, are used to capture grain size effects. In addition, the influence of heterogeneities, such as annealing twins, is assessed. Subsequently, fatigue indicator parameters (FIP) are post-processed from the simulation data, thereby inheriting the sensitivity to the grain size and microstructural heterogeneities.

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