A numerical framework for full scale simulations of polycristalline turbine blades

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Abstract

Aircraft and helicopter turbine blades are subjected to severe thermomechanical loads. Often made of a Ni-based superalloy, such as the IN718, the microstructure influences the plastic strain localization and plays an essential role in its creep resistance, oxydation resistance, and fatigue strength. The influence of the microstructure on the mechanical resistance of the blade is usually taken into account by means of extensive experimental campaigns and/or numerical homogenization.
However, these approaches may fail to capture the full complexity of the blade's behavior under operational conditions, necessitating full-scale simulations.

This work proposes a numerical framework to perform full-scale simulations of turbine blades that directly consider their microstructure.
This approach presents several challenges, including the generation of realistic microstructures of the turbine blade; the development of a complex crystal plasticity model accounting for grain size effects; and the resolution of large, highly nonlinear, finite element problems. To tackle these challenges, this work integrates several key advancements:

- Crystal plasticity modeling: a finite strain dislocation density-based model incorporating geometrically necessary dislocations to account for grain size effects.

- High performance mesh generation: a robust and fast mesh intersection process for embedding the microstructure into the blade's finite element mesh.

- High performance solver: multipreconditioned domain decomposition solvers with a specific grain-based partitioning approach for improved efficiency and scalability.

This framework enables the direct study of grain orientation and size effects on plastic strain localization within the turbine blade. What's more, this framework paves the way for the generation of synthetic databases on the blade, which will be used for statistical analysis and reduced order models. As an illustrative application, a graph neural network based machine learning model of the blade will be presented, highlighting the potential of this framework for advanced turbine blade design and analysis.

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