Experiments supporting ICME of single crystal Ni-based turbine blades

“Integrating Computational Materials Science and Engineering”

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Introduction

As the geometrical complexity in turbine blade design increases (Fig.1), so does the demand for better materials and materials processing for sustaining performance in high temperature engine environments. For example, at a minimum, the turbine blade material must exhibit the following characteristics:

- good castability and machinability, lightweight,
- high melting temperature, high creep resistance,
- oxidation resistance or cost compatible,
- resistant to thermal distortion/fatigue,
- and impact resistance.

This requires knowledge of the 3D microstructure of the blade, its evolution in extreme environments, and how the material behaves when cast in the fine details of a modern high pressure turbine blade1.

Objective & Experimental Approach

The objective of this research is to characterize the 3D microstructure in the turbine blade and couple this with critical mechanics experiments from the blade related to high temperature performance. The approach involves:

1. Obtaining etched optical images through serial sectioning a single crystal nickel-based superalloy (PWA 1484) turbine airfoil
2. Characterizing the 3D dendritic structure and eutectic particles and measuring microstructural statistics
3. Setting up techniques for critical high temperature mechanics experiments on specimens extracted from airfoils, including:
   a) Milli-test apparatus for creep/fatigue at 1100°C
   b) In situ SEM tensile experiments

Multi-scale Microstructure Representation

Characterization is performed at multiple length scales using optical, SEM, and OIM methods to develop a descriptor-based microstructural representation. The goal is to couple microstructural heterogeneities to micromechanics ‘damage’ models for concurrent multi-scale FEM methods.

Experimental Methodology2

A single crystal nickel-based superalloy turbine blade was sectioned, mounted with markers for positioning, and then iteratively polished, etched, and imaged for the dendritic structure and interdendritic defects, such as pores, carbides and eutectic particles2.

Symmetry-based Automated Extraction of Dendrite Cores3

Once relevant microstructure features have been identified, microstructure descriptors can be correlated with microstructure-sensitive properties to help describe phenomenological relationships between processing and properties, which can then be integrated into computational materials models.

Dendrite Core Results3

This method includes two important steps for unassisted eutectic particle characterization: (1) automated identification of seed points within each particle and (2) a region growing algorithm with an automated stop point.

Automated Eutectic Particle Detection4

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Microstructure Descriptors

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3D MICROSTRUCTURE CHARACTERIZATION

High temperature mechanics of miniature specimens6

What is the variability in high temperature properties of specimens from an as-processed blade? How do these compare to properties taken from a bulk slab material? Here, miniature specimens with dimensions influenced by the blade geometry are used in a test frame designed to test specimens at 1100°C in creep and fatigue6. There are a number of challenges in designing the experimental technique for this setup is currently ongoing.

Local strain behaviour via in situ SEM tensile experiments7

In situ SEM tensile experiments were designed to correlate localized strain behavior at the surface with crystallographic-based parameters6, such as the Schmid factor. While this experiment was run on a polycrystalline, microstructure-property relationships in experiments of this ilk may be important for understanding damage nucleation in superalloys at high temperatures.

Conclusion

Property and design constraints on next generation turbine blades will require tailoring properties and microstructure for different regions of the component. Information on 3D characterization and local properties are necessary to advance the integrated engineering of these highly engineered devices. Characterization and representation techniques are being developed to address these issues combined with small scale mechanical testing (creep and fatigue) to assess properties at the scale of the component features.