The effect of prior exposures on the notched fatigue behavior of disk superalloy ME3

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Motivation: Environmental attack has the potential to limit turbine disk durability [1, 2], particularly in next generation engines which will run hotter; there is a need to understand better oxidation at potential service conditions and develop models that link microstructure to fatigue response.

Introduction

More efficient gas turbine engine designs will require higher operating temperatures. Turbine disks are regarded as critical flight safety components; a turbine is a serious hazard. Low cycle fatigue is an important design criteria for turbine disks. Powder metallurgy aluminosilicate, like ME3, have led to major improvements in temperature performance through refractory additions (e.g. Mo,W) at the expense of environmental resistance (Al, Cr). Service conditions for aerospace disks can produce major cyclic periods extending from minutes to hours and days with total service times exceeding 1,000 hours in aerospace applications. Some of the effects of service can be captured by extended exposures at elevated temperature prior to LCF testing [3, 4]. Some details of the work presented here have been published [5].

Gas Turbine Engine

Disk Rim

Current < 650 °C Long-range goal < 800 °C

Experimental approach

Oxidation can reduce fatigue life in disk alloys above 650 °C by accelerated crack initiation and growth at defects; however, it is not well studied at 650 °C - 800°C.

Part I - Identify microstructural features associated with oxidation

• Map microstructural features over time and temperature (isothermal kinetics)

Part II - Examine the effect of environmental attack on fatigue resistance

• Pre-expose fatigue specimens using a subset of mapped conditions

• Examine effect of pre-exposure on fatigue life, crack initiation & propagation

• Correlate / model fatigue life to microstructural evolution

Part III - Linking existing microstructure to fatigue response

• With excellent fits to a simple power law normalized fatigue life decay with thickness of oxide scale, γ-disolution layer, and δ-carbide dissolution layer, and, by inference, total damage depth with an exponent of 3.

• It follows that normalized fatigue life is proportional to (time) (thickness of oxide scale)

• Sligh exposures

• Moderate exposures

• Aggressive exposures

Additional fatigue testing

• Tests on specimens exposed in vacuum or exposed prior to machining showed no fatigue debit.

• Confirm defects observed for prior exposures in air from environmental attack, not overaging during exposure.

• Tests on specimens, pre-exposed at 815 °C 201 h and where the oxide and subscale were removed mechanically showed a marginal improvement (3X) in mean fatigue life compared to 815 °C 2020 h tests.

• The absence of carbide make GBs weak; layer removal tests establish that GB strength is important to crack initiation mechanism.

Linking existing microstructure to fatigue response

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• Sligh exposures

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Aggressive exposures were found to degrade grain boundary strength well beyond the resulting surface damage. It is known that segregation of O or Al can cause weak grain boundaries in similar nickel base superalloys [6], and it is hypothesized that long-range GB diffusion of these light species caused embrittlement. Precise measurement with atom probe tomography showed equivalent B, C, P and O chemistries for bimodal distribution. It is known that segregation of O or Al can cause weak grain boundaries in similar nickel base superalloys [6], and it is hypothesized that long-range GB diffusion of these light species caused embrittlement. Precise measurement with atom probe tomography showed equivalent B, C, P and O chemistries for bimodal distribution.

Summary

Static loading at optimal service temperatures over extended periods was mapped for superalloys ME3 from 704 °C to 815 °C.

• Cross-section evaluation uncovered complex near-surface damage, including extensive GB carbide dissolution.

• Fatigue debit reductions showed a power law correlation with total damage depth, that decay as (TDO) and by substitution, (time) 3.

• Fatigue debit is independent of temperature and is caused by environmental surface damage from air exposure not overaging, while for specimens removal past carbide dissolution layer led to full recovery in fatigue life for aggressive prior exposures.

• For slight exposures, specimens failed from single surface cracks that initiated and propagated transgranularly, as exposures became more aggressive, multiple cracks initiated in surface oxide and propagated intergranularly for distances well beyond the total damage depth.

References:

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