CONTRIBUTIONS OF OXIDATION AND CREEP TO HIGH TEMPERATURE FATIGUE CRACK SUSCEPTIBILITY IN WASPALOY

Alex Jennion[1]*, Zach Harris[1], David Mills[2], and James Burns[1]

[1]*University of Virginia, Charlottesville, VA, USA*
[2]*Rolls-Royce, Indianapolis, IN, USA*
** Presenting Author email: amj3rq@virginia.edu*

Abstract

The aggressive mechanical and environmental conditions in the hot sections of jet engines leads to creep and oxidation enhanced fatigue damage on high-performance metal components. Understanding the relative contribution of oxidation, cyclic damage accumulation, and creep is needed. Crack growth kinetics data were gathered on SENT fracture mechanics specimens using the direct current potential drop method. Specimens were tested in lab air and vacuum at elevated temperature at a constant ΔK and loaded according to a trapezoidal waveform with dwells ranging from 1 to 300 seconds. A grain-to-grain analysis for each dwell time and temperature was performed by assessing the plastic damage and dislocation cell structure of [100], [110] and [111] grains along the crack wake using high resolution electron backscatter diffraction and TEM. An approach for decoupling creep, fatigue, and oxidation damage mechanisms, in the context of understanding and modeling high temperature fatigue, was developed using fractography and quantitative comparisons of crack growth kinetics for each test condition.

1. Introduction

Operating turbine engines as higher temperatures increase the engine efficiency, however, increasing the operating temperature accelerates fatigue crack growth. This is further exacerbated by applying dwell fatigue, resulting in a large increase in crack growth kinetics. In some cases, increasing temperature under dwell fatigue can cause a significant decrease in growth rate, making fatigue life predictions difficult. Understanding which damage mechanisms are active and how damage evolves at a crack tip is critical for improving fatigue life predictions as well as future alloy design. High temperature dwell fatigue has three operative mechanisms; fatigue, creep and oxidation, however, the relative contribution of these mechanisms is not well understood. A comprehensive dataset that systematically probes different stress intensity ranges, temperatures and dwell times is required to decouple each of these mechanisms. By determining under which loading conditions and environments each mechanism is active, better fatigue life predictions can be made that take into account the appropriate damage mechanism. The work presented here probes dwell fatigue crack growth rates as a function ΔK, dwell time, temperature, and environment (lab air and vacuum) and assesses the plastic damage at the crack tip and along the crack wake for each combination of these variables.

2. Methods

Dwell fatigue experiments were conducted on Waspaloy single edge notch tensile (SEN(T)) fracture specimens with gage sections 13.71 mm in width (W) and 4.99 mm in thickness (B). An initial 3962 ± 10 μm long and 90 μm tall notch was placed in the center of the gage length using wire EDM with a 75 μm diameter wire. Testing was done using dcPD active crack length feedback coupled with software controlled applied load allowed each experiment to be run under a constant ΔK. Trapezoidal waveforms of the form 1-1-X-1 were used to produce dwell fatigue conditions. Holds at peak loads were held for the different times (1, 30, 60, 120, and 300 seconds). Each specimen was fatigued using each dwell time for approximately 750 μm, with approximately 200 μm of cracking at 1 Hz between each different dwell time. This protocol was performed at a constant ΔK (where ΔK = 30, 40, 50 or 60 MPa √m) with R = 0.1 in 550 and 700 °C lab air environments. The experiments were interrupted after a K_{max} hold to preserve an intact crack tip for characterization. SEM in conjunction with EBSD was used to perform fractography on cross sections of each specimen to determine fracture morphology under each condition. CBS imaging was performed using with an accelerating voltage of 20 keV and spot size 4. EBSD was performed using a with an accelerating voltage of 20 keV and a beam current of 3.2 nA. EBSD was done at 250x and 800x with

500 and 150 nm step sizes respectively, 2x2 binning, and 10 µs exposure times. The patterns were collected using Oxford Aztec software and inverse pole figure (IPF), kernel average misorientation (KAM) and geometrically necessary dislocation (GND) density maps were produced using the MTEX matlab toolkit.

3. Results

1. Fatigue crack growth data shows a dependence of da/dN on dwell time, consistent with observations in literature
2. Effect of dwell time is much more pronounced at 700 ^{o}C than 550 ^{o}C
3. Effect of dwell time is consistent across each ΔK
4. Initial analysis of the crack wake using EBSD and calculating geometrically necessary dislocation density shows no significant differences in plastic damage between each dwell time at 700 ^{o}C and ΔK = 60 MPa √m

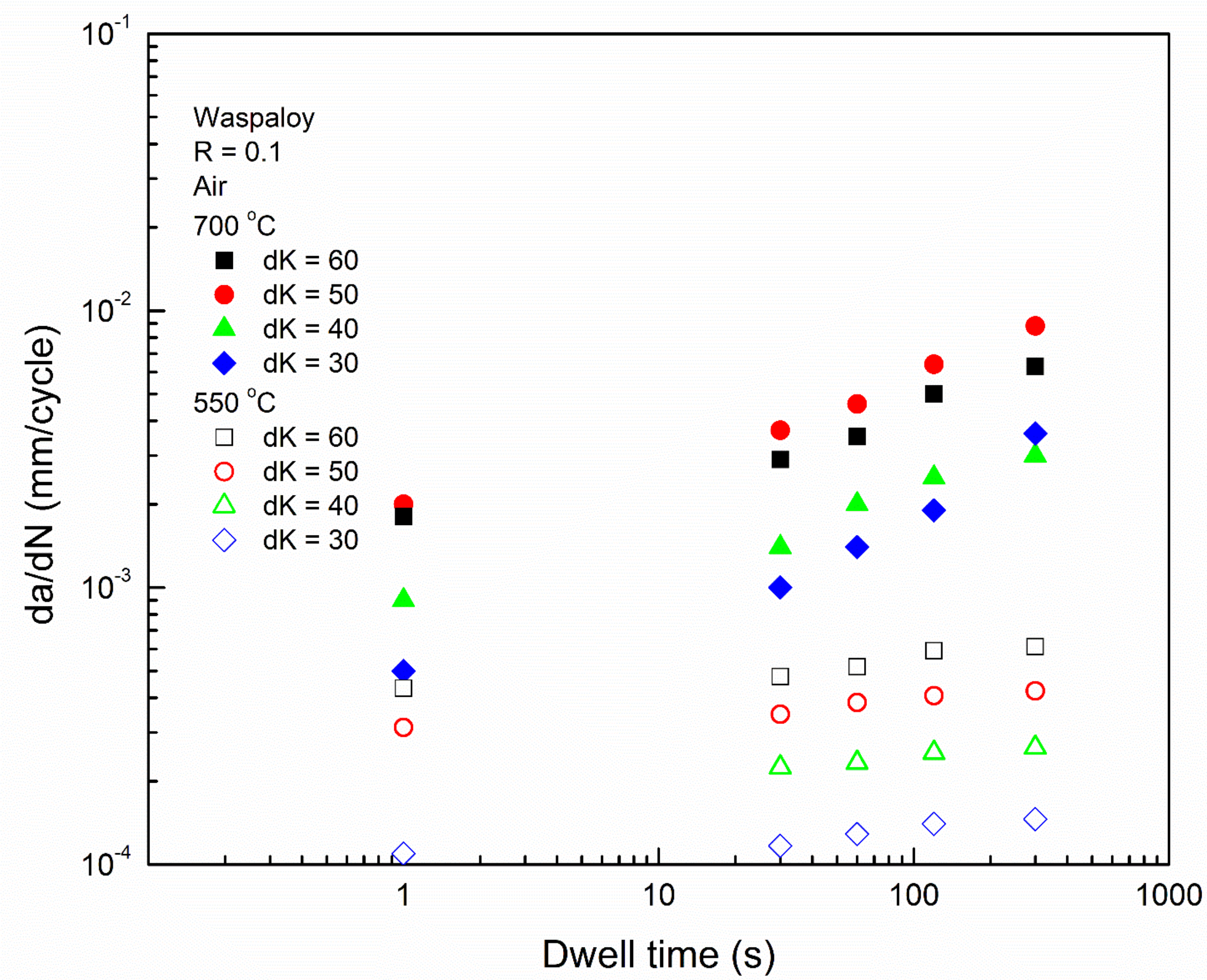

Fig.1 – FCGR behavior of Waspaloy in lab air at 700 and 550 ^{o}C for a range of dwell times and ΔK.

4. Conclusions

The presented lab air dwell fatigue da/dn data in conjunction with vacuum data under the same loading conditions and characterization of the crack wake and crack tip will provide the necessary dataset for improving high temperature dwell fatigue life predictions and inform future alloy design.