

Influence of overloads on dwell time fatigue crack growth in Inconel 718



Jonas Saarimäki ^{a,*}, Johan Moverare ^{a,b}, Robert Eriksson ^a, Sten Johansson ^a

^a Division of Engineering Materials, Department of Management and Engineering, Linköping University, SE-58183 Linköping, Sweden

^b Siemens Industrial Turbomachinery AB, Materials Technology, SE-61283 Finspång, Sweden

ARTICLE INFO

Article history:

Received 14 January 2014

Received in revised form

3 June 2014

Accepted 18 June 2014

Available online 27 June 2014

Keywords:

Nickel based superalloys

Fatigue

Fracture

Mechanical characterization

Electron microscopy

ABSTRACT

Inconel 718 is one of the most commonly used superalloys for high temperature applications in gasturbines and aeroengines and is for example used for components such as turbine discs. Turbine discs can be subjected to temperatures up to $\sim 700^\circ\text{C}$ towards the outer radius of the disc. During service, the discs might start to develop cracks due to fatigue and long dwell times. Additionally, temperature variations during use can lead to large thermal transients during start-up and shutdown which can lead to overload peaks in the normal dwell time cycle. In this study, tests at 550°C with an overload prior to the start of each dwell time, have been performed. The aim of the investigation was to get a better understanding of the effects of overloads on the microstructure and crack mechanisms. The microstructure was studied using electron channelling contrast imaging (ECCI). The image analysis toolbox in Matlab was used on cross sections of the cracks to quantify: crack length, branch length, and the number of branches in each crack. It was found that the amount of crack branching increases with an increasing overload and that the branch length decreases with an increasing overload. When the higher overloads were applied, the dwell time effect was almost cancelled out. There is a strong tendency for an increased roughness of the crack path with an increasing crack growth rate.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

In gas turbine development, engineers and manufacturers strive to optimize performance and efficiency. This is achieved through the use of superalloys, which enable high operating temperatures which can result in better efficiency.

Inconel 718 belongs to the more commonly used superalloys and is a polycrystalline Ni–Fe-base superalloy. Inconel 718 derives its strength from solid solution alloying elements and, more so, from gamma prime (γ') and gamma double prime (γ''), precipitates. Other beneficial properties are good corrosion resistance and weldability.

The alloy is frequently used for high temperature components subjected to cyclic loading, particularly when there is a risk for fatigue and creep deformation, such as turbine discs for land based gas turbine engines. Turbine discs can be subjected to temperatures up to $\sim 550^\circ\text{C}$ in land-based gas turbines and up to $\sim 700^\circ\text{C}$ in jet engines at which the mechanical properties start to degrade [1].

Aircraft turbine engines can be exposed to overloads caused by unusual service conditions, e.g. harsh weather, turbulence or

rough landings; whilst land-based gas turbines may be exposed to overloads initiated by the malfunctioning of other components that lead to unexpected stops. Primary overloads can also occur on a more regular basis, these are ordinarily detected in gas turbine components due to strong thermal transients during turbine start-up. Aircraft turbine engines, on the other hand, are pushed to their limits for shorter periods of time during take-off and landing while, at cruising speed, the loading is considerably lower.

The turbine is subjected to several different damage and fracture modes such as fatigue, creep, and oxidation. These fracture modes can be tested with different cycles that are often simplified in lab-tests when used for life assessment. One of these cycle types is the overload dwell time cycle [2], which is the focus of this paper.

Previous studies [3–5] have shown that Inconel 718 mainly cracks transgranularly during cyclic testing in the lower temperature range and intergranularly during fatigue at higher temperatures and with dwell times. The same behaviour has been observed in other superalloys such as Waspalloy [6]. Grain boundary embrittlement has been studied by Ref. [6–8] where it was shown that the crack growth per cycle during unloading–reloading is much higher after a dwell time period compared to pure cyclic loading. Similar observations have been reported to occur during thermomechanical fatigue crack growth tests [9].

* Corresponding author. Tel.: +46 13 28 11 93.

E-mail address: jonas.saarimaki@liu.se (J. Saarimäki).

Other crack growth mechanisms, such as dynamic recrystallization, strain localization in persistent slip bands, deformation bands, and vacancy diffusion, have also been proposed in references [10–14]. The purpose of this study is to examine the effects of dwell times and overloads on the crack growth mechanisms in Inconel 718. This is important and needed to enable more reliable fatigue life calculations for structures subjected to complex loadings.

2. Experimental procedure

The material used in this study was standard heat-treated Inconel 718 according to AMS 5663; solution annealing for 1 h at 945 °C, followed by ageing for 8 h at 718 °C and 8 h at 621 °C. It had a chemical composition as shown in Table 1 and an average grain size of 10 µm.

2.1. Fatigue testing

2.1.1. Specimens

Fig. 2 shows an instrumented Kb-type test specimen that was used for all tests with a rectangular cross-section of 4.3×10.2 mm and an electro-discharge machined starter notch measuring: depth 0.075 mm, width 0.15 mm, and length 0.3 mm. One specimen was used for each test condition.

2.1.2. Experimental details

A fatigue pre-crack was propagated at room temperature by using a load ratio of $R = \sigma_{\min}/\sigma_{\text{dwell}} = 0.05$, and a cyclic frequency of 10 Hz which resulted in a semi-circular crack with a depth of approximately 0.2 mm before the high temperature was applied and cycling was started. After which, the specimens were subjected to: (1) pure fatigue at 0.5 Hz, (2) fatigue with a high-temperature dwell time and (3) fatigue with a high-temperature dwell time and overloads. The overload was always applied before the dwell time part of each cycle as illustrated in Fig. 1. The overload level, OL, was calculated as

$$OL = \frac{\Delta P_{\text{unloading}}}{P_{\text{dwell}}} \quad (1)$$

with $\Delta P_{\text{unloading}}$ and P_{dwell} defined in Fig. 1.

All overload tests were done in laboratory air at 550 °C with overloads of 2.5%, 5.0%, and 15% followed by a 2160 s dwell time using Kb-type specimens with a semi-circular crack.

Crack growth was measured according to ASTM E 647 using a 12 A channel pulsed DCPD (Direct Current Potential Drop) system. Crack length was calculated by dividing the potential drop (PD) over the crack by the PD on the opposite side as a reference. This ratio was then converted to crack length assuming a semi-circular crack front via an experimentally acquired calibration curve for Inconel 718 which showed the PD ratio as a function of crack length based on the initial and final crack lengths measured on the fracture surface as well as by measured induced beach marks [15]. The analytical solution for the stress intensity factor, K , was obtained using a pre-solved case for a semi-elliptic surface crack according to ASTM E740-03. When a crack length of 2.5 mm was reached, according to the PD value, the test was interrupted.

Testing was done using a 160 kN MTS servo hydraulic tensile/compression testing machine, equipped with a three zone high temperature furnace. The nominal load during the dwell time was $\sigma_{\text{dwell}} = 650$ MPa and all tests were conducted with the load ratio $R = 0.05$, as given by the following equation:

$$R = \sigma_{\min}/\sigma_{\text{dwell}} = 0.05. \quad (2)$$

2.2. Microscopy and image analysis

After fatigue testing, some specimens were cross-sectioned and mounted as-is, so that the crack path could be studied, while others were tensiled until fracture and used for studying the fracture surfaces. The cross-sectioned specimens were cut roughly at the centre line of the semicircular crack. A Hitachi SU70 FEG analytical scanning electron microscope (SEM), operating at 1.5–20 kV, was used together with Electron Channelling Contrast Imaging (ECCI) [16] to get high quality, high contrast pictures of the crack growth appearance and the microstructure.

On the cross-sectioned specimens, the crack path was identified through image analysis and characterized by a number of parameters such as crack path length, mean crack branch length and number of branches; when necessary (i.e. for crack path length and number of branches), the parameters were normalized by the horizontal crack path length to enable comparison of cracks of different lengths. Some measurements were performed without including crack branches, here referred to as the *main crack*.

In addition, the crack roughness (an R_a -like value), C_R , was calculated for each crack, quantifying the roughness of each crack where high C_R indicated a rough crack path. A reference line was fitted to the crack and the crack path was then described by its distance from the mean line, $z(x)$, see Fig. 3. C_R was calculated as

$$C_R = \frac{1}{L} \int_0^L |z(x)| dx \quad (3)$$

where L is the projected crack path length.

The C_R was calculated for an unmodified crack path and, as is common for R_a , filtered crack paths. The filtering was conducted using a Gaussian high-pass filter which passes wavelengths shorter than the cut-off wavelength, λ_{co} . Several different λ_{co} were tried. Fig. 3 shows an example for $\lambda_{co} = 100$ µm where Fig. 3(a)

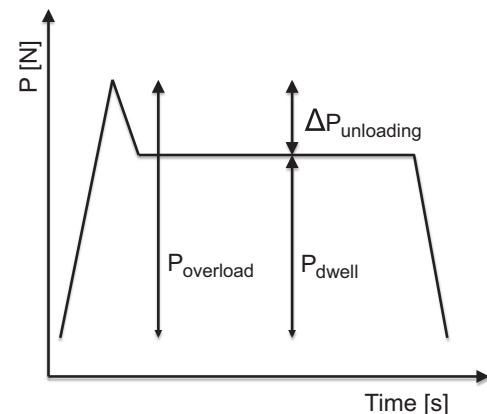


Fig. 1. The overload cycle.

Table 1
Composition of elements for Inconel 718.

Alloy	Wt%	Ni	Cr	Fe	Mo	Nb	Co	C	Mn	Si	S	Cu	Al	Ti
Inconel 718	Min.	50	17	Balance	2.8	4.75							0.2	0.7
	Max.	55	21		3.3	5.5	1	0.08	0.35	0.35	0.01	0.3	0.8	1.15

Download English Version:

<https://daneshyari.com/en/article/7980899>

Download Persian Version:

<https://daneshyari.com/article/7980899>

[Daneshyari.com](https://daneshyari.com)