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Influence of the different salt deposits on the fatigue behavior of a directionally solidified nickel-based superalloy

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ABSTRACT

The influence of hot corrosion on the fatigue behavior of a directionally solidified nickel-based superalloy DZ125 was investigated at 850 °C in air using bare and salt-coated specimens with different amount of salt deposit. Experimental results showed that the fatigue life of salt-coated specimen decreased compared with that of the bare specimen, and this decreasing trend accelerated with increased salt-deposit amount. The hot-corrosion-induced damage to fatigue life was found to be associated with decreased net area and early crack initiation from the surface corrosion layer. Fracture surfaces of the specimens were examined to reveal the characteristics of fatigue-crack initiation.

1. Introduction

Nickel-based superalloys are used for high-performance components of turbine blades in aircraft and power engines because of their excellent properties at elevated temperatures. Combined corrosion and oxidation resistance, good mechanical performance, and microstructure stability at high temperatures [1] are among the desirable attributes of these superalloys [1,2]. In marine environments, salt from seawater, in combination with sulfur, vanadium, and other alkali metals present in the fuel, melt under the engine operating temperature, and induce hot corrosion of engine components [3–6]. Hot corrosion refers to the accelerated oxidation of materials at elevated temperatures induced by the fused salt deposit [7,8]. This process can be classified into two types: low-temperature hot corrosion (LTHC), which takes place at 600–750 °C; and high-temperature hot corrosion (HTHC), which occurs between 800 and 950 °C [9,10]. At high temperatures, the problem of hot corrosion does not occur because of salt evaporation. HTHC mainly occurs in turbine blades of modern gas turbine engines. Thus, the present study focuses exclusively on HTHC. Engines are exposed to extremely high temperatures and marine environment, which results in significant material degradation at a much faster rate because of hot corrosion, and consequently, to catastrophic failure during service [11–14]. Therefore, the performance of the superalloys in such a corrosive environment under concurrent fatigue load has gained attention.

To date, few efforts have been exerted to investigate the effects of HTHC on the mechanical properties of nickel-based superalloys [5,6,15–17]. Related studies have evaluated the effect of hot corrosion on fatigue behavior of superalloys by depositing salt mixture on fatigue test specimens. Significant reduction in fatigue life was observed for the salt-coated specimens compared with the bare specimens. In addition, some studies explored the effect of LTHC on fatigue [18–20], but their findings are not relevant to the scope of the present study. The effect of hot corrosion on fatigue life may be associated with many factors such as temperature [19], loading rate [16,17], and applied load magnitude (stresses or strains) [5,6,18,19]. Besides, increase in thickness of salt coating was observed to enhance the rate of hot corrosion [21]. However, only a few works were conducted to determine the effect of different amounts of salt coatings on fatigue life.

In this study, the effect of different salt deposits on the fatigue behavior of a directionally solidified (DS) superalloy DZ125 was investigated at 850 °C. This study aimed to (1) investigate the fatigue life difference between DZ125 bare and salt-coated specimens with different amounts of salt deposit and (2) understand the fracture behavior of both DZ125 bare and salt-coated specimens.

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2. Experimental

2.1. Materials and specimen preparation

The DS Ni-based superalloy DZ125 was subjected to standard treatments before use. The aging heat treatment conditions and steps are as follows: 1180 °C for 2 h, 1230 °C for 3 h followed by air cooling (AC), 1100 °C for 4 h followed by AC, 870 °C for 20 h followed by AC. The chemical compositions (in wt.%) of the superalloy are given in Table 1.

For the fatigue test, standard rod specimens with a single orientation [001] were machined. The specimen illustration for the fatigue test is shown in Fig. 1. In the present paper, the specimen preparation and test procedure were carried out based on the ASTM and ISO standards [22,23]. All of the specimens were polished using 400, 800, and 1200 grit SiC sandpaper before testing to exclude the surface machining defects.

In the present study, a salt mixture consisting of 75% Na_2SO_4 and 25% NaCl was uniformly deposited on fatigue test specimens to simulate a hot corrosion environment because DZ125 superalloy suffers from severe corrosion of deposited Na_2SO_4 with NaCl during operation over seawater. Three coatings of different amounts of salts (2, 5, and 10 mg/cm^2) were applied for the evaluation of the effect of salt-deposit amount on fatigue behavior.

2.2. Fatigue tests

High-temperature fatigue testing were conducted by the load-control mode using a 100 kN servo-hydraulic Material Testing System (MTS 810). Triangular waveforms were generated for different σ_{max} values at 400 MPa/s constant stress rate to control the fatigue tests. The test matrix is shown in Table 2. The external thermocouples were attached in the vicinity of the specimen for continuous temperature measurement during the progress of the test, as shown in Fig. 2. The fatigue tests were conducted at 850 °C for all of the σ_{max} values on bare and salt-coated specimens. The temperature variation was kept below 2 °C within a gauge section. Strain measurement was accomplished by means of a high temperature extensometer mounted in gauge section of the specimen. The gauge length of the high temperature extensometer used in the fatigue tests was 20 mm and had a travel of ±10%. The fatigue life was determined by the number of loading cycles to failure for the specimens. The average values of 4 specimens in each condition have been used as a data point.

Table 1
Nominal chemical compositions of the DS Ni-based superalloy (wt.%).

Ni	C	Cr	Co	W	Mo	Al	Ti	Ta	Hf	B
Bal	0.1	8.90	10	7	2	5.20	0.9	3.8	1.5	0.015

Table 2
Load-controlled LCF test matrix of the DS Ni-based superalloy ($R = 0$).

Salt amount/mg/cm^2	Temperature/°C	σ_{max}/MPa	Stress rate/MPa/s
0	850	680	400
2	850	680	400
5	850	680	400
10	850	680	400

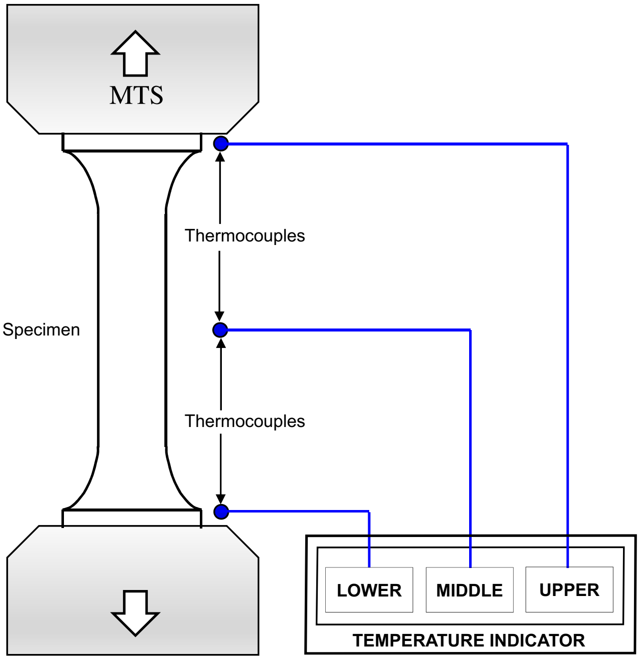

Fig. 2. Schematic illustration of the locations of thermocouples.

2.3. Measurements and observations

The cross-sectional morphologies and fracture surfaces of all specimens were characterized by scanning electron microscopic (SEM; JEOL JSM-6010), and electron probe micro-analysis (EPMA; JEOL JXA-8100).

3. Result and discussion

3.1. Influence of HTHC on microstructure

The most conspicuous effects of HTHC on the specimens at high temperature conditions can be categorized as those affecting either the surface or the subsurface of the microstructure. Fig. 3 shows the SEM high magnification view of the surface of salt-coated specimen at 5 mg/cm^2. When the superalloys are exposed to 850 °C in

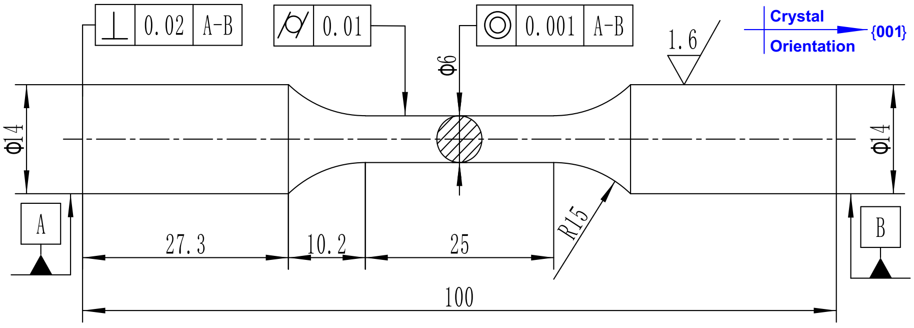

Fig. 1. Shape and dimensions of the specimen for the LCF tests (all dimensions in mm).