Engineering Failure Analysis 68 (2016) 197–209

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Short communication

Investigation of Intergranular Corrosion in 2nd stage gas turbine blades of an aircraft engine

Zubair Khan [a,*], Samia Fida [a], Fateeha Nisar [b], Noman Alam [c]

[a] Mechanical Engineering Department, Institute of Space technology
[b] Material Science and Engineering Department:Institute of Space technology
[c] Mechanical Engineering Department, UET lahore

ARTICLE INFO

Article history:
Received 18 February 2015
Received in revised form 19 May 2016
Accepted 22 May 2016
Available online 25 May 2016

Abbreviations:
IGC
Topic:
Intergranular Corrosion
GBs
Topic:
grain boundaries
ET
Topic:
Eddy Current Testing
SEM
Topic:
Scanning Electron Microscopy
Cr
Topic:
chromium
Mo
Topic:
molybdenum
ppt
Topic:
precipitates

Keywords:
Intergranular Corrosion (IGC)
Gas turbine blades
Grain boundaries
Udimet 500

ABSTRACT

Intergranular corrosion is one of the decisive tools for the life of turbine blade for its continuous use. The study was to ascertain the occurrence of Intergranular Corrosion (IGC) in the turbine blades of an aircraft. For this purpose 2nd stage turbine blades made up of Nickel Based Superalloy Udimet 500 were used to find out attack of IGC in the top & middle portion of blades as the same was detected during Eddy Current Testing. The turbine blades having different flying hours (700, 1700 & 2700) were selected for specimen while simulating actual conditions which the turbine blades encounter during flight & maintenance/overhaul. High temperature exposure (at 900°C for 1min & 950°C for 1min) and alkaline media exposure (at normal and aggressive condition) were introduced to find out the damaging results. It was found that Cr carbide is precipitated at GBs on exposure to 900°C and an excessive Cr carbide precipitation at GBs on exposure to 950°C due to Intergranular Corrosion. On exposure to alkaline media, pitting was observed within grains and at grain boundaries on the specimen of blades.

Abbreviations: IGCIntergranular Corrosion; GBsgrain boundaries; ETEddy Current Testing; SEMScanning Electron Microscopy; Crchromium; Momolybdenum; pptprecipitates

* Corresponding author at: Department of Mechanical Engineering, Institute of Space Technology, Islamabad, Pakistan.
E-mail address: zubair_kj@yahoo.com (Z. Khan).

http://dx.doi.org/10.1016/j.engfailanal.2016.05.033
1350-6307/

1. Introduction

The super alloys are frequently used in aerospace and power industry because of their high mechanical strength, resistance to creep and corrosion at high temperatures [1]. Universally used super alloys include iron-based, cobalt-based and nickel based alloys which can be strengthened by precipitation hardening, work hardening and solid-solution hardening techniques. Udimet 500 super alloy is a nickel-chromium-cobalt alloy. Nickel-based super alloys form almost 40–50% of an aircraft engine and are widely used in gas turbine and combustor sections, which encounter elevated temperatures during operation [2]. It can be age-hardened for high temperature strength, high temperature creep resistance, fatigue life, phases stability, oxidation and corrosion resistance which are the basic requirements of gas turbines. In Udimet 500 the basic strengthening mechanism is achieved by the fine precipitation of gamma prime (γ') particles. As the temperature increase with time it is observed the γ' particles start getting coarse. Noveed Ejaz et al. [3] studied Udimet 500 alloy subjected to 850–1000 °C for almost 25–100 h in air. This study was done to characterize the changes that occur due to increase in the size of γ' precipitates with high temperature exposure. Size changes of γ' from 0.1 μm to 1 μm were identified by using scanning electron microscopy. Degradation of the carbides in super alloys of Ni-Cr-Co was another factor observed at high temperature.

At temperatures ≥1000 °C prominent changes occur at the near surface i.e. de-alloying, formation of needle like Ti-rich precipitates and reduction of γ' were observed and all these changes lead to speeded corrosion of alloy. In order to understand the effect of heat treatment and formation of different phases, the microstructure of cobalt-rich nickel based super alloys samples were observed using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The alloy was annealed at 1150 °C and then oil quenched followed by two intermediate heat treatments: (i) aging at 843 °C for 24 h, (ii) aging at 703 °C for 20 h. Mohamed Retima et al. [4] suggested the presence of high quantity of γ' particles in γ matrix. It was observed that the precipitation of primary carbides during heat treatment and large precipitation of secondary carbides at grain boundaries occur as a result of intermediate treatment. N·Lambert et al. [5] studied the various heat treated microstructures of Udimet 500 superalloy by using three different techniques that are optical microscopy, transmission electron microscopy and electron diffraction. Alloy was exposed to short-time aging after different solution treatments. After the 3–4 stage heat treatments they observed both stressed and unstressed conditions for almost 10,000 h at various temperatures. Analysis showed that γ' particle size depends only on two parameters that are the temperature and the rupture time. The carbide reactions on the other hand were largely effected by stress conditions.

In another study done by Z. Mazur et al. [6] the failure analysis of the third stage buckets of gas turbine made up of Udimet 500 super alloy was done. Bucket of the gas turbine undergo repetitive tip shroud fractures aided by hot corrosion at low temperature. The bucket damage identified by author was the increased stresses because of the thinning of tip shroud by corrosion. Other reasons include evidence of the transgranular origination and intergranular creep mechanism that spread on the metallic structure. Recently research has been carried out to find out the new methods for evaluating the microstructures of alloys. Michael [7] investigated the presence of intergranular corrosion in Ni-based super alloys by using Focused Ion Beam (FIB) imaging. He suggested that the technique is very useful in identifying the grain boundary corrosion, as secondary ion yield from the metallic samples can be enhanced in the presence of oxygen. The increased oxygen yield helps FIB in rapid detection of grain boundary corrosion up to few tens of nanometers thickness. This study focuses on the Udimet 500 super alloys that undergo intergranular corrosion during operating and maintenance conditions. These conditions are simulated by subjecting specimens to high temperature (900 °C and 950 °C) and to alkaline environment (normal and aggressive conditions).

2. Experimental procedure

The main objective of the study was to characterize Intergranular Corrosion (IGC), to find out its causes, to evaluate its effects and then suggest suitable remedial measures. The following tests were conducted for Failure investigation on turbine blades samples:

i. Eddy Current Testing & Replica Metallography
ii. Energy Dispersive X-ray spectroscopy.

In addition to above mentioned tests, operational conditions were simulated, which the turbine blades encounter during actual flight & during maintenance/overhaul. These are as follows:

i. High temperature exposure (at 900 °C for 1 min & 950 °C for 1 min)
ii. Alkaline media exposure (at normal and aggressive condition)

Three different types of turbine blades having different flying hours (700, 1700 & 2700) were chosen. After each set of exposure, micro structural examination and EDS analysis were performed on Scanning Electron Microscope with attached EDX spectrometer to study & compare the changes in composition and structure.

2.1. Eddy Current Testing (ET)

Eddy Current Testing is done to find out the areas affected by the corrosion. Each of the specimens was subjected to Eddy Current Testing. Fractography of Eddy current tested turbine blades showed that inter-granular corrosion (IGC) occurs mostly in the top & middle portion of the blades as it can be seen in Fig. 1(a, b, c). No corrosion was observed in the bottom portion near root of