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Failure analysis of gas turbine first stage blade made of nickel-based superalloy

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ABSTRACT

Various degradation mechanisms are characterized in gas turbine rotor blades due to service conditions such as: high temperature and stress. Failure of turbine blade can have the tremendous effects on the safety and performance of the gas turbine engine. This paper investigates a first stage turbine blade failure in a 6.5 MW gas turbine. The blade is made of nickel-based superalloy, and the failure occurred in the airfoils after 6500 h of operation. Several examinations were carried out in order to identify potential failure reasons such as: visual examination, fractography and microstructural characterization used by optical and scanning electron microscopes (SEM) and energy dispersive X-ray (EDX). The precipitated phases morphology (carbides and γ′ (Ni3Al)) changed in the airfoil for example γ′ resolved and re-deposited in addition to decomposition of carbides. Furthermore, the fracture surface exhibits the local melting occurred and re-solidified in the leading edge. From analysis and experimental results of this study, overheating is shown to be the main reason of blade failure.

1. Introduction

Rotor blades are critical components of gas turbines in power plants. Operating conditions are such that the high temperature of the gas stream passes over blades and the complex stress is exposed to blades resulting in various degradation mechanisms. When degradation mechanisms become active in blades with time, they can reduce service life. Studies show that the most important failure mechanisms in industrial turbine blades are creep damage, fatigue, corrosion, erosion and environmental attack (oxidation, hot corrosion, erosion and foreign object damage) [1,2]. Some of these modes interrelated and can simultaneously occur. For example, cracking can occur by creep and/or fatigue mechanisms [3,4]. It is well known that creep damage can significantly reduce the fatigue strength and leads to failure of components [4].

In the event of the blade failure, the power plant shuts down, potentially leads in to prolonged outages and economic loss. When this occurs, it is necessary to conduct a detailed failure analysis of on turbine blades in order to understand the problem and improve turbine system reliability [5,6].

Over the last few decades, operating temperatures of gas turbine engines have been increased to achieve increased engine power and efficiency. For this reason gas turbine blades are made of nickel-based and cobalt-based superalloys since these materials are able to withstand the combination of high stress and high temperature [7]. Nickel-base superalloys are an unusual class of metallic materials with an exceptional combination of mechanical properties such as high temperature strength, toughness (650–1100 °C), resistance to degradation in corrosive or oxidizing environments [8].

Superalloy IN738LC is one of the most widely used nickel base superalloys utilized to manufacture rotor blades for first stage gas

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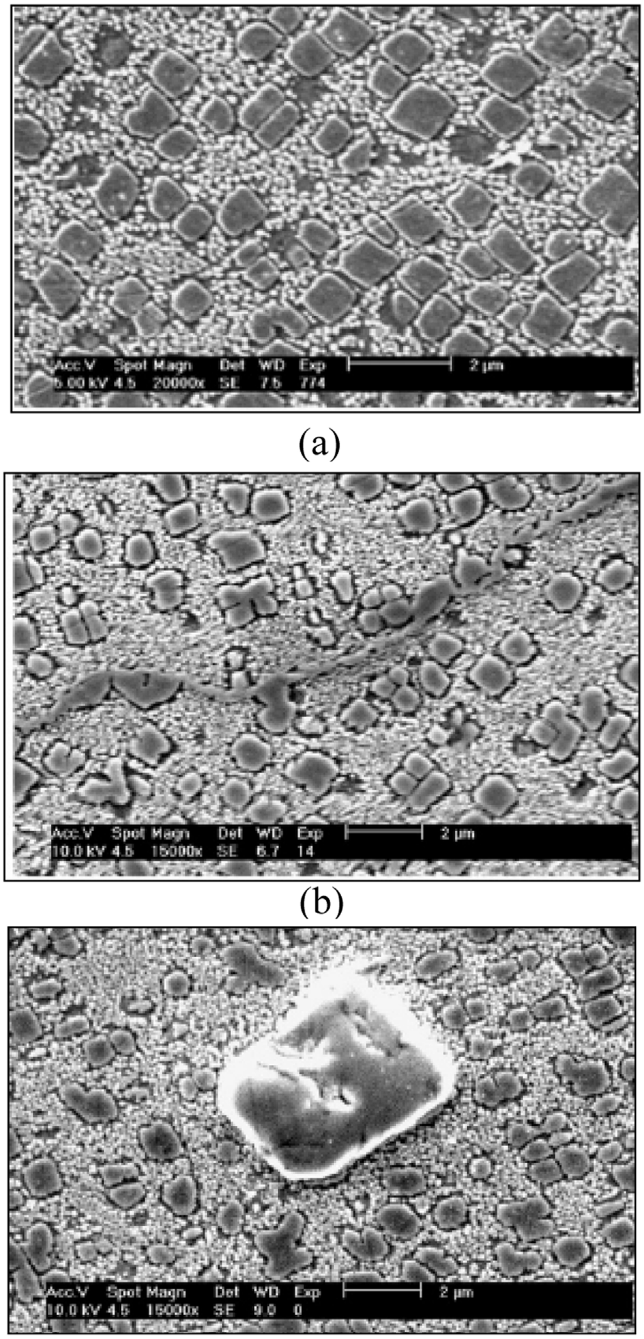

Fig. 1. The microstructure of superalloys IN738LC under standard heat treatment (a) including cubic and spherical γ′ precipitates (b) discontinuous carbides in grain boundaries (c) carbide inside grains of γ matrix of new blade [13].

turbines. It is well known that IN738LC has a multiphase microstructure and owns its high temperature strength from the precipitate of γ' intermetallic compound phase (Ni_3Al), FCC nickel base solid solution matrix, carbide phases such MC inside grain and $M_{23}C_6$ formed through grain boundary. MC carbide may include some elements such as Ti, refractory elements like W, Ta and a little Cr, Ni [8,9]. Significant amount of bulk-like MC type carbides are mainly precipitated during solidification of alloys, while the precipitate $M_{23}C_6$ in alloys are mainly deposited from the matrix along the boundaries during heat treatment and service (at 760–980 °C) [10]. This type of carbide is formed due to super-saturation of carbon in the matrix and degeneration of the MC type carbide. The equation of decomposition is as follows: