International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 4, No. 1, January 2015

Review Aticle

GAS TURBINES BLADES—A CRITICAL REVIEW OF FAILURE ON FIRST AND SECOND STAGES

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Gas turbine blades have numerous applications in the aerospace industry. In this study, the stresses and deformations of a turbine were studied. The goal was to highlight the stress and deformation distribution to assist in the design of a blades. The stresses and deformations developed as a result of the blade operating conditions at high rotational speeds and thermal gradients were evaluated using two types of heat transfer modes-conduction and convection, taking into consideration the material behavior at elevated temperatures. The greatest stresses in the blades result from the thermal load caused by conduction, and they are located between the blades and disc. In addition an analytical method was used to evaluated and predict the stresses along the blades it gave a good estimate of the stress values compared to the finite element. It is important to design for as high temperatures gas as possible in order to attain a high thermal efficiency in gas turbines. In the case of power generating gas turbines, the increase of temperature leads to lower fuel consumption, reduced pollution and thus lower costs.

Keywords: Fretting fatigue, Super alloy, Failure analysis, Elevated temperature

INTRODUCTION

Turbine components (rotor disks, blades, blade attachments) are heavy duty components which can be classified as critical components. Gas turbine blades are made of nickel-base and cobalt-base super alloys principally. During the past few decades, the operating temperatures of gas turbine engines have been on the rise to achieve higher and higher engine power and efficiency. This has necessitated a continuing advancement in the temperature withstanding capabilities of materials used in the air construction (Bhaumik and Sujata, 2006).

Gas turbine blades are critical components in power plants which in the event of their failure the power plants will shut down. This case can cause long time current failure and economic loss. Therefore, it is necessary to settle the failure analysis of turbine blades in order to

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increase the reliability of turbine systems (Wang and Xuan, 2007; and Vardar and Ekerim, 2007).

Turbine blades are susceptible to damage and crack formation in regions of component contact that experience both centrifugal and oscillatory vibrations (Garcia and Grandt, 2005). A component subjected to fatigue in the presence of mating component under a contact load experiences micro-slip along the contacting interface, and causes a significant reduction in fatigue life. This is commonly referred to as fretting fatigue that results in an increase in tensile and shear stresses. at the contact surface, which acts as a damage generator leading to crack nucleation, growth, and eventually failure faster than that under the conventional fatigue condition without fretting (plain fatigue). The reduction in life of machine components under fretting fatigue as compared to plain fatigue has been demonstrated by a number of researchers (Bhaumik and Sujata, 2006; and Wang and Xuan, 2007).

The blade/disk attachment at the firtree joint, in gas turbine engines is one of critical components which can fail due to fretting fatigue. This component is subjected to high cycle

Fatigue (HCF) condition that involves high frequencies and vibrational type loads often superimposed on a high mean stress (Garcia and Grandt, 2005; Rybnikov *et al.*, 2005; and Vardar and Ekerim, 2007).

During the fretting fatigue process, cracks will nucleate and propagate according to severe stress gradients that are generated from of the effective shape of contact, coefficient of friction, and the applied loads (Bhaumik and Sujata, 2006). These fretting cracks are initially very small, but may eventually lead to severe component damage (Garcia and Grandt, 2005).

WHAT IS FAILURE ON TURBINE BLADE

Turbine blades are subjected to very strenuous environment inside a gas turbine the phase high temperature high stresses and a potentially high vibration environment all three blades factors can lead to blades failures which can destroy the engines and turbine blades are carefully designed to resist those condition. Turbine blades are subjected to stress from centrifugal force (turbine stages can rotate at tens of thousands of revolution per minute and fluid forces that can causes failure yielding or creep failure.

CAUSES OF FAILURE

Different failures of blades made from super alloys may be observed during gas turbine plant testing and operation. The cause of these failures is usually identified both by metallographic methods (micro structural studies, fractography, X-ray crystal analyses), bench and laboratory strength tests, and by strength calculation methods, including non-conventional methods.

Long-term gas turbine operation leads to the structural degradation of super alloy blades—there is a change in a number, shape and size of ¥'-phase particles and in carbide amounts, distribution and composition. The formation of close-packed topological phases (±, «, ª-phases) can also be observed. In a number of cases, the structural degradation results in a significant change in the mechanical properties, which can cause blade failures? The present paper deals with several investigations into the causes of typical blade failures during long-term service.

Static Stress Failure of Gas Turbine Blades Made of Super Alloys

The industrial production of blades by different manufacturers may involve process violations causing a displacement of the mass centre and, as a consequence, the static failure of blades at a fairly high carrying capacity strength margin. Such blade failures were observed in aircraft, marine and stationary gas turbine plants. Thus, 13 cases of rotor blade failures were discovered in a generating gas turbine plant after operation for 1000 to 6000 h. The fractographic study revealed a static cracking mechanism initiated at blade edges. Blade strength calculations were carried out by the finite element method with regard to creep under the conditions of centrifugal forces and mass centre displacement. It was determined that, due to the stress increase at edges and the difficulties associated with stress redistribution during creep, the stresses can reach the material long-term strength values corresponding to rupture life. Another cause of static stress failure of blades is blade overheating related to the departures from normal operating conditions. Such failures are detected by metallographic methods based on metal structural variations throughout the entire blade section.

Thermal Fatigue Cracking of Rotor and Guide Blades

Thermal fatigue cracks are the characteristic type of edge failures in gas turbine cooled blades, including those manufactured from single-crystal and directional-solidified alloys. In long-term operation, such cracks also form on blades made from wrought high-temperature alloys. Based on the metallographic studies of micro-crack propagation in wrought alloys at elevated temperatures, a diagram has been developed in order to predict a type of alloy rupture depending on the temperature and frequency of cyclic loading. The diagram allows diagnostics to be made of blade damage detected in operation.

Thermal Fatigue Cracking of Rotor and Guide Blade Coatings

Coating cracking is induced by a local corrosion failure of blade base metal under the coating. A method for testing small-size coating specimens has been developed. The method makes it possible to observe strain relief characteristics during testing and to study the mechanisms of crack initiation and propagation in a coating up to specimen failure. A series of thermal fatigue tests was performed using different super alloy specimens with different coatings. The mechanisms of micro-crack initiation and suppression in multi-layer coatings have been determined.

Corrosion and Corrosion Fatigue Cracking of Rotor and Guide Blades

High-temperature sulfideoxide corrosion and high-temperature alloy surface de-alloying processes have been investigated by blade surface metallography (X-ray, EDS spectrum analysis). It has been found that after operation for 100000 h, the uncoated rotor blades made from wrought alloy EI893 experience a decrease in chromium content in a layer up to 100 μm thick. The analysis of surface layer composition in the region of cracks in blades made from high temperature alloys EI929, ZMI-3 and CNK-7 after operation for 25000 to 35000 h revealed a local increase in sulphur content related to sulfide-oxide corrosion attack (Rybnikov *et al.*, 2005).

FAILURE ANALYSIS OF FIRST AND SECOND STAGE TURBINE BLADE

First Stage

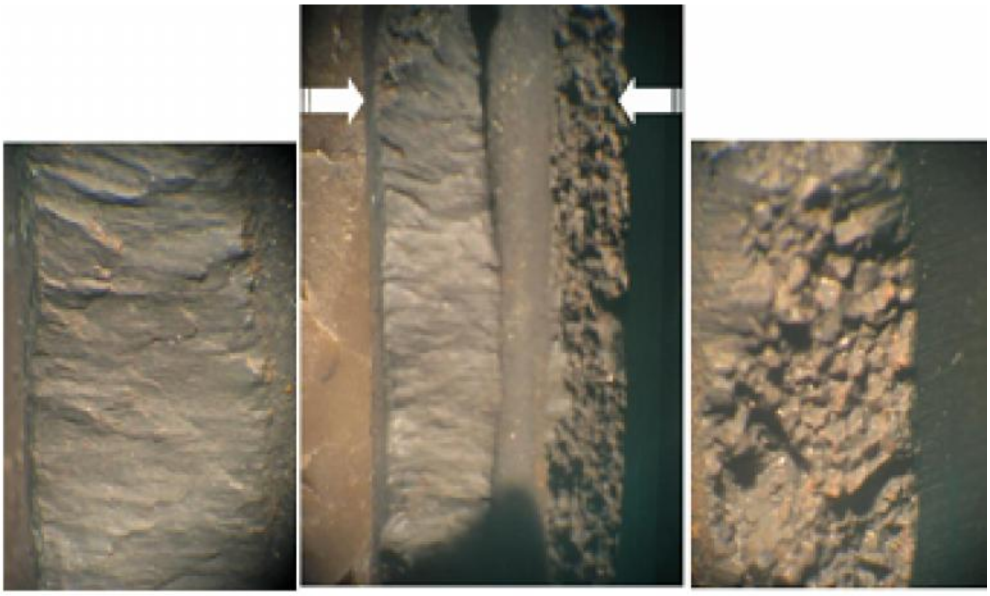
Visual observation indicates that more than 90% of the first stage blades were damaged. Most of the damages are on the tip of the leading edge and also, bulk separation is obvious in this region. There are some signs of Foreign Objects Damage (FOD) on top of the leading edge and convex side (suction side) of the airfoil. Figure 1 shows the general view of the first stage blade. Similar conditions were observed in other stages.

Fractography

Figure 2 shows the stereo micrographs of the fracture surface of a selected first stage blade. As can be seen, the fracture surface has two distinct types of flat and rough zones. There are some signs of erosion on the flat zone and brittle inter-granular fracture on the rough zone. Demonstrate the fracture surfaces in the concave (pressure) side and the cooling channel respectively. As seen in these figures, brittle inter-granular fracture is obvious near the pressure side and some surface cracks can be detected in the cooling channel surface because of exposure at high temperatures after being damaged, surface oxidation has occurred (Kazempour-Liacy *et al.*, 2011).

Figure 1: The General View of the First Stage Blade

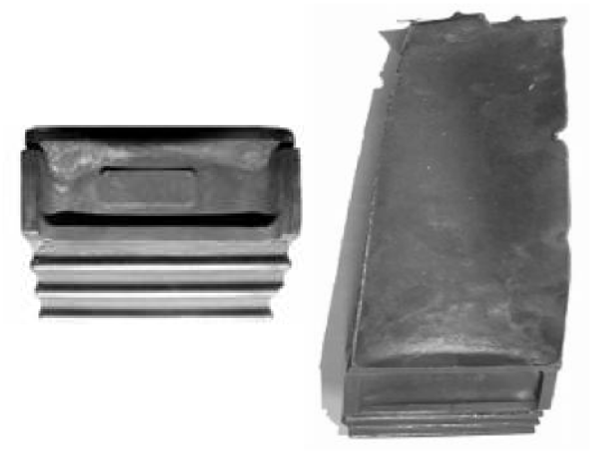
Figure 2: Stereo Microscopy of the Main Fracture Surface



Second Stage

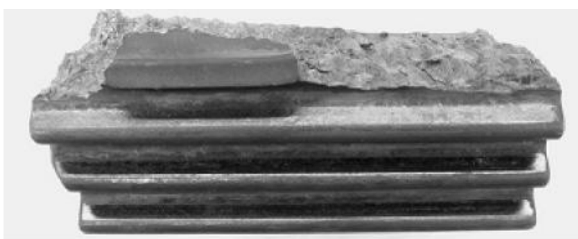
A damaged turbine blade which was retrieved from the accident site is shown in Figure. The firtree joint is also separately presented in the above mentioned figure. The remaining portion of the main fractured turbine lade under investigation which only includes the firtree root region, due to complete separation of the air foil section of the blade in the fracture process, is shown in Figure.

Figure 3: Blade Geometry and the Firtree Joint of a Damaged Turbine Blade



Following visual examination and digital camera photo documentation, portions of the fracture surface were cut for microfractographic studies by scanning electron microscope equipped with an energy dispersive spectroscopy, EDS analysis facility. The specimens were subjected to SEM examinations in the as received condition as well as following ultrasonic cleaning. All the specimens used for material characterization were prepared from locations beneath the

Figure 4: The Remaining Firtree Root Region of the Fractured Blade



fracture surface. Chemical analysis was carried out using optical emission spectroscopy method. Specimen preparation for macroscopic and microscopic metallurgical evaluations on longitudinal and transverse sections was carried out using standard metallography techniques, followed by etching the specimens with Marble reagent. Macro hardness measurements were performed using Rockwell C hardness testing method (Hassan Faranghi and Ali Asghar Fouladi Moghadam, 2007).

Fractography

The side view of the fractured blade presented in Figure 5 shows that the failure surface is located at the top firtree root.

The general orientation of the fracture surface is nearly normal to the longitudinal axis of the blade. Visual examination of the fractured blade indicates that the fracture process involved minimal gross plastic deformation with no visible sign of any change in the cross section area at the fracture location. Thus the failure of the blade can be considered as a macroscopically brittle fracture process. Macroscopic appearance of the fracture surface is shown in Figure 6. Two distinct regions denoted as A and B, which is delineated by a curved superposed boundary

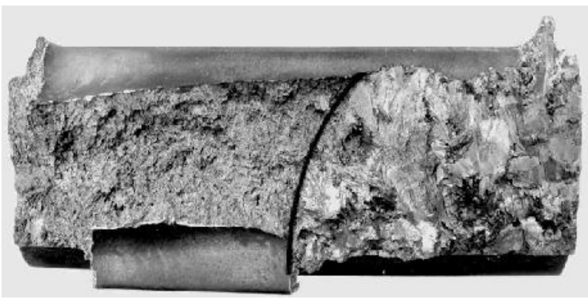


Figure 5: Fracture Surface of the Blade

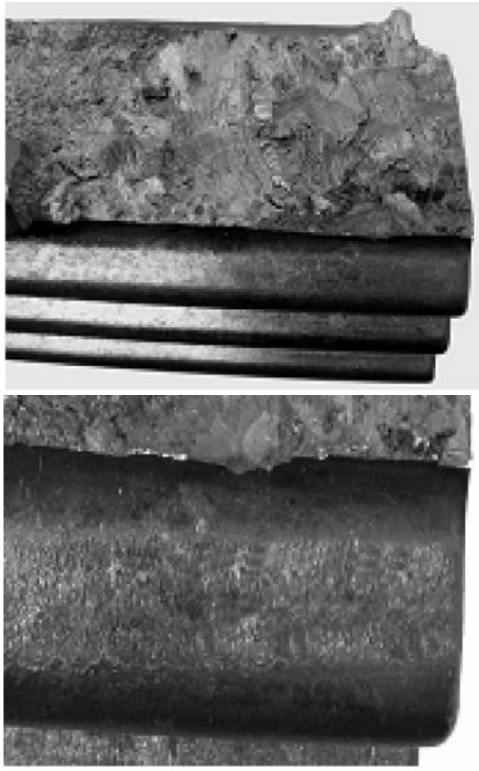


Figure 6: Magnified Views of Fatigue Facture Region and a Wear Track

(a)

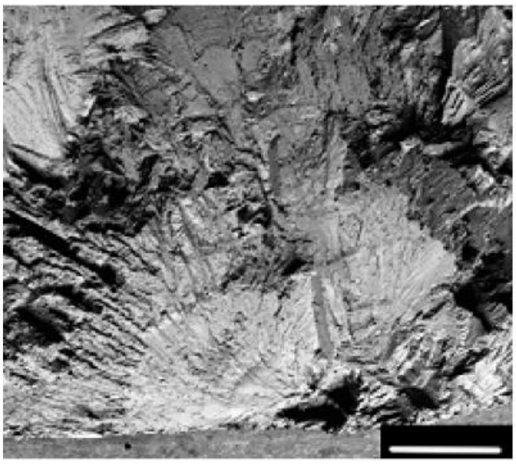
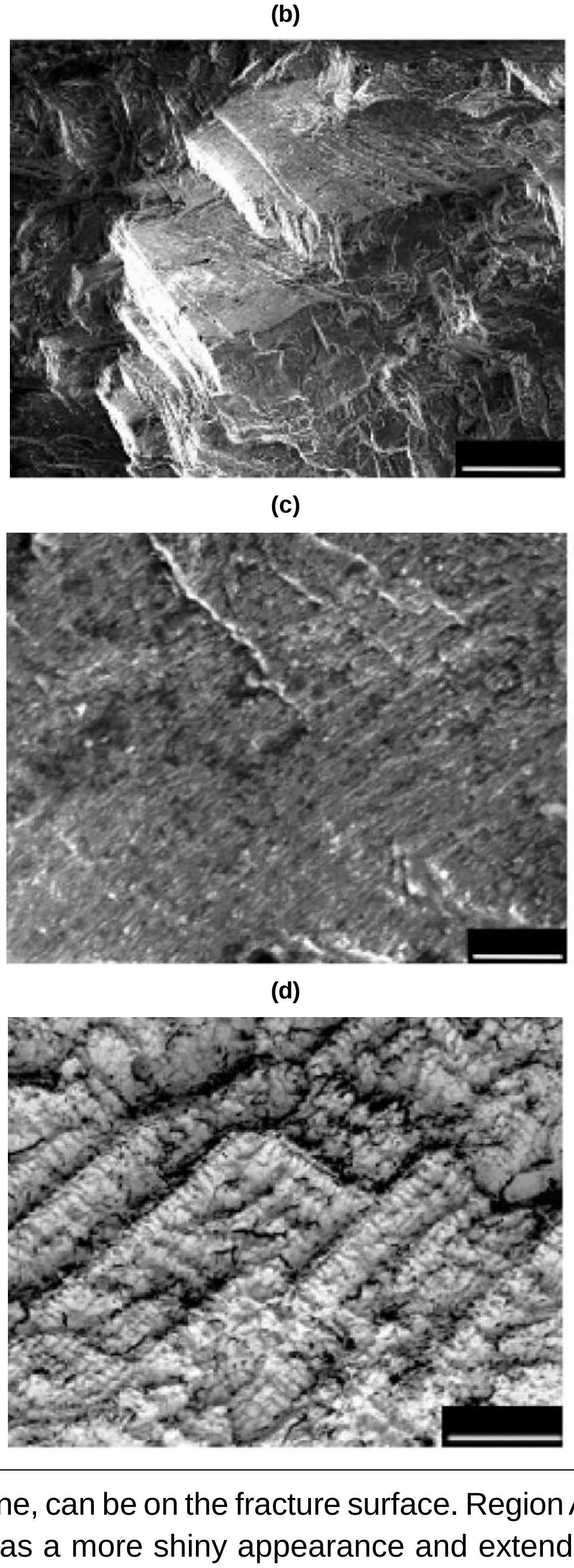


Figure 7: SEM Fractographs Showing (a) Semielliptical Crack in the Iniation Region, (b) Crystallographic Fatigue Crack Growth, (c) Characteristic Fatigue Striations, and (d) Interdendritic Fracture Morphology in the Final Fracture Region

Figure 7 (Cont.)



line, can be on the fracture surface. Region A has a more shiny appearance and extends from the boundary to the trailing edge side of the blade and covers about 40% of the fracture surface. Region B located in the opposite side extends up to the leading edge side of the blade. The fracture mechanisms in these regions are analyzed by SEM fractography.

CONCLUSION

The main reason for early and premature failure of the insert ring was due to severe service condition such as high temperature and oxidizing atmosphere of the combustion chamber near the burner that could be due to switching the gas fuel to gasoline or even inclination of the burner flam. The failure analysis was carried out on a 1 gas turbine engine Its blades were made of Nickel based superalloy to sustain high temperature conditions and other corrosive environmental conditions. The micro-structural evaluation of the blade material at three different regions (root, midspan and tip) of the blade revealed that there was no microstructural damage took place due to operation of the blades at elevated temperatures, indicating that the turbine blades were operated in designed/ normal operating temperature condition. Finally, it was concluded that the turbine blade failure of gas turbine used for marine application thickness decreased the fatigue strength of the blade which finally led to the failure of the turbine blades was caused by multiple failure mechanisms such hot corrosion, erosion and fatigue. The hot corrosion reduced the thickness of the blade material and thus weakened the blade.

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