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Causes and Mechanisms of Cracks in Gas Turbine Blades

Zakaria Boumerzoug* and Sara Amouria

LMSM, Mechanical Engineering Department, University of Biskra, Algeria

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***Corresponding author:** Zakaria Boumerzoug, Mechanical Engineering Department, LMSM, University of Biskra, Algeria

Abstract

The aim of this study is to present the causes and mechanisms of cracks in gas turbine blades. The turbine blade chosen is manufactured from a nickel alloy. Defective blade was studied by visual observation, penetrant testing, and optical microscopy. The zone and causes, as well as the mechanism of crack development were determined.

Keywords: Cracks; Gas Turbine; Blades; Nickel alloy

Introduction

A gas turbine is a type of turbine which is a is an internal combustion engine that can convert natural gas or other liquid fuels to mechanical energy (into rotary motion). Natural gas is used as fuel by the gas turbine to rotate the turbine blades and convert mechanical energy into electrical energy. Turbine blades are subject to high operating temperatures and high centrifugal tensile stresses due to rotational speeds [1]. Power plants that use turbine blades to produce electricity typically need them to have certain qualities, such as high fatigue and corrosion resistance, as well as temperature tolerance. Superalloys and ceramic composites are common materials used in their construction [2]. The main causes of gas turbine blade degradation are: [3-8] creep, overheating and melting, fatigue corrosion and cracking, Intercrystalline and thermal corrosion, low and high cycle fatigue, erosion, and burning. During the manufacturing and maintenance of gas turbine blades, various types of defects are formed and rapidly develop due to the extremely harsh working environment, which poses a huge threat to the safe operation of gas turbines. Aust [5] reported that there are four main categories of damage:

Surface damage: Surface damage, such as roughness, waviness, layout, and defects [9]. This may include material separation and/or loss of base material or coating [10,11]. This is often aggravated by the external environment.

Wear: removal of material from the part by mechanical means [9]. This may be caused by the impact of a foreign object, such as gravel, sand, or soil debris [12,13].

Material deformation: Material deformation manifests itself as a significant change in the original contour of the part. The deformation may be caused by mechanical or thermal means [11].

Material Separation: This describes a condition in which material is split but not removed. An example of this damage is cracks.

Study of crack formation in turbine blades is of interest to several researchers because understanding the origin of crack formation can avoid industrial disasters. A large percentage of all failure events in gas turbine power plants are caused by blade damage [14]. Choi and Lee [15] studied the failure of gas turbine blades. The results show that the fatigue fracture of the blade was caused by transient events internal to the combustion chamber. According to Zhang et al. [16], fatigue failure is the main type of failure that occurs in gas turbine engine blades. Different failures of superalloy blades can be observed during testing and operation of gas turbines. The cause of these failures is usually identified by both metallographic methods (microstructural studies, fractography, X-ray crystal analyses), bench and laboratory strength tests, and strength calculation methods, including unconventional methods [17]. The aim of this study is to present the causes and mechanisms of cracks in gas turbine blades made from a nickel alloy.

Experimental procedure

The type of turbine blade studied in this research work was made of nickel alloy (INCONEL 718). The blade was taken from a gas turbine after the operation of its periodic maintenance (Figure1). The sample taken was studied by visual observations, penetrant tests, and microscopic observation. The optical microscope used is equipped with a digital camera for taking micrographs after chemical attack

Figure 1: Gas turbine during the operation of its periodic maintenance.

Results and discussion

Visual observations

Figure 2 shows a macrographic view of the formation of a crack observed in one of the gas turbine blades. This crack is very wide at its initial point and then narrows as it moves inside the blade. It is noted that this crack can be due to one of the following factors:

a) Temperature of the burnt gases which is very high

b) Thermal stresses

c) Thermal properties of the material

d) The phenomenon of fatigue of the material

e) Vibration fatigue in certain areas

Figure 2: Macro view of a crack formed in a gas turbine blade.

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It has been reported that turbine blades are susceptible to damage and cracking in the contact areas of components that experience both centrifugal and oscillatory vibrations [18]. By definition, a component subjected to fatigue in the presence of a mating component under contact load experiences micro-slip along the contact interface and results in a significant reduction in fatigue life. This behavior is called contact fatigue which 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 eventual failure faster than in conventional non-friction fatigue conditions (simple fatigue) [17] (Figure2).

Figure 3 shows another crack formed at another location on the gas turbine blade. This crack is not large compared to the first crack shown in Figure 1, but it is in its early stages of propagation (Figure3).

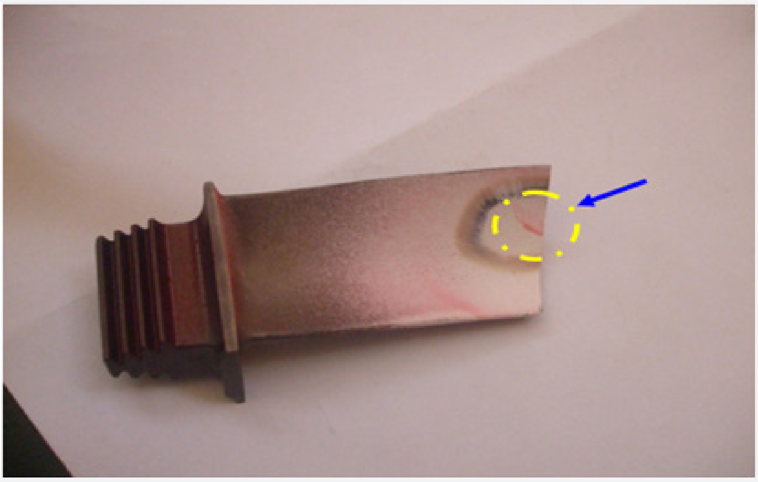

Figure 3: Macro view of a crack formed in a gas turbine blade.

Penetrant tests

Figure 4 shows a macro view of the gas turbine blade after the penetrant test which revealed only the crack visually observed and no other cracks (Figure 4).

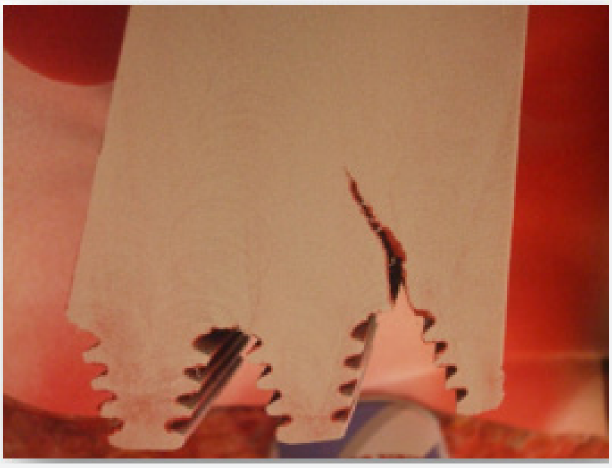

Figure 4: Macrographic view of the crack after penetrant test.

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Microscopic observations

Optical microscope observation of the crack tip (Figure 5) shows that the crack propagates in a zig-zag shape with some small ramifications of small cracks as mentioned by rectangles a, b and c. It is noted that the crack type is transgranular (Figure5). Turbine blades are susceptible to damage and cracking in the contact areas of components that experience both centrifugal and oscillatory vibrations [18]. A fatigued component in the presence of a mating component under contact loading experiences micro-slip along the contact interface and results in a significant reduction in fatigue life. This behavior is called contact fatigue which results in increased tensile and shear stresses at the contact surface, which acts as a damage generator leading to crack nucleation, growth and ultimately failure at a faster rate than in conventional non-friction fatigue conditions (simple fatigue) [17].

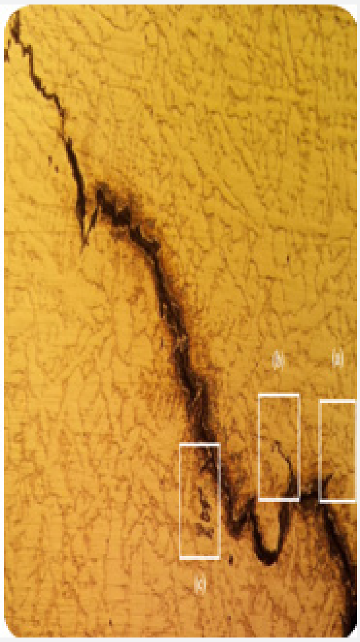

Figure 5: Optical microscope observation of the crack.

Conclusion

From this study on gas turbine blades, it can be concluded that:

a) Blades are the origin of gas turbine failure

b) Cracks are commonly observed after a long service of gas turbines.

c) Cracks can form anywhere on the blades.

d) The origin of its cracks is due to the fatigue phenomenon in the first place and to the environment in which its blades operate.

e) Our case study revealed a transgranular crack.

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