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Failure Analysis of a Gas Turbine Blade Made of Inconel 738LC Super Alloy

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ABSTRACT: Gas turbines have important role in energy generation plants and blades are valuable and critical components of a gas turbine. Blade failures in gas turbine engines often lead to loss of all downstream stages and the power plant will shut down, which can lead to prolonged outages and severe economic loss. In this paper, the failure of a GE-F5 gas turbine blade has been studied by metallurgical and mechanical examinations. The blade was made of a nickel base alloy Inconel 738LC. This blade has fractured after about 65,000 hours of service in one of the Iran's power plants during operation. Due to the blade failure, the turbine engine was damaged severely. The study was started with a thorough visual inspection of blades and continued with hardness measurement, chemical composition checks, and microstructural evaluation as well as examination of the fracture surface. The investigations showed that serious pitting was occurred on the blade surface and there were evidences of fatigue marks in the fracture surface. It was found that the crack initiated by the hot corrosion from the leading edge and propagated by fatigue and finally, as a result of the reduction in cross-section area, fracture was completed.

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1- Introduction

Gas turbines are used extensively for aircraft propulsion, land-based power generation, and industrial applications [1]. Gas turbine blades are the critical components of a power plant [2] which work mostly at a high temperature [3]. The major root cause of the sudden failure of gas turbines has been reported as being the fracture of turbine blades [4-10]. In general, most blades have severe operation conditions characterized by the following factors [11]:

- Operation environment (high temperature, fuel, etc.).
- High mechanical stresses (due to centrifugal force, vibratory and flexural stresses, etc.).
- High thermal stresses (due to thermal gradients).

2- Experimental Procedure

The blade under evaluation was the second stage blade of a gas turbine. In order to identify the failure root cause, several investigations such as visual inspection, chemical composition analysis, hardness measurement, microstructural characterization and SEM fractography were carried out.

3- Experimental Results

3- 1- Visual inspection

Fig. 1 shows an upper view of the failure occurred in the second stage of the gas turbine.

3- 2- Chemical analysis

To determine the chemical composition of the blade material, a bulk analysis was performed. The chemical composition of the blade is given in Table 1.

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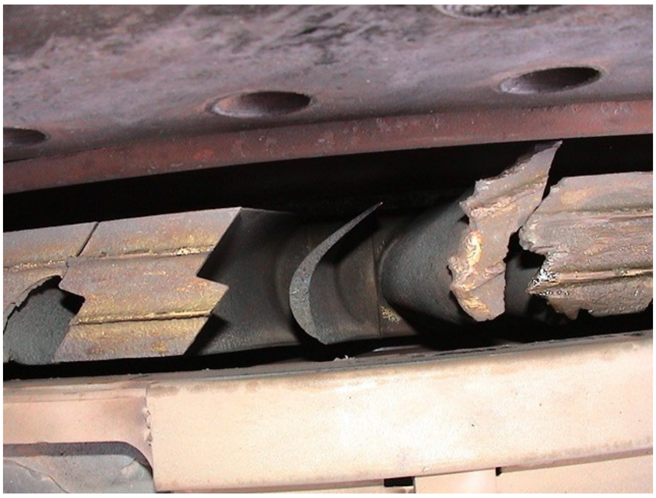

Figure 1. Upper view of the failed blade.

The chemical analysis shows that the blade material is Inconel 738LC.

3- 3- Hardness measurement

Hardness testing was performed to evaluate the mechanical properties of the damaged blade in 11 points. It was shown that there was no substantial change in material hardness, and thermal condition did not any effect on the material strength. The results are given in Table 2.

3- 4- Metallography

Samples for microstructural evaluation were taken from the blade airfoil near the fracture surface. Fig. 2 illustrates the

Table 1. The chemical composition of the blade (Wt. %).

Element	Wt. %
Ni	61.5
C	0.16
Cr	16.2
Co	8.1
Mo	1.83
W	2.55
Al	3.49
Ti	3.4
Nb	2.11
Zr	0.14
B	0.006

Table 2. Hardness values of the cross-section of the blade.

Points	Hardness (HV30)
1	415
2	409
3	403
4	395
5	394
6	397
7	391
8	388
9	405
10	412
11	418

micrograph of the material. There is a relatively compact scale on the surface of the blade. Underneath this scale, a severe deterioration can be noticed. The severity of this deterioration was to a greater degree in the samples of leading edge, especially on the concave surface. Also, the rare precipitation of grain boundary carbides can be seen in Fig. 3.

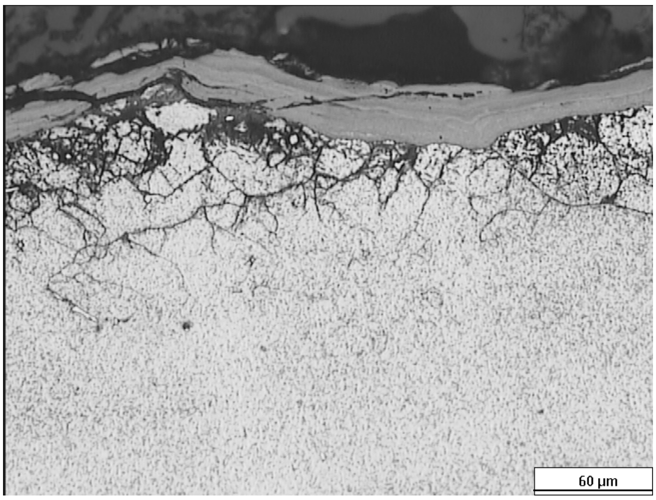

Figure 2. Surface scale and deterioration of subscale.

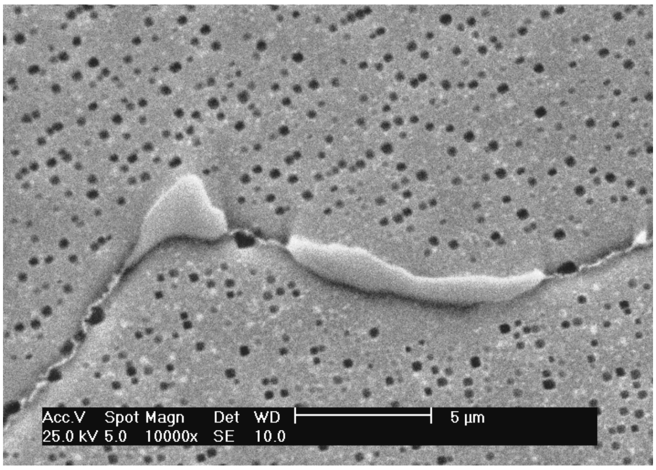

Figure 3. The grain boundary carbides.

3- 5- Analysis of the fracture surface

The fracture surface of the failed blade was examined by scanning electron microscope. Fig. 4 shows a crack in the leading edge.

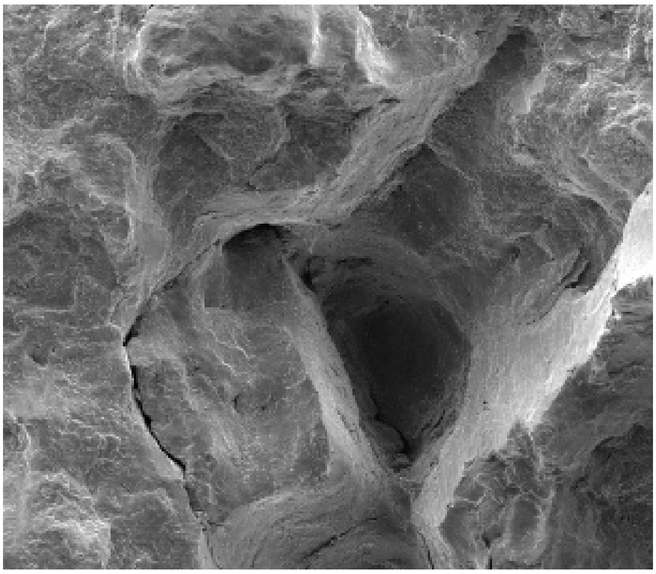

Figure 4. A crack on the surface of the blade (×50).

In Fig. 5, fatigue marks (striations) are evident. It indicates that after the initiation of the crack, propagation has been conducted by the fatigue mechanism due to the vibration of the blade. After the crack growth and subsequent reduction in cross-section area, the final fracture occurs in the blade.

4- Conclusions

The catastrophic failure of the blade has occurred by the following sequence:

1. Formation of the non-protective nickel and cobalt oxides.
2. Formation of the chromium sulfide and depletion of the alloying elements.
3. Progression of the pitting over the concave and convex surfaces of the blade.
4. Development of the corrosion at the leading edge and initiation of the crack.
5. Reduction of the blade stiffness because of grain boundary carbides.

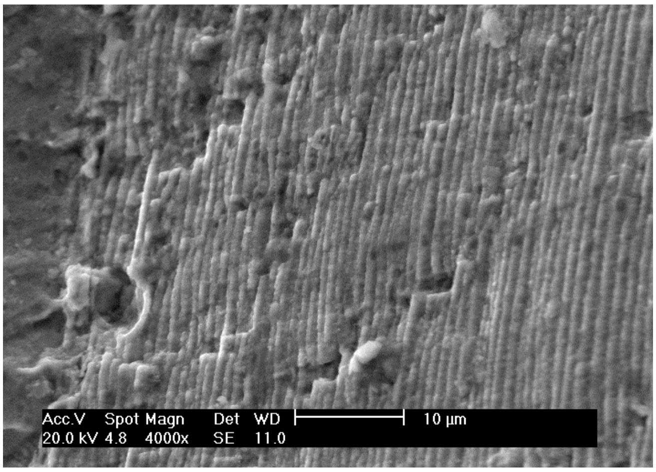

Figure 5. Fatigue striations (×4000).

6. The propagation of the crack by the fatigue mechanism because of the vibration of the blade.
7. Reduction of the cross-section area and the final fracture at the tip of the blade.

5- Solutions

1. Control of unit start-ups, shut-downs, and trips.
2. Using high-quality fuel.
3. Manufacturing of blade by direction solidification method.
4. Using thermal barrier coating.

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