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Failure Analysis of a Heavy Duty Gas Turbine Blade*

S. Asadikouhanjani,[1] M. Torfeh, and R. Ghorbanf

Mapna Turbine Blade Engineering & Manufacturing Company, Iran

[1] asadi.saeed@mapnablade.com

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Анализ разрушения высоконагруженной лопатки ГТД

С. Асадикуханджани, М. Торфех, Р. Горбанф

Научно-производственная компания “Мапна”, производитель лопаток ГТД, Тегеран, Иран

Выполнен анализ разрушения лопатки ГТД после 25 тыс. ч. эксплуатации. При этом использовались методики оценки фрактографических и металлургических характеристик материала. Данные фрактографического анализа показывают, что инициирование трещин происходит в пере лопатки в очагах высокотемпературного коррозионного питтинга, а распространяются они по механизму высокотемпературной коррозионной усталости, в результате чего имеет место хрупкое разрушение.

Ключевые слова: анализ разрушения, высокотемпературная коррозия 2-го типа, высокотемпературная коррозионная усталость, ГТД.

Introduction. Generally speaking, most of blades and vanes have severe operation conditions characterized by the following factors:

(i) operation environment (fuel and air contamination, solid particles);

(ii) high mechanical stresses (due to centrifugal force, vibratory and flexural stresses);

(iii) high thermal stresses (due to thermal gradients).

Among them, fuel and air contamination can cause hot corrosion which can consume the material at an unpredictably rapid rate [1]. Consequently, the load-carrying ability of the component is reduced or the risk of HCF increases and results in a reduction of engine reliability and availability. In the gas turbines, the air and fuel frequently contain corrosive contaminants that can cause serious hot corrosion problems. Hot corrosion may be defined as an accelerated corrosion, resulting from the presence of salt contaminants such as Na_2SO_4, NaCl, and V_2O_5 that combine to form molten deposits, which will damage the protective surface oxides [2]. A wide range of fuels can be used in gas turbines (ranging from clean gas to crude oil), and these fuels can contain sulfur, sodium, potassium, vanadium, lead, and molybdenum as contaminants. The airborne pollutants entering with the inlet air depend on the turbine location, but include sodium, sulfur, chlorine and calcium. Especially onshore power plants, where salt spray may occur, are exposed to the fouling of compressors, and even hot salt corrosion of the turbine blading [3]. These impurities in the fuel and the air can lead to the deposition of alkali metal sulphates such as Na_2SO_4 on the blade or vane surfaces, resulting in the hot corrosion attack [2]. Two types of hot corrosion reactions are known to occur in gas turbines. A high temperature reaction, known as type I hot corrosion, which occurs at 850 to 1000°C after a short incubation period. A low

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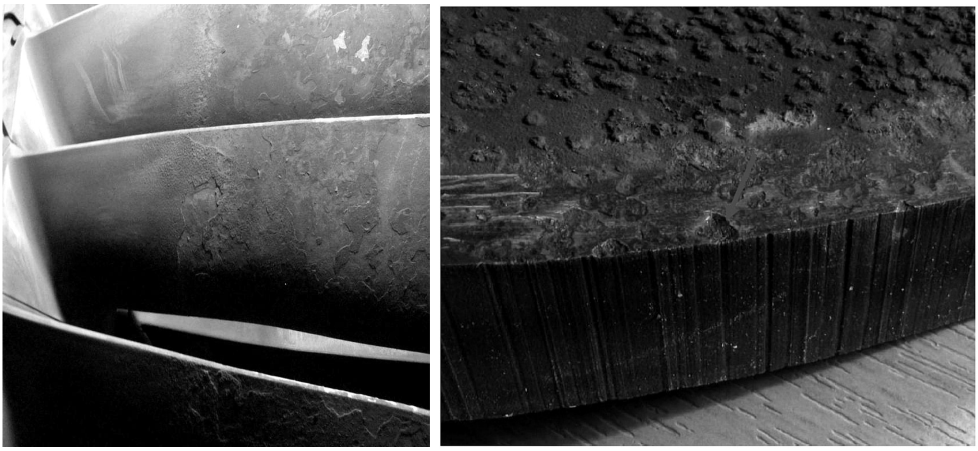
temperature reaction, also referred to as type II hot corrosion, is favored at 600 to 750°C after a long incubation period [4]. This paper reports the failure analysis of a blade in a heavy duty land-base gas turbine. The power plant is located near the coastal area and also in vicinity of deserts of Iran, as a consequence, the airborne pollutants entering with the inlet air into the turbine. Most of the blades from one stage of this gas turbine had deteriorated after nearly 25,000 EOH of service. One of these blades was broken through the airfoil from the section located at almost two-third of span. The predicted service life was 100,000 h. The turbine runs with gasoline and filtered air. The broken blade was received for study. The objective of the present work is to determine the root cause of the blade failure.

Experimental. In order to make an insight into the premature failure of the damaged blades, one of the broken blades was taken for investigation. The blade was removed from the turbine after trip due to high level of vibration. The received blade was subjected to a series of examinations, including visual and fractographic examinations. Optical and scanning electron microscops (SEM) equipped with an X-ray energy dispersive spectrometer (EDS) were used to observe the microstructure and analyze the chemical composition of local regions.

Results and Discussion.

Visual Examination. The as-received blades are shown in Fig. la. The surface of the blades exhibited deterioration or signs of corrosion, and many deposits can be seen on them. The deposits can be removed easily and underneath of them there are many pits at the surface of the blades (Fig. 1b). Consequently, the surface of the blade was uneven and rugged, and base metal of the blade appeared to be damaged and/or missing in several areas.



a b

Fig. 1. Overview of the damaged blades (a); existence of pits underneath of deposits (b).

Furthermore visual evaluations revealed that one of the blades was cut off at 12 cm from tip, about two–third of the airfoil span (Fig. 2a), showed fatigue marks at the fracture surface, which is presented in Fig. 2b. So, a series of analysis were performed on this blade to identify the possible cause of failure. Moreover, the detached piece of the blade had caused some damage to other blades and the exhaust inner wall.

Investigation of Corroded Blades. Typical results of investigation for corroded blades are described as follows:

The blade under investigation was covered with mixed thin deposits, which showed blackish. The deposits have been sampled for the analysis, and then blade's airfoil has been cut off for metallographic evaluation by grinding, polishing, and etching. According to

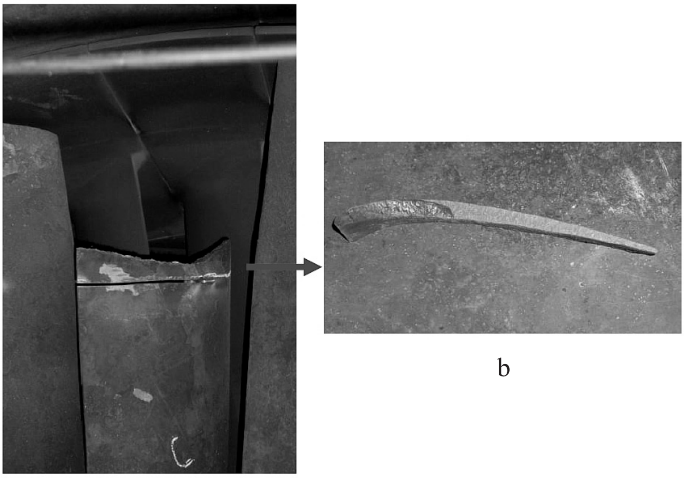


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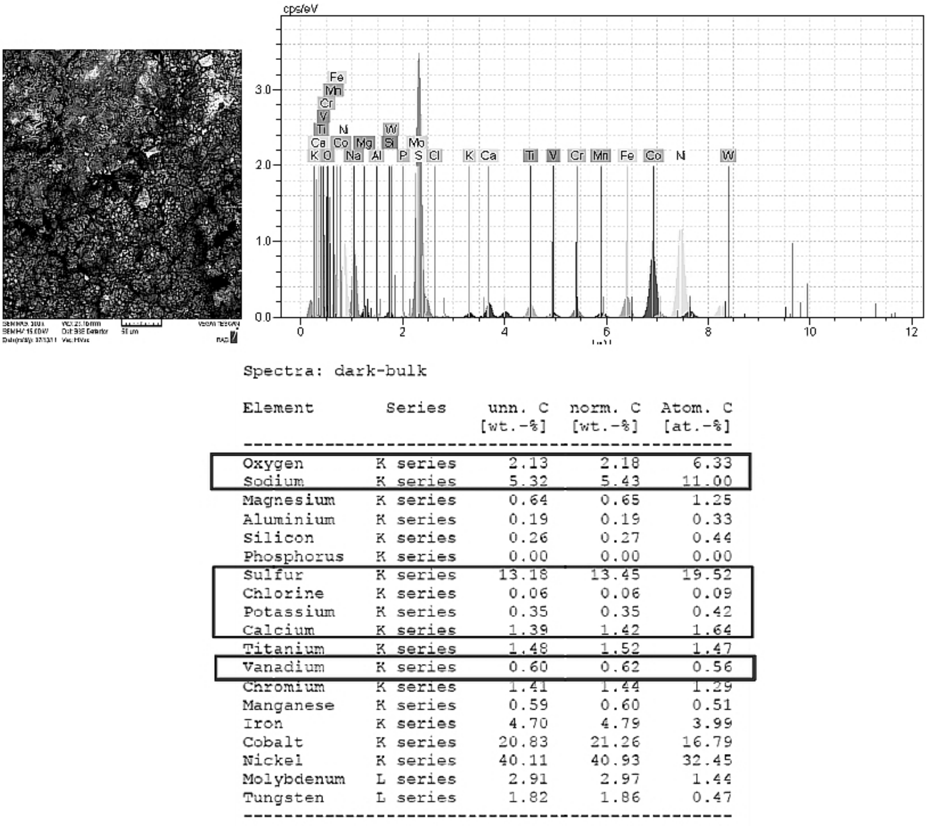
Fig. 2. Broken blade (a); fracture surface of the broken blade with fatigue marks (b).



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Spectra: dark-bulk

Element       Series     unn. C    norm. C   Atom. C
                        [wt.-%]   [wt.-%]   [at.-%]
-----------------------------------------------------
Oxygen        K series     2.13      2.18      6.33
Sodium        K series     5.32      5.43     11.00
Magnesium     K series     0.64      0.65      1.25
Aluminium     K series     0.19      0.19      0.33
Silicon       K series     0.26      0.27      0.44
Phosphorus    K series     0.00      0.00      0.00
Sulfur        K series    13.18     13.45     19.52
Chlorine      K series     0.06      0.06      0.09
Potassium     K series     0.35      0.35      0.42
Calcium       K series     1.39      1.42      1.64
Titanium      K series     1.48      1.52      1.47
Vanadium      K series     0.60      0.62      0.56
Chromium      K series     1.41      1.44      1.29
Manganese     K series     0.59      0.60      0.51
Iron          K series     4.70      4.79      3.99
Cobalt        K series    20.83     21.26     16.79
Nickel        K series    40.11     40.93     32.45
Molybdenum    L series     2.91      2.97      1.44
Tungsten      L series     1.82      1.86      0.47
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Fig. 3. Chemical composition of the deposits.

Fig. 3, EDS analysis of deposit revealed that its components contained several percents of S, Na, Ca, O, and V, as contaminant elements (probably in the form of corrosive components of Na_2SO_4 and V_2Os). Existence of these components makes the blade susceptible to occurrence of hot corrosion of types I and II.

A typical cross-sectional microstructure of severely corroded part is shown in Fig. 4. A layer type of hot corrosion with an uneven scale base metal interface without any subscale sulphides and precipitate-depleted zones was found to be present. According to results of visual examination, chemical and metallographic analysis, type II of hot corrosion is an active damaging mechanism in this turbine.

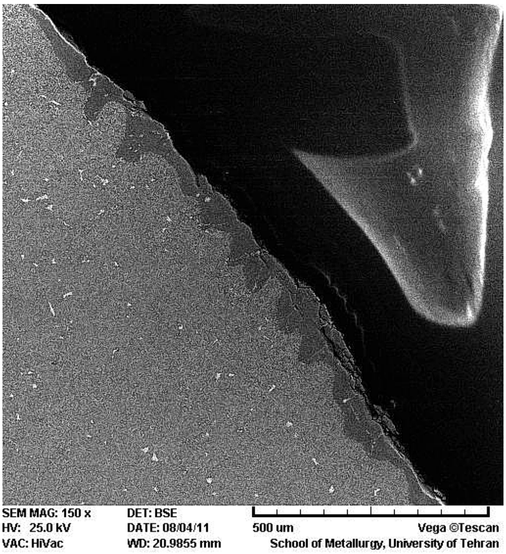


Fig. 4. SEM micrograph of the corroded blade material.

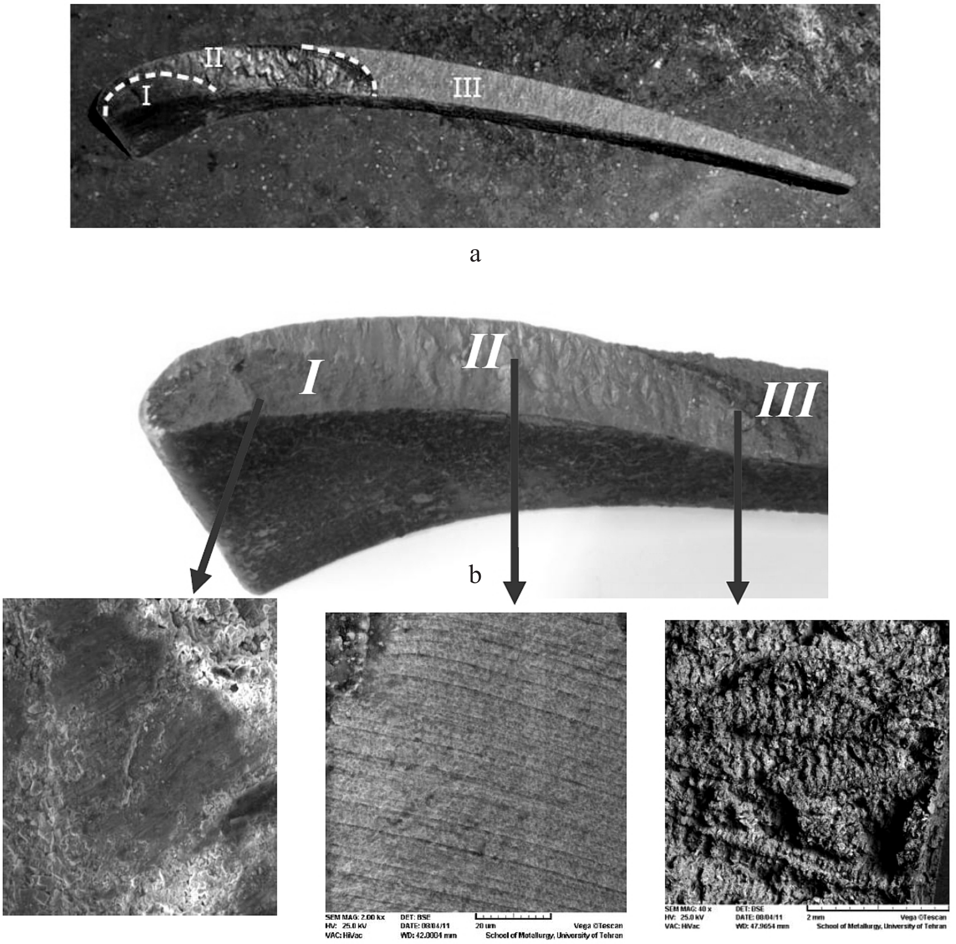
Fractographic Analysis. The upper view of the broken blade is presented in Fig. 5a. The general orientation of the fracture surface is nearly 45° to the longitudinal axis of the blade (Fig. 5b). Three distinct regions denoted by *I*, *II*, and *III* in Fig. 5a can be identified at the fracture surface. Visual examination clearly showed the typical fatigue fracture surface with a propagation area and a final fracture zone (Fig. 5a). The fracture mechanism in three regions is analyzed by SEM. Details of the fracture surface are shown in Fig. 5c–e. Region *I* shows a dark fracture surface. EDS analysis of the fracture surface in this region revealed the presence of S, Na, O as corrosive elements. In addition, some isolated typical fatigue striations could be identified in region *I*. In fact, the fracture surface of region *I* was corroded by some components like Na_2S0_4, or a mixed mode of fatigue-hot corrosion mechanism seems to occur. Details of the fracture surface of region *II* shows sharp fatigue striations (Fig. 5d). In regions *I* and *II*, the crack propagation occurred in the pressure-suction side direction. Region *III* reveals a rough dendritic fracture surface. This is the sign of a final fracture because of the overload.

Discussion. Alloy surfaces exposed to high temperatures and gas environments can become coated with foreign deposits (sulfates, oxides, chlorides, etc.) from combustion air or fuel contaminants. These corrosive components react with the surface of the blade and layer-type corrosion (type II) characterized by an uneven scale/metal interface and the absence of subscale sulphides has been observed. Hot corrosion of type II forms typical pitting. Occurrence of pitting at the surface of the blades and existence of alternative aerodynamic loads on them make the blades prone to HCF.

Conclusions. As for the hot corrosion-fatigue damages observed in a blade of high-temperature heavy duty gas turbine, following results were obtained.

1. The corrosion was that of a typical hot corrosion type II caused by Na_2S0_4.

2. The hot corrosion is caused by a large quantity of corrosive impurities present in the air which get into the gas turbine, in addition to those in the fuel.



c d e

Fig. 5. General view of the fracture surface (a); higher magnification of three regions (b); presence of striations and corrosion products in region *I* (c); presence of striation in region *II* (d); dendritic fracture surface in region *III* (e).

3. Hot corrosion of type II forms typical pitting that make the blades prone to HCF.

4. In order to prevent the hot corrosion, the air and fuel filter should be reinforced, and CoCrAIYRe (VPS) or NiCoCrAIY (VPS) coating with higher anticorrosive properties should be used over the surface of the blade.

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Резюме

Проаналізовано руйнування лопатки ГТД після 25 тис. годин експлуатації. При цьому використовувалися методики оцінки фрактографічних і металургійних характеристик матеріалу. Дані фрактографічного аналізу показують, що ініціювання тріщин відбувається в пері лопатки в осередках високотемпературного корозійного пітингу, а розповсюджуються вони по механізму високотемпературної корозійної утоми, в рузультаті чого має місце крихке руйнування.

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