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Fatigue fracture analysis of gas turbine compressor blades

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ABSTRACT

Gas turbine compressor blades are subjected to centrifugal and vibratory loads. This repeated loading and unloading can reduce the life of the compressor blades. An experimental procedure has been done to investigate the fatigue crack propagation in blades. Microstructure and fracture surface of the blade have been investigated by optical and scanning electron microscopy. Fatigue crack propagation considering the effect of corrosive environment has been studied. Environmental and micro-structural features revealed that the catastrophic fracture was initiated from the corrosion pit on the leading edge of the blade.

1. Introduction

Life time of real components is defined by a broad range of manufacturing, design and service factors. Compressors are one of the main components of oil and gas industries. The major function of a compressor is to compress air which is used in combustion process. Compressors use arrays of fan-like air foils to progressively compress the working fluid. Compressor blades are variously made by forging, extrusion or machining. These blades play important role and are designed to operate at high temperatures and aggressive environments and are subjected to high rotational velocity which results in high centrifugal forces on the blades. Cyclic loading causes the blades to metallurgically and mechanically degrade during service which limit their useful life service. In sea water environment, corrosion pits can appear on the blades. These corrosion pits can have detrimental influence on the fatigue strength of the material and raise the stress level locally. It is reported in the most of corrosion fatigue failures of components, cracks initiate from corrosion pits [1,2]. Becker et al. [3] reported the effect of pitting corrosion on fatigue and fracture behavior of 13% Cr stainless steel and studied the interactive effects of corrosion pit nucleation and growth. Philips and Newman [4] established the importance of short crack analysis and used Paris law for crack growth in Al 2024-T_3 alloy. During stress fluctuations the crack propagates and reaches the critical size, leading to sudden rupture. Failure due to initiation and propagation of fatigue cracks originating from service defects is typical of compressor blades and has been investigated by researchers [5–7]. The reliability and performance of a gas turbine compressor is strongly dependent on the environment in which it operates and the materials that are used. In the past, the blades were made of coated AISI403 stainless steel. As far as the coating is worn away on the pressure side of the blades, in 1980s they were substituted with GTD-450 alloy. This is an age-hardenable, martensitic stainless steel. It has the strength characteristics of a martensitic stainless steel combined with corrosion resistance which is comparable to an 18Cr-8Ni stainless [8,9]. The objective of the presented study is to

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Table 1
Chemical analysis of the fractured blade.

Chemical analysis of the fractured blade												
Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	Nb	Fe
Result	0.029	0.22	0.58	0.003	0.005	15.00	6.25	0.75	1.72	0.01	0.32	Rem.
GTD 450 alloy												
Min.	*	*	*	*	*	14.00	5.00	0.5	1.25	*	0.04	Rem.
Max.	0.05	1.00	1.00	0.03	0.03	16.00	7.00	1.00	1.75	*	*	Rem.

investigate the reason for sudden and early failure of a gas compressor blade working for about 34,000 h at sea water environment. Note that according to the blade manufacturer their working life is about 48,000 h to 100,000 h depending on environment and blade surface modification.

2. Materials and methods

2.1. Chemical analysis

Chemical analysis of the fractured blade was done by emission spectrometry. The results are shown in Table 1. According to this analysis, it was found that the blade material is consistent with GTD-450 alloy analysis which is a common alloy for fabricating gas compressor blades.

2.2. Mechanical tests

According to the supplier documents, the blades have been age hardened at H1000 condition. In this condition age hardening is performed at 1000 °F or 540 °C for about 4 h. In order to be confident about the mechanical characteristics of the blades at H1000 condition and compare it with the standard values, hardness test and tensile test were performed on the crack free blades.

2.2.1. Hardness test

Brinell hardness measurements were carried out on the polished cross section of the blades using 30 kgf load. The average hardness of the three different locations was reported.

2.2.2. Tensile test

Tensile test was performed at room temperature by a Gotech machine based on ASTM E8 standard [10]. The average value for ultimate strength, yield stress, percent elongation and percent reduction in area is taken after testing two specimens.

2.3. Microscopical investigation

The metallographic specimens obtained were rubbed with 120–2000 mesh sand paper, as a result, their surface were cleaned and the cross sectional surfaces were polished by 3 μm diamond paste and solvent. For microstructural examination the specimens were etched with a solution of 1.5 g $CuCl_2$, 33 ml hydrochloric acid, 33 ml ethanol and 33 ml distilled water. A scanning electron microscope (SEM) was used to evaluate the microstructure of selected samples. X-ray analyses (EDX) of selected areas were also obtained.

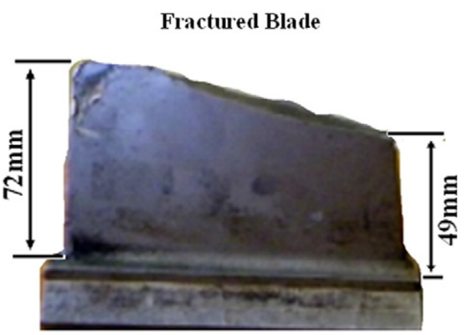

Fig. 1. The fractured blade and the failure location on it.