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Technical Report

Cement kiln dust induced corrosion fatigue damage of gas turbine compressor blades – A failure analysis

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ABSTRACT

Compressor of one of the gas turbines installed in a power plant was stopped under emergency conditions. Primary investigation showed that almost all of the first stage blades and some of the next stages were severely damaged. In this study, one of the first stage broken blades was failure analyzed. The results showed that the corrosion pits were formed on the compressor blade surface due to the presence of Cl and S elements in the compressor inlet air. Since the power plant located in the vicinity of a cement company and also an oil refining company, the inlet air of compressor had large amounts of Cl and S containing compounds. The corrosion pits acted as stress concentration sites, and facilitated fatigue crack initiation and propagation, leading to final fracture of the blades.

1. Introduction

The required air for combustion and cooling applications in gas turbines is provided by the compressors. After passing through the filters, air is entered into the compressor and passes through different stages, as it becomes denser and hotter [1]. Dimensions of the compressor and aerodynamic shape of moving or stationary blades varies on the basis of gas turbine type and its manufacturer.

In this study, failure of the first stage compressor rotor blades of a 30 MW gas turbine was investigated. The compressor had 18 blade rows. Based on the power plant documents, the blades had been made by a reputable company and they had worked more than 100 thousand hours before fracture. The blades were regularly washed during the periodic inspections (intervals around 30 thousand hours of operation).

A survey of the compressor manufacturer documents showed that the material of the blades must be the martensitic stainless steel grade AISI 403, and no coating was applied on the surfaces of blades. Stainless steel grade AISI 403 is a modified turbine quality version of the well-known AISI 410 steel. AISI 403 is now widely used for the manufacturing of compressor blades of gas turbines, as well as steam turbine blades [2,3].

The main mechanisms of the failure of the compressor blades are low cycle and high cycle fatigue, corrosion, erosion, impact of foreign objects or FOD, and surge-induced heavy vibrations/deflections or sudden failure of blades [4–7]. In many cases, multiple mechanisms act simultaneously, resulting in the complete fracture of the component. At all events, precise analysis of the failure of the compressor blades is necessary to prevent future fractures.

In this study, failure of the first stage rotor blades of a compressor of a 30 MW gas turbine was investigated, and the prevention methods were proposed for similar cases.

2. Experimental procedures

To determine the failure mechanisms of the blades, following experiments were conducted.

2.1. Visual examination

All rows of the compressor blades and vanes were visually examined to determine the type and degree of damage for each group. Also, the broken blade surfaces were inspected for the presence of corrosion products, foreign object and erosion damages.

2.2. Chemical analysis of blade material and some dusts

To determine the chemical composition of the compressor blade alloy, after preparation of the suitable sample of the blade, chemical composition was determined by emission spectroscopy. Also, the chemical analyses of some cement kilns dusts were determined by X-ray fluorescence (XRF) and analytical chemical techniques.

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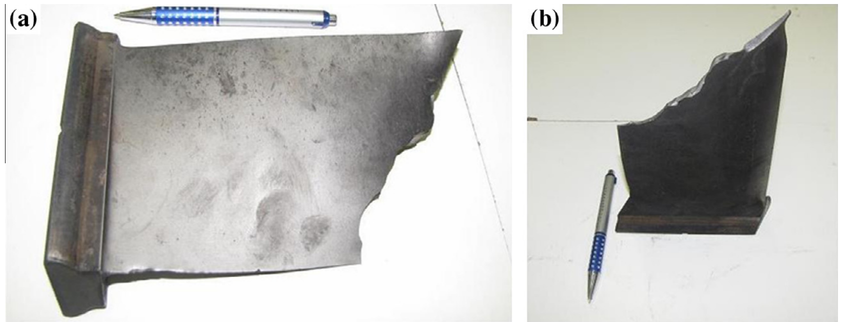

Fig. 1. (a and b) Images of the broken blades from different views.

2.3. Metallography

To investigate the microstructures of the blades and the possible microstructural changes in different locations of the broken blades, various samples were prepared by grinding and polishing using standard metallographic methods and etched with Marble's reagent (10 g $CuSO_4$, 50 mL HCl, 50 mL water). The etching time was approximately 5 s. Then, these metallographic specimens were examined by optical microscopy using a Leitz microscope model Aristomet, as well as by scanning electron microscopy (SEM) using a Tescan-Vega SEM. The SEM microscope equipped with an EDS detector for chemical analysis.

2.4. Fracture surface analysis

Macroscopic and microscopic examinations of the fracture surfaces are needed to determine the failure mechanisms of the blades. For this purpose, the suitable fracture surfaces of the broken blade were selected and investigated. The fracture surfaces were evaluated after ultrasonic cleaning, using a stereo microscopy, as well as a scanning electron microscopy (model Tescan-Vega).

2.5. Hardness measurements

To evaluate the mechanical properties, Vickers hardness of the broken blade was measured using an Eseway hardness tester model DV RB-M under a load of 30 kg on the airfoil and root sections of the blade.

3. Results and discussion

3.1. Visual investigations

The investigated compressor had 18 rows of rotor blades, 18 rows of stationary blades (vanes), and one row of stationary guide vanes. A great number of first stage rotor blades and some of the blades and vanes of other stages were damaged.

The first stage stationary blades (vanes) had not suffered significant damage. This can be a sign that the surge phenomenon has not been occurred [8,9]. The first stage rotating blades were suffered more damage, and some of them were completely broken in the middle. Bottom section of a broken blade was studied in this study (Fig. 1).

As can be seen in Fig. 1, the fracture surface makes an angle of 45° with respect to the longitudinal blade axis. There was a black greasy deposit on the surfaces of the blade. After cleaning the blade surfaces, small traces of erosion were observed on the blade leading edge.

3.2. Chemical composition

Table 1 presents the results of the chemical composition of the blades measured by emission spectroscopy. Also, the chemical composition of standard AISI 403 stainless steel in accordance with ASTM: A982 and ASTM: A1028 is given in this table. The comparative study of these results shows that the compressor blade alloy has chemical composition similar to that of AISI 403 stainless steel, but the amount of molybdenum in the composition of the blade is higher than that of the standard AISI 403 Steel.

Table 1
Chemical composition of the compressor blade alloy and standard AISI 403 stainless steel (wt.%).

Element	Fe	C	Cr	Si	Mn	P	S	Ni	Mo
Compressor blade	Base	0.115	12.95	0.175	0.42	0.015	0.013	0.14	0.544
AISI 403	Base	0.15max	11.5–13	0.5max	1max	0.04max	0.03max	–	–

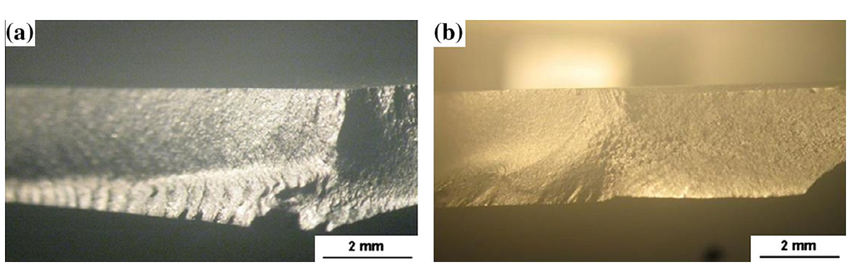

Fig. 2. (a and b) Stereo microscopy images of different regions of the broken blade fracture surface.