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Fatigue failure analysis of rotor compressor blades concerning the effect of rotating stall and surge

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ABSTRACT

Detailed investigation was performed on the effect of the rotating stall and surge on the fatigue failure mechanisms of the axial compressor first stage rotor blades. The static stress distribution of the blades was analysed using three dimensional (3D) finite element method (FEM). The critical fracture stress was calculated using the linear elastic fracture mechanics. Fractographic observation revealed different fatigue fracture modes corresponding to the different fatigue loads. Results demonstrated that during operation two kinds of fatigue loads can occur which are tension-torsion fatigue and bending fatigue. The tension-torsion fatigue stems from the periodic tension-torsion stress induced by the surge, while the bending fatigue load is caused by the rotating stall.

1. Introduction

Blade is one of the most important components of the axial compressor used to transfer the kinetic energy of the gas to pressure. The failure of the compressor occurred mostly in the blade due to the complex working environment, not only the constant centrifugal force, but also the air exciting vibration force. In general, compressor blade failures can be grouped into two categories: (a) creep rupture; (b) fatigue failure, including both the high-cycle fatigue (HCF) and low-cycle fatigue (LCF) [1–4].

The analysis of the fatigue fracture of the compressor blades has received much attention from researchers [5–6]. Sabbah Ataya et al. [7] investigated the fracture of a wind turbine blade. They found out that the fatigue crack initiated at a surface damaged by rubbing and then cracked by a fatigue mechanism over a period of time, and failed by overload at the last moment. B.Y. He et al. [8] and Y.M. Ji et al. [9] both studied the fracture of the turbine blade and observed that the turbine blade is initially damaged from rubbing and corrosion over a period time before cracking by a fatigue mechanism. Experimental procedures and numerical simulation methods have been developed to understand the fracture mode of the compressor blade. P. Matheron et al. [10] applied a cyclic tension and torsion test to produce a biaxial fatigue database. They examined the analytical methods describing the fatigue under the conditions of the tension and torsion loading. Fayza et al. [11] simulated the dynamic and fatigue behavior in composite axial compressor blades using a full 3D FEM. They found out that the centrifugal force and aerodynamic force play different roles during compressor events, the low frequency load component is characterized by high load amplitude in contrary to a high frequency aerodynamic load of small amplitude. Witek [12–14] calculated the stress state of the blade under the operating conditions using finite element method, and compared with the analysis results of the fracture mechanism for the

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Table. 1
Mechanical properties of 2Cr13 stainless steel.

Yield strength, σ_s (MPa)	Tensile strength, σ_b (MPa)	Specific elongation, δ (%)	Percentage reduction in area, ψ (%)	Fracture toughness, K_{IC} ($Mn/m^{3/2}$)	Microhardness, HV
690	829	18.7	64.0	230.1	192

compressor blades. However, few investigations studied the effect of the rotating stall and surge on the fatigue modes and fracture mechanisms of the first stage rotor blades.

In the present work, the characteristics of the failure of the axial compressor blades were studied by combining the FEM calculation of the stresses and the fractographic analysis.

2. Failure analysis

The 2Cr13 martensitic stainless steel, having a chemical composition of 0.17–0.22 wt.% C and 12–14 wt.% Cr, is commonly used in petroleum industries, as a structural material for blades of air compressor operated under fatigue loading and relatively low corrosion environment [15]. The mechanical properties of 2Cr13 stainless steel were obtained using tensile test and fracture toughness test, which are listed in Table 1.

Mechanical test results and the analysis of the chemical composition using Energy Dispersive Spectrometer (EDS) showed that the mechanical properties and the chemical composition of the blade material are in accordance with the 2Cr13 steel standard.

2.1. Visual examination

The typical failure of the axial compressor rotor blades is shown in Fig. 1. It can be seen that the failed blades were mostly first stage blades, and the crack was located at or close to the root of the compressor blades. The sketch of the compressor blade is shown in Fig. 1b.

Based on the fracture morphology, failed blades can be divided into two types, as shown in Fig. 2. Type-1 was oblique fracture with multiple fracture platforms. Type-2 was plane fracture with ribbon shell pattern structure.

Fig. 2 shows the Type-1 fracture morphology and Fig. 3 illustrates the failure position with the arrow indicating the crack initiation site. It can be seen that the crack was initiated at the tip of outlet edge, which is 20 mm from the blade root, and then propagated to the inlet edge and formed the fracture region I (Fig. 2). During operation, the fatigue crack continued with an uphill propagation to form the II, III, IV and V regions on the fracture surface, in which the region III was damaged by foreign object. The boundaries between different regions may result from the interruptions of operation, for maintenance for example. The final rupture started from region VI. The different appearances of regions VI, VII, VIII and IX may be due to the complex loading states such as tensile and torsional loads.

a

b

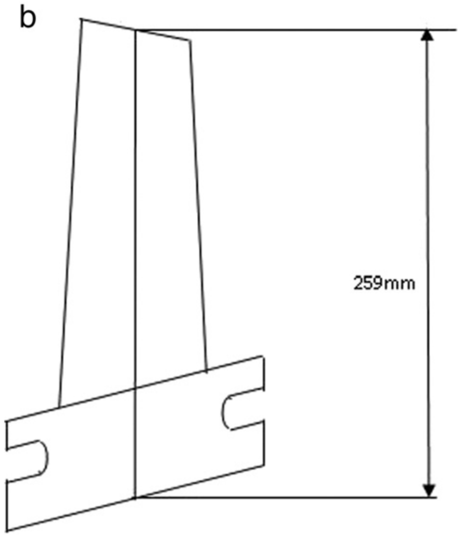

Fig. 1. (a) The images of failed blades; (b) the sketch of compressor blade.