Engineering Failure Analysis 56 (2015) 142–149

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis and fatigue performance evaluation of a failed connecting rod of reciprocating air compressor

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ARTICLE INFO

Article history:
Received 1 September 2014
Received in revised form 31 December 2014
Accepted 11 March 2015
Available online 1 April 2015

Keywords:
Connecting rod
Rounded fillet
Inclusions
Fatigue

ABSTRACT

A connecting rod of a reciprocating air compressor is subjected to complex dynamic loads therefore it is of a critical machine element. Failure of this type of connecting rod was reported to occur at the rounded fillet of the big connecting rod end. The present investigation is aimed to identify the cause of failure and to evaluate fatigue performance of the failed connecting rod. Factors affecting failure including structural design, type of material and dynamic loads were assessed using standard failure analysis method. This method included analysis of chemical composition, microstructural examination using optical microscopy, hardness and tensile tests, scanning electron microscopy (SEM) fractography and stress analysis. To evaluate fatigue performance, fatigue crack growth rate (FCGR) test was performed using a sinusoidal load with a constant load amplitude. Results of this investigation suggest that the cause of failure was low cycle fatigue and the initial crack location was consistent with high stress concentration, i.e. fillet radius. From metallurgical point of view, the connecting rod was made of cast steel, not forged steel, with a considerable number of non metallic inclusions such as Al_2O_3, SiO_2 and FeO. These inclusions which were present near the surface of the rounded fillet seemed to act as stress raiser and they were responsible for crack initiation. In addition, the presence of inclusions could increase fatigue crack growth rate, da/dN (in m/cycle) as indicated by a high value of Paris' constant (n), typically of 5.2141.

1. Introduction

Reciprocating compressors find their applications in gas pipelines, chemical plants, natural gas processing plants and oil refineries. A reciprocating compressor is a device that converts power from prime movers such as an electric motor, a diesel engine, a steam engine or a turbine, into kinetic energy by compressing and pressurizing air or gas then discharging it into receiver or pressure system. In this mechanism, the compression is accomplished by transforming the rotary motion of a crank shaft into reciprocating piston motion in a cylinder through a connecting rod. In such operating condition, the connecting rod experiences complex dynamic loads during service and therefore, it is considered to be a critical component [1].

Materials used for connecting rods are required to have good mechanical properties, in particular rigidity, hardness, tensile and fatigue strengths [2]. To date, the selected materials for connecting rods are malleable irons, nodular cast irons, high carbon steels and microalloyed steels and they are manufactured by forging, casting, powder metallurgy or more recently, fracture splitting technology. The use of forging for production of connecting rods has advantages, i.e. the connecting rod

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http://dx.doi.org/10.1016/j.engfailanal.2015.03.010
1350-6307/

materials become compact and lightweight hence reducing inertia forces during service whereas cast connecting rods are cheaper but their strength is relatively low so that their use is limited to small and medium size connecting rods.

Failure of connecting rods is mainly caused by fatigue and factors which contribute to the failure include improper material selection, poor design or fabrication defects [3,4]. The majority of damages have been reported to take place at some parts of connecting rod such as a small head of the connecting rod, crank pin, roller bearing and connecting rod bolt [5]. A number of efforts have been made to improve performance of connecting rods. Apart from experimental studies using fracture analysis and microstructural examination, the use of a finite element model (FEM) could aid to improve the design of a connecting rod [6,7].

Recently, premature failure of a connecting rod of a reciprocating air compressor has been reported to occur and based on visual examination as shown in Fig. 1, the initial crack was found at the rounded fillet of the big connecting rod end which was connected to a crankshaft assembly. The cross section of the connecting rod was designed in the form of I-profile with a drilled oil passage was located in the middle I-section. This oil passage was designed for lubrication system. As fracture occurred, the connecting rod shank (or I-beam) was crashed for many times before crankshaft motion was stopped and as a result, the rod shank near the small connecting rod end was broken. The present investigation aims to study the probable cause of failure and to propose recommendations for improving the quality of the connecting rod.

2. Materials and experimental methods

The first step of the failure analysis procedure is to inspect the location and appearance of fractured surface followed by a complete analysis of the failure. Fig. 2 shows the locations of test specimens for fractography, chemical analysis, metallography, hardness measurement, tensile test and fatigue test. The fractured surface of the connecting rod was maintained free from scratch for fractography study using scanning electron microscopy (SEM). Microstructural examinations were carried out using optical microscopy and SEM where samples were cut at a region near the fractured surface. The samples were prepared according to standard metallographic technique including grinding, polishing and etching using nital (2% HNO_3 + 98% propanol). The hardness was measured using Vickers microhardness tester whereas tensile test specimens were taken parallel to the axis of I-beam.

The fatigue behaviour of the connecting rod was studied using fatigue crack growth rate (FCGR) test. Specimens for FCGR test were machined in the form of compact tension specimen (CTS) according to ASTM E647 with the initial crack was parallel to the actual crack direction to simulate the fatigue crack growth behaviour.

3. Results and discussions

3.1. Chemical composition

The chemical composition of the connecting rod material is given in Table 1. The amount of C in steel material was around 0.462 with low percentages of alloying elements suggesting that the connecting rod was made from a medium carbon steel. According to AISI standard, this steel is categorized as AISI 1045.

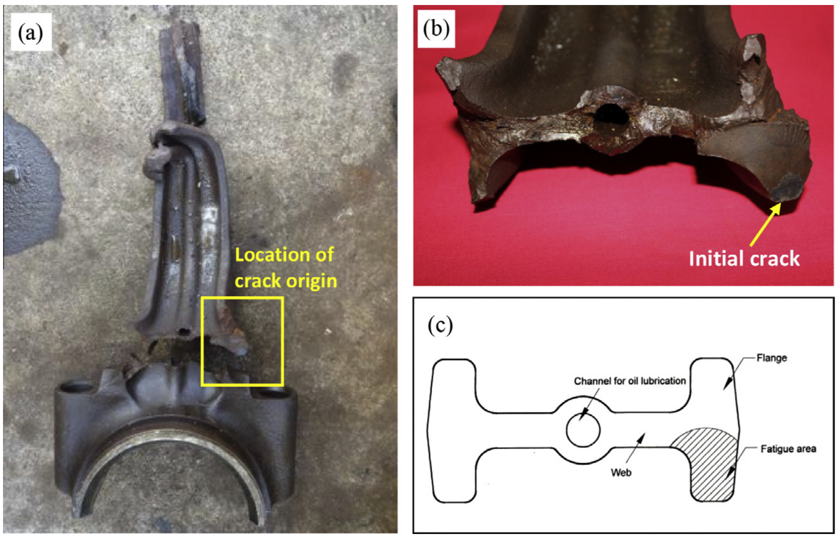

Fig. 1. The failed connecting rod: (a) location of initial crack, (b) magnified photograph of fractured surface outlined by a square in this figure (a), and (c) I-section of the connecting rod.