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Failure analysis of submersible pump system collapse caused by assembly bolt crack propagation by stress corrosion cracking

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ABSTRACT

Mechanically fastened joints using bolts are critical components in submersible pump systems. These bolts are subjected to aggressive environments in oil wells. Tightening torque preload and motor's weight are the principal loads that bolts support mechanically plus an occasional pipe flexure. Additionally, a corrosive sulfide-rich water environment presents an extremely demanding chemical condition. A better understanding of those failure mechanisms affecting such components could provide more safety, as well as costs and time saving during the operation of pump systems in wells.
An assembly bolt from a submersible pump was fractured during service. Failure was the result of stress corrosion cracking (SCC) originated by pit corrosion. Mechanical and optical tests were performed to identify property changes. SEM with EDS, XRF and OES analyses were used to characterize the material and crack propagation. The fractured bolt material specification was medium carbon steel, while the material specified by the manufacturer was Ni–Cu alloy. The origin of the crack was located on a stress concentration region, but its nucleation was a result of high corrosive conditions.

1. Introduction

The use of submersible pumps in well applications is common nowadays in oil and gas production. The system presents better efficiency and higher production rates than other lift methods when used under the same conditions [1]. Since pump components are submitted to high corrosive environments, such as pumping underground water in a well, characteristic failures of components may be attributed to localized pit corrosion, stress corrosion cracking, inter-granular corrosion, erosion-corrosion, fatigue and/or corrosion fatigue and microbiologically influenced corrosion (MIC), and, of course, combinations of all the above mechanisms [2]. In the case of mechanically fastened joints, engineering alloys such as nickel or nickel-molybdenum alloys are used to reduce the rate of corrosion as a result of the thin (nanometer scale) oxide layers that naturally form over the metal surface. Such passive films are often susceptible to localized breakdown resulting in accelerated dissolution of the underlying metal [3]. Pit corrosion can be a crack generator during exposure to the service environment forming inclusions that intersect the free surface or by a breakdown in the protective film. Such cracks are then propagated by the combined and synergistic interaction of mechanical stress and corrosion reactions [4].

The objective of this study was to determine the possible failure sequence by examining the microstructure and performing mechanical and chemical analyses to explain the bolt crack propagation that led to the subsequent submersible pump system failure.

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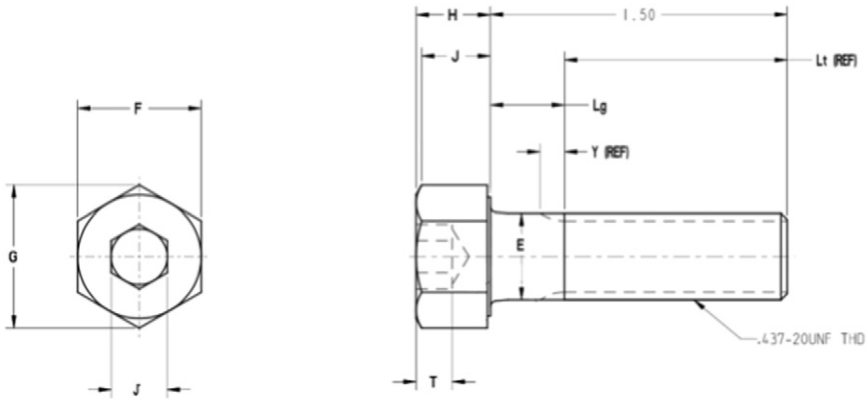

Fig. 1. Dimensions of the bolt based on ANSI B18.2.1.

2. Background

Two casing assembly bolts (Hex Head Socket Cap Screw .437-20UNF X 1.50) were received; the first one was fractured near the head, while the second one was in good condition. The material specified by the manufacturer is Monel K-500 and the dimension of the bolt follows ANSI B18.2.1 specifications as shown in Fig. 1. The function of these bolts was to connect the casings of two 390HP motors used in a submersible pump as shown in Fig. 2a.

The bolt that failed after 561 days of service and the failure location is presented in Fig. 2b. As it is seen, the bolt fractured zone is 5 mm above the thread. Working conditions for both bolts are: temperatures around 300 °C, corrosive water environment (1% petrol and 99% water), predominantly static mechanical loads resulting of the weight of the components as well as the loads produced by operation or manipulation in the well.

3. Experimental procedure

In the present study several analyses were used to determine the root cause of failure. Hardness tests (macro- and micro-indentations) were carried out to determine mechanical properties and chemical composition measurements, visual examination, and microstructural analysis were done for material characterization.

3.1. Hardness test

The hardness scale used for the measurements was Rockwell C (HRC, at a load of 150 kg), following standard ASTM E18 [5]. The surface of samples was cleaned and polished. In order to compare mechanical properties of material with Monel K-500, five

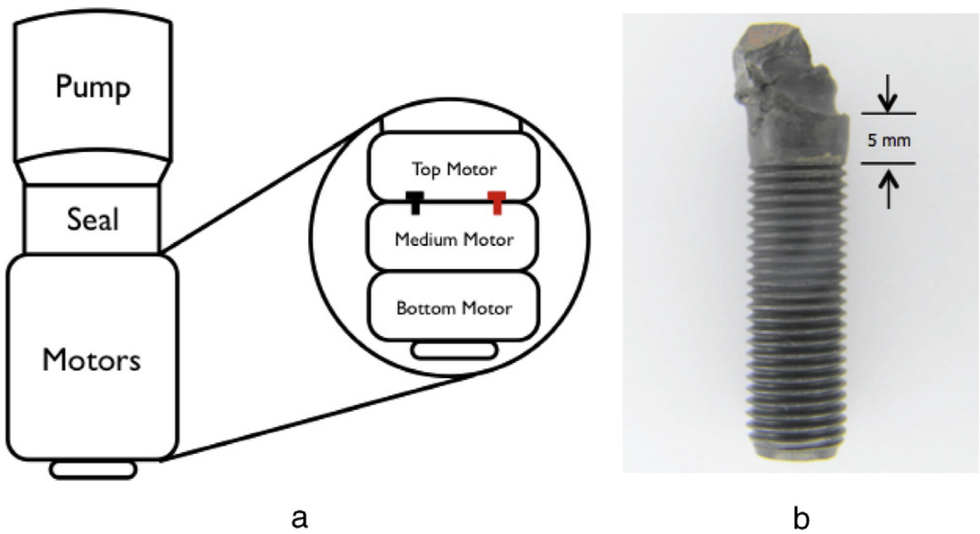

Fig. 2. (a) Diagram showing the location of the assembly bolts. (b) General view of the fractured bolt.