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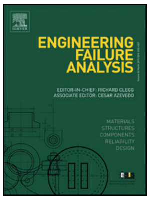

Failure of alloy steel socket-head cap screws used in offshore oil production

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ABSTRACT

Low alloy quenched and tempered steels are widely used as screws and studs. In this work screws of AISI 4140 steel were used to bolt the Christma's tree to his cap in offshore oil and gas production. In the moment of the cap re-motion to perform a routine maintenance five 1″ screws failed. The screws worked under cathodic protection, which means that they must have undergone hydrogen pick-up. The investigation showed that the screws had been correctly heat treated by quenching and high temperature tempering, but the sulfur content and the level of inclusions were too high. As a consequence, the screws were highly susceptible to hydrogen induced cracking (HIC). On the other hand, the analysis of the fracture surface revealed that the main cracking mechanism was fatigue. The main recommendation resulted from this work is that the specification for new screws for this kind of service must be more restrictive to sulfur and inclusions contents.

1. Introduction

The wet Christma's tree is a complex equipment which commands and controls the oil and gas production in offshore operations. The Christma's tree and it's cap, showed schematically in Fig. 1, must be subjected to cathodic protection against corrosion of the low alloys steels used in the construction.

The tree's cap is a heavy piece installed to protect the wet Christmas tree and to make easier some maintenance operations. The re-motion of the tree cap is a procedure done when simple repairs in the Christmas tree are necessary. In the present study, the tree Cap was accomplished and tied to the Christma's tree by six 1″ screws, called socket-head cap screws. The failure occurred when the tree cap had to be removed to perform a work over. During the re-motion operation all screws failed. The load estimated during the re-motion operation was 4000 kgf, distributed by the six screws.

The data sheet of the Tree's Cap indicates that the screws must be designed for H_2S service. Although the screws are not in direct contact with the oil produced, they are subjected to cathodic protection, which can provoke hydrogen pick-up. Under these conditions hydrogen embrittlement can occur, mainly in high strength steels [1–3]. The failure mode may be cleavage, intergranular, or ductile, but in the latter case the dimples are smaller and more shallow as compared to uncharged specimen [1]. Hydrogen embrittlement is also referred to as hydrogen-assisted fracture, which can include the atomic scale mechanisms due to de-cohesion (HEDE-hydrogen enhanced de-cohesion) [2,3] and localized plastic deformation (HELP-hydrogen enhanced localized plasticity) [4,5]. The prevention to this type of hydrogen assisted cracking in carbon and low alloy steels is to specify a maximum

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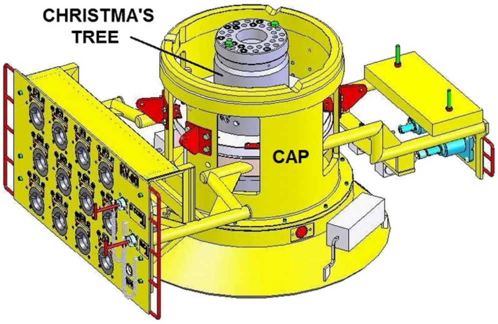

Fig. 1. Schematic of Christma's Tree with the Tree's Cap (yellow) (model provided by the manufacturer). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

hardness of 250 HV (~22 HRC) [6]. However, in practice, certificates of materials are not always reliable, and the hardness control of screws and bolts in large industrial units is not a simple task.

Hydrogen assisted cracking (HIC) is another type of hydrogen effect which can occur with or without applied or residual stress. It results from the combining of hydrogen atoms to form H_2 in preferential locations in the microstructure, such as inclusions interfaces [1]. The formation of H_2 molecule results in a local increase of pressure which provokes the nucleation of cracks in non-metallic inclusions [7]. In a second stage the cracks may become interconnected with others from parallel planes, resulting in a morphology known by "stepwise cracking" [8,9]. Blistering is another type of hydrogen damage associated to H_2 molecule formation [7,8]. These types of damages cannot be prevented only by limitation of hardness, once it can occur in low and medium strength steels. Since the inclusions are the sites for cracks nucleation, the impurities control and the reduction of sulphides and oxides is the best practice to produce steels less susceptible to HIC.

2. Experimental procedure

Fig. 2 shows the tree cap after re-motion with the location of the screws failed indicated by circles.

Four failed screws were selected for chemical analysis and hardness measurements, and two of them were selected for detailed microstructural and fractographic analyses.

Chemical analysis was performed by combustion method (C and S) and X-ray fluorescence (Cr, Ni, Mo and Mn). Vickers microhardness measurements were performed with load of 0.50 kgf (HV0.5) in two positions of the longitudinal section of the screws: ½ radius and in the filet root.

Microstructure was investigated by optical and scanning electron microscopy. First, the level of non-metallic inclusions were evaluated without etching. Then, the general microsctructure was revealed with nital 2%, and the prior austenite grains were revealed with a solution of $FeCl_3$, picric acid and distilled water. The inclusions were analyzed by energy dispersive spectroscopy (EDS) in the scanning electron microscope (SEM).

Fig. 3 shows parts of the two screws analyzed, as received. Before examination in the SEM the specimens had to be cleaned with Clark's solution ($SnCl_2 + SbO_2 + HCl$) to remove the excess of corrosion products.

One of the screws was cut longitudinally to observe the inclusions in the rolling direction. This specimen was also subjected to a hydrogen charging experience in 3.5%NaCl solution to simulate the cathodic protection. Before charging the sample was embedded in resin with a wire for electric contact. The specimen was polished with 0.1 μm alumina paste finishing. After 48 h of charging with current density of 30 mA/cm^2, the specimen was cleaned and observed in the optical microscope.

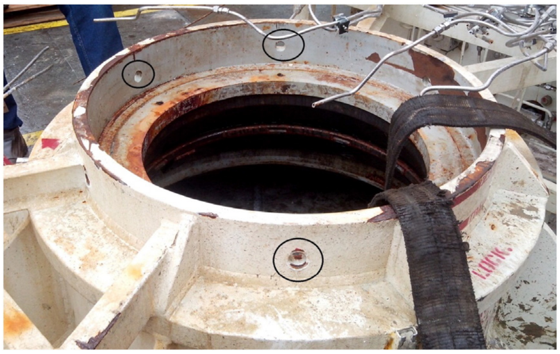

Fig. 2. Tree cap after re-motion – the location of three screws is indicated by circles.