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Failure Analysis on Stud Bolts of Chock Valve

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ABSTRACT. Laboratory investigation was performed on the damaged stud bolts of choke valve which has been installed on offshore platforms. The used and keep stud bolt of the same production batch were also examined as a reference. The damaged sample was found badly corroded and parted in a brittle manner. The fracture surface of damaged stud bolt was found has a sign of excessive torsional stress. The chemical composition of keep and used samples proven that stud bolts were in compliance to ASTM A320 grade L7 specification. The coating thickness analysis was conducted on keep and used sample by scanning electron microscope using backscattered signal. A significant depletion occurred on the top coat. Metallographic analysis shows the presence of branched cracking on a damaged stud bolt. It proves that there was a slightly residual stress suffered by the damaged sample. The microstructure for keep and damaged sample were tempered martensite whereas the microstructure of used sample was characterized as fine grained ferritic-bainitic microstructure. The laboratory analysis revealed that the root cause of failure was primarily as a result of overtightened of the stud bolts to choke valve during installation. The hardened steel in form of tempered martensite structure is indeed brittle and easily cracked by means of slightly overloaded stress. Another factor was a depletion problem of top coating creates exposure of underneath the metal to corrosive environment.

Keywords: *Failure Analysis, Stud bolts, Hardened steel, Over-tightened, Tempered martensite, Ferritic-bainitic steel;*

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1. INTRODUCTION

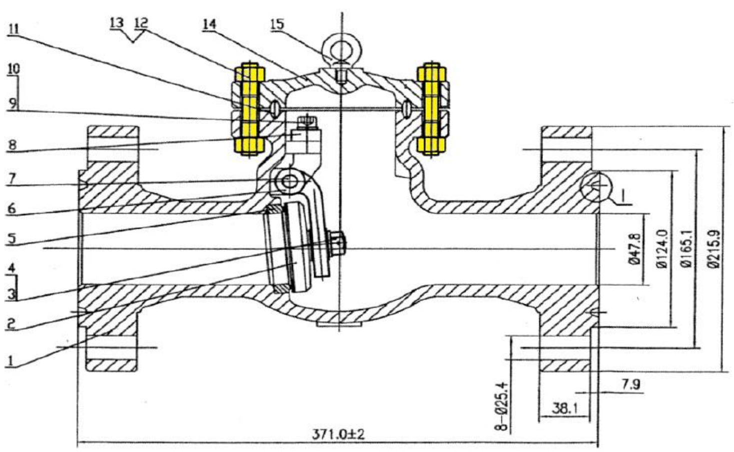
Stud bolt is a threaded rod with 2 hexagon nuts for assembly of the choke valve. In particular, stud bolts can be a major source of concern engineers. Frequently, assumptions are made to assess whether the assemble parts are capable of sustaining the force applied upon it. Failure of stud bolts can have disastrous consequences for the reliability and safety of assembling parts. Stud bolts are typically made from high strength steels, which when fully tightened, exert high clamp force onto assemble area [1]. The area directly under the stud bolts head or but face sustains the high bearing stress. If the maximum stress limit of the joint material is exceeded, then deformation occurs over a period of time. This leads to the extension being lost in the stud bolts, resulting in the clamp for subsequently being reduced [2].

Before this, the stud bolt failure has occurred during drilling operations in the Gulf of Mexico (GOM). Leakage was detected as a cause of failure due to severe stress-corrosion cracking fracture of the bolts on the valve. The failure of the GE H4 connector bolts at the same place was primarily caused by due to hydrogen embrittlement. It was found out that the material hardness and strength were not in compliance with the recommended specification [3]. Due to that, almost 10,000 bolts were replaced over a relatively long time frame and long-term disruption of offshore activities and cost more than billions [4] .

Over torqueing is another cause of failure. Overtightened after the bolt fails is difficult, but would be a significant help in determining the circumstances leading to failure. The intergranular fracture

mode was also suggestive of an environmental cause [5] .One case was examined in which slew ring bolts on an offshore crane were twisting off when tightening with a calibrated system to the specified torque. The torque specified was for dry threads; however Loctite had been applied to the threads prior to torqueing. Calculations showed that lubricity from the Loctite increased bolt stresses to failure levels at the specified torque points [6].

In this case, an investigation has been carried out for stud bolts installed at a choke valve in one of the Malaysia's offshore platforms. The damaged bolts were assembling the body and bonnet parts of a chock valve. According to valve general drawing (Fig.1), body and bonnet material was duplex stainless steel (ASTM A995 4A), while bolt and nut materials were ASTM A320 grade L7 and ASTM A194 grade 4 respectively. General drawing has specified fluorocarbon coating for bolts and nuts. The coating systems include a cermet basecoat, which provides the corrosion resistance, and a fluoropolymer topcoat, which is intended to reduce torque-up friction. According to the client, stud bolts had been assembled in vertical position and had been in service for less than two years. This paper reports the failure investigation of damage stud bolts of choke valve. Some materials characterization of keep and used stud bolts was also reported as a reference



BILL OF MATERIALS		
NO.	PART NAME	MATERIAL
1	BODY	A995 4A
2	DISC	A995 4A
3	WASHER	316
4	LOCK NUT	A193 B8M
5	SEAT	A182 F51 + ST6
6	ARM	A995 4A
7	HINGE PIN	A182 F51
8	ARM YOKE	A995 4A
9	WASHER	316
10	BOLT	A193 B8M
11	SEAL RING	SS316 OVAL RING
12	STUD	A320 L7 + FLUOROCARBON COAT
13	NUT	A194 4 + FLUOROCARBON COAT
14	BONNET	A995 4A
15	SCREW RINGS	COMMERCIAL STEEL

Fig. 1 Assembly drawing of choke valve. The stud bolt was marked in yellow color

2. MATERIALS AND METHODS

The material characterization was carried out on two types of stud bolt samples, i.e. keep and used stud bolts. The keep the stud bolt is the same production batch, which was actually keeping by the manufacturer. The used stud bolt is the different production batch and it has been operated to the platform for two years. The used sample did not suffer any abnormal failure and visibly there were some scratches on the top coat and rusty threads. The damage stud bolts were parted and badly corroded.

Firstly, the chemical composition analysis was carried out on keep and used samples. It was done by using the optical emission spectrometer (Q8 Magellan, Bruker) to ascertain the compliance of stud bolt material to the ASTM A320 Gr. L7 specification. The damaged stud bolts were electrostatically cleaned by chemical solution. Visual inspection was documented by using digital DSLR camera (D3100, Nikon) to record the original condition before and after the cleaning process (Fig. 2). The closed-up photographs were zooming by stereo-microscope (SZX16, Olympus) on damaged sample. Then all the specimens were grounded up to 1200 SiC grit paper and polished using 6 µm and 1 µm diamond solution. The metallographic analysis was examined by metallurgical microscope (BX41, Olympus) on the keep, used and damaged samples. The samples were then etched by using 2% nital solution to figure out the microstructure. The coating thickness of fresh and used specimen was analyzed by means of field emission scanning electron microscope (Nova NanoSEM™450, FEI) using backscattered detector.

3. RESULTS AND DISCUSSION

The visual inspection found that the keep stud bolt appeared as a dark-blue coated color. The used stud bolt sample was worn and faded to be light-blue, there were some light scratches on the surface and rusty threads. Although it has been used for 2 years on the choke valve on the same platform, but this sample still looks good and can be operated in service again. The damage sample was catastrophically parted and appeared as badly corroded stud bolt (Fig. 2a). Some coating layer was observed still remain on the surface. It shows the uniform corrosion was penetrated under coating layer. Fig. 2(b) shows the as-cleaned of damage sample. When the rust was cleaned, then it was obvious that bolt studs were mainly suffered by uniform corrosion and some wide and shallow type pitting in several areas. Visibly, the stud bolts were parted with no visible distortion. All of the stud bolts were fractured in the brittle manner and this normally happens to hardened steel which known has brittle properties.

(a) (b)

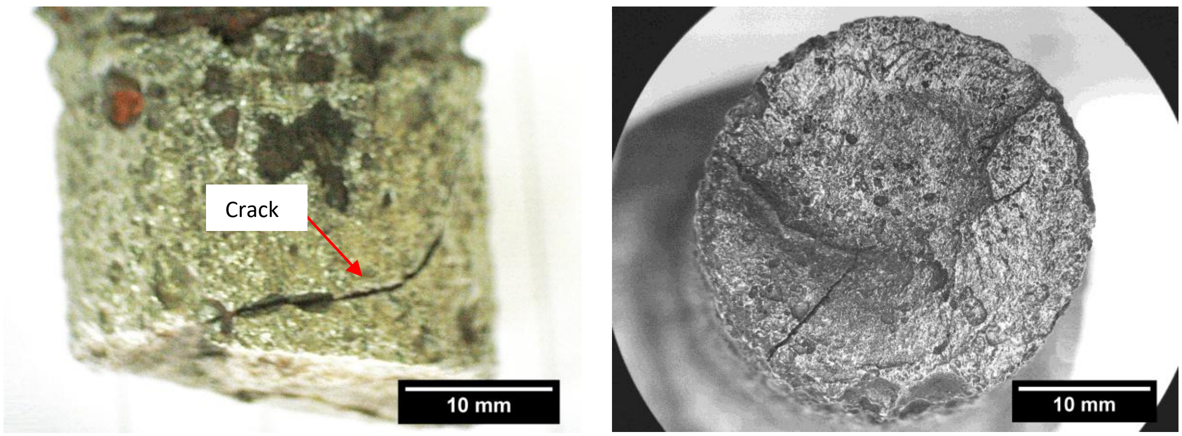
Fig. 2 Camera photographs of (a) as-received damaged and (b) as-cleaned of damaged stud bolt samples

The steel composition of the keep and used stud bolts shown in Table 1. The analysis result was compared the material classification of the American Society for Testing and Material (ASTM). It was observed the chemical composition of both stud bolts were within the specification of ASTM A320 grade L7. Therefore, a failure due to chemical composition can be neglected.

Table 1 Chemical composition (wt.%) of stud bolt sample

Element	ASTM A320 grade L7	Keep	Used
C	0.38 - 0.48	0.385	0.378
Si	0.15 - 0.35	0.313	0.283
Mn	0.75 - 1.00	0.785	0.827
P	0.035 max	0.012	0.013
S	0.04 max	0.0061	0.0059
Cr	0.8 - 1.10	1.072	0.982
Mo	0.15 - 0.25	0.17	0.18
Fe	Balance	Balance	Balance

The closed-up photographs by stereo-microscope on damaged specimen were displayed in Fig. 3. As referred to Fig. 3(a), the excessive transverse cracked occurred at 30° to 40° direction which indicates that there was a torsional stress effect. The pitting corrosion marks on the stud bolt surface were seen. Fig. 3(b) shows the fracture surface of the parted stud bolts. Generally, the fracture looks like a torsional fatigue failure. This photographic image illustrates the fault that begins on the outer surface and ended at the center of the stud bolt bar. It was not very clear due to rust effect, nonetheless there were some multiple crack nucleation sites around the outer surface. With residual stress together with the vibrations inherent as the operation of the choke valve, the stud bolt finally cracked, propagated inward and finally breakdown at the center.



(a) (b)

Fig. 3 Stereo microscope image on as-cleaned failed stud bolts focusing on (a) side and (b) top of the fractured area

Metallographic analysis was carried on keep, used and damaged stud bolt samples. The keep sample consists of some ferrite (white) in fine tempered martensite (Fig. 4a) whereas the structure of the used sample was ferrite (white) and carbide (black) constituents in fine grained ferritic-bainitic microstructure (Fig. 4b). Microscopically, the damaged stud bolt structure consisted of largely tempered martensite with the formation of cementite particles at the martensite lath boundaries and within the laths (Figs. 4(c,d)). The cracks occurred transgranularly (Fig. 4(b,c)) and branched (Fig. 4d). The transgular crack proved the fractured was caused by overloading stress, whereas the branched crack demonstrated the stud bolts was suffered by the residual stress during the installation works. As the used sample exhibits a different microstructures than others, it was thus clear that there is an inconsistent pattern of microstructure pattern among the different manufacturing batch of stud bolts. This may happen coincidentally or might be due to a mistook that occurs during the manufacturing process level. However, in the choke valve operation condition at offshore platform, this type of fine grained ferritic-bainitic microstructure have proven that it has a better toughness than tempered-martensite structure. It did not fail under torsional residual stress.

The coating layer thickness was measured by means of scanning electron microstructure as displayed Fig. 5. The thickness of top and base coat for keep sample was approximately 30 μm and 20 μm respectively (Fig. 5a). On the other hand, the damaged specimen meanwhile, suffers depletion problem by time where the top coat decrease to 10 μm (Fig. 5b). The depletion of top coat was also believed to occur with the damaged sample. The weakness of this top coat causes the exposure of underneath metal to corrosive environment resulted in the occurrence of under-coating corrosion leads to pitting and finally accelerates the crack propagation process of stud bolts.

Overall, out of all the analysis findings, it can be summarized that stud bolt bar failure was due to the hardening process of steel that forms a hardened and brittle martensite microstructure. The brittle metal materials are easilly to crack or fracture. The probability for contractor worker to make a careless mistakes during stud bolt installation using the torque wrench is might be happened or maybe the installation is done manually. Based on the evidence that there were signs of torsional stress on the stud bolt studs, therefore one of these human errors is indeed true. Therefore, with the metal residual stress due to faulty during installation, coupled with the brittle metal and the vibration condition of choke valve service, then the cracking process has indeed occurred. In addition, the faulty process also occurs due to the depletion of top coat that leads to pitting problems

on surfaces that are a factor to the occurrence of stress riser. With this pitting, the cracking propagation of stud bolts began started from this surface discontinuity.

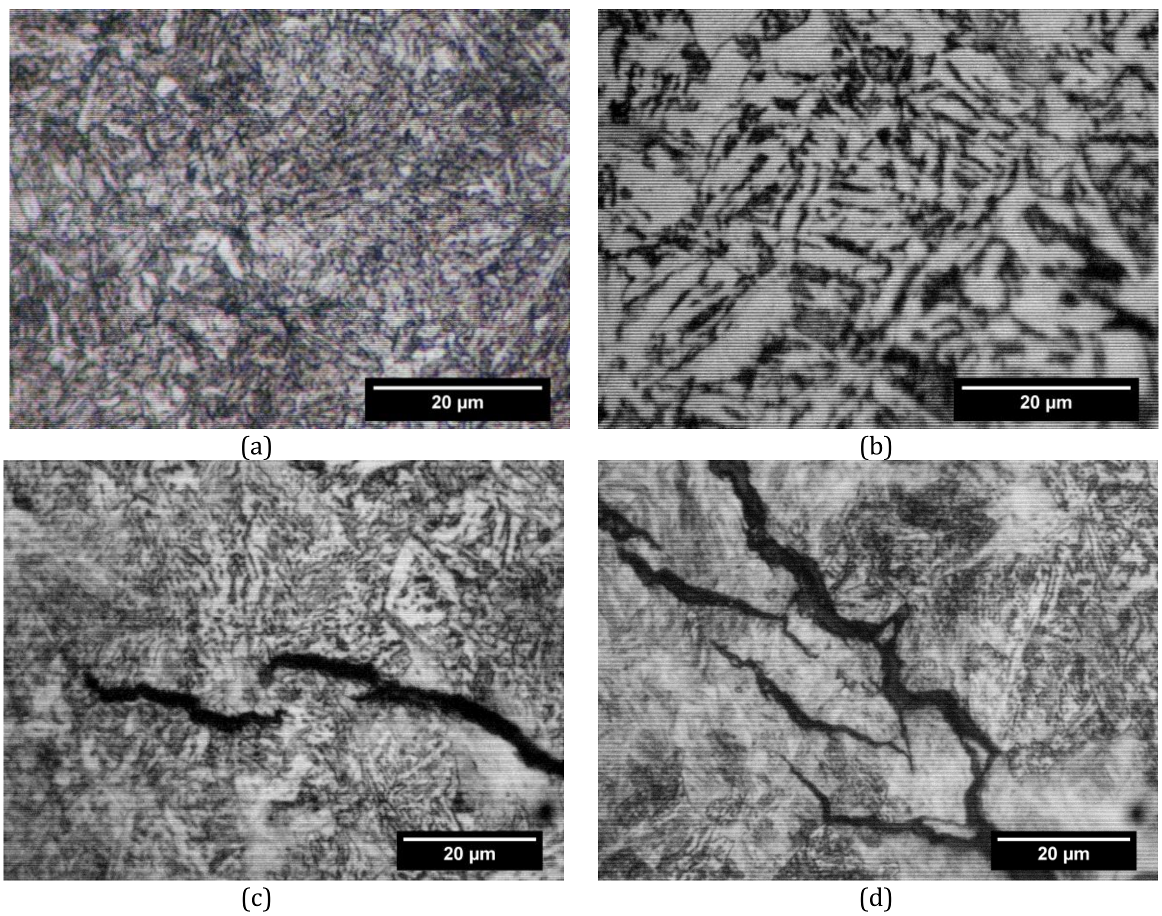
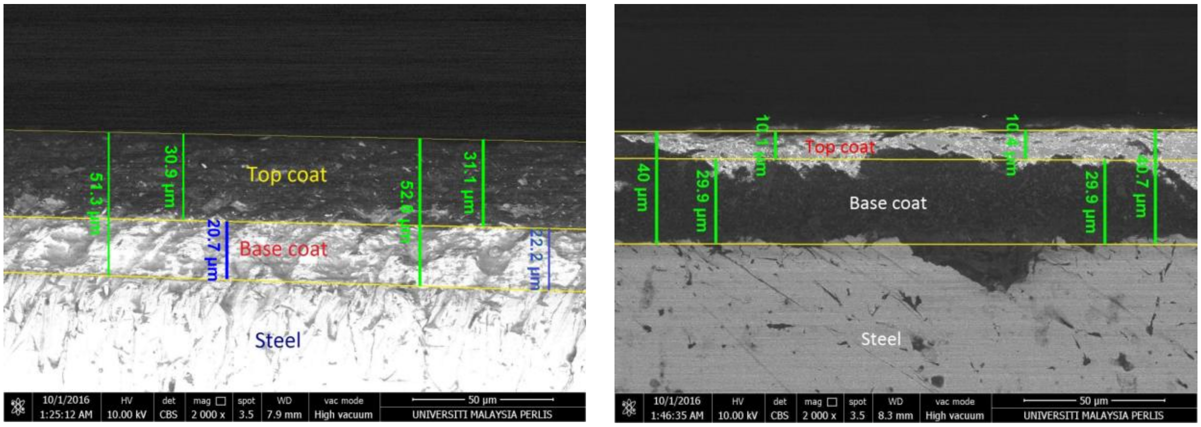


Fig. 4 Optical metallographs on the etched cross-sectional surface of (a) keep, (b) used and damaged stud bolts shows (c) a transgranular and (d) branch cracking



(a) (b)

Fig. 5 SEM micrographs of the cross-sectional surface for (a) keep and (b) used stud bolts to show the thickness measurement

The application of tempered martensite hardened steel as suggested by ASTM A320 grade L7 could be replaced by ferritic-bainitic steel. The microstructure of ferritic-bainitic steel consists of a softer ferrite matrix with fine bainite as second phase. The second hard-phase bainite and grain refinement make ferritic-bainitic steel a materials with excellent formability, improve stretchability of sheared edges [7]. Ferritic-bainitic steel provide higher strain hardening exponent at the same level of strength as reported by Pathak et al. [8]. They also good fatigue properties and crash performance, allowing a good performance under dynamic loading [9]. In order to overcome the top coating problems, the coating materials are recommended to replace by pure epoxy materials by electrostatic powder coating technology. The powder coating technology has been known producing a high corrosion resistance, robust and wear resistance.

4. SUMMARY

The failure of stud bolt was essentially due to the nature of the hardened steel containing tempered martensite structure which have hard and brittle properties. The existence of internal residual stress by reason of excessive torque resulted the stud studs metal has low ability to absorbed the stress attributed from overtightening. This condition become worsen when the stud bolt in which have been assembled on a choke valve that operates in vibration conditions. In addition, the depletion of top coat also contributes the the exposure of steel surface to corrosive environment to caused pitting corrosion which creates a starting point of crack propagation.

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