Failure of 316/316L Grade Stainless Steel Tubing & Analysis of Corrosion in Corrosion Resistant Alloy

Sujit CHAKRAVARTY
Velosi (M) Sdn. Bhd.
Telephone: +60 (85) 435 978; Fax: +60 (85) 435 997; Email: sujit@velosi.com

Abstract: AISI- 316/316L is an Alloy Widely Regarded as One of the Favorite Corrosion Resistant Alloy(CRA) for Offshore Operators in Oil and Gas Sector. A recent failure occurred to a hydraulic oil tubing for wellhead inside a remote controlled offshore platform that leads to unplanned shut down and huge production loss. This study was made to know the root cause of such failure and find out possible mitigation. The study employed visual examination together with photography, Scanning Electron Beam Microscopy (SEM) and X-ray Diffraction Spectroscopy (EDS) to do the metallographic and fractographic analysis. Result of the analysis shows the sign of development of pinholes due to external surface corrosion created by deposits (due to sea water exposure) specially at the clamps, leads to leakage. Reliability of the hydraulic control always dependent on containment of hydraulic fluid within the system. A leakage can jeopardize the operation of oil and gas producing organization added cost of failure and production losses. This study can be very much useful to offshore oil & gas operators who has similar kind of assets. The choice of CRA sometimes gives a kind of confidence that corrosion will not happen at all in those assets but may not be 100% sure that it will not fail leads to a costly shut down. Sea water corrosion can be marginalized by using alloys like Inconel/Monel.

Keywords: Corrosion Resistant Alloy(CRA); Failure Analysis; Scanning Electron Beam Microscopy (SEM); X-ray Diffraction Spectroscopy (EDS).

1. Introduction

Remote controlled offshore platforms are key assets for oil and gas industry, often faced with sudden failures of components, which compels the operator to have unplanned shutdown and face production loss. The failure analysis of AISI 316/316L stainless steel (CRA) instrument control tubing of a wellhead had occurred in recent past and following investigation was done to address the causes of the failure and probable mitigation.

2. Methods of Investigation

2.1. Visual Inspection:

Hydraulic oil tubing, which control instrument of a remotely operated oil and gas platform wellhead was leaked and leads to immediate shutdown. Inspection team was sent to do visual inspection of the same and found leaked stainless steel (AISI 316/316L) tube at the clamp contact point. It was noted that the leakage is located at 12 O'clock position and surface contaminant accumulated at 6 O'clock position. There was no sign of contaminant found in inside surface. The failed tube was taken out of service after depressurization of hydraulic system and sent for failure analysis laboratory (Figure 1&2).
2.1.1. Result of visual inspection after cleaning

The collected tube sample was ultrasonically cleaned in acetone and further visually examined. The corrosion pits observed on the surface were very small (less than 0.5 mm). Refer to the Figure 3 below.
2.2. **Analysis by Optical Emission Spectroscopy:**

Chemical composition analysis was done by using optical emission spectroscopy on small sample of the tube to verify base metal chemical composition and the test result as the table below.

<table>
<thead>
<tr>
<th>Element</th>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% P</th>
<th>% S</th>
<th>% Cr</th>
<th>% Mo</th>
<th>% Ni</th>
<th>% N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>0.029</td>
<td>0.427</td>
<td>1.65</td>
<td>0.028</td>
<td>0.01</td>
<td>17.471</td>
<td>2.43</td>
<td>13.441</td>
<td>0.035</td>
</tr>
<tr>
<td>316/316L*</td>
<td>≤ 0.035</td>
<td>≤ 1.00</td>
<td>≤ 2.00</td>
<td>≤ 0.045</td>
<td>≤ 0.03</td>
<td>16 - 18</td>
<td>2 - 3</td>
<td>10 - 14</td>
<td>-</td>
</tr>
</tbody>
</table>

* Table 1 ASTM 312/A 312M-09 "Standard Specification of Seamless, Welded and Heavily Cold Worked Austenitic Stainless Steel Pipes"

The Pitting Resistance Equivalent No. (PERN) of the tube is approximately 26 for this material using formula $\text{PERN} = \%\text{Cr} + 3.3 \times \%\text{Mo} + 16 \times \%\text{N}$ [1]. PERN of AISI 316/316L in this case is insufficient for services in marine environment.

2.3. **Hardness Testing**

The tube was tested for the Vickers hardness on its cross section near the leakage area by applying 1Kgf penetration load and following result was obtained.

<table>
<thead>
<tr>
<th>Sample</th>
<th>HV/ 1Kgf</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tube</td>
<td>136</td>
</tr>
</tbody>
</table>

It shows that mechanical properties are persistent with the grade of stainless steel. AISI 316/316L shall have HV 217 (maximum) or below.

2.4. **Metallographic Examination**

The tube was cut through the longitudinal direction to prepare a cross section for metallographic examination. The cross section was mounted on polymeric resin ground polished and etched as per conventional metallographic examination procedure. Microscopic view as per figure 4 below shows that the initial corrosion pitting was started on the surface, propagated inside and made a bulbous cavity before the break through the internal surface to make the leakage happen. The magnified defect cross sectional view (Figure 5 & 6) shows the surface opening is very small compare with the through thickness damage.
2.4.1. *The Result of the Metallography*

The result of metallographic testing suggests that the sea water together with rainwater exposure was taken place to from the very small pitting corrosion in CRA material.

2.5. *Analysis by Scanning Electron Beam Microscopy (SEM):*

Scanning electron beam microscopy (SEM) was employed to the failed tube to determine the topographical study of stainless steel at the area of failure. This method was selected to analyze and investigate corrosion pitting under high magnification and high resolution surface viewing. The observation of Figure 7 & 8 revealed details of SEM images.

Figure 6
Showing details of through wall cavity of the tube
(a& b) Corrosion pitting; (c) Corrosion pits filled with deposits; (d) Corrosion pitting with traces of deposits; (e & f) Deposits at the edge of the intergranular space.
2.5.1. Result of SEM

The result of the SEM suggests that there are traces of deposits at the pits and further magnification shows the deposits also propagates to intergranular space. The marine environment have dissolved salt, which can be slowly fill up the intergranular space further propagates corrosion deep inside the metal and break the structural strength at micro-structural level.

2.6. Analysis by X-Ray Diffraction Spectroscopy (EDS):

The sample was investigated by using X-Ray Diffraction Spectroscopy (EDS) and traces of Chlorine (Cl) was found, which leads to predominant chloride induced corrosion. The intergranular corrosion can happen in AISI 316L stainless steel by electrochemical reactivation [2]. Figure 9 & 10 shows the result of EDS. The analysis confirms that accumulation of salt deposit, specially at the clamp, which works like trap, in the marine environment. Sea water/vapor exposure and rain water starts reactivation of electrolytic for the corrosion cell.
3. Conclusion

The well accepted CRA material (AISI 316/316L) had failed under certain boundary condition (environment, weather condition) may found it unfit for its serviceability objective. Sea water is very often described as 3.5% NaCl solution[1] and PREN 26 is considered low
pitting resistivity and there are eight separate types of corrosion with a few having major impact on stainless steel[3][4]. Intergranular corrosion (IGC) can proceed to the point, when the whole grain of the metal falls away and the metal loses its strength[9]. In this case phase morphology did not took place, which was one of the suspect leading to failure, case like austenitic to martensitic transformation may have been considered a major factor to create displacive/diffusionless phase transformation[5][6]. Crevice corrosion in 316L stainless steel is now accepted as one of the probability under sea water environment [7]. Chromium carbide formation in elevated temperature above 30˚ C can cause less density of Chromium at the grain boundary effectively lowering the corrosion resistance furthermore [8]. The Super Duplex Stainless Steel, which has PREN about 40 may considered more resistive in marine environment. INCONEL 622 Alloy is widely used in fire deluge systems using sea water as fire extinguishing medium in the platforms is also an interesting alternative provided its cost obligation fits with the project cost/budget. It has a greater sea water corrosion resistance in this regards[9]. MONEL 400 Alloy can be treated a good alternative to have better pitting resistence[9]. INCONEL® alloy 625 is a nickel-chromium-molybdenum alloy is stabilized against intergranular attack by precipitation of niobium carbides at a 927 to 1038˚C (1700 to 1900°F) annealing temperature [10].

4. Acknowledgement

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5. References:

[1] Corrosion of 316L Stainless Steel in Sea Water; By Prof. Em. Dr. Ir. J. Defrancq.
[2] DETERMINATION OF SUSCEPTIBILITY TO INTERGRANULAR CORROSION IN AISI 304L AND 316L TYPE STAINLESS STEELS BY ELECTROCHEMICAL REACTIVATION METHOD: By GÜLGÜN HAMİDE AYDOĞDU; The Graduate School of Natural and Applied Science; Middle East Technical University.


