ANALYSIS OF A CRACKED HEAT EXCHANGER TUBE

EXAMPLE REPORT

OVERVIEW & OUTCOME

A heat exchanger tube had leaked in service and NDT inspection found several other tubes to contain cracks. This heat exchanger been installed in 2009 yet three other identical heat exchangers had run for fifteen years without issue. As failure had occurred rather quickly, the inspector had the cracked tube analyzed to (a) determine the details of cracking and (b) assess is an issue with the material quality had contributed to cracking.

The analysis found that cracking and pitting had occurred from stress corrosion cracking (SCC) driven by the presence of chlorides. The material was of reasonable quality. Therefore, cracking was associated with operation factors specific to excursions of (a) chloride treatment and/or (b) operating temperatures. Due to the nature of damage, the other tubes would have sustained damaged and it was recommended that the tube bundle be replaced. Similar heat exchangers on the same feedwater may also have sustained similar damage and warranted inspection.

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ANALYSIS OF A CRACKED HEAT EXCHANGER TUBE

1.0 INTRODUCTION

A heat exchanger tube had leaked during service and subsequent eddy current testing had found numerous additional indications within the leak region. Steel Image was requested to determine the nature of cracking.

The heat exchanger had been built in 2009. The 5/8 inch seamless, 14 gauge tubes comprised of SA-789 31803 duplex stainless steel. The tubes held hydrogen at an approximate pressure of 1300 psig and at temperatures of ~200ºF. Surrounding the tube was cooling lake water. The region of cracking/leaking had occurred within an insulated portion of the tube and therefore, had not experienced the full cooling effect of the water.

It was reported that the heat exchanger may have experienced a spike in the chloride level for less than one day.

2.0 EXAMINATION

2.1 Visual / Macroscopic Examination

Figure 1 displays the submitted tube for analysis. The tube comprised of two large cracks and obvious pitting on the outer diameter. The primary crack appeared to correspond to three large pits illustrated in Figure 2b,c. Numerous smaller cracks were visible under 10x magnification and two examples are presented in Figure 2d,e. The pitting and cracking had only occurred on one side of the tube within a small vicinity.

No obvious damage or deterioration was observed on the inner diameter surface.
2.2 SEM Examination

After cleaning, SEM examination found the outer diameter surface pitting within the vicinity of interest to be more extensive than that observed visually. Corrosion had preferentially attacked one of the phases (Figure 3). Optical examination would later find that within the surface pitting, the ferrite had been preferentially corroded.

2.3 Optical Examination

Cross-sections were taken (a) at a remote location, (b) through the primary crack and (c) through the adjacent vicinity containing micro-cracks. Samples were prepared for metallographic evaluation in accordance with ASTM E3. Optical examination found all locations, including within the cracked vicinity, to comprise of a core structure typical of SA-789 31803 duplex stainless steel. As illustrated in Figure 4, the core structure comprised of a ferrite and austenite with an approximate ratio of 60:40 respectively.

The primary crack and numerous other cracks were identified to have occurred by stress corrosion cracking (SCC). The cracks exhibited branching features classic for stress corrosion cracking. The cracks had initiated from the outer diameter surface, generally from surface pitting. Figures 5, 6 and 7 illustrate the primary crack and examples of additional cracks.

No damage or deterioration was observed along the inner diameter surface of the tube.

2.4 EDS Analysis

The corrosion product within Cracks #2 and #3 were analyzed using energy dispersive spectroscopy (EDS) techniques. The corrosion product within the surface pitting and the cracks consisted of numerous elements typical of the duplex plus the addition of oxygen, chlorine, magnesium and calcium (Figures 8 and 9). Of these additional elements, chlorine was of the greatest interest. Chlorides are known to cause stress corrosion cracking within duplex stainless steels. Thus, the cracks were likely chloride induced stress corrosion cracking.

2.5 Hardness Testing

Microhardness testing was conducted on the tube at the remote location and within the vicinity of the cracking. Testing was performed in accordance with ASTM E384 using a 500gf load. Table 1 lists the obtained results. The hardness values conformed to the SA-789 31803 hardness requirements.
Table 1: Microhardness Test Results

<table>
<thead>
<tr>
<th>Location</th>
<th>Measurements (HV$_{500gf}$)</th>
<th>Avg. Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA-789 31803 Req</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remote</td>
<td>290, 282, 279, 274, 279</td>
<td>280</td>
</tr>
<tr>
<td>Through Primary Cracks</td>
<td>265, 269, 278, 286, 278</td>
<td>275</td>
</tr>
</tbody>
</table>

2.6 Chemical Analysis

Chemical analysis of the tube was performed in accordance with ASTM E1019, E1097mod and E1479. Table 2 lists the obtained results. The chemical composition conformed to the SA-789 31803 requirements.

Table 2: Chemical Analysis Results

<table>
<thead>
<tr>
<th>Composition (wt%)</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.013</td>
<td>1.30</td>
<td>0.38</td>
<td>&lt;0.005</td>
<td>0.03</td>
<td>5.42</td>
<td>22.4</td>
<td>3.09</td>
<td>0.174</td>
</tr>
</tbody>
</table>

3.0 CONCLUSIONS

Tube cracking had occurred from chloride stress corrosion cracking. Pitting and stress corrosion cracking had occurred/initiated on the outer diameter of the tube. This side corresponded to the cooling lake water.

Chloride stress corrosion cracking occurs as a function of (a) chloride concentration, (b) stress, (c) temperature and (d) material susceptibility. No issues with the core material were found which would have decreased the material’s corrosion resistance. Assuming the hydrogen pressure was maintained at typical levels, excursions of either temperature or chloride concentration had likely caused conditions leading to stress corrosion cracking. Note that at least one short term spike in the chloride levels had been reported.

As other tubes within this bundle would have also experienced similar service conditions, it was likely other tubes had also experienced damage from stress corrosion cracking. It is recommended that the remainder of the tube bundle.

The tube material conformed to the compositional and hardness requirements as per SA-789 31803. The core microstructure was typical for a SA-789 31803 duplex stainless steel. No issues with the material quality were observed.
Figure 1: Photographs displaying the submitted sample and the visible, primary cracks. In addition to these large cracks, numerous small cracks were observed. Surface pitting was present at the cracks and within the neighbouring vicinity.
Figure 2: Macrographs displaying the (b,c) primary crack and (c,d) examples of small, micro-cracks present in the near vicinity.
Figure 3: SEM images of the pitting and primary crack. The pitting damage appeared to have been caused by preferential corrosion of one phase within the duplex steel. Optical examination would show the ferrite had been preferentially attacked. SE1, 20kV.
Figure 4: Micrographs displaying the core material structure (a,b) far remote from the cracking, (c,d) at the primary crack, (e,f) within the vicinity of the micro-cracks. The core structure was typical of SA-789 31803 duplex stainless steel, comprising of ferrite and austenite. Electrolytically etched using 10% NaOH.
Figure 5: Micrograph displaying the cross-section through the primary crack. The stress corrosion crack had initiated at the outer diameter. (b,c) electrolytically etched using 10% NaOH.
Figure 6: Micrograph displaying a stress corrosion crack growing from pitting damage on the outer diameter surface. (b,c) electrolytically etched using 10% NaOH.
Figure 7: Micrographs displaying a third example of a stress corrosion crack initiating on the outer diameter surface. (b,c) electrolytically etched using 10% NaOH.
Figure 8: EDS analysis detected chlorine within the corrosion deposits of the surface pitting and Crack #2. Chlorides are known to cause stress corrosion cracking of duplex stainless steels.
Figure 9: EDS analysis of the Crack #3. Chlorine was detected within the corrosion product within the crack and at the crack tip. Chlorides are known to cause stress corrosion cracking of duplex stainless steels.