

Failure Analyses On A Super Duplex Stainless Steel Tube Material Before And After Slow Strain Rate Testing In Sour Conditions – Part 2: A Case Study On Local Corrosion

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ABSTRACT

A failure analysis has been performed and discussed in Part 1 on the tube material of UNS S32750 and the specimens which showed SCC susceptible after the SSRT in a sour environment in pH 2.8, pH 3.5 at 80 °C.

In this Part 2, a case study has been performed on local corrosion on surface corrosion attack observed on two specimens. Scanning electron microscope (SEM) equipped by energy-dispersive X-ray spectrometer (EDS) analysis and Electron backscatter diffraction (EBSD) measurements have been used. On a specimen tested in pH 2.0 at 50 °C, selective dissolution (SD) has been identified in austenite and thin uniform corrosion on the surface in ferrite, no crack has been observed under the corrode surface. On a specimen tested in pH 4.5 at 80 °C, both SD and cracking have been observed under the line corrosion in shoulder area. EBSD revealed that micro cracks initiated in ferrite with enhanced strain/deformation in frontend of selectively dissolved austenite. Dry-wet condition is supposed, which would make the local condition of a thin liquid layer more severe compared to the bulk liquid testing condition. The surface analysis methods showed a good way for failure analysis, which might be helpful in other complicated cases.

Key words: Duplex stainless steel (DSS), super duplex stainless steel (SDSS), stress corrosion cracking (SCC), selective dissolution (SD), scanning electron microscope (SEM) equipped by energy-dispersive X-ray (EDS) analysis, and electron backscatter diffraction (EBSD) measurement.

INTRODUCTION

In an earlier study¹, a final tube product of super duplex stainless steel (UNS S32750) has been tested in NACE⁽¹⁾ standard solution A (50 g/L NaCl, 5 g/L NaCH₃COO), under 0.5 bar (7.25 psi) H₂S at temperature 23 °C, 50 °C, 80 °C and pH 2.0, 2.8, 3.5, 4.5, and 6. The super duplex tube product showed SCC susceptible and underwent selective dissolution in austenitic phase (γ) at 80°C when pH $\leq$ 3.5, see T-pH domain and stress-strain curves in Figure 1.

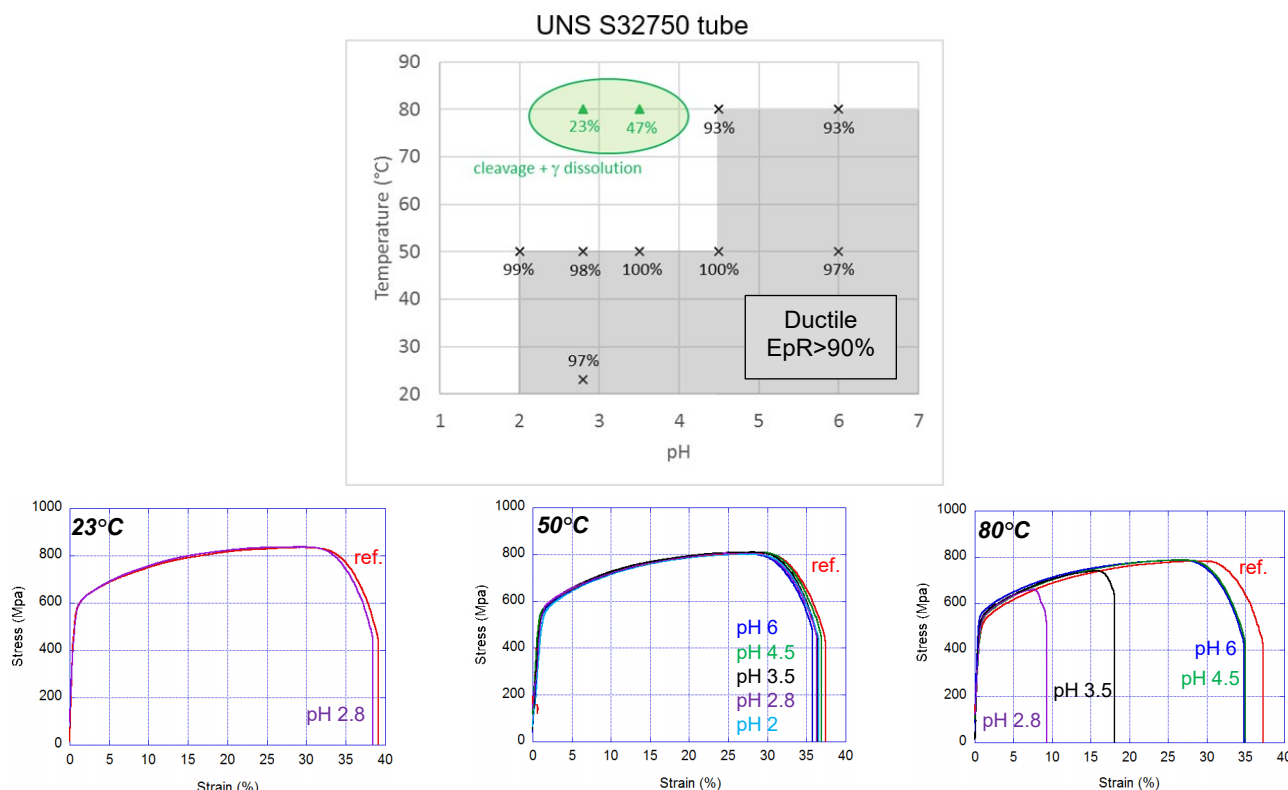


Figure 1: T-pH domain (upper picture) for a UNS S32750 tube material by SSRT in NACE Solution A: 50 g/L NaCl, 5 g/L NaCH₃COO, acidified by HCl for reaching the specified pH, 0.5 bar (7.25 psi) H₂S. Plastic elongation ratio (EpR > 90%) in the grey condition area; SCC and austenite SD were observed in the green condition area. Stress-strain curves in lower pictures.

The investigation on the specimens in the SCC susceptible conditions is included in Part 1, AMPP conference paper C2022-17998². In this Part 2, a case study is presented on the local corrosion on specimen surface or shoulder area although high ductility ratios in two testing conditions.

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RESULTS AND DISCUSSION

Optical microscope observations of SSRT specimens

All the SSRT specimens have been observed using an optical stereo microscope. The specimens with local corrosion shown in **Figure 2**, are included in case study using SEM-EDS and EBSD in this case study. Although the high ductility ratios, corrosion has been observed on specimen surface tested at 50 °C, pH 2.0; whereas, localized corrosion has been observed on the specimen tested at 80 °C, pH 4.5, in one of the specimen shoulders, including two parts of circumferential corrosion lines, no corrosion observed on the fracture surface and gauge section.

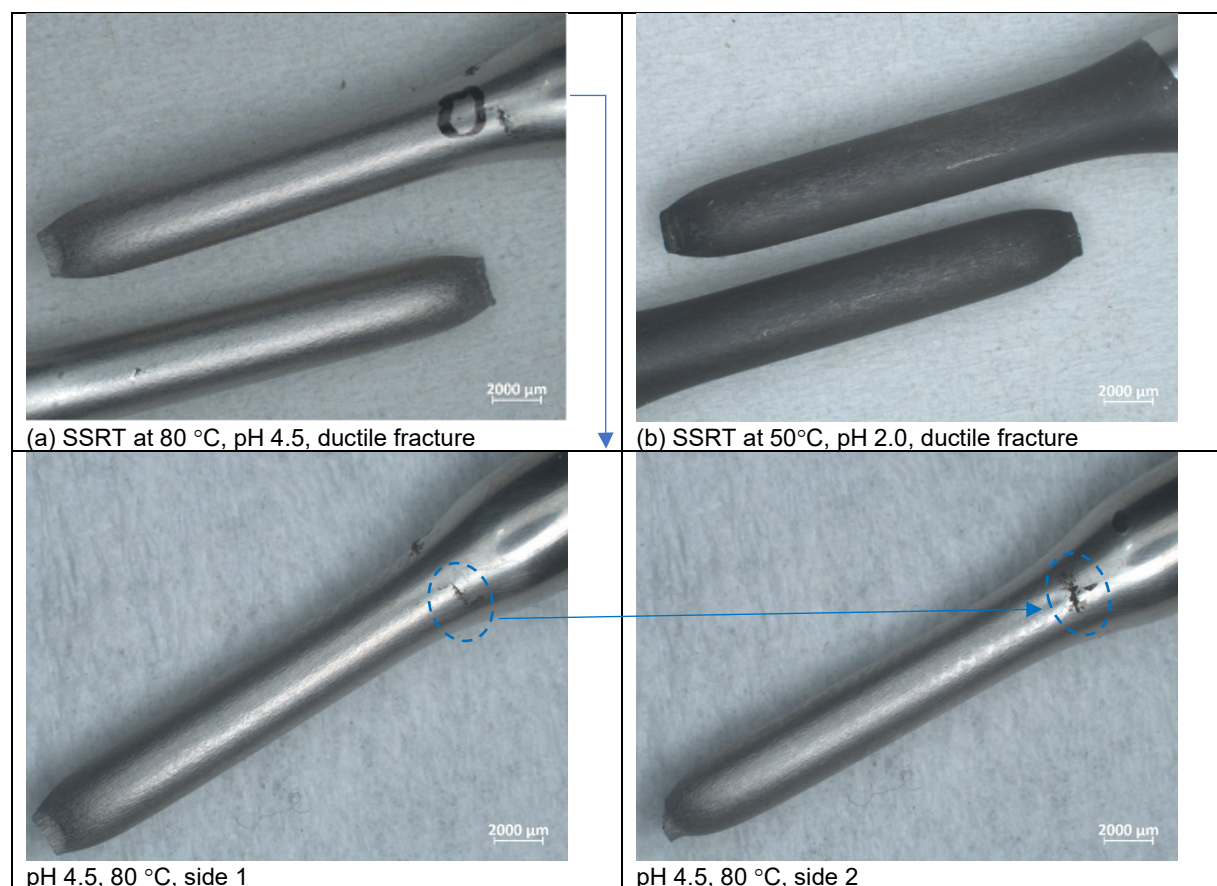


Figure 2: Although high ductility, no SCC has been observed on two SSRT specimens tested in the sour environment at 80 °C, pH 4.5 (a) and 50 °C, pH 2 (b), localized corrosion has been observed on one specimen shoulder (a) and uniform corrosion on specimen surface (b).

SEM-EDS investigation on specimen surface and fracture surface

SSRT specimen, 50 °C, pH 2.0

SSRT specimen after testing in pH 2.0 at 50 °C showed ductile fracture with high ductility ratios and no secondary cracks. However, the specimen was covered by black corrosion products, see image (d) in **Figure 2**. SEM images show that both uniform corrosion and selective corrosion have occurred, no secondary cracks observed. EDS elemental mapping confirms that selective dissolution occurred in austenite and Ni-S-O formed on austenite; while uniform corrosion is observed on ferrite and formed Fe-Cr-O corrosion products on ferrite, see in **Figure 3**.

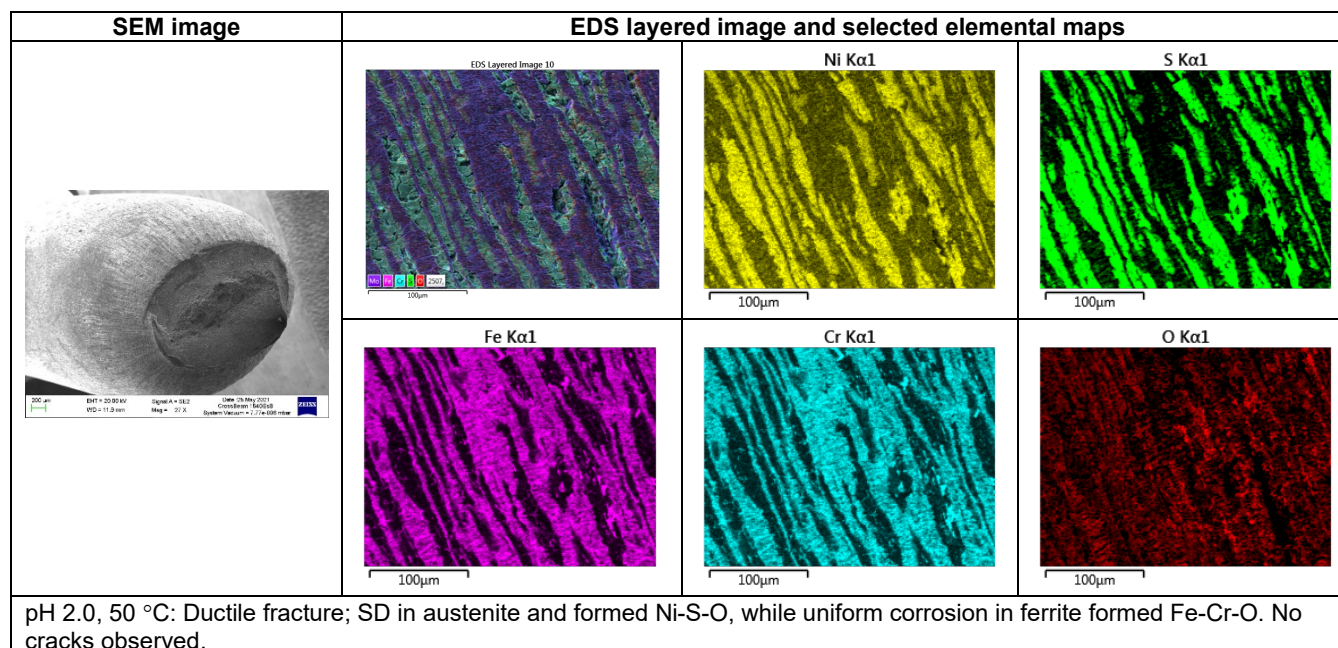


Figure 3: EDS elemental mapping on SSRT specimen surface after testing in the sour environment at 50 °C, pH 2.0.

SSRT specimen, 80 °C, pH 4.5

Although the high ductility ratios and no corrosion has been observed on the fracture surface and gauge section, the localized corrosion observed on the one side of specimen shoulder has been investigated in order to find out how corrosion was initiated and if any cracking initiated underneath the corrosion area. SEM observation and EDS point analysis showed that the circumferential corrosion lines observed in the shoulder consist of some thick corrosion products and thin corrosion with selective dissolution in the lower part nearby the thick corrosion products. See images in **Figure 4**. Compared to the non-corroded area as reference matrix, the thick corrosion products are Fe-S-O rich while the thin corrosion area contains more Ni-S-O. Trace chloride has been identified in the thin corrosion area.

The EDS elemental mapping on the edge of the corrosion area of thick- and thin corrosion products is shown in **Figure 5**. Selective dissolution with micro-cracks and non-corroded surface are captured in one image. Selective dissolution/corrosion initiated in austenite and phase boundaries, formed Fe-S-O rich corrosion products in the thick corrosion part, whereas Ni-S-O remained on corroded austenite. Micro-cracks linked through both phases have been observed.

With consideration of the circumferential linear corrosion damage in one shoulder area observed on specimen tested at 80 °C, pH 4.5, half-immersion of dry-wet condition might be supposed. The half-immersion condition would not be the same as the testing condition in the bulk solution, where local concentration of chloride and H₂S could be high in the dry-wet condition in thin liquid layer.