

A recent case of intermetallic precipitations in super duplex stainless steel

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ABSTRACT

This article is based on a failure analysis, where a pressurized 4" super duplex (UNSS32760) elbow from a hydrocarbon system suddenly leaked during service, due to a 90 mm long crack.

The crack originated from a corrosion pit and was caused by intermetallic precipitations in the microstructure in a small area of the elbow. The intermetallic precipitations were the result of inadequate heat treatment of the elbow during production. A screening procedure based on ferrite measurements applying handheld ferrite measurement devices was developed. If the screening revealed ferrite values outside nominal values, in-situ metallography was performed to either confirm or deny the presence of intermetallic precipitations. On-site metallography was performed by grinding, polishing and electrolytical etching with NaOH. Images were recorded, applying a portable USB microscope at 450x magnification.

Intermetallic precipitations were found in other SSDS (Super Duplex Stainless Steel) items from other suppliers as well. In total, 5681 items were screened, 96 (1.7 %) had a ferrite content lower than 35%. Of these 96 items, 25 were examined with in-situ metallography and all 25 had significant amounts of intermetallic precipitations. Impact toughness testing (Charpy V-notch) of SSDS items with intermetallic precipitations at different temperatures ranging from -50°C to +20°C revealed very poor toughness without any indications of a transition temperature.

Key words: Intermetallic phases, sigma phase, super duplex, ferrite measurement, in-situ metallography, screening program, failure, toughness, brittle fracture, Charpy-V impact.

INTRODUCTION

Production of oil and gas is well known to cause potential corrosion issues due to the CO₂ content in the well stream. Carbon steel is widely used for production facilities as e.g. flowlines and manifolds, however, aging of the reservoir increases the number of corrosive agents, such as e.g. CO₂, which are known to cause high corrosion rates in carbon steel. Therefore, carbon steel piping is often being replaced with super duplex stainless steel due to its high strength, excellent toughness and good corrosion resistance. Replacing carbon steel with super duplex has been conducted on several mature offshore oilfields in the European North Sea region.

On an early morning in March 2017, an offshore technician was working below the cellar deck on a well head platform. Suddenly a bump was heard followed by a wheezing sound. A visual inspection revealed that a 4" super duplex elbow had cracked near a weld, and the flowline was shut down immediately. A review of the material certificate showed that the elbow was cold bent from pipe and afterwards solution annealed. The operating pressure was 90 bar and the operating temperature was approximately 40° C. The elbow has been in service for approximately 10 years. During operation, periods with slug flow were reported to occur. Figure 1 below provides an overview of the elbow with crack.



Figure 1: Overview of elbow with crack

Failure investigation

The cracked elbow was sent onshore for root cause analysis. The fracture surfaces were laid free in the laboratory revealing two different morphologies. The appearance of the initiation area showed a local corrosion pit, corrosion products and stepwise crack growth. The remaining fracture surface appeared with a brittle morphology and had propagated as a sudden fracture, cf. figure 2. Detailed examination of the fracture initiation area in SEM (Scanning Electron Microscope) confirmed material loss caused by corrosion. This corrosion pit has initiated on the outside surface - probably due to a local surface imperfection or possible local iron contamination. The saline marine environment leads to chloride contamination on the outside surface of the elbow. Due to the operating temperature of 40° C, water will slowly evaporate leading to an increased chloride content on the outside surfaces. which normally would not initiate pitting corrosion on super duplex material. Once the corrosion pit has initiated the corrosion reaction causes a very low pH value in the pit and the corrosion process becomes self-sustained. The corrosion process will also develop hydrogen that may promote crack growth if the material is sensitive towards hydrogen induced cracking (HIC).

A metallographic cross section perpendicular to the fracture surface was examined in light optical microscope after electrolytical etching in 20% sodium hydroxide. This revealed a microstructure with austenite, ferrite and severe precipitations of intermetallic phases in the grain boundaries, indicating inadequate heat treatment, c.f. figure 3. The ferrite content is normally specified to be between 35 and 65 % for super duplex material but the ferrite content in the area here with precipitations was measured by a hand-held ferrite scope to be approximately 20 %, thus confirming inadequate heat treatment. This has resulted in a part of the ferrite phase having been transformed to intermetallic phases and secondary austenite. Precipitations of intermetallic phases are well known to reduce the toughness, corrosion resistance, fatigue strength and make the material sensitive towards hydrogen induced cracking. The opposite area of the fractured area appeared with a ferrite content within the specified range and free from intermetallic precipitations. Thus, the area with inadequate heat treatment and precipitations was local.

Standards for super duplex stainless steel state that the materials shall be free from carbides and intermetallic precipitations by solution annealing. Some standards however allow 1% of either carbides or intermetallic precipitations but to our knowledge, no standards define a test method to determine the actual amount of possible carbides or intermetallic precipitations.

Based on the above findings, it can be concluded that the root cause of the fracture was inadequate heat treatment which has reduced the corrosion resistance and toughness of the material. A local corrosion attack has initiated and propagated until the critical flaw size was exceeded. The dynamic impact loads from service have caused the crack to propagate to a length of approximately 90 mm in a sudden fracture causing a severe gas leak.



Figure 2: Overview and close-up of fracture surface

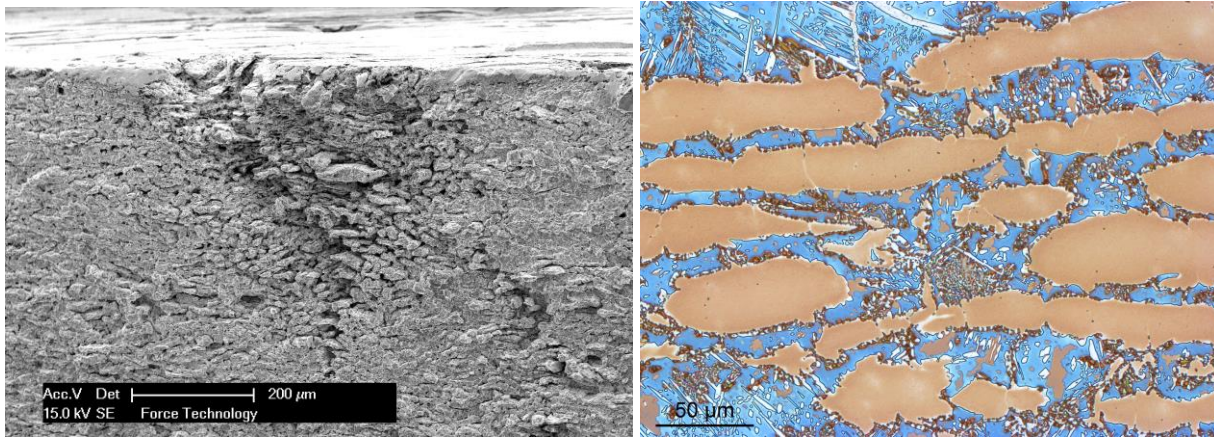


Figure 3: SEM image of fracture initiation and photo of microstructure with sigma phase – amber colored precipitations at grain boundaries.

Ferrite measurements and screening for intermetallic precipitations in the plant

A review of the original fabrication documentation revealed that the elbow originated from a batch with 250 elbows in total and that several of the elbows were installed in the client's facility. After the cracked elbow had been examined, 12 elbows from the same flowline were removed from the plant and sent onshore for detailed examination. Ferrite measurements applying handheld ferrite measurement devices were conducted on the elbows, in circumferential bands located in different positions along the curvature. Out of the 12 elbows, 4 were found with low ferrite content in local islands on the outside surfaces, c.f. figure 4. Examination of metallographic cross sections from the areas with low ferrite content confirmed presence of severe intermetallic precipitations. Metallographic cross sections were also cut from areas with acceptable ferrite content displaying a microstructure with austenite and ferrite and free from intermetallic precipitations.

Offshore ferrite screening was performed on 6" elbows. From an elbow where a ferrite level of approximately 20% was recorded on the outside surface, metallographic cross sections were cut out and examined in detail. The examination of the microstructure performed in a light optical microscope revealing austenite and ferrite but no intermetallic precipitations. It was observed that the ferrite content was low and thus the austenite content high in a band with approximately 150 μm in thickness, c.f. figure 5. This may be the result of heat treatment in nitrogen containing atmospheres, where the growth of austenite may be promoted by the nitrogen. Straight pipes were also measured, and low ferrite content recorded in some of these. Detailed examination of metallographic cross sections in light optical microscope revealed superficial corrosion of the ferrite phase. This phenomenon is thus related to the pickling agent.