

After 30 Years of Duplex Stainless Steel Experience in Oil & Gas - Do we still face challenges?

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ABSTRACT

Duplex stainless steel (DSS) materials are extensively used for various critical applications in the Oil & Gas industry. During the past 30 years, Petroleum Development Oman (PDO) an upstream operator is one of the major end-user of DSS materials. A variety of applications such as wellhead piping, flow lines, headers, pipelines, vessels, coolers, tubing, pump and piping components, etc. are installed with DSS materials. Fabrication, quality assurance and quality control measures of these DSS components are critical elements for achieving long-term plant design integrity with a minimal life cycle cost. The objectives of this paper are to share selected case studies of premature failures (less than two years) experienced with DSS components during operation and to discuss recent quality assurance (QA) & quality control (QC) challenges encountered during procurement, forming/ forging, welding, heat treatment, and inspection & testing of DSS components. Even with thirty years of user experience, the well-known DSS material issues continue to challenge the material, corrosion & quality engineers, as the quality failures recurrence is alarming.

Key words: Duplex stainless steel (DSS), Quality assurance, Oil & Gas, Pitting corrosion.

INTRODUCTION

In recent decade, the applications of DSS have significantly increased in oil & gas industry, due to their attractive properties compared to austenitic grades with similar corrosion resistance¹. The DSS products exhibit a better resistance to pitting, stress corrosion cracking and higher mechanical properties compared to other austenitic stainless steel grades. The microstructure of these materials consists of approximately 50% austenite (γ) and 50% ferrite (α) phases, obtained by means of a solution heat treatment.²⁻⁴ The temperature of solution annealing is chosen to obtain the equal distribution of ferrite and austenite. However, if the DSS is incorrectly heat-treated, these materials suffer from precipitation of intermetallic phases such as sigma-phase (σ -phase) and chi-phase (χ -phase), which effect the corrosion and mechanical properties of the materials⁵⁻⁹. Therefore, the quality of fabrication, heat treatment and lab testing/evaluation of DSS is critical to ensure integrity of the

product. PDO has been one of the major end-users of DSS materials, for wide range of applications as shown in Figure 1. The expanding use of DSS material means it has been increasingly being treated as a commodity alloy and the manufacturers do not always pay sufficient attention to the QA/QC of these materials. The impact of DSS quality failures during various stages of manufacturing, commissioning and operations was not always recognized⁵⁻⁹. Various standards and specifications considered DSS as a traditional routine material under the family of stainless steels.

Over the last thirty years, there has been a number of cases where inadequately heat-treated or incompletely tested components are delivered and later identified as defective during fabrication and construction activities. Figure 1, shows some examples where the majority of failures have been reported.

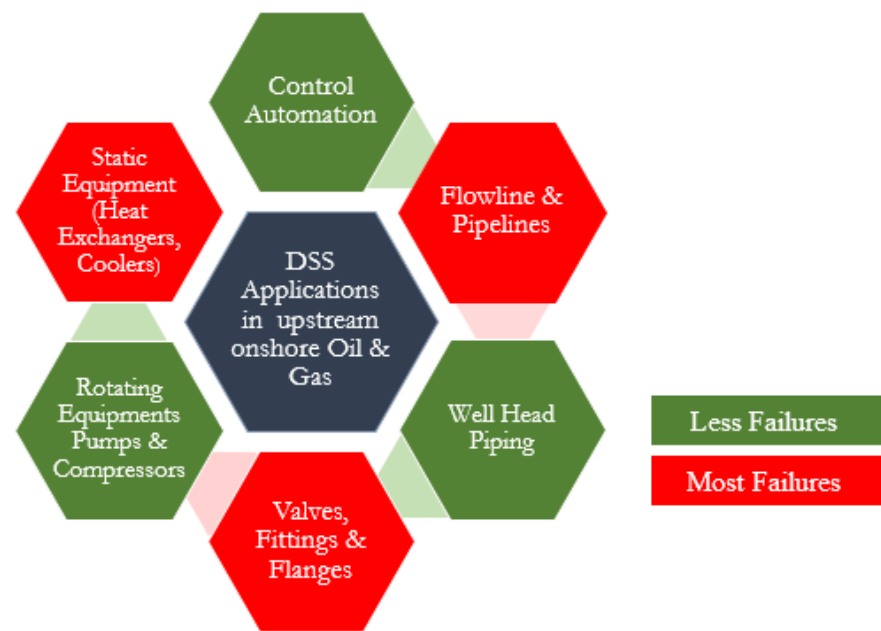


Figure 1: DSS failures reported in the last 30 years

Unanticipated failures have a major impact on Oil & Gas business operations, people and assets. In addition DSS failures had significant effect on project delivery, project costs (both capital and operational). Many failures and challenges in DSS products have been captured during the last 30 years of operations, and their occurrence can be divided into five key stages as shown in Figure 2.

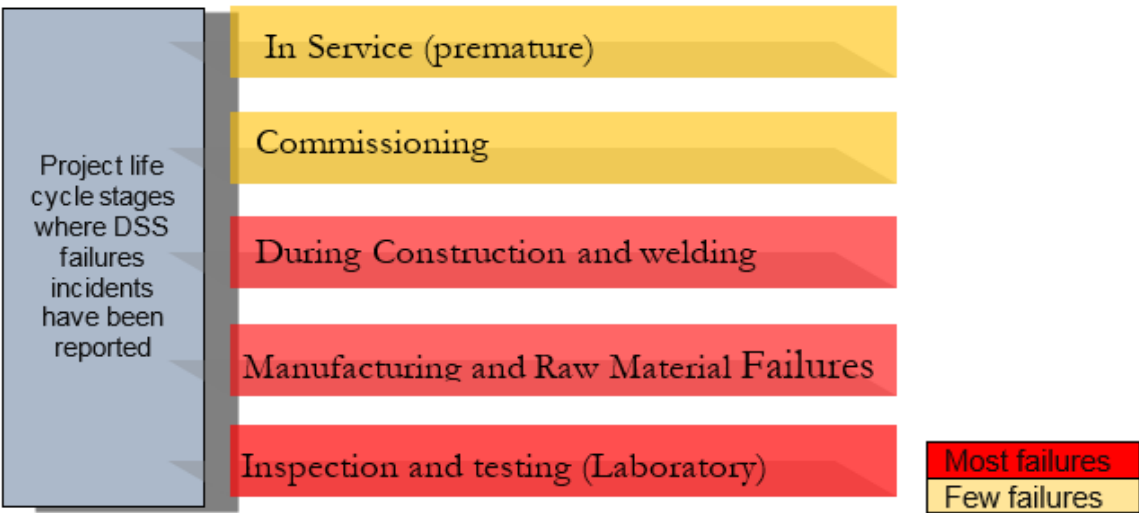


Figure 2: Key stages of DSS failures occurrence

PREMATURE FAILURES IN SERVICE

Oil & Gas operators are always seeking for operations excellence, and any un-planned shutdowns are very costly and impact production targets of the business. The numbers of premature failures of DSS products have increased in the last decade. Two case studies will discuss the root cause analysis and the recommendations arising from these cases.

Case Study 1#: Heat Exchanger Tube failures

The procured ASTM A 789⁽¹⁾ DSS tubes of a discharge fin-fan cooler have failed in less than 9 months operation. The cooler was designed to operate under fully dry conditions. The process conditions (chloride, temperature, partial pressures of H₂S etc.) of the cooler (Table 1) are within the material design envelope of DSS material as per the company specifications and ISO international standards.

Table 1: Operating Process Conditions of the failed cooler tubes

CO2 Mole %	ppH ₂ S mbar	Max. Operating Temp. deg.C	Chloride level ppm
1	0.21	160	120000

Failure Analysis

The damage mechanism attributed to the failure of DSS tubes was pitting corrosion (Figure 3 and Figure 4). The laboratory analysis has shown that all the mechanical properties (Hardness, tensile strength, impact etc.), composition and the microstructure analysis were typical with material standards.

A detailed inspection task was carried to cover the full process loop from the upstream compressor to the inlet of the “finfan” cooler. The inspections of the compressor rotor showed salt deposition as a result of carry over from the upstream scrubbers.



Figure 3: Visual observation of pitting and localized corrosion across the tubes

The boroscopic inspection of the first-top inlet tubes witnessed pitting along all the tubes. However, the bottom discharge tubes of the cooler did not suffer corrosion. The carryover of salts and chloride deposition during upset and stagnant conditions was the primary cause of the premature failure of the

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cooler. The ingress of oxygen in the system during shut down condition could have contributed to the pitting corrosion.

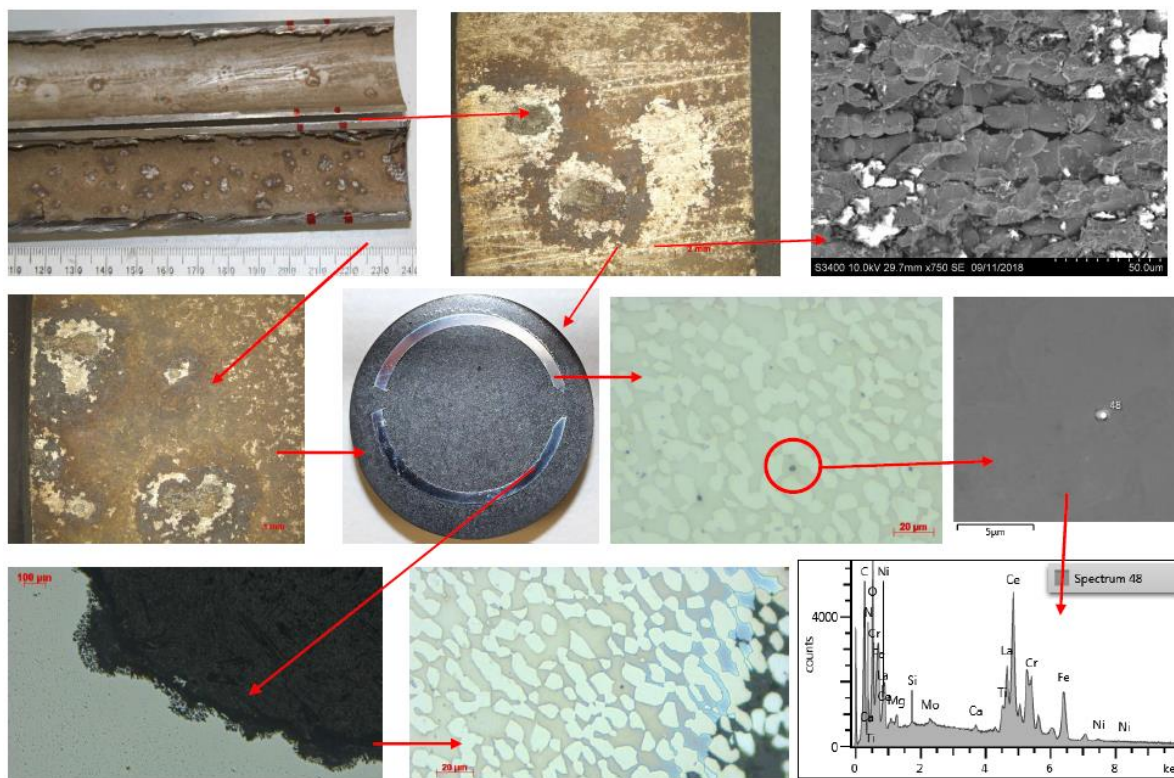


Figure 4: Overview of failure analysis of the pitting corrosion

Recommendations to avoid future failures

- DSS tubes procurement shall comply with the most recent changes to ASTM A789 with the additional quality control tests such as ASTM G48.
- Comply with hydrotest procedures & test water quality ensuring draining and drying requirements are in place prior to operational service.
- Inspection of the tubes with boroscope after hydrotest – e: g 10% of the tubes. Robust compliance to hydrotest procedure is mandatory.
- Monitor chloride levels in upstream of coolers to avoid upset scenarios.
- Create plan to mitigate Integrity Operating Window (IOW) excursions and quarterly review of sampling of upstream of the cooler against IOW need to be reported.
- Conduct boroscopic inspection inside header box & tubes during shutdown for to confirm no presence of salt deposition.
- Avoid stagnant conditions during shutdown.
- Ensure correct preservation of coolers to avoid oxygen ingress.

Case Study 2#: DSS Flange to Elbow weld joint failure

A leak was reported on a ½ inch DSS UNS S31803 flange to elbow weld of a discharge pump line (Figure 5). This flange was in service since 2017 and was constructed as per ASTM A182 F51. The design temperature of the stream is between 5-82° deg.C and the design pressures is approximately 150 bar.