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Rapid MIC attack on 2205 duplex stainless steel pipe in a yacht

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ABSTRACT

A duplex stainless steel (2205) pipe in a new yacht suffered an extremely high corrosion rate (40 mm/y) failure. ESEM/EDS and XPS analyses indicate that the failure mode was MIC. The bacteria attached preferentially on the austenite grains forming the colony "centre". The preferential corrosion on the austenite grains formed the "sponge" feature. The remaining ferrite grains became the "skeleton" structure. The sulphate detected by XPS suggests SOB involvement in the MIC. A hypothesis of SRB and SOB proliferating symbiotically proposed in this paper can explain the extremely high corrosion rate. SRB transferred sulphate from seawater to sulphide. SOB converted the sulphide to the extremely acid (H_2SO_4). SOB should be the main culprit of the failure through its high corrosion rate. The nitriding effect around the FZ had been confirmed by SES and EDS analyses. The high nitrogen contents attracted the bacteria to attach and proliferate. This finding may uncover the mystery of why weldments are susceptible to MIC.

1. Introduction

Duplex stainless steels (DSS) contain the microstructures of both austenite (ϒ) and ferrite (δ) phases. Because of their desirable mechanical properties and excellent resistance to stress corrosion cracking, DSS have been widely applied in pressure vessels and pipe lines [1,2]. Owing to their high PREN (pitting resistance equivalent number), DSS have also been extensively used in offshore oil facilities [3]. In recent years, DSS, typically grade 2205, have been applied in the seawater pipelines of yachts.

Generally, DSS exhibit satisfactory pitting resistance in seawater. However, DSS can also be vulnerable to be attacked by MIC (microbiologically influenced corrosion) [4–6]. SRB (sulphate-reducing bacteria) can selectively corrode austenite phase of DSS [4]. The mixed culture accelerated the corrosion [5]. The depletion of chromium due to the formation of secondary phase in SDD also enhanced the MIC attack [5].

Due to the low concentration of dissolved oxygen in seawater, the anaerobic SRB species were blamed as the main culprit of MIC failure. Hence, research of MIC in SRB species has been an active topic in recent years [7–11]. In the MIC fundamental researches, single SRB specie was usually cultivated in the laboratory simulation tests. Then, the coupons were analysed by various techniques. SEM/EDS are the most common techniques.

Unlike aboitic corrosions, MIC has its own unique characteristic – biofilm. Biofilm is mainly composed of microbial production of extracellular polymer substance (EPS) and the metabolizing cells [12,13]. Any MIC produces biofilm. Based on this fact, biofilm can be applied for MIC judgement. Hence, in engineering failure analysis, it is not necessary to do the

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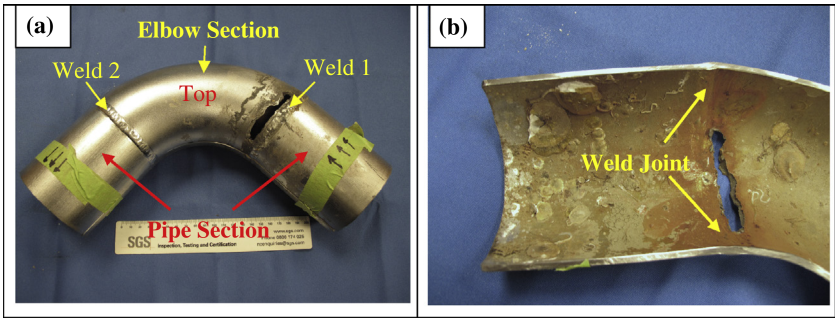

Fig. 1. (a) The pipe coupon from a new yacht with a significant corrosion hole formed in merely 3 months after its launching, (b) the inside surface of the pipe coupon.

time-consuming microbe cultivation if merely for the MIC failure mode judgement. In recent year, this non-cultivation approach has been applied in the MIC research in the industrial real process environments [14].

Biofilm has its own morphologic features under SEM which differentiates from aboitic corrosion products. As biofilm is the organic substances, EDS analysis generally shows high percentages of carbon and oxygen contents. Based on these characteristics, biofilm can be easily distinguished by SEM/EDS. Therefore, MIC can be quickly judged by biofilm examination under SEM/EDS. This method has been successfully applied in industrial practice by the author for many years.

It has been recognised for decades that MIC attach weldments preferentially [7,15]. In industrial practice, the author found that MIC is especially prone to attack the stainless steels around the weld. Fig. 1a shows a rapid corrosion on a 3.5 mm thick DSS pipe in a luxury yacht. It is surprising that in merely 3 months after the yacht was launched, a 10 mm $\times$ 60 mm corrosion hole has formed, with average corrosion rate approximately equal to 40 mm/year. For abiotic corrosions through seawater, it is impossible that such extremely high corrosion rate can occur even in plain carbon steels.

2. Case background

The yacht was launched on 1st November 2012 and three months later, a significant corrosion hole appeared on the seawater intake piping system. The seawater intake piping system provided cooling water to the main engine and generators in the vessel. After its launching, the new yacht had spent 90% of its time dockside in Auckland, New Zealand. Whilst it was dockside and idle, the pipe system contained stagnant seawater. The average temperatures of the seawater was 18 °C, and the pipe's ambient temperatures was approximately 25 °C.

The entire pipe system was fabricated of DSS, grade 2205. The pipe was welded to a seamless elbow. The welding of the pipe to elbow has been protected by shielding gas (99.9% argon) and backing gas (99.9% nitrogen). Consumable filler wire was grade ER 2209.

3. Preliminary examination

Preliminary examination on the corrosion surface by ESEM/EDS (environmental scanning electron microscopy/energy-dispersive spectroscopy) found significant amount of biofilm (Fig. 2a), indicating the MIC attack. Fig. 2b shows the biofilm at high magnification. The metabolizing cells with the coccus feature in the biofilm were the sound evidence of MIC although the species of the bacteria had not been identified.

In situ EDS analysis on the biofilm shows very complicated results (Fig. 3). The high carbon and oxygen contents in the EDS results confirm the biofilm. Considerable amount of sulphur (0.87%) in the EDS results suggests that the sulphur species involved in the rapid MIC attack. As the yacht was dockside and idle for most of the time after it launching, the stagnant seawater and the ambient temperatures provided favourable conditions for bacterial proliferation.

In the previous single species of SRB cultivation tests, the corrosion rates were reported to be low. After various laboratorial cultivations, minor to moderate pitting were observed on the coupons of mild steels and stainless steels [8–12,16]. A corrosion rate up to 1.7 mm/year was reported in SRB cultivation test [8]. However, the laboratorial tests cannot simulate the actual complex chemical and biological interactions as natural seawater is rich in microorganism's community [9]. The extremely high corrosion rate in this case was due to actual MIC of the complex microorganism's communities in the seawater. To the author's knowledge, such extremely high corrosion rate has not been reported in any kind of metal through either MIC or corrosion-erosion processes in industry.

In addition to the extremely high corrosion rate, why the MIC occurred only in weld 1, not in weld 2 although both welds had been exposed to the identical seawater conditions (Fig. 1a)? This was an interesting industrial case which worth to be further studied. Due to the complexity of the microorganism's community in the seawater, laboratory culturing cannot simulate the extremely high corrosion rate at present stage. Therefore, the research methods in this paper were limited to material science approaches.