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Sulphide stress cracking of a valve stem of duplex stainless steel

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ABSTRACT

The present paper describes a failure investigation of a double disc valve stem made of duplex stainless steel 329 (UNS S32900). The valve stem which operated in moist H_2S environment at 128 °C in a heavy water plant had undergone cracking during operation. The microstructure of the stem material showed precipitates of σ-phase at ferrite/austenite boundaries and elongated oxide inclusions. The formation of σ-phase had occurred during the manufacturing stage of the stem. The crack propagation was more favourable in the ferrite phase and along the ferrite/austenite boundaries where precipitates of σ-phase were formed. It was concluded that the valve stem failed by sulphide stress cracking due to hydrogen embrittlement of ferrite phase. Recommendations to avoid such failures are also suggested.

1. Introduction

Duplex stainless steels (SSs) are widely used as material of construction in various chemical industries owing to their superior strength and corrosion resistance as compared to austenitic stainless grades. Duplex stainless grades have dual microstructure with almost equal fraction of both ferrite and austenite phases.

Although, duplex SSs are more resistant to stress corrosion cracking (SCC) than austenitic grades [1], they are not completely immune to this type of failure. Especially, when there is a source of hydrogen, theses alloys show high susceptibility to hydrogen embrittlement, which are well documented [2–7]. The ferrite phase present in duplex SSs suffer more extensive embrittlement than the austenite phase in the presence of hydrogen. Similarly, it is well known that steels as-well-as ferritic or martensitic grades of stainless steels are readily embrittled by hydrogen, in contrast to austenitic SSs [8]. Cracking of susceptible metals such as high strength steels and even duplex SSs have been reported in hydrogen-containing environment [9]. One such failure of duplex SS 329 caused by sulphide stress cracking (SSC) is analyzed in the present paper.

SSC is a form of hydrogen embrittlement cracking [9] that occurs in an environment containing H_2S and water under the combined action of corrosion and external tensile stress. Hydrogen induced cracking (HIC) e.g., blistering, fissuring, and step-wise cracking observed in carbon and low alloy steels is different from SSC in that it does not require an application of externally applied tensile stress [9, 10]. HIC involves recombination of atomic hydrogen to molecular hydrogen at weak internal interfaces (e.g. inclusions, and laminations) in the material resulting in generation of pressure or stress which is enough to crack the material. On the contrary, SSC is a solid-state embrittlement reaction resulting from the interaction between the metal lattice and the atomic hydrogen [9]. Hydrogen ions are the product of corrosion processes, which pick up electrons from the corroding metal forming hydrogen atom. Some of these hydrogen atoms can diffuse into the metal and embrittle its crystalline structure. H_2S environment is considered to be highly aggressive with respect to SSC and hydrogen embrittlement because of two reasons: one is that H_2S increases the corrosion rate

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Fig. 1. The image of the failed valve stem showing corrosion attack and axial cracks (indicated by arrows) at several locations.

of metals in aqueous solutions and the other is that it poisons the hydrogen recombination/evolution reaction leading to increased absorption of atomic hydrogen into the metal.

Duplex stainless steel has another problem in that the ferrite phase is not stable and transforms to various embrittling phases when exposed at temperatures greater than 300 °C. Spinodal decomposition consisting of phase separation of ferrite into Fe-rich α and Cr-rich α′ occurs in the temperature range 300–500 °C [11]. At still higher temperatures in the range 600–1000 °C [12], intermetallic phases such as σ and chi can form. These phases (σ and chi) can even precipitate during the production of the component especially when the cooling rate is low after solution annealing or welding. These intermetallic phases lead to degradation in mechanical properties and corrosion resistance of duplex SSs and hence, limit their service life [1].

2. Background

A double disc valve stem (diameter 62 mm) made of duplex SS 329 (UNS S32900) in a heavy water plant failed due to cracking during operation. The photograph of the failed stem is presented in Fig. 1 that shows a long longitudinal crack (indicated by arrows). There were several other cracks as well as patches of corrosion attack on the cylindrical surface of the stem. The stem was used in a moist H_2S gas environment at pH = 4 and at a temperature and a pressure of 128 °C and 19 Kg/cm^2 respectively. The valve stem was in service for 30 years.

3. Material

The chemical composition of the failed stem was analyzed and the result is presented in Table 1. Some deviation in the chemical composition was observed (Ni, Mn and P contents are higher) compared to the standard grade of duplex SS 329 as per ASTM A240 [13]. The average ferrite content of the stem rod as measured by a ferritscope was 66%.

4. Stereo microscopic examination

The cylindrical surface of the failed stem was examined at higher magnifications using a stereo microscope. Fig. 2a shows corrosion attack on the surface as several shallow pits. One of the cracks on the cylindrical surface of the failed stem rod is shown in Fig. 2b. It appears that the corroded regions or pits on the surface are joined together to form a large crack.

5. Microstructural examination

Samples cut from the failed stem were polished to a finish of 1 μm. The microstructure of the stem was revealed after electrolytic

Table 1
Chemical composition (wt%) of the failed stem, which is compared with the standard composition of duplex SS 329 as per ASTM A240 [13].

Element	Stem rod	SS 329 as per ASTM A240
Cr	25.4	25–28
Ni	5.3	2.0–5.0
Mo	1.7	1.0–2.0
Mn	1.35	1.0 max
Si	0.27	0.75 max
C	0.08	0.08 max
P	0.05	0.04 max
S	0.03	0.03 max
Fe	Bal.	Bal.