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Failure investigation of 321 stainless steel pipe to flange weld joint

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ABSTRACT

Failure investigation was conducted on a refinery pipe-to-flange weld joint that suffered cracking. Both the pipe and flange are made of AISI 321 stainless steel. The flange was circumferentially welded to the pipe which is seam welded. The investigation revealed that both the circumferential and seam welds were in sound conditions, namely no evidences of sensitization, lack of weld penetration, and voids or porosities. Thus, welding practices were not suspected to be the cause of failure. The failure of the weld joint was found to have started at the δ-ferrite phase in the flange material and propagated through the circumferential and seam welds. The failure mode was concluded to be chloride stress corrosion cracking synergized by the presence of H_2S. The presence of corrosive compounds in the refinery stream and the residual stresses at the weld joint triggered active anodic dissolution of the δ-ferrite precipitates, resulting in cracking of the material.

1. Introduction

Austenitic stainless steels (SSs) are engineering alloys with good corrosion resistance in environments containing various compounds of sulfur, normally experienced in refinery process streams. However, austenitic stainless steels are susceptible to stress corrosion cracking (SCC) under certain conditions involving high stress, changes in metallurgical structure due to high temperature operation, and the presence of specific chemicals that promote cracking. The chemicals present in refinery streams known to induce SCC in these alloys are chlorides and polythionic acids [1]. However, recent reported failures and research of annealed austenitic stainless steels under sour gas conditions with insignificant amount of chlorides suggested the contribution of H_2S in promoting SCC [2–6]. Cracking is derived from either H_2S enhanced hydrogen absorption or H_2S enhanced breakdown of the passive film by synergistic action between H_2S and Cl^-. Due to the H_2S/Cl^- synergism, the presence of H_2S extends the environmental domain of Cl^- SCC to lower temperatures and lower Cl^- concentrations [7].

Traditionally austenitic stainless steels are joined with welding electrodes that contain 5–10% residual δ-ferrite in the interdendritic boundaries. This retained metastable ferrite phase is believed to be influential in reducing hot cracking and microfissuring of the weld metal. However, the presence of δ-ferrite ferrite in austenitic stainless steel weldments can be both beneficial and detrimental depending upon the amount and distribution of δ-ferrite, the morphology of ferrite, the steel composition, and the corrosion conditions [8–10].

The present paper presents the results of a failure investigation carried out on a refinery pipe to flange weld joint that suffered stress corrosion cracking. The cracks were found to have initiated at the δ-ferrite phase in the flange material.

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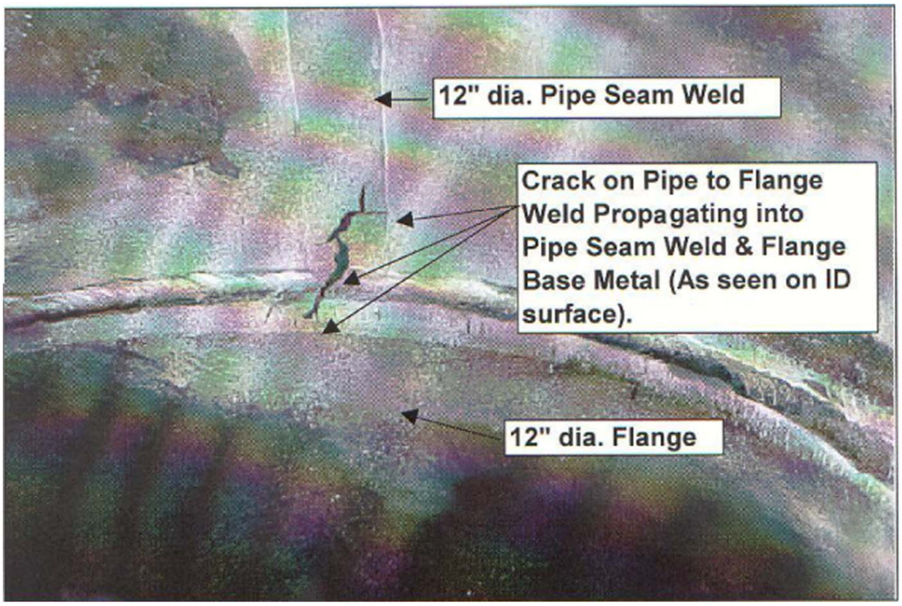

Fig. 1. Photograph showing location and appearance of the crack found in the weld joint at the internal surface.

2. Background

A leak was observed at the external surface of a pipe to flange weld joint located in the downstream of a refinery heat exchanger tube side outlet. The pipe is 12″ in diameter and is seam welded. It is circumferentially welded to the flange. Both the pipe and flange are made of 321 SS. The leak was in the form of a pinhole at the heat affected zone (HAZ) of the circumferential weld. When dye penetrant test was applied, a crack was found in the internal surface at the weld joint (Fig. 1). The internal surface was covered with an adherent black scale. The crack propagated across the circumferential weld and extended towards the pipe seam weld. Table 1 shows the composition of the fluid stream going through the pipe. The operating temperature and pressure through the pipe are 192 °C (377 °F) and 1780 psig, respectively. The hydrogen pressure is 2850 psig.

3. Experimental details

Two samples were cut from the failed pipe/flange section. The first sample contained the cracked portion of the circumferential pipe to flange weld and pipe seam weld, while the 2nd sample was taken at 90° angle away from the failure location for comparison purposes. This later sample did not contain the seam weld, but contained pipe to flange circumferential weld. Fig. 2 shows the locations of the cut samples.

Small sections were machined from the two cut samples for optical and scanning electron microscopic (SEM) examinations. The flange/pipe direction was engraved on each section. The examinations were made before and after metallographic preparations. The metallographic preparations included grinding, polishing, and etching. The metallographic preparations were made on two perpendicular surfaces; namely, the surfaces parallel to the pipe axis and the cross-sectional surfaces. For general microstructure, etching was made in villela's reagent through immersion for 1 min in 5 ml HCl + 1 g picric acid in 95% ethanol. To reveal grain boundaries, the material was electrolytically etched in 10% oxalic acid at 6 V for 1 min. Electrolytic etching was also made in 20% NaOH at 20 V

Table 1
Constituents of fluid stream going through the pipe.

Component	% V/V
Hydrogen	80.62
Hydrogen sulfide	2.88
Ammonia	0.28
Methane	8.15
Ethane	0.48
Propane	0.37
Isobutan	0.07
N-Butan	0.18
C5 & heavier	1.3
Water	5.67