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Failure of a furnace outlet pipe in a benzene plant by internal oxidation due to improper welding practice

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ABSTRACT

A furnace outlet pipe made of INCOLOY® alloy 800H to handle gaseous hydrocarbon in a benzene plant developed cracks in the weld heat-affected zone during operation at 595 °C. Microstructural characterization revealed that the cracks were of the ductile intergranular mode, which could be related to localized plastic deformation alongside the grain boundaries. The microstructure of the heat-affected zone was distinguished from the base metal by a coarser grain structure and intergranular oxidation in addition to higher hardness indicating the presence of residual stresses from the welding process. Intergranular oxidation was found to result in a mixture of Cr and Fe oxides enveloping a Ni-rich solid-solution adjacent to the grain boundary. Therefore, the observed ductile intergranular cracking could be related to localized plastic deformation in the relatively "soft" zone of Ni-rich solid-solution. Most evidence indicated that the failure occurred because of improper welding atmosphere leading to internal oxidation under relatively low oxygen potential, which is oxidizing to Cr and to a lesser extent Fe, and reducing to Ni.

1. Introduction

Solid-solution strengthened high-temperature alloys such as the wrought INCOLOY®[1] alloy 800H are used in many structural applications because of their potentially useful combination of mechanical strength, environmental resistance, and ease of fabrication, e.g. [1]. Manufacturers usually supply these alloys in the solution-annealed condition with given sets of properties corresponding to certain microstructural features. Production of hardware items, however, involves fabrication processes, which can significantly alter the initial microstructure and properties. It is therefore important to take into account these effects while selecting a material for a given application in order to improve product reliability and reduce cost. Furthermore, the interaction between mechanical and chemical properties in certain environments must be considered. Many applications in the petrochemical industry rely upon the use of high-temperature alloys in the form of pipes to handle various types of gaseous hydrocarbon. A primary concern in these applications is thermal and environment-induced embrittlement. The importance of these aspects were demonstrated in the case study presented in this paper.

A furnace in a benzene plant is used to handle a gaseous hydrocarbon consisting of 64.27% H2, 18.92% C1, 3.48% C2, 0.96% C3, 0.03% C4, 0.24% C5, 1.05% C6–C8 non-aromatic, 5.91% benzene, 1.45% C8 aromatics, 0.04 C9, and 0.15% diphenyl. The furnace has four anchored outlet pipes made of INOLOY® alloy 800H tubing (internal diameter = 110 mm, wall thickness = 14 mm). Anchoring of the pipes is carried out by fillet welding as schematically illustrated in Fig. 1. During operation the temperature was maintained at about 595 °C and the internal pressure was about 30 atm. (3 MPa).

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[1] ®INCOLOY is a registered trademark of the Inco family of companies.

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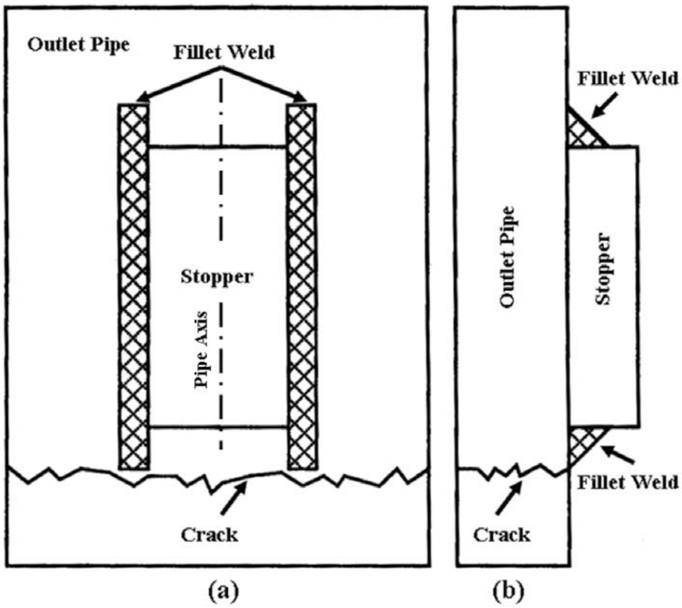

Fig. 1. A schematic illustration of the outlet pipe showing the location of the transverse crack. (a) Surface and (b) Cross-section.

After an unspecified period of operation the outlet pipes developed transverse cracks near the fillet weld as shown in Fig. 1. A section of the failed pipe containing the crack was received for analysis to determine the cause of failure.

2. Experimental procedure

Representative samples were machined from the as-received tube section for detailed microstructural characterization. The tube material was verified by chemical analysis using Inductively-coupled plasma atomic energy spectroscopy (ICP-AES). Light optical metallography and scanning electron microscopy (SEM) combined with energy dispersive X-ray spectroscopy were used to examine the microstructural features.

3. Results and discussion

3.1. Macroscopic features of the failed pipe

A light optical macrograph showing the general appearance of the transverse crack near the weld is shown in Fig. 2. It is observed that the crack is oriented nearly normal to the pie axis suggesting that it was not related to the stresses generated by the internal pressure since the respective maximum tensile stress tends to produce longitudinal rupture. Also, the maximum circumferential (hoop) stress (σ_1) estimated on the basis of a thick-walled cylinder ($d_i/t = 7.85 < 10$ where d_i is the

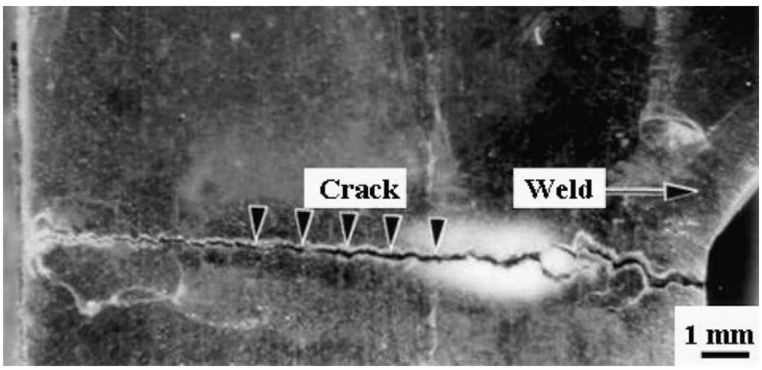

Fig. 2. A macrograph illustrating a transverse crack in the outlet pipe near the weld.