Weld Failure Analysis: A Case Study

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Introduction

Failure analysis identifies the root-cause and mechanisms of fractures in structural assemblies and test specimens. In both cases, the purpose is to provide recommendations to prevent a recurrence of the identified failures. Depending upon the nature of the fracture, the failure analysis can be as simple as a visual examination using a light microscope, or may require more sophisticated methods and the use of a scanning electron microscope (SEM), a transmission electron microscope (TEM), or electron backscatter diffraction (EBSD) analysis. Independent of the techniques and equipment required, the success of a failure analysis depends upon an investigator's expertise in metallurgy and materials, as well as his field-engineering experience. The following case study provides an example of a failure analysis conducted for a customer in the steel fabrication industry.

Case Study

After a 439 stainless steel (SS) oil tank was heated to a high temperature in service, a through-thickness crack was found in a circumferential weld between a carbon-steel pipe fitting and the 439 stainless steel (SS) tank panel. This surface-breaking crack can be clearly seen in Figure 1. The chemical compositions of the dissimilar base materials are provided in Table 1.

The consumable specified for manual gas tungsten arc welding (GTAW) was a 309L SS rod using argon shielding gas. The cracked portion of the joint was extracted and opened to reveal the crack surface (Figure 2). From the discoloration of the surface, it was determined that the crack initiated at the location where the pipe fitting met the seam weld of the SS tank. This examination also revealed that complete joint penetration was not achieved.

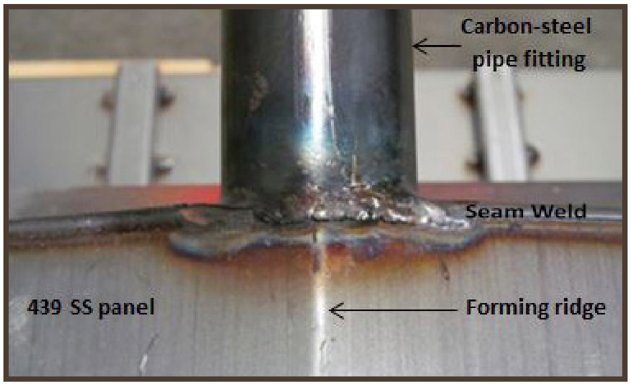

Figure 1: Weld joint between the carbon steel pipe fitting and the SS tank panel.

SEM Energy-dispersive X-ray spectroscopy (SEM-EDS) was then used to identify the local chemical composition (Table 2) of the fractured weld surface. This examination revealed that the weld contained a significant amount of oxygen (O). A layer of chromium oxide residue was also found on the joint groove surface, indicating contamination due to improper cleaning of the joint after plasma cutting prior to welding.

Microstructural evaluation revealed a $\gamma+\delta$ duplex microstructure at the toe of the cracked weld at the SS panel side (Figure 3). This was a significant finding as the different thermal-expansion coefficients of austenite and ferrite can lead to significantly increased local stresses.

It was concluded that chromium oxide contamination from the upstream plasma cutting

Table 1: Carbon steel pipe (CSP) and 439 stainless steel panel (SSP) chemical compositions.

Material	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	O	N	W	Ti
CSP	0.049	0.15	0.016	0.009	0.005	0.016	--	0.002	--	0.009	0.006	0.004	--	0.001
SSP	0.010	0.19	0.31	0.024	0.001	17.6	0.27	0.028	0.05	0.16	0.003	0.011	0.04	0.15

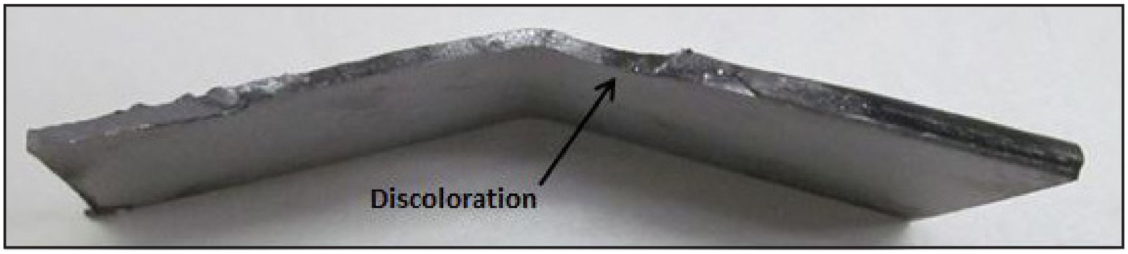

Figure 2: Opened crack surface showing a discoloration site to be cracking origin.

Table 2: Local chemical composition on the fracture surface.

C	Mn	Si	Cr	Ni	O	P	Ca
9.12	0.38	0.29	12.18	2.26	31.82	0.21	0.24

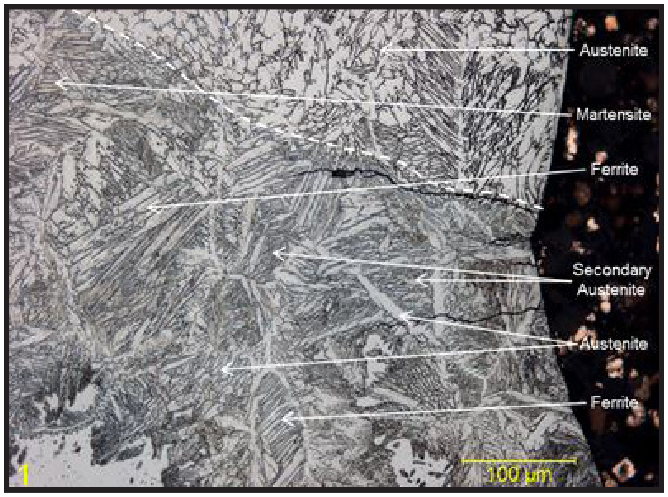

Figure 3: Micrograph of the weld toe showing the austenite and ferrite duplex microstructure.

operation – a problem easily solved with a light grinding – initiated the crack under a local stress concentration. Secondary cracking was caused by high residual stresses in the austenite/ferrite duplex matrix.

EWI Expertise

With decades of industrial and research experience in welding, materials, and metallurgical engineering, EWI's experts conduct extensive failure analyses on a wide range of ferrous and non-ferrous alloys, including nickel, titanium, aluminum, stainless steel, and clad materials. EWI has provided failure analysis services to our customers for more than 30 years, working across many industries including aerospace, oil and gas, automotive, rail, energy, steel fabrication, defense, and heavy manufacturing.

***Wesley Wang** is a senior engineer in EWI's Materials group. His expertise includes ferrous and nonferrous welding materials (selection, development, evaluation/analysis, and qualification), WPS design, welding processes, weldability evaluation, failure analysis, microstructure and phase transformation, similar/dissimilar alloys welding, corrosion, pipeline welding, underwater welding, and hardfacing. He possesses an in-depth understanding of welding metallurgy and strategies to optimize welding performance and weldment mechanical properties.*