

Failure Analysis of 4-Inch Welded Fittings in Treated LPG Service

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ABSTRACT

Caustic stress corrosion cracking occurs in carbon steels under tensile stress and exposure to caustic solutions. In this paper, we present metallurgical analyses performed on a pipe-to-tee weld and a tee-to-flange weld that leaked during operation. The pipe was in treated LPG service in a saturated gas plant. Wet fluorescent magnetic particle inspection indicated the presence of crack-like indications parallel to the welds on the outside and inside surfaces of the pipe, with more crack branching being observed on the inside surface. SEM fractography revealed that the fracture surface of these cracks was predominantly intergranular, which was confirmed during metallographic examination as well. Several temperature spikes above the acceptable range for caustic SCC were also reported by the client. Based on these observations, it was concluded that the cracks occurred as a result of caustic SCC and initiated on the inside surface of the welds.

Key words: Caustic SCC, intergranular cracking, post weld heat treatment, SEM fractography.

INTRODUCTION

Caustic stress corrosion cracking (SCC) is known to occur in carbon steels under tensile stress and exposure to caustic solutions from 115°F to boiling temperatures.^{1,2} Alternating wet and dry conditions tend to increase SCC susceptibility. Localized overheating of the metal, such as solar radiation, heat tracing, steam outs and excursions should also be considered.³ Caustic SCC was first reported in 1980 when the top of a continuous kraft digester vessel blew off in Pine Hill, Alabama.^{4,5} It was found that the tensile residual stresses present in non-stress relieved carbon steel weld seams and the corrosive environment (caustic) were responsible for the cracking. It was postulated that selective dissolution of the metal coupled with dislocation interaction led to caustic SCC. This damage mechanism has also been reported in superheated steam piping in heat recovery steam generators.^{6,7}

This case study adds to the body of literature on this topic with real examples of caustic SCC occurring on non-post weld heat treated carbon steel pipe fittings. SES was contacted by a client to perform a metallurgical analysis to determine why a pipe-to-tee weld and a tee-to-flange weld leaked during operation. The pipe was in treated LPG service in the sats gas plant, with some caustic carryover. As reported by the client's process engineer, the LPG is routed from the debutanizer bottoms/depropanizer

feed heat exchanger (shell side) to the depropanizer tower (LPG Merox unit) which uses caustic for extraction and about 1 ppm of carryover was expected. It was believed that caustic was concentrated within the exchanger bypass piping resulting in the cracking of these welds. Temperature monitoring at the exchanger outlet over the past 1 year indicated temperature spikes (up to 300°F from the average of 140°F), which likely increased cracking susceptibility. Leaks were found at three locations downstream of the heat exchanger during a Snoop® leak detection test of the welds, as shown in Figure 1.

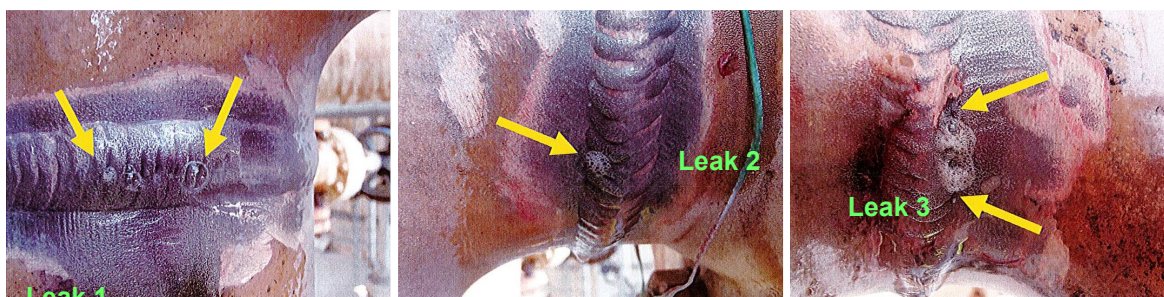


Figure 1. Photographs showing the locations on the welds where leaks were found.

LABORATORY RESULTS

Visual Examination

Figure 2 shows as-received photographs of the three leak locations (arbitrarily labeled 1, 2, 3). Leak 1 occurred at the pipe-to-tee weld, while leaks 2 and 3 occurred tee-to-flange weld. The flow direction was upwards, with the leaks 1 and 2 facing north, while the leak 3 was facing south.

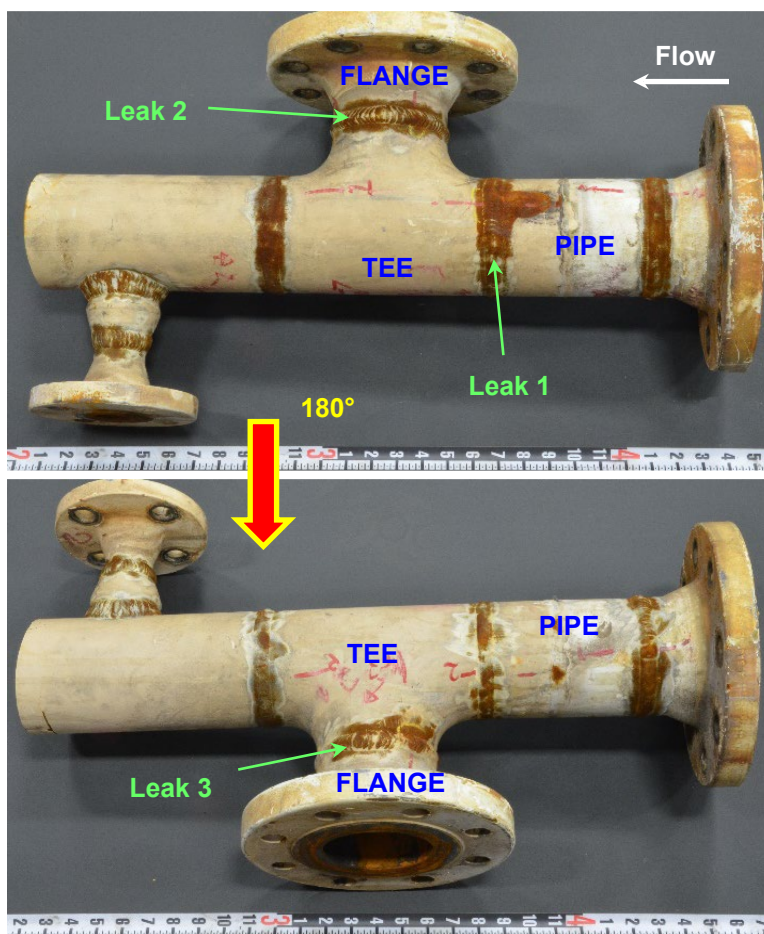


Figure 2. As-received photographs showing the leak locations. Numbered scale divisions are feet.

The tee was sectioned longitudinally in order to isolate the leak locations as shown in Figure 3. Light corrosion was observed on the inside surface of the tee.

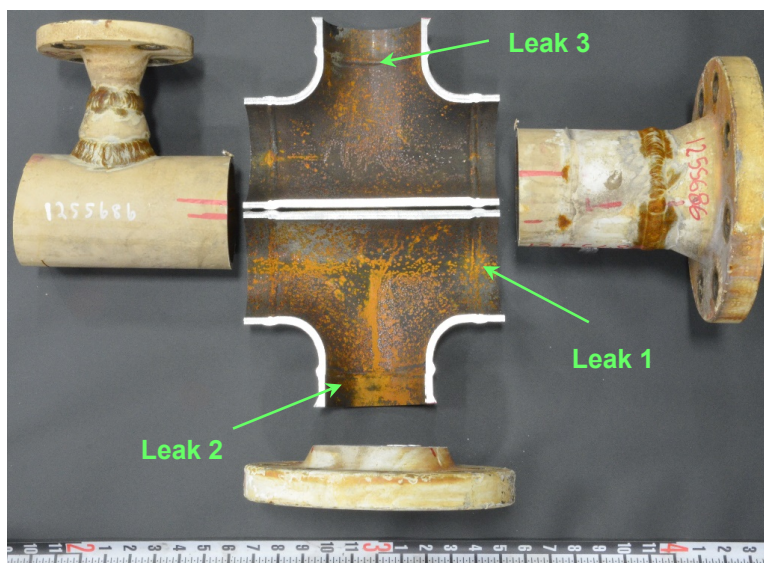


Figure 3. Leak locations following sectioning in the lab. Numbered scale divisions are inches.

Non-destructive examination (NDE) using wet fluorescent magnetic particle (WFMP) inspection was performed at the three leak locations. Crack-like indications were observed on the outside (OD) and inside (ID) surfaces of leak 1 as shown in Figure 4. More crack branching was observed on the ID than the OD. Similar observations were made for leaks 2 and 3 are shown in Figures 5 and 6 respectively.

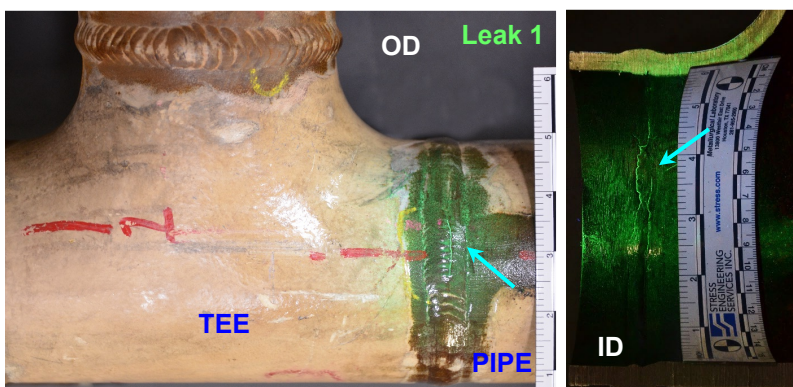


Figure 4. WFMP inspection of leak 1. Blue arrows indicate cracks. Numbered scale divisions are inches.

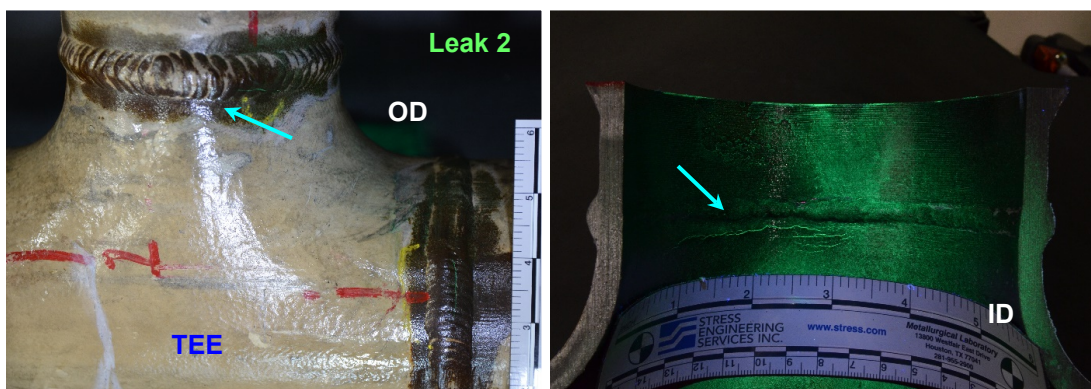


Figure 5. WFMP inspection of leak 2. Blue arrows indicate cracks. Numbered scale divisions are inches.

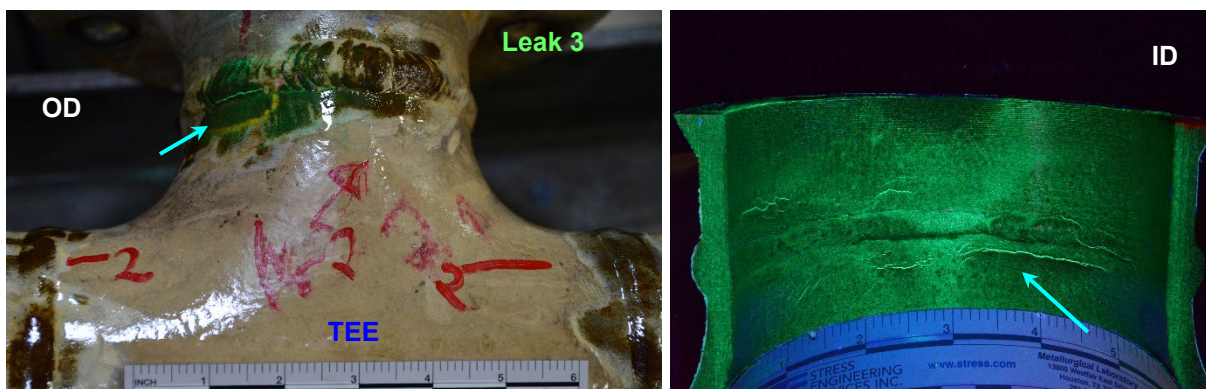


Figure 6. WFMP inspection of leak 3. Blue arrows indicate cracks. Numbered scale divisions are inches.

These crack-like features were broken open in the lab using liquid nitrogen. Figure 7 show photographs of these fracture surfaces following the lab fracture. The cracks initiated on the ID and all the fracture surfaces were covered with a brown corrosion product.

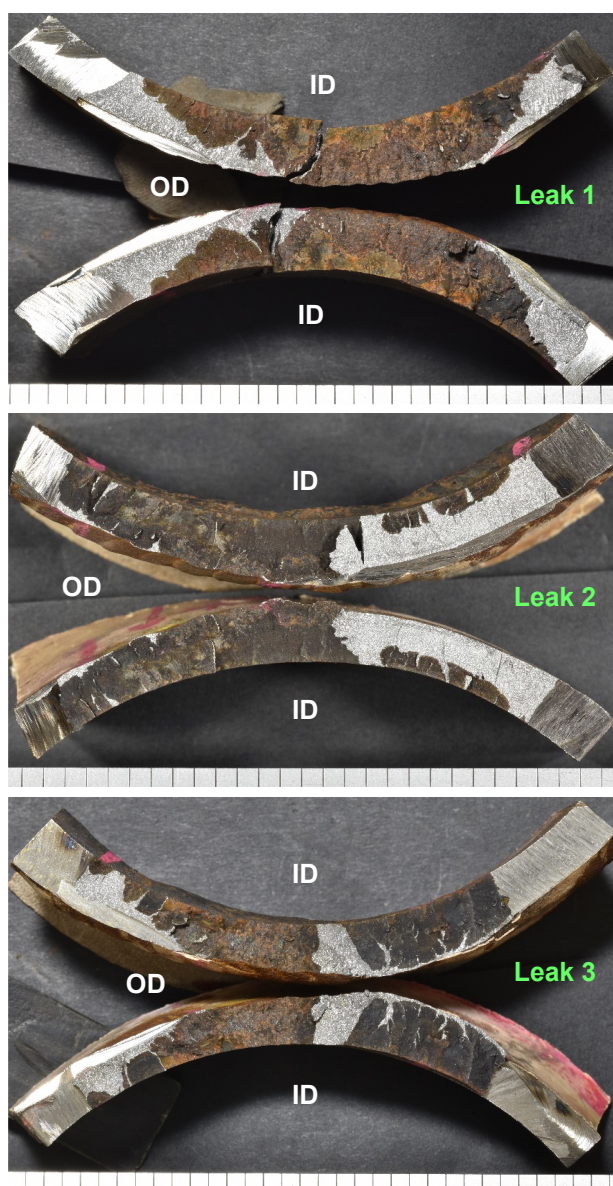


Figure 7. Photographs of fracture surfaces following lab break open. Scale divisions are 0.1 inches.

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Scanning Electron Microscopy (SEM) Examination

The fracture surfaces from the three leak locations were analyzed using energy dispersive x-ray spectroscopy (EDS) prior to performing SEM fractography. Since standardless EDS analyses do not accurately measure carbon contents, the results for the leak 2 fracture surface are shown twice in Figure 8, once with carbon included in the analysis and once with it deliberately excluded. The primary elements present were iron and oxygen, with traces of silicon, sodium and manganese. Similar results were obtained for EDS analyses performed on leak 1 and leak 3 fracture surfaces.

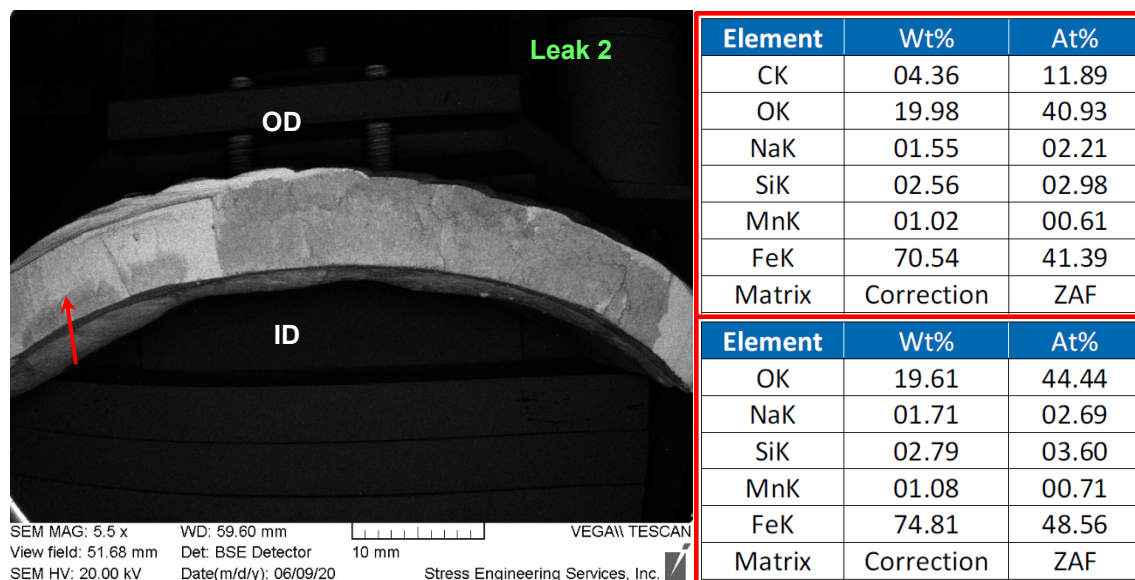


Figure 8. EDS analysis of leak 2 fracture surface.

As shown in the SEM fractographs (Figures 9-11), the morphology of the fracture surfaces for the three leaks was predominantly intergranular.

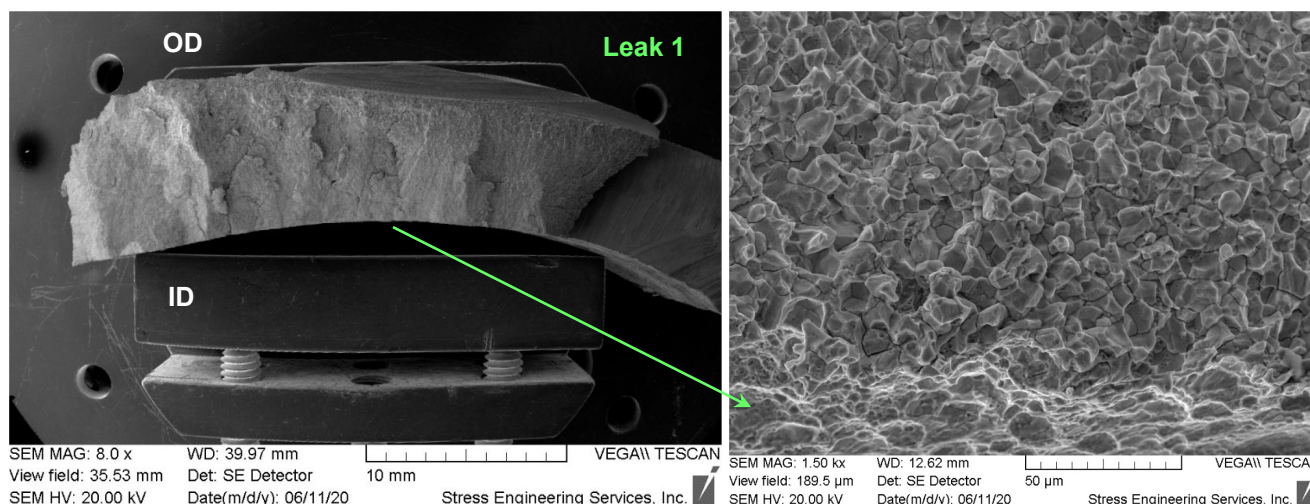


Figure 9. SEM images showing part of the leak 1 fracture surface.