Incident

Amine stress corrosion cracking of carbon steel pipework

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Introduction

Amine stress corrosion cracking (SCC) is a well-documented damage mechanism affecting carbon and low-alloy steels in gas sweetening and refining environments. Despite the widespread use of carbon steel in amine systems, failures continue to occur, particularly in welded regions exposed to tensile stress and lean amine solutions.

Gas sweetening units remove acid gases such as hydrogen sulphide (H_2S) and carbon dioxide (CO_2) from natural gas using aqueous amine solutions (e.g., MEA, DEA, MDEA). While these systems are essential for product specification compliance and downstream asset protection, they introduce a corrosive service environment that can promote environmentally assisted cracking under certain conditions. Figure 1 illustrates a simplified gas sweetening process.

Amine SCC typically occurs in:

- Weld metal and heat-affected zones (HAZ)
- Areas with high residual stress
- Regions exposed to lean or degraded amine
- Sections where stagnant amine accumulates

This paper presents a case study of through-wall cracking in a 4" carbon steel pipework section operating in amine service and discusses both the metallurgical findings and the systemic contributors to failure.

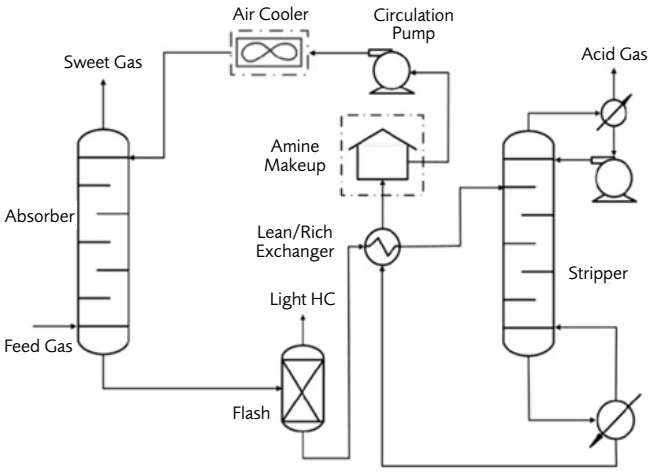


Figure 1 - A basic amine sweetening process flow diagram[5]

Background

A section of 4" carbon steel pipework, used in amine service, was found to exhibit cracking near a circumferential weld.

While the line normally carried fresh amine, operational practices allowed lean amine to be transferred back to the storage tank during shutdowns. Additionally, parts of the pipework were not self-draining, allowing lean or fresh amine to accumulate and remain stagnant for extended periods. The affected pipework is shown in Figure 2.

The system utilised aqueous amine for acid gas removal. Lean amine, containing absorbed acid gases prior to regeneration, is typically more aggressive than fresh amine due to dissolved contaminants and potential degradation products.

The affected section operated at moderate temperature during normal service and at near-ambient temperature during shutdown periods. Importantly, shutdown conditions allowed stagnant lean amine to remain in non-draining pipework, increasing exposure duration.

No evidence of post weld heat treatment (PWHT) was identified for the circumferential weld. In the absence of PWHT, residual tensile stresses from welding would have remained in the weld metal and adjacent heat-affected zone. Inspection records did not indicate prior SCC detection in this location.



Figure 2 - Cracking observed in the circumferential weld of the pipe section

The investigation

The cracked section was split longitudinally to examine the internal surface. The cracks extended through the entire wall thickness (Figures 3 and 4). The internal surface displayed a black scale, concentrated around the weld root.

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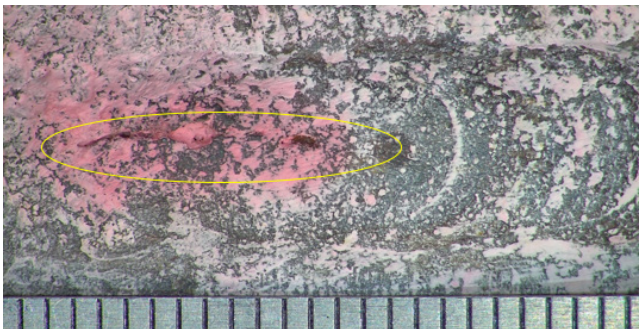


Figure 3 - External circumferential indication in the weld

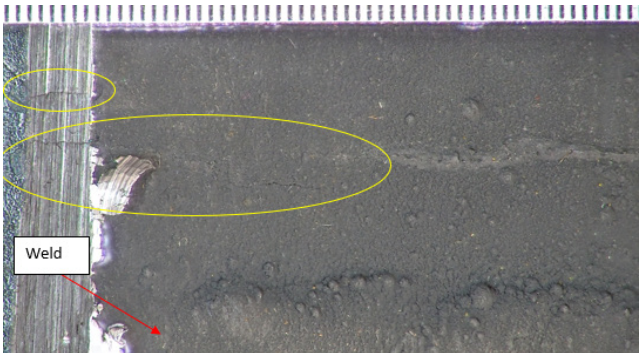


Figure 4 - Internal circumferential indication near the weld

Longitudinal sections revealed fracture surfaces that were flat and crystalline, suggesting brittle fracture (see Figure 5). Scanning electron microscopy confirmed the fractures were intergranular (propagating along grain boundaries, see Figure 6).



Figure 5 - Fracture surface after longitudinal sectioning

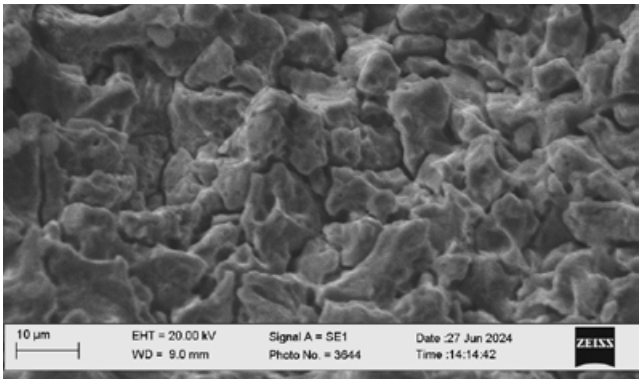


Figure 6 - Intergranular fracture observed under scanning electron microscope

Metallographic examination indicated the cracks initiated from the weld root and propagated through the weld material (Figure 7). Secondary cracks were noted at other weld roots, likely initiated at pitting sites. Additional internal cracks were observed in the parent material (Figures 8–10). These cracks were branched, intergranular, and associated with deposits. Pitting and corrosion deposits often acted as stress concentrators, promoting crack initiation.



Figure 7 - Crack initiating from the weld toe

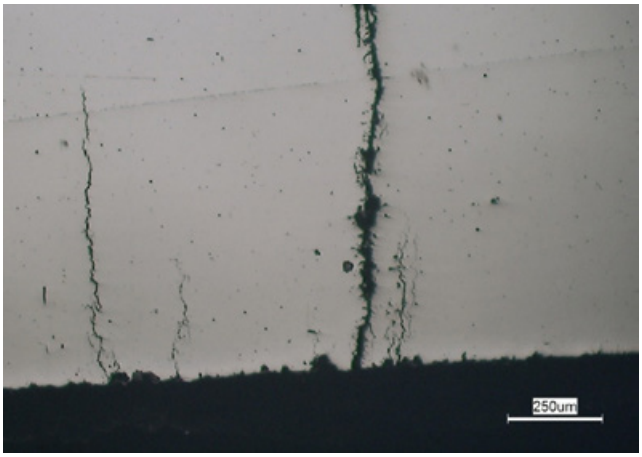


Figure 8 - Cracks initiating from the internal surface of the pipe

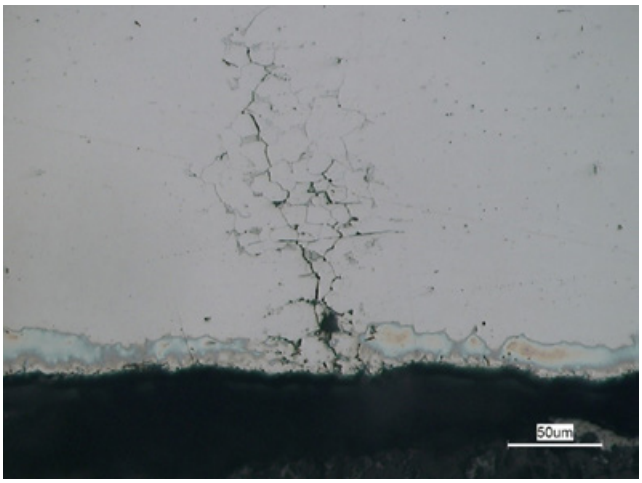


Figure 9 - Crack initiating from the internal surface, pipe section

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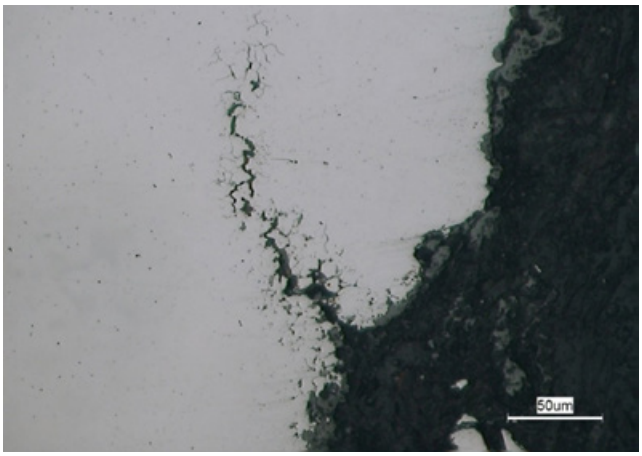


Figure 10 - Additional internal cracks showing branched and intergranular features

The cause of failure

The presence of branched, intergranular cracking in an otherwise ductile material points to an environmentally assisted cracking mechanism. The cracks and the presence of amine suggest amine stress corrosion cracking (SCC).

Amine SCC occurs in susceptible materials under tensile stress when exposed to amine-rich environments. Amines are used in gas sweetening to remove H_2S and CO_2, but they can also cause corrosion if certain conditions are met. Cracking typically occurs in carbon or low-alloy steels, often around welds or heat-affected zones.

Critical factors

- Tensile stress
  - External stresses arise from service loads.
  - Internal stresses arise from welding, uneven cooling, or material deformation.
  - Residual stresses from fabrication can be more critical than operating stresses.
- Amine type and service
  - Lean amine (amine + water) is more likely to cause SCC than fresh amine.
  - Non-draining sections were present in amine service.
  - No documented SCC susceptibility envelope (temperature vs. concentration).
- Temperature
  - Higher temperatures increase the risk and severity of SCC.
  - Cracking has been reported at ambient temperature with some amines, especially MEA.
- Operational practices
  - Shutdown procedures allowed lean amine pooling.
  - Prolonged stagnation increased local corrosion severity.
  - Potential oxygen ingress during maintenance may have exacerbated corrosion.

Prevention

To reduce the likelihood of amine SCC, the following measures were recommended:

- Stress relief of welds
  - Carbon steel welds should be stress relieved following API 945 and NACE SP0472.
  - Minimum stress-relief temperature: 635 ± 15°C.
  - Applies to production, repair, and attachment welds.
- Inspection and testing
  - Surface-breaking cracks can be detected using wet fluorescent magnetic particle testing (WFMT), alternating current field measurement (ACFM), or eddy current testing (ECT).
- Material selection
  - Consider using solid or clad stainless steel in vulnerable areas to resist the environment.
- Amine management
  - Maintain proper concentration, filtration, and temperature.
  - Minimise oxygen ingress to prevent corrosion.
- Operational practices
  - Implement shutdown procedures that prevent amine pooling in non-draining sections.

Summary

Amine SCC is a serious form of environmentally assisted cracking that can compromise carbon steel pipework in gas sweetening systems. Cracks initiate primarily at welds or pitting sites under tensile stress, and prevention relies on stress relief, careful material selection, regular inspection, and controlled operational practices. Proper understanding and management of these factors are essential to avoid failures with potentially significant consequences.

References

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