

Preferential Weld Corrosion of Carbon Steels

Dale McIntyre and Mohsen Achour

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Preamble

1. Introduction

Preferential Weld Corrosion (PWC) develops when piping or pipeline weld deposits, Heat Affected Zones (HAZ), or both exhibit accelerated corrosion compared to the nearby base metal. In the oil and gas industry, PWC has caused unplanned shutdowns and the premature retirement of assets in wet gas and seawater injection (SWI) systems.

PWC usually develops in older facilities, rather than in newer facilities. When PWC is a concern, frequently asked questions include:

1. Is the attack ongoing or did it occur only when the piping was new?
2. Does the attack result from transient or steady-state operating conditions?
3. Is the PWC isolated or is it located throughout the system?
4. How accurate are PWC detection and sizing methods?
5. How should PWC zones be assessed for fitness-for-service?
6. What are the environmental and operating variable effects on the PWC rate (for example, temperature, velocity, CO₂ and H₂S concentration, or fluid conductivity)?
7. Does PWC indicate other forms of degradation?
8. What is the best method for PWC control or remediation in the facility or system?

There are no universal answers for any of these questions. A sound approach requires an integrated effort with a complete understanding of the system at hand, any inspection and corrosion monitoring data, relevant literature review, and laboratory testing.

This volume focuses on wet gas and SWI piping systems and offers details about the potential mechanisms of PWC, recommended methods for detecting and assessing PWC severity, and requirements for an adequate PWC mitigation or inhibition program. It also includes PWC monitoring tools to help judge the current mitigation program's efficacy.

2. Executive Summary

- PWC occurs when the weld metal, the heat-affected zone (HAZ), or both become anodic to the base metal.
- PWC rates vary widely: damage may occur slowly over many years of service, but failures within three years of installation have also occurred with pipe that is part of a corroding system.
- Low levels of H₂S worsen PWC in uninhibited systems, due to unstable iron-sulfide film

formation that increases localized corrosion at welds. In general, H₂S increases corrosion rates at low temperatures and decreases corrosion rates at high temperatures.

Inhibition:

- Under-dosing of corrosion inhibitors may increase PWC rates, so optimizing treatment rates and the delivery system is critical for successful PWC control.
- The corrosion inhibitor concentration for suppressing PWC may be significantly higher than that required to protect base metals.

Metallurgy:

- For new construction, select consumables for girth welds carefully:
 - a. With seawater systems, small additions of Nickel and Copper are beneficial, but more than 0.5%, Nickel in the weld metal can provoke HAZ corrosion.
 - b. With wet gas systems, match root-pass welding consumables with the base metal to help minimize PWC. Weld metal that contains Ni may have a high corrosion rate in environments with CO₂.

Mechanism:

- In seawater injection systems:
 - a. Unstable, non-protective surface films cause PWC, which is driven by oxygen and other oxidants or loss of microbiological control.
 - b. Corrosion inhibitor injection is an option for PWC control, but the first priority should be to reduce oxidants to low ppb levels and controlling bacteria.
- In wet gas systems:
 - a. PWC is driven by condensing water and volatile acids, and it accelerates with turbulence.
 - b. Corrosion inhibitor injection suppresses PWC if inhibitor chemistry and dosage rate are validated and optimized through carefully controlled laboratory testing at realistic shear, field trials, and corrosion monitoring.

3. Monitoring:

- Once detected, PWC should be monitored for rate and effectivity of mitigation measures, using sensitive, real-time ultrasonic monitoring collars, electrochemical testing, or welded corrosion coupons.
- Time-of-flight (TOFD) inspection and radiographic densitometry offer significantly improved accuracy with sizing PWC zone depth.

Fitness for service:

- Whenever possible, avoid fitness-for-service assessments of PWC zones based solely on manual ultrasonic thickness (UT) testing. These may overestimate the depth of damage due to a rough base at the PWC zone and an uneven weld cap.
- PWC zones are usually not cracks, but corrosion grooves of varying profile and stress concentration. For computational convenience, screen PWC zones as “crack-like flaws,” then re-analyze them as corrosion grooves using classical mechanics or finite element analysis.

Repair:

- Repair-replace decisions for deep PWC damage require critical assumptions about residual stresses, inspection accuracy and uncertainty, and environmental material properties. Consult with subject matter experts about these critical assumptions.
- Repair of PWC zones must permit continued monitoring of the repaired areas, since PWC may remain active.

PWC Mechanisms

For an existing production system, PWC mechanisms strongly depend on the type of system, the metallurgical design, the historical operating philosophy, and production profile. This volume has been limited to wet gas and SWI piping systems that contain flowing CO₂, H₂S, organic acids, or combinations thereof.

1.1. Definitions and current state of knowledge

PWC is the preferential attack of the weld or heat affected zones (HAZ) in a welded structure exposed to a corrosive environment. It may be associated with severe, mild, or even the absence of base metal corrosion. Figures [1.1](#) and [1.2](#) show photos of typical PWC, showing general and pitting corrosion of the base metal.

Like any corrosion mechanism, the traditional corrosion triangle (shown in [Figure 1.3](#)) applies to PWC. The three segments of the triangle define the corrosion mechanisms and offer various mitigation options. The electrolyte leg in the triangle represents the required presence of water in the system for corrosion to take place. Water chemistry plays a major role. For PWC, the anode segment represents the weld metal, the HAZ, or both: the metallurgy of the steel is one of the key components in PWC assessment and mitigation. The cathode leg represents cathodic reactions and can be driven by the presence of CO₂, H₂S, bacteria, organic acids, and any other oxidative species. Cathodic reactions are key components in the extent of corrosion.

Weld Corrosion – Carbon Steel



Figure 1.1. Preferential weld metal corrosion with some general attack on base metals

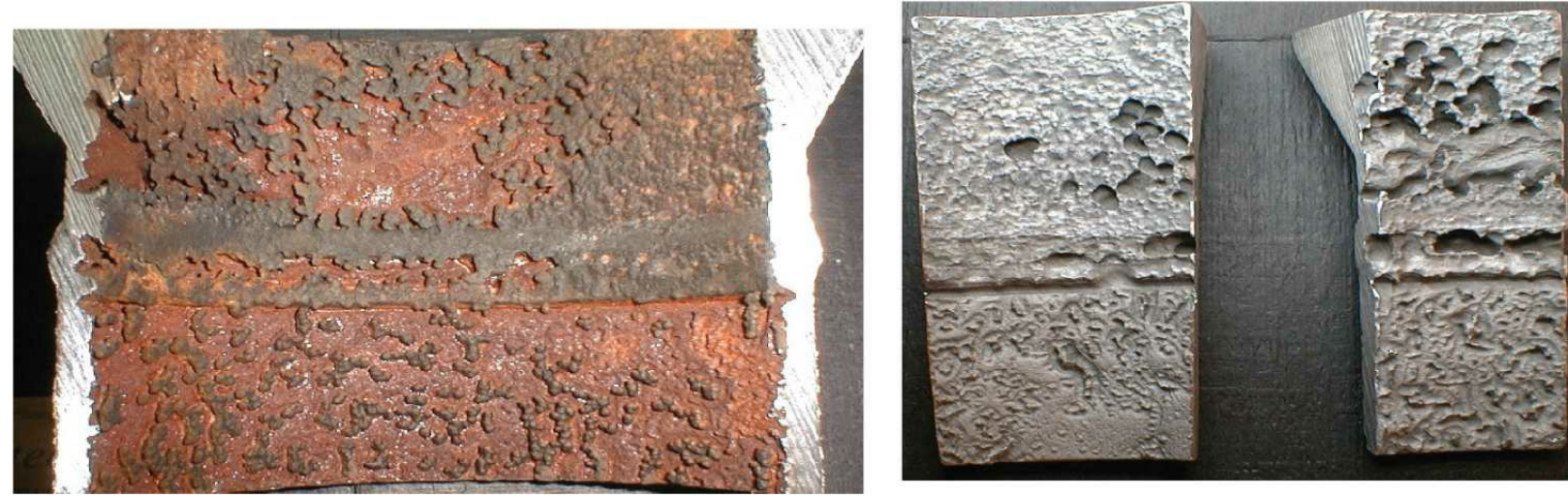


Figure 1.2. Preferential weld metal corrosion with pitting attack on base metal

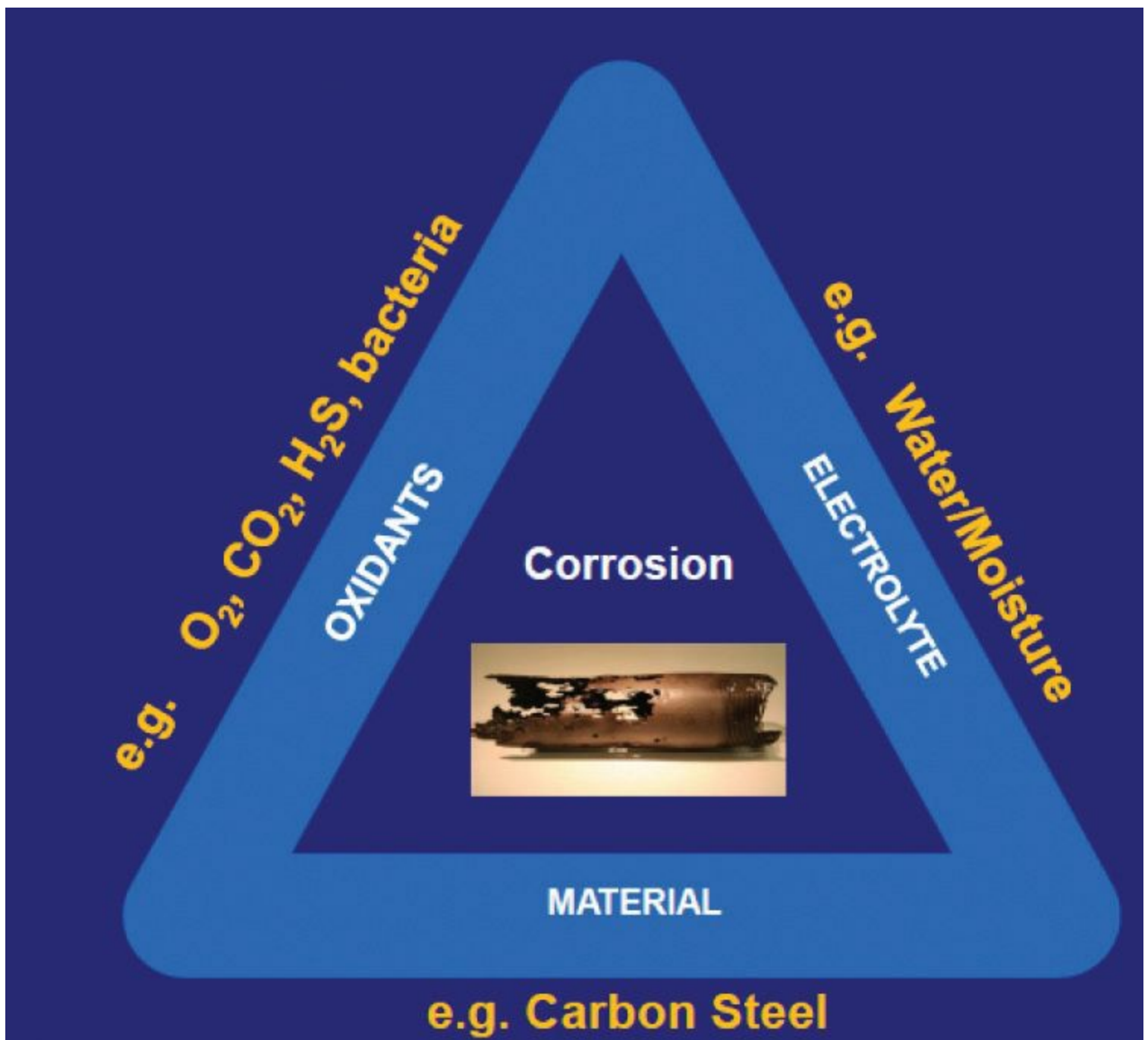


Figure 1.3. Corrosion triangle

The following sections report the current state of knowledge about PWC, focusing on the anodic and cathodic segments of the triangle when applied to it. The bibliographical review covers two areas tightly linked to the occurrence and severity of PWC:

- The effect of weak acids (CO_2 , H_2S , and organic acids) on carbon steel corrosion when all are present in a given system. Particular attention will be paid to the case of low H_2S content in a relatively high CO_2 environment. This case has proven to be more prone to PWC in both wet gas and SWI systems.
- The effect of low concentrations of alloy, particularly Nickel, on the PWC of carbon steels.

1. Effect of H_2S on CO_2 Corrosion of Steel

The synergetic effect of H₂S and CO₂ corrosion of steel is important for understanding the potential corrosion mechanisms in PWC. Two distinct scenarios prevail:

- Low temperature/low H₂S content: Corrosion increases with increasing H₂S content. Low temperature is considered to be below 140°F (60°C).
- High temperature/low and high H₂S content: Corrosion rate decreases with increasing H₂S content. At very high temperatures (over 212°F, or 100°C), this effect occurs even with low (ppm) levels of H₂S concentrations.

A literature review reveals a number of papers that have addressed this issue. As expected, the answer is complex, depending on various environmental parameters. Ikeda¹ has shown that low ppm levels of H₂S increase corrosivity at low temperatures.

The work of Murata² confirms an increase in corrosivity by H₂S at 77°F (25°C). At high temperatures, the H₂S lowers corrosion rates. This trend was confirmed by Alberto Valdes and Raymundo Case³.

Previous research showed that low concentrations of H₂S (less than 30 ppm in a CO₂ saturated water solution) can accelerate the corrosion rate⁴. The effect seems to vanish at higher H₂S concentrations and high temperatures⁵ (>176°F, or >80°C) when a protective film forms on the steel surface.

Das^{6a} tested steels in solutions pressurized with pure CO₂ or with CO₂ containing 0.004 ppm H₂S. With this level of H₂S, only minor effects on the corrosion rate were found in 48-hour tests through the temperature range of 86 to 248°F (30 to 120°C). Apparently, the concentration of H₂S was too low to have an effect. Other researchers have found different trends. Nestic^{7,8} reports that all concentrations of H₂S from 10 ppm to 250 ppm (in gas phase) reduced corrosion rates of steel at 68-176°F (20-80°C).

2. Metallurgical Effects on Preferential Weld Corrosion

If PWC is detected in an existing line, the weld alloy chemistry cannot be adjusted. As-deposited welds must be continued in service with inhibition or replaced.

In sea water, an empirical relationship exists between the base metal's alloy content, the weld deposit, and the potential for PWC⁹.

$$\Delta = 3.8 (\%Cu_{base} - \%Cu_{weld}) + 1.1 (\%Ni_{base} - \%Ni_{weld}) + 0.3$$

Positive Δ values indicate that base metal is the cathode;

Negative values indicate that weld is the cathode (desirable)