

Failure Analysis of Hydrotested 12-Inch Type 304 Stainless Steel Pipe Sections

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ABSTRACT

Hydrostatic testing of pipelines is an important step prior to commissioning. In this paper, we discuss two case studies wherein leaks were detected during hydrotesting of a newly constructed 12-inch pipeline at a client site. The first failure occurred in the body of a pipe segment coated with fusion bonded epoxy. The second failure occurred at a girth weld of a different pipe segment in the same line, which had been coated with an abrasion resistant outer wrap. Visual examination and stereomicroscopy revealed the presence of pits adjacent to the leaks. Scanning electron microscopy, energy dispersive x-ray spectroscopy, bacteria culture testing and metallography confirmed that the pitting occurred as a result of internal microbiologically induced corrosion.

Key words: Stainless steels, pitting, microbiologically induced corrosion, MIC, sulfate reducing bacteria, water treatment.

INTRODUCTION

Pre-commissioning hydrostatic testing of pipelines and the resulting corrosion (MIC) issues are often linked to test water quality, as well as post-test cleaning operations.¹ In a 1998 study, it was reported that localized corrosion (pitting/crevice corrosion) accounted for 20% of failures in the chemical process industry with an estimated one half of those being MIC failures.² Identification of MIC failures is not straightforward. Common characteristic features such as pit clustering, “tunneling” of pits, tuberculation, high microbiological counts, presence of sulfides (in the case of sulfate reducing bacteria (SRB)) and preferential weld attack have been used to anecdotally pinpoint field failures towards MIC.^{3,4} Some of these morphologies are similar to those found in other damage mechanisms, such as chloride pitting in stainless steels (SS), making it challenging to accurately diagnose MIC failures.^{3,5} However, corrosion rates for MIC could be too rapid to be explained by conventional pitting/crevice corrosion. Additionally, electrochemical studies for Type 304 stainless steel (SS) have shown that in the case of MIC damage, the corrosion potential within the pit is ennobled due to formation of microbes; while in the case of chloride-induced pitting corrosion, the pitting/breakdown potential becomes more negative due to local pit acidification.⁶ No evidence was found to support ennoblement of corrosion potential due to microbial acid production. In other studies, this ennoblement of corrosion potential (above pitting potential of

austenitic SS) has been linked to the presence of manganese oxidizing bacteria (MOB), with manganese being observed in the corrosion products that were examined.^{7,8}

Conceptual studies on MIC of SSs have followed an open-ended approach, wherein field observations are used to develop more accurate MIC models, followed by lab trials, and feedback to the field for validation.^{7,9} Current techniques used to justify MIC as a contributor to observed corrosion damage involve a 4-fold evidence collection process: metallurgical, chemical, biological and operations.^{5,10} In a case study involving hydrotesting of Type 304L SS using untreated, low chloride potable water; classic MIC pits – pit clusters with larger pit dimensions subsurface compared to the surface opening – were observed when the hydrotest water was inadvertently left stagnant in the line for nine months.¹¹ In a research study on Type 304L SS GMAW welds prepared using Type 308L electrodes, it was found that bacterial attachment was higher on the weld regions compared to the base metal.¹² Elemental segregation and longer grain boundaries per unit area were identified as likely reasons for the increased bacterial adhesion at the welds. Additionally, weld surface effects such as heat tint, residual stresses and gouges/scratches have been reported to increase MIC susceptibility at welds.⁶ Although MIC damage during hydrotesting has been well documented, it continues to occur despite the most stringent mitigation measures. This paper shows how MIC can occur in Type 304 SS pipe body and girth welds alike. These real-world examples will tremendously add to the existing knowledge on this subject.

Three pipe sections 12-inch outside diameter (OD), 0.375-inch wall thickness, that leaked during hydrostatic testing were evaluated – one from the pipe body that leaked, a second pipe body section from a different joint of pipe that has not leaked (about 30 feet from the leaked section), and a third pipe section containing a girth weld. These sections were part of the same line that was installed in May 2020, failed the same hydrotest at less than 100 psi test pressure (immediately after pressure was applied), located 1.5 miles apart. City water was reportedly used for the hydrotest. Information on water quality, such as chemical treatment, storage and water chemistry was not provided. The pipe body sections were located above ground and were coated with Scotchkote™ 212 spray coating. The girth weld sections were located underground, buried underneath a creek, and were coated with an abrasion resistant outerwrap (ARO) coating. It was reported that the line was open to the environment for several months prior to the hydrotest. Figure 1 shows a picture indicating the location of the leak on the pipe body section onsite.



Figure 1. Photographs showing the leak during hydrostatic testing.

The girth weld leaks were retrieved from pipe that had been newly installed by horizontal directional drilling (HDD). These pipe segments – identified as GW-36, GW-38 and GW-41 – leaked at the girth welds as shown in Figures 2 and 3 (yellow arrows). The girth welds in two of these segments contained internal voids (red arrow in Figure 2) identified earlier by radiography as shown in Figure 4.

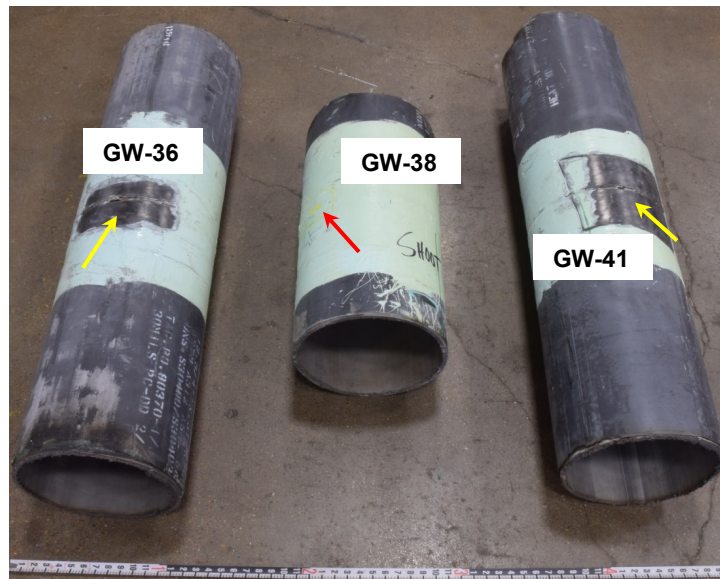


Figure 2. As-received photographs showing the GW-36, GW-38 and GW-41 pipe segments.

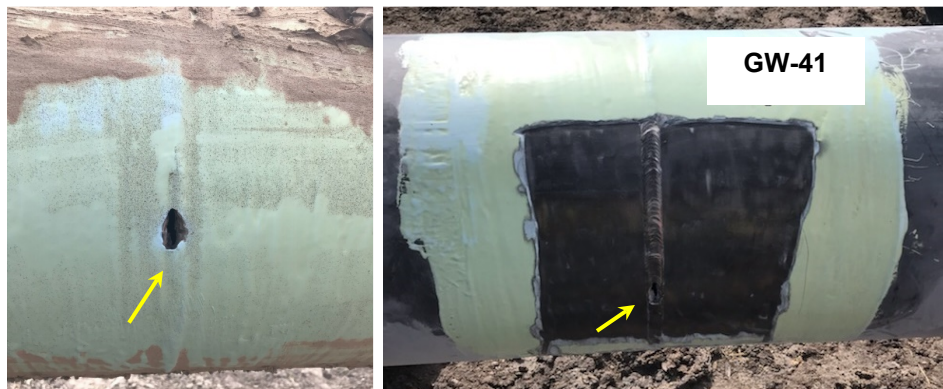


Figure 3. Photographs of leak at the girth weld for pipe segment GW-41 (before/after removal of ARO).



Figure 4. Section of the radiograph showing internal voids for pipe segment GW-38.

LABORATORY RESULTS

Visual Examination

Both the pipe body and the girth weld sections were examined. Photographs of the pipe body section that leaked and the loose piece of spray coating are shown in the as-received condition in Figure 5. Very little corrosion product was observed on the coating piece. One section of the pipe was sent out to an

outside laboratory for chemical analysis and tension testing. The segment containing the leak (yellow arrow) was further sectioned longitudinally in order to document the inner surface of the pipe.

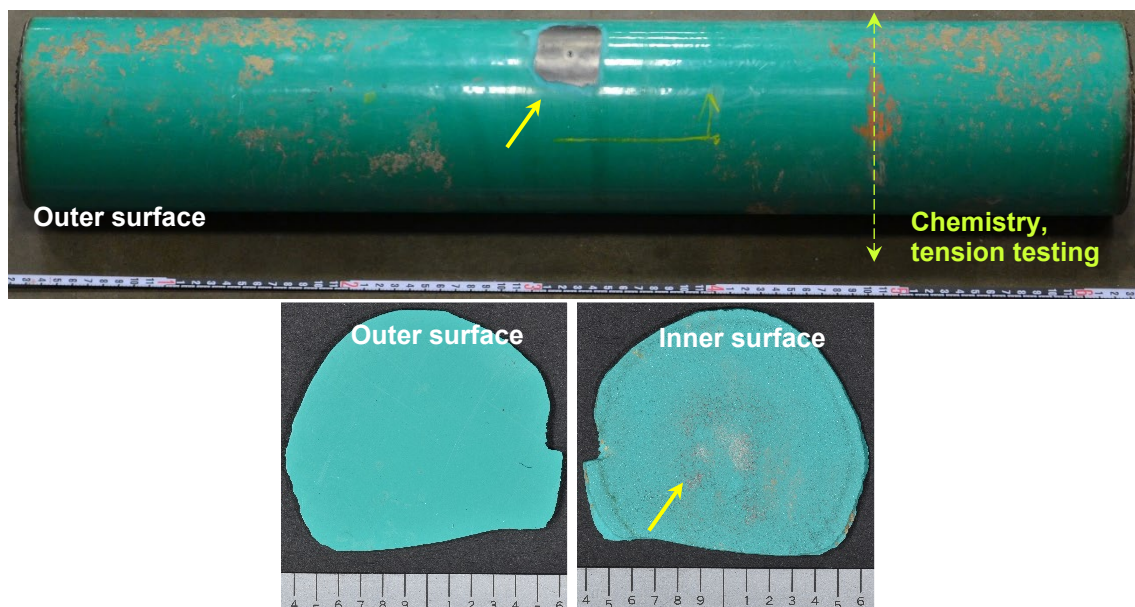


Figure 5. Pipe section that leaked (top) and the loose coating piece (bottom) shown in the as-received condition. Numbered scale divisions are inches (top), 0.1 inch (bottom).

Figure 6 shows close-up photographs of the pit at the inner and outer pipe surface that led to the leak. The outer surface of the pipe exhibited a rough, pitted appearance surrounding the leak region. A green layer was also observed on the inside of the pit (blue arrow in the figure). However, this green layer was easily removed when an air blower was used. This implies that the layer/powder was a remnant of some non-destructive examination performed onsite by the client.

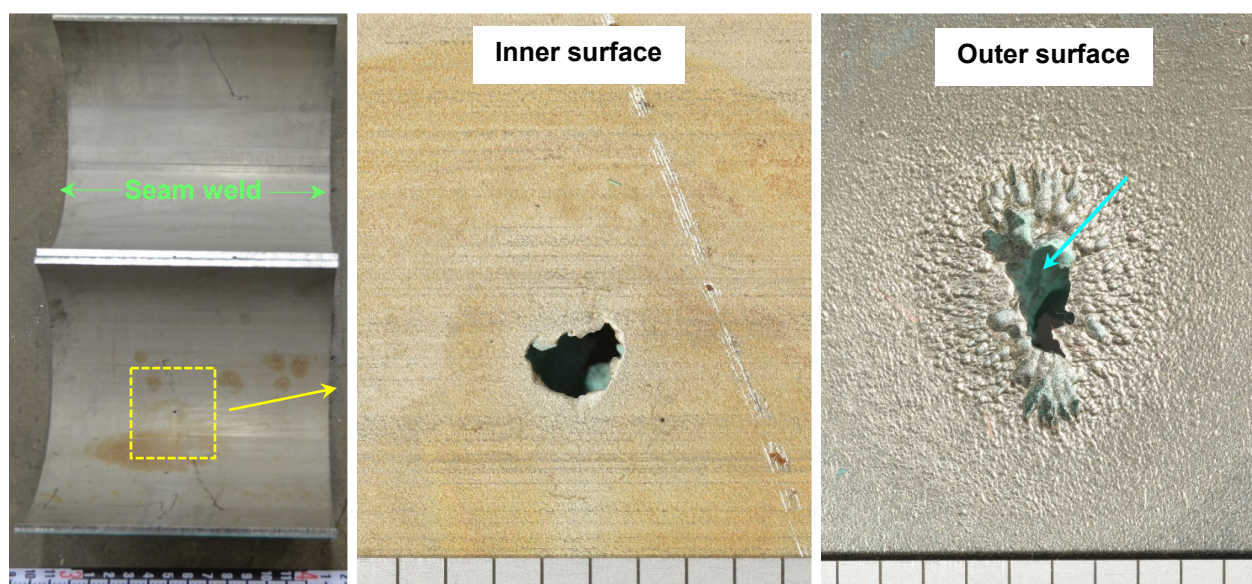


Figure 6. Close-up photographs of the pit at the leak site. Scale divisions are 0.1 inch.

The pitted region was sectioned in the transverse direction as shown in Figure 7 to prepare a metallographic cross-section. The pit appeared to be tunnel-shaped, i.e., wider at the mid-wall region as compared to the inner/outer surface regions.

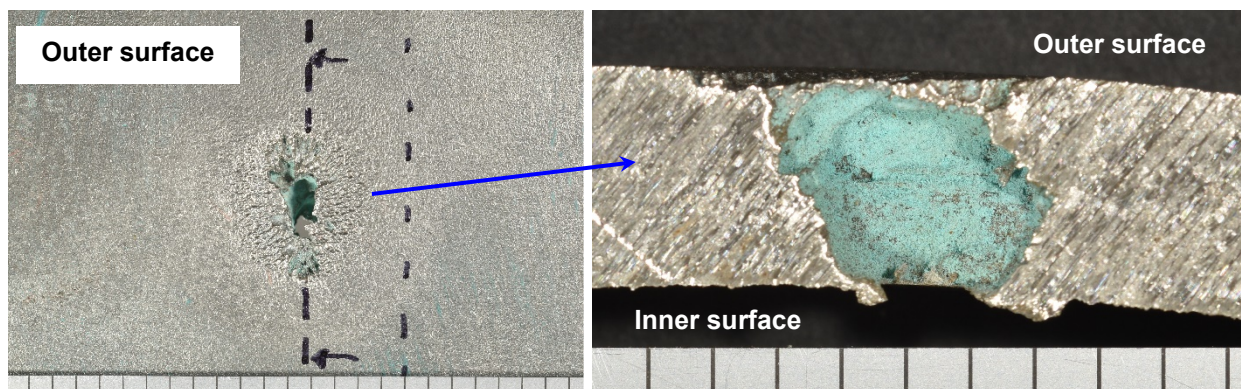


Figure 7. Photographs of pipe body pit before and after sectioning. Scale divisions are 0.1 inch.

Similar sectioning was completed for the second pipe body section as shown in Figure 8. Close-up photographs of the inner surface pits were taken and are presented in Figure 9. One of the pits was sectioned in the transverse direction to prepare a metallographic cross-section as shown by the dotted line. Some of the corrosion products in these pits were retrieved and submitted for microbiological testing (see section below).

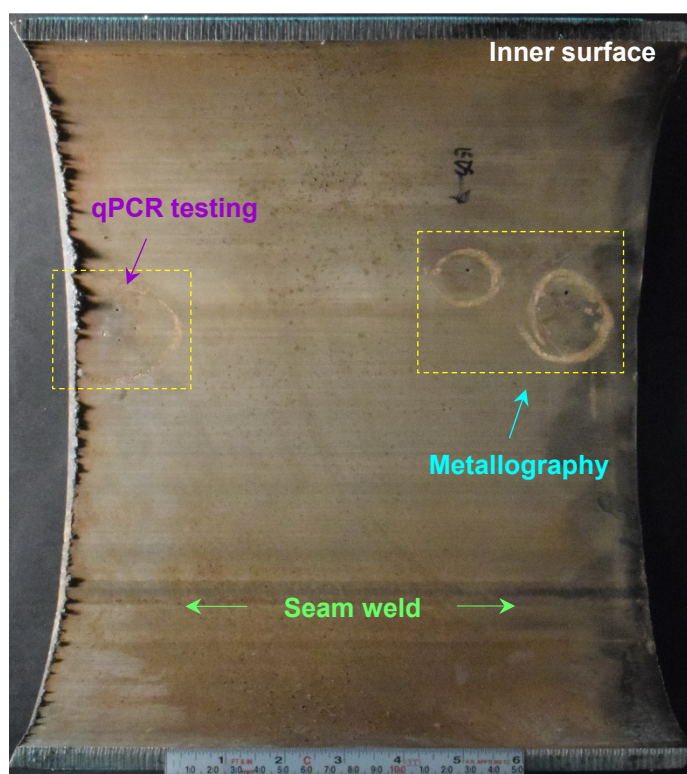


Figure 8. Photograph showing the second pipe section's inner surface. Pits are indicated using yellow boxes. Numbered scale divisions are inches.