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MULTIPARAMETRIC EXPERIMENTAL INVESTIGATION OF MARINE ANTIFOULING COATINGS

Enhancing the Performance and Quality of Internal FBE Coating for Field Joints in Line Pipes

Laboratory Examination Methodology for Internal Pipeline Crack

Phorgotten Phenomenon: Corrosion of Underground Zinc-Coated Piping

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Special Feature:

Chemist Puts Intumescent Coatings to the Ultimate Test

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IN THIS ISSUE

JANUARY 2026
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CORROSION PREVENTION AND CONTROL WORLDWIDE

MATERIALS PERFORMANCE

SPECIAL FEATURE

16 **Chemist Puts Intumescent Coatings to the Ultimate Test**
Kerry Cole

COATINGS AND LININGS

20 **Enhancing the Performance and Quality of Internal FBE Coating for Field Joints in Line Pipes**
Sangki Chi, Abdullah Alwayel, Hassan Sagour, and Abdullah Shaiban

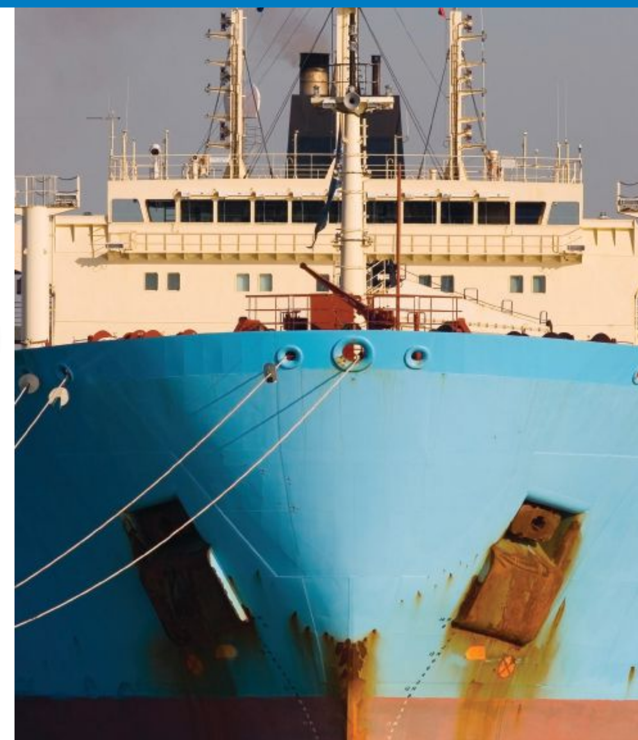
MATERIALS SELECTION AND DESIGN

24 **Multiparametric Experimental Investigation of Marine Antifouling Coatings**
Evangelia Kiosidou and Antonis Karantonis

PHORGOTTEN PHENOMENA

30 **Corrosion of Underground Zinc-Coated Piping**
Michael J. Szeliga

34 **Laboratory Examination Methodology for Internal Pipeline Crack**
Sudhakar Mahajanam, Scott Harding, Chris Miller, and Sean Moran



About the Cover

Marine structures like ships and platforms face significant risks from corrosion and biofouling, which can lead to structural, environmental, hydrodynamic, and economic problems. In the technical article Multiparametric Experimental Investigation of Marine Antifouling Coatings, authors Evangelia Kiosidou and Antonis Karantonis say to mitigate these issues, environmentally friendly antifouling coatings are essential, and their effectiveness in antifouling, anticorrosion, and mechanical integrity remains a critical area of ongoing research.

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Laboratory Examination Methodology for Internal Pipeline Crack

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Defects and anomalies routinely occur during the manufacturing, construction, and operation of oil and gas pipelines. For critical defects, identifying and repairing them is mandated by the regulatory agencies to ensure pipeline integrity. In this case study, an effective methodology for metallurgical examination of an internal anomaly is demonstrated on a Grade X52 pipe sample using industry-accepted laboratory techniques such as wet fluorescent magnetic particle inspection, scanning electron microscopy, and optical microscopy. The anomaly was confirmed to be a pre-existing defect that had been weld repaired around the time of installation.

Pipeline defects and anomalies, such as dents, gouges, and internal/external corrosion damage, are often found in oil and gas pipelines.[1] These defects can occur during manufacturing, construction, and operation of the pipelines. With the increased regulations being imposed on the midstream oil and gas sector, it is important to reliably identify critical defects and perform appropriate repair techniques. A recent notice published by the Pipeline and Hazardous Materials Safety Administration (PHMSA) advises pipeline owners and operators to evaluate defects, such as hard spots, on all pre-1970 pipe in service, irrespective of manufacturer.[2] This would ensure the long-term integrity, and safe and efficient operation, of the millions of miles of pipelines currently in service across the U.S. Proper metallurgical examination is a critical tool in identifying the root cause of pipeline defects.

In this laboratory investigation, metallurgical examination of a unique pipeline imperfection was conducted on a 30-inch (76.2-cm) outside diameter (OD), 0.312-inch (7.9-mm) wall thickness, Grade X52 pipe sample. API 5L X52 pipe is commonly used in the midstream oil and gas industry for transportation of hydrocarbons. API Specification 5L details several acceptance criteria for line pipe, including chemical composition and tensile properties, which need to be met prior to qualifying the pipe for service.[3] The pipeline described in this case study was in natural gas service since 1949, with an operating pressure of 583 psi and a maximum allowable operating pressure of 780 psi. It was reported that the pipe contained an internal feature, initially identified during electromagnetic acoustic transducer (EMAT) ultrasonic testing (UT) inspection in the field. The presence of a 1-in-long (2.54 cm) anomaly was further confirmed through phased array ultrasonic testing (PAUT) and radiography. The depth of the anomaly was estimated to be 0.126 to 0.141 in (3.2 mm to 3.6 mm). A slight dent (0.016-in [0.4 mm] depth) was observed on the outside surface of the pipe near the detected feature. In the pipeline industry, an indication/imperfection/anomaly/feature is only classified as a defect/crack following a detailed metallurgical analysis. The objective of this project was to perform an extensive laboratory examination to accurately characterize the anomaly detected during the EMAT run, given the possibility that such anomalies might be prevalent in the millions of miles of aging pipelines located country-wide.

Testing Methodology

Material property testing of the pipe sample was performed in accordance with the traceable, verifiable, and complete (TVC) records requirement of the PHMSA Gas Gathering Rule Part 1.[4] Based on the budget available for this project and direction from the client, an optimal scope of work was agreed upon and the following test methods were used: visual examination, wet fluorescent magnetic particle (WFMP) inspection, stereomicroscopy, scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), mechanical testing, macro-etching, metallography, and Vickers microhardness testing (HV10). The comprehensive list of testing techniques typically utilized in metallurgical analysis of pipe samples is summarized in Table 1. The yield and tensile strengths and elongation values measured through mechanical testing were compared to the requirements for Grade X52 steel per API 5LX (1953) standard[5] — the closest available standard to the year of installation of the pipe.

TABLE 1 LIST OF TESTING TECHNIQUES FOR METALLURGICAL ANALYSIS OF PIPE SAMPLES

Technique	Purpose
Visual examination	Photographic documentation
WFMP inspection	Document size and location of the anomaly
Stereomicroscopy	Fracture surface examination, anomaly dimensions
SEM analysis	Fractography
EDS analysis	Characterize corrosion products
Tensile testing per ASTM E8 standard[6]	Determine yield strength, tensile strength, and elongation
Charpy V-notch (CVN) testing per ASTM E23 standard[7]	Determine impact energy (toughness)
Optical emission spectroscopy (OES) per ASTM E415 standard[8]	Pipe chemical composition (not performed)
Macro-etching	Identify any "macro"-structural features associated with feature/anomaly
Metallography	Evaluate fracture morphology, material microstructure
Vickers HV 10 microhardness testing	Identify variations in hardness across the microstructure and as an indication of approximate tensile strength
Automated hardness mapping	Identify hard spots/zones (not performed)

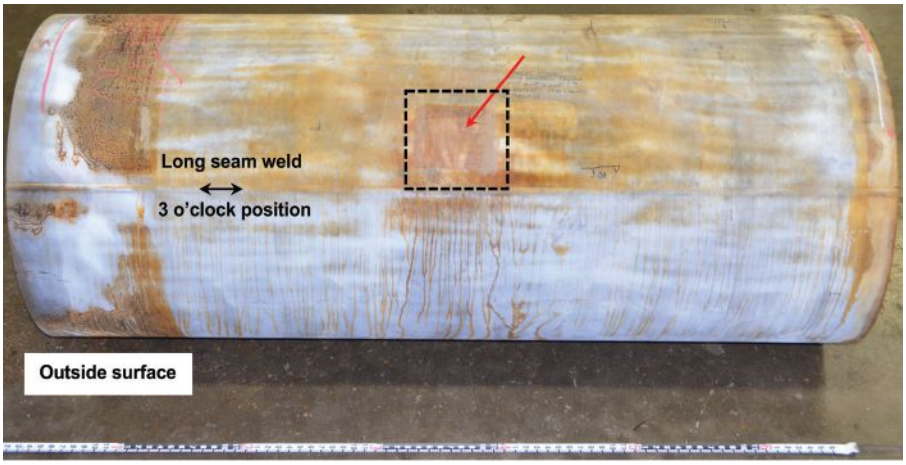

FIGURE 1 As-received photograph showing the location of the anomaly. Scale divisions are inches.

Laboratory Investigations

Visual Examination

Figure 1 shows an as-received photograph of the 6-ft 3-in. (1.91-m)-long pipe sample that was provided for laboratory examination. The reported anomaly was located close to the long seam weld, approximately between the 2 and 3 o'clock positions as per how the pipe was oriented in service. Wall thickness readings were taken at one end of the pipe, with the average value being 0.324 in (0.8 cm). The WFMP inspection performed on the outside surface of the pipe did not show any indications. A window containing the internal feature was flame cut (dotted box in Figure 1) for further examination.

The WFMP inspection was also performed on the inside surface of the pipe as shown in Figure 2. A linear, longitudinal indication about 1 in long was observed.

The indication was broken open after chilling in liquid nitrogen to allow for examination of the fracture surfaces. Figure 3 shows a macro-photograph of the fracture surface following lab break-open procedures. A distinct crack surface with black corrosion product was observed. Within the region of the crack, two visually distinct zones were observed: a darker region

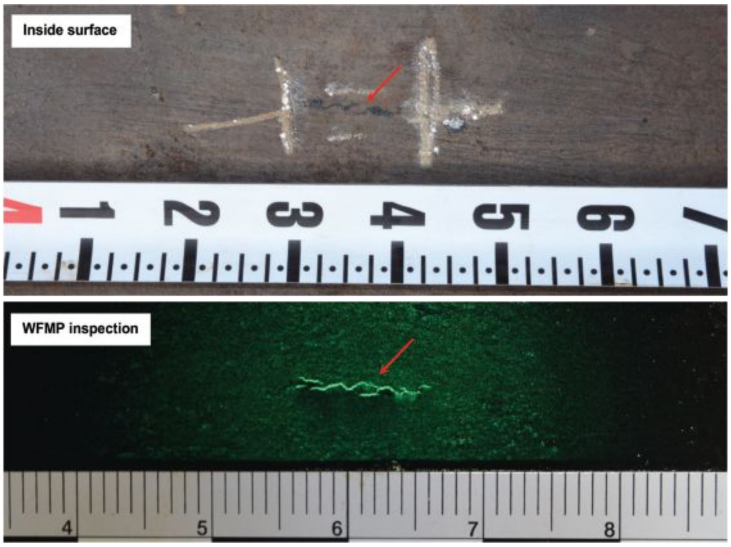

FIGURE 2 Photographs of pipe inside surface at crack location. Scale divisions are inches.

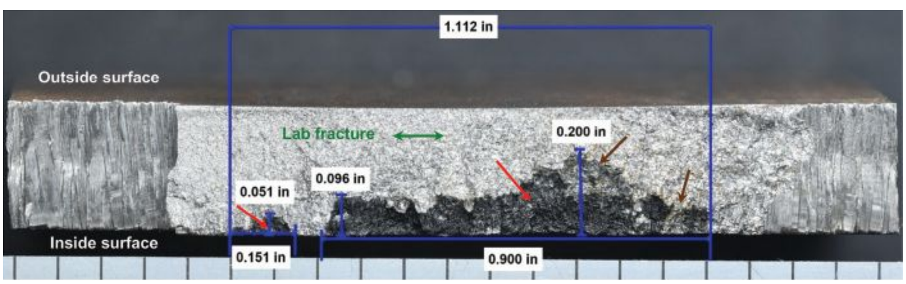

FIGURE 3 Photograph showing one half of the crack surface. Scale divisions are 0.1 in (2.5 mm).

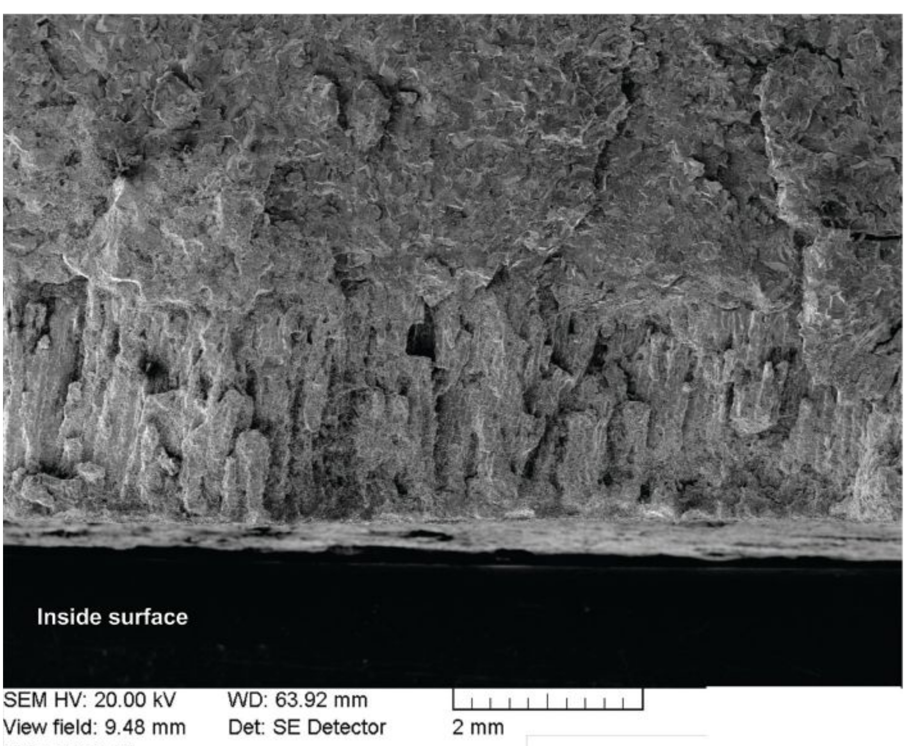

FIGURE 4 SEM image of crack surface showing columnar grains close to the inside surface.

marked by red arrows (likely original, pre-existing crack) and a lighter region marked by brown arrows (likely crack growth). Crack length and depth dimensions were also determined and appeared to confirm the field PAUT measurements.

SEM Examination

SEM imaging of the crack surface was performed both before and after ultrasonic cleaning. Prior to cleaning, EDS analysis of the crack surface indicated the presence of iron, oxygen, and sulfur, which are typical of oilfield corrosion products. After cleaning, SEM fractography revealed columnar fracture morphology close to the inside surface, as shown in Figure 4. No distinct transgranular or intergranular features were identifiable on the crack surface. The mid-wall regions appeared to contain corroded cleavage facets. Additional SEM images can be found in AMPP paper no. 20700.[9]

Metallographic Examination and Microhardness Testing

A matched fracture mount was prepared for metallographic examination, as shown in Figure 5. Three distinct weld passes were located, with the crack bisecting the middle weld pass. Higher magnification light micrographs taken in the vicinity of the crack are presented elsewhere.[9] The region close to the outside surface consisted of acicular/Widmanstatten ferrite and pearlite. The region close to the inside surface also consisted of acicular/Widmanstatten ferrite and some pearlite. Such microstructures are typically formed from fast, non-equilibrium cooling rates. The pipe base material consisted of polygonal ferrite and pearlite, typical of low-carbon steel.

Given the SEM and metallographic findings, the inside surface of the pipe sample in the vicinity of the crack was examined further. The inside surface was lightly sandblasted to prepare for macro-etching of the crack region with Nital. Grinding marks were observed close to the crack, along with a distinctly etching region. An expanded macro-etch was then performed, as shown in Figure 6, to include the areas containing the grinding marks. The expanded mac-

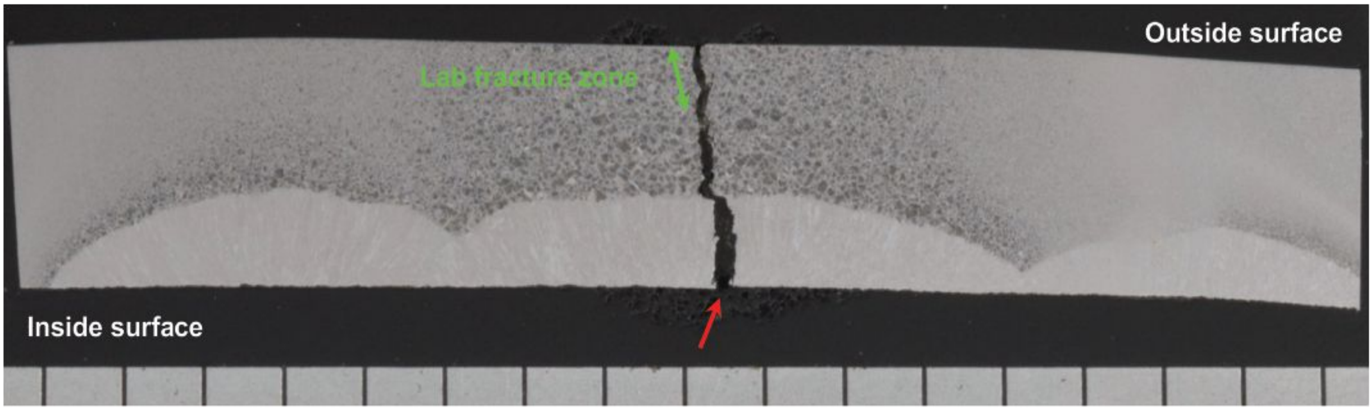

FIGURE 5 Macro-graph of crack cross-section. Scale divisions are 0.1 in. Etchant: Nital.

ro-etch revealed the entire extent of the weld zone region surrounding the crack, and indicated the presence of a weld repair of a pre-existing defect using three weld passes. The repair welding likely was performed around the time of installation.

HV10 measurements were taken across the match fracture mount. The equivalent Rockwell B-scale (HRB) values were also determined. The hardness values in the weld repair region ranged from 91-97 HRB. The pipe base material hardness was 87 HRB. These values are typical of X52 low-carbon steel. There are no hardness requirements for X52 steel per API 5LX (1953)[5] specification.

Mechanical Testing

The material testing performed for this project consisted of two transverse tensile tests conducted 180° from the long seam weld, as shown in Table 2. The reported yield and tensile strengths, and elongation values met the requirements for X52 steel per API 5LX (1953) specification.[5] Full Charpy V-Notch (CVN) transition curves were also developed for the pipe body, longitudinal seam weld, and weld heat affected zone (HAZ) as prescribed per the current API 5L (2018) specification.[3] The CVN tests were conducted at temperatures ranging from 0 °F to 160 °F (–17.8 °C to 71.1 °C), as shown in Tables 3 through 5. The impact energy values were typical of X52 steel. There are no impact toughness requirements per API 5LX (1953).

Investigation Findings

Based on the metallurgical examination of the 30-in pipe, the following conclusions can be drawn:

1. The internal anomaly was likely a pre-existing defect that was weld-repaired around the time of manufacturing or installation. Grinding marks and a distinct weld zone with three weld passes were observed in the region surrounding the crack.
2. SEM fractography of the crack surface revealed the presence of columnar grains close to the inside surface that are typical of shrinkage/solidification cracking in a carbon steel weld.
3. EDS analysis indicated that the corrosion products consisted of iron, oxygen, and sulfur, which are typically found in oilfield corrosion products.

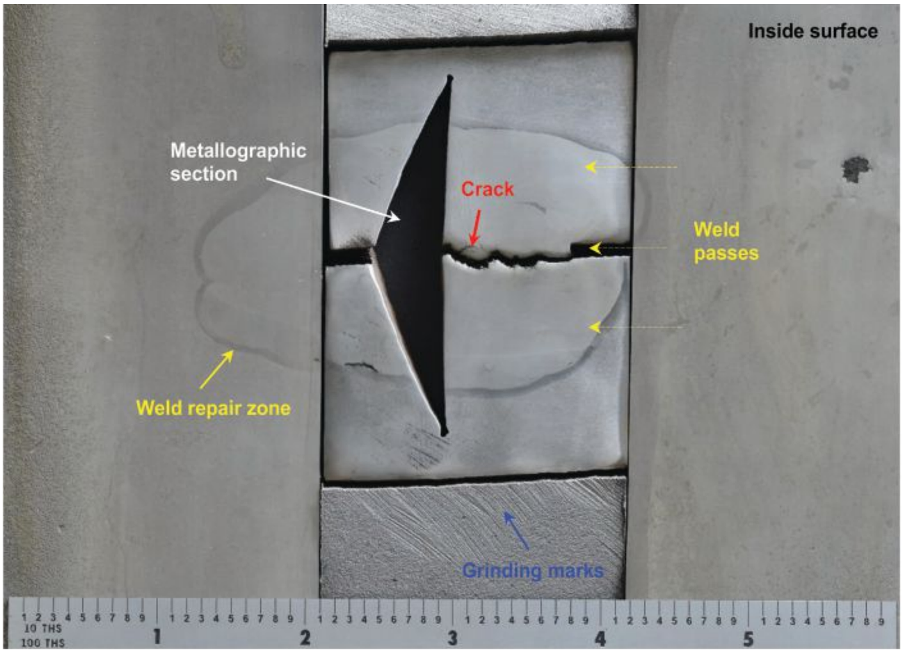

FIGURE 6 Macro-etching performed in the vicinity of the crack. Scale divisions are inches. Etchant: Nital.

TABLE 2 TENSILE TEST RESULTS (TRANSVERSE, 1½″ WIDE REDUCED SECTION, 180° FROM SEAM WELD)

	0.5% Yield (psi)	Tensile Strength (psi)	Elongation in 2″ (%)
Average value	*55,850*	*79,450*	*27.7*
API 5LX (1953)	52,000 min.	66,000 min.	20.00

TABLE 3 CVN TEST RESULTS FOR PIPE BODY (TRANSVERSE, ½ SIZE, 90° FROM WELD)

Test Temperature (°F)	Average Absorbed Energy, ft-lb	Average % Shear
0 (–17.8 °C)	5.5	10
32 (0 °C)	8.7	33
64 (17.8 °C)	11.5	63
80 (26. 7 °C)	16.7	77
96 (35.6 °C)	17.8	90
128 (53.3 °C)	19.3	97

TABLE 4 CVN TEST RESULTS FOR WELD HAZ (TRANSVERSE, ½ SIZE, HAZ)

Test Temperature (°F)	Average Absorbed Energy, ft-lb	Average % Shear
0	7.5	15
32	9.8	38
64	13.7	63
80	16.2	68
96	18.3	93
128	20.2	100

TABLE 5 CVN TEST RESULTS FOR WELD SEAM (TRANSVERSE, ½ SIZE, ACROSS WELD)

Test Temperature (°F)	Average Absorbed Energy, ft-lb	Average % Shear
0	6	17
32	10.2	25
64	11.7	47
96	15.8	65
128	19.3	88
160 (71.1 °C)	21.8	95

4. The tensile properties met the requirements for X52 steel per API 5LX (1953) specification.
5. The microstructure of the pipe base material was typical of Grade X52 low-carbon steel.

Summary

This case study describes an effective, industry-recognized methodology to perform a metallurgical examination of a Grade X52 pipe sample containing an internal anomaly. Appropriate laboratory techniques, such as wet fluorescent magnetic particle inspection, SEM fractography, and optical microscopy, were successfully utilized to confirm that the anomaly was a pre-existing defect that had been weld-repaired around the time of installation.

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1 Rosen Group, *The Encyclopedia of Pipeline Defects,* 3rd ed. (Houston, TX: Clarion Technical Publishers, January 2017).

2 U.S. Department of Transportation, "Pipeline Safety: Identification of Potential Hard Spots–In-Line Inspection Tools and Analysis," *Federal Register* 89, no. 222 (November 18, 2024).

3 American Petroleum Institute, *API Specification 5L*, 46th ed. "Line Pipe" (Washington, DC: API, May 2018).

4 U.S. Department of Transportation, "Pipeline Safety: Safety of Gas Transmission Pipelines: MAOP Reconfirmation, Expansion of Assessment Requirements, and Other Related Amendments," *Federal Register* 84, no. 190 (October 1, 2019).

5 American Petroleum Institute, *API 5LX Standard*, 4th ed. (Washington, DC: API, March 1953).

6 ASTM International, *ASTM E8*, "Standard Test Methods for Tension Testing of Metallic Materials" (West Conshohocken, PA: ASTM, 2010).

7 ASTM International, *ASTM E23*, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials" (West Conshohocken, PA: ASTM, 2025).

8 ASTM International, *ASTM E415*, "Standard Test Method for Analysis of Carbon and Low-Alloy Steel by Spark Atomic Emission Spectroscopy" (West Conshohocken, PA: ASTM, 2021).

9 S. Mahajanam, et al., "Metallurgical Analysis of 30-Inch Pipe Containing an Internal Crack," AMPP 2024, paper no. 20700 (Houston, TX: AMPP, 2024).

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TECHNICAL ARTICLE **RESOURCES**

At *Materials Performance*, we strive to provide content that our readers find beneficial. Therefore, we have decided to begin including a comprehensive list of standards referenced in each issue. The following table contains all standards referenced in the January technical articles with an emphasis on AMPP standards. We hope you find this resource helpful and welcome your feedback.

MP Issue	Primary Author Name	Paper Title	Standard Institution Name	Standard No.	Latest Revision Date	Standard Title
January 2026	E. Kiosidou	Multiparametric Experimental Investigation of Marine Antifouling Paints	American Society for Testing and Materials	ASTM G 154-23	2023	Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Materials
			American Society for Testing and Materials	ASTMD3623-78a (2020)	2020	Standard Test Method for Testing Antifouling Panels in Shallow Submergence
			International Organization for Standardization	ISO 1522:2022	2022	Paints and varnishes — Pendulum damping test
			International Organization for Standardization	ISO 14993:2018	2018	Corrosion of metals and alloys — Accelerated testing involving cyclic exposure to salt mist, dry and wet conditions
January 2026	S. Mahajanam	Laboratory Examination Methodology for Internal Pipeline Crack	American Petroleum Institute	API 5L	2018	Line Pipe
			American Society for Testing and Materials	ASTM E8	2022 (2024)	Standard Test Methods for Tension Testing of Metallic Materials
			American Society for Testing and Materials	ASTM E23	2025	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
			American Society for Testing and Materials	ASTM E415	2021	Standard Test Method for Analysis of Carbon and Low-Alloy Steel by Spark Atomic Emission Spectroscopy
January 2026	M. Szeliga	Corrosion of Underground Zinc-Coated Piping	None	None	None	None
January 2026	Sangki Chi	Enhancing the Performance and Quality of Internal FBE Coating for Field Joints in Line Pipes	International Organization for Standardization	ISO 8501-1	2007	Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness-Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
			International Organization for Standardization	ISO 8502-3	2017	Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness
			International Organization for Standardization	ISO 8503-5	2017	Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates - Part 5: Replica tape method for the determination of the surface profile
			Association for Materials Protection and Performance	**SSPC-PA2**	**2022**	**Procedure for Determining Conformance to Dry Coating Thickness Requirements**
			Association for Materials Protection and Performance	**NACE SP0188**	**2024**	**Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates**
			American Society for Testing and Materials	ASTM D5402	2024 (2019)	Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs
			American Society for Testing and Materials	ASTM D6677	2022 (2018)	Standard Test Method for Evaluating Adhesion by Knife

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