

# Thermal Spray Metallic Coating for Offshore Platform Risers

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*Carbon steel samples coated with a Ni-Al base coat and a Ni-Cr-Fe topcoat passed both the cathodic disbondment (ASTM G42) and galvanic corrosion tests in simulated saline environments. The porosity levels determined in these coatings are <5%. There was no evidence of apparent permeation of the saline solution through the coating and no effect on the coating/base metal interface bonding.*

A review of the literature suggests that although increasing Cr contents in Fe-base and Ni-base austenitic alloys improve resistance to crevice corrosion, the addition of Mo is required for better lifting.<sup>1</sup> Additions of Cu will also be beneficial to mitigate the effects of microbiologically influenced corrosion (MIC), since any metallic structure immersed in seawater is liable to be “colonized” by a wide range of organisms, from bacteria to algae.<sup>2</sup>

The Ni-Cr-Fe/Ni-Al coating system seems adequate for the protection of risers subjected to cathodic protection (CP) at relatively high temperatures. Thermal spray coatings, with chemistries prone to passivation in oxidizing environments, may have improved resistance to seawater corrosion.

This article describes the testing accomplished and the results gained from the experiments.

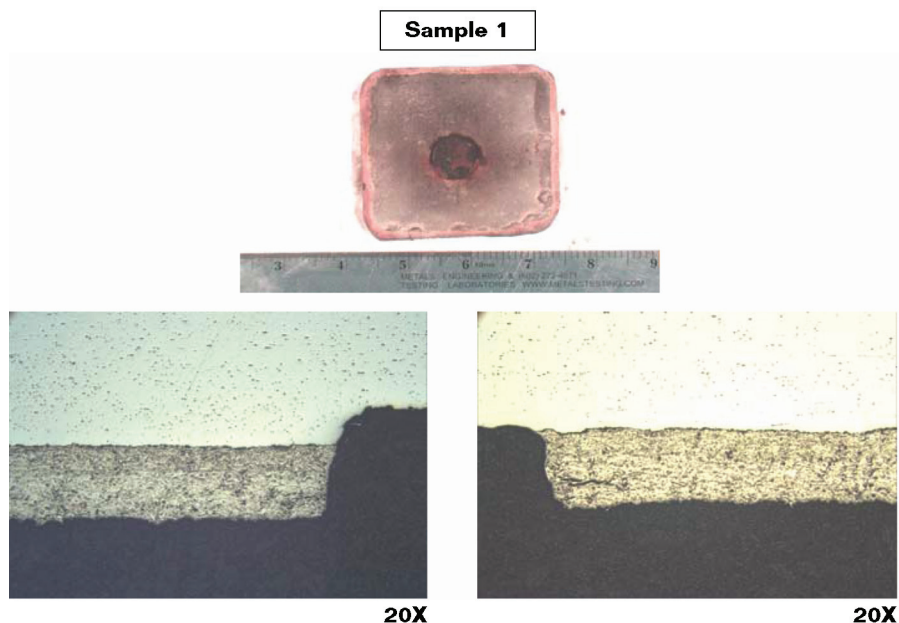
## Experimental Procedures

Twelve 3 by 3 by 1/4-in (76.2 by 76.2 by 6.35-mm) samples of carbon steel (CS) coated with ArcMelt<sup>†</sup> products were submitted for testing at the Gulf Coast Laboratories in Houston, Texas. The samples were coated with AMC 4302<sup>†</sup> (Ni-Al) applied as the base coat, and AMC 3201<sup>†</sup> (Ni-Cr-Fe) applied as the topcoat. The combined coating thickness was estimated at 40 to 45 mils. The samples were tested in a bath of Instant Ocean Electrolyte<sup>†</sup> kept at 80 °C (176 °F) for a period of 90 days. The CS backing of the test pieces was coated with Armor-Gard<sup>†</sup> Agent 4808 prior to immersion in the test electrolyte. The cathodic disbondment test was conducted for 30 days. The tests included:

- Galvanic corrosion

<sup>†</sup>Trade name.

FIGURE 1



Appearance of Sample 1 of the galvanic corrosion test after 90 days of exposure.

- Cathodic disbondment (ASTM G42<sup>3</sup>)
- Impact related corrosion (ASTM G14<sup>4</sup>)
- Crevice corrosion testing (ASTM G78<sup>5</sup>)

After completion of the tests, 11 test pieces were returned to the coating manufacturer for complementary destructive metallographic examination. A limited number of samples, representative of all test conditions, were submitted to Metal Engineering and Testing Laboratories (Phoenix, Arizona) for subsequent destructive metallographic evaluation. Optical and scanning electron microscopy (SEM) were used to document the as-received appearance of the samples, the characteristics and features of the coated layers, and the failure mechanisms. Electron dispersive spectrographic (EDS) analysis was used to determine the chemistry of the coating system, base metal, and corrosion product layers. The results of this analysis are semiquantitative.

## Results

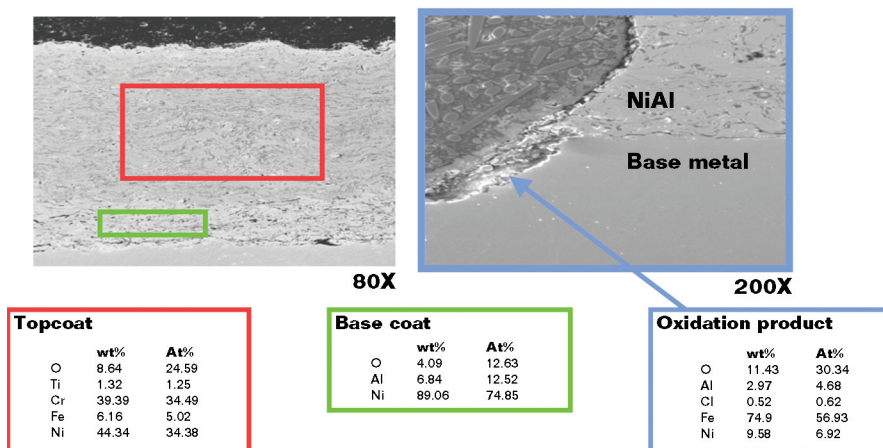
### Galvanic Corrosion Test

This test was conducted by creating a 3/4-in (19-mm) diameter holiday at the center of 3 by 3-in CS steel plates coated with the Ni-Cr-Fe/Ni-Al system. Figure 1 depicts the appearance of the sample and optical micrographs of the holiday after 90 days of exposure.

As evident in the optical micrographs, the CS oxidized upon exposure to the saline electrolyte. Oxidation was limited to the CS substrate with no apparent progression along the coating/base metal interface, as shown in Figure 2. The oxidation of the base metal led to the formation of Fe oxide.

The EDS analysis of the coating system confirmed the chemistry of the base and topcoat layers.

FIGURE 2



SEM showing a close-up of the coating/base metal interface at the bottom of the holiday shown in Figure 1.

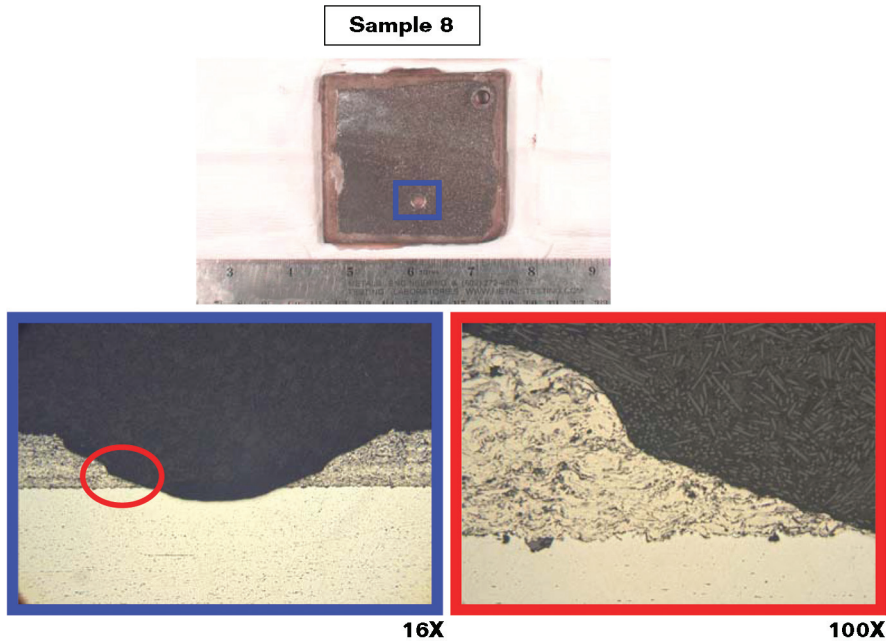
### Cathodic Disbondment Test— ASTM G42

This test is an accelerated procedure to determine the ability of a coating system to prevent or mitigate steel pipe corrosion that may occur in underground service where the pipe will be exposed to high temperatures under CP.

A holiday is created prior to the test, and during the test, the coating on the

test specimen is subjected to electrical stress in a highly conductive electrolyte at relatively high temperatures (80 °C [176 °F]). Physical examination consists of assessing the effective contact of the coating with the base metal surface in terms of observed differences in the relative adhesive bond. Usually, the cathodically disbonded area propagates from an area where adhesion is zero to an area

FIGURE 3



Optical and SEMs of the coating/base metal interface after disbondment test according to ASTM G42 (Sample 8).

where adhesion is at the original level. That is not the case with these samples. Disbondment of the tested coating system is nonexistent after 30 days of CP using  $-1.5$  V.

Figure 3 shows the test results. Thermal spray application of alloys, with potential passivating characteristics in oxidizing environments, may have improved resistance to seawater corrosion.<sup>6</sup> The presence of a finely distributed oxide network generated during the application of the coating seems to contribute to the formation of pseudo-protective passive films.

#### Impact Related Corrosion Test— ASTM G14

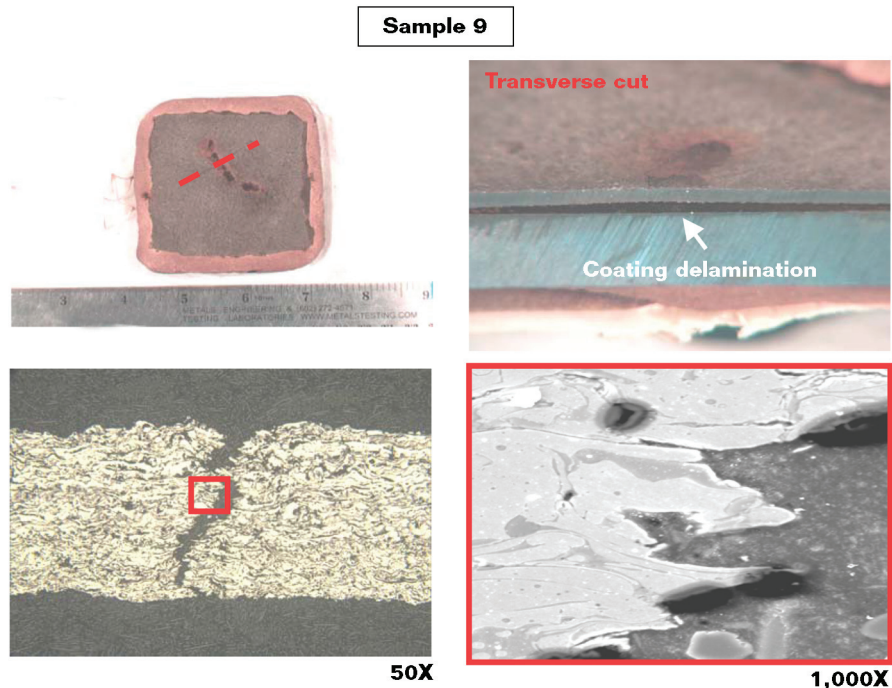
This test method covers the determination of the energy required to rupture coatings applied to pipe under specified conditions of impact from a falling weight. The impact load caused tearing of the coating system due to the relaxation of the coating stresses as the base metal yielded. Although there is evidence of base metal oxidation upon subsequent exposure to the electrolyte at  $80$  °C ( $176$  °F) for 90 days, delaminating of the coating system along the coating/base metal interface is suspected to be related to the relaxation of tensile stresses due to the impact force (Figure 4).

The SEM microstructure shown in Figure 4 confirmed that no oxidation of the Ni-Cr-Fe or Ni-Al coatings took place. Permeation of the electrolyte through the interconnected porosity (if any) of the coating system was not apparent.

#### Crevice Corrosion— ASTM G78

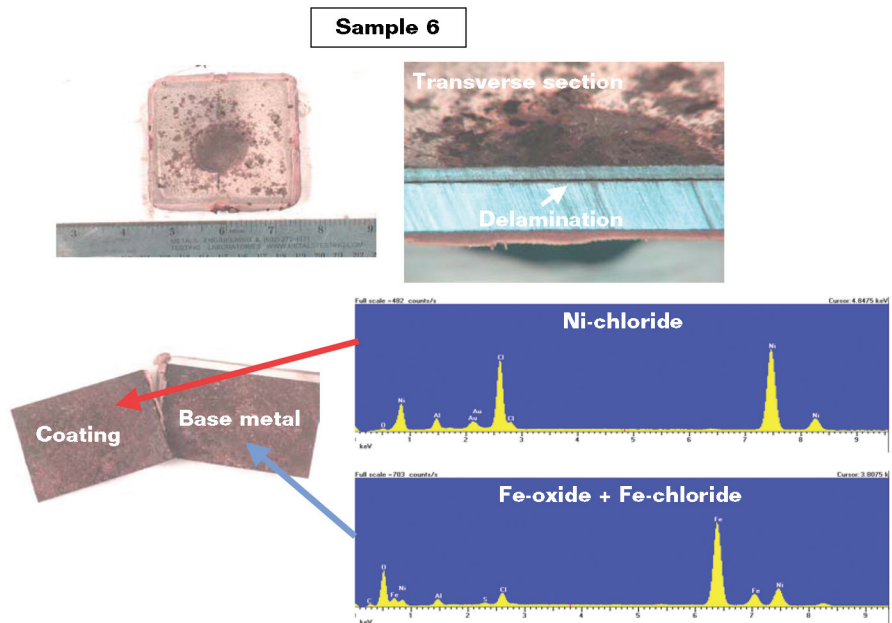
Crevice corrosion of iron-base and nickel-base stainless alloys can occur when an occlusion or crevice limits access of the bulk environment to a localized area of the metal surface. Localized environmental changes in this stagnant

FIGURE 4



Results from the immersion of the coated samples for 90 days after the impact resistance ASTM G14 test.

FIGURE 5



Results of the exposure to crevice corrosion test condition of ASTM G78.

area can lead to the formation of acidic/high chloride conditions that may initiate crevice corrosion of susceptible alloys. ASTM G78 covers the procedures for crevice corrosion testing of both Fe- and Ni-base stainless alloys in seawater. Because of the many interrelated metallurgical, environmental, and geometric factors known to affect crevice corrosion, the results of a given test may not be indicative of actual performance in service applications where the conditions may be different from those of the test. Figure 5 depicts the results from the ASTM G78 tests.

The reaction, under the man-made crevice, led to the formation of Cr-chloride at the expense of the metallic network in the topcoat. This reaction product was apparently soluble since the electrolyte reached the base coat, resulting in the formation of another soluble chloride, Ni-chloride. Eventually, the electrolyte reached the coating/base metal interface where the CS reacted to form a mixture of Fe-oxides and Fe-chlorides that caused coating delamination from the local generation of hydrogen.

EDS analysis of the surface of the coating system confirmed the presence of surface deposits of pure Fe-chloride that can only be explained by the dissolution of the reaction products under the localized environment under the man-made crevice. It is worth noting that permeation of the coating was not apparent away from the crevice area. A reference in the state-of-the-art crevice corrosion<sup>1</sup> suggests the benefits of adding Mo to both Fe- and Ni-stainless alloys. Molybdenum raises the pitting potential in alloys containing high Cr and minimizes the susceptibility to pitting attack that is thought to be the precursor to crevice corrosion. Further addition of Cu would also provide mitigation against MIC under microbial deposit prone to be found in the immersed section of the riser.<sup>7-8</sup>

## Conclusions

- The Ni-Cr-Fe/Ni-Al coating system has shown to be adequate for the protection of offshore platform risers subject to CP at relatively high temperatures in oxidizing environments.
- Thermal spray coatings, with chemistries prone to passivation in oxidizing environments, may have improved resistance to seawater corrosion.
- Mo and Cu additions to the Ni-Cr-Fe formulation may improve crevice corrosion and MIC susceptibility resistance.

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