Evaluation of Zn-rich Primers and Rust Converters for Corrosion Protection of Steel

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Zinc-Rich Primer Evaluation

Objective

- Improve corrosion performance and reduce overall life cycle costs of Marine Corps metallic components by using Zn-rich coatings on steel.

Test Expectations

- Degree of galvanic corrosion/protection.
- Best Zn-rich coating corrosion performance (function of time to recoat)

Introduction

- Current protective coatings rich in $ZnPO_4$ do not provide sufficient long-term corrosion protection, especially if the coating is disrupted.
- High Zn pigmentation level in a binder is needed for optimal electrical contact between Zn particles and between these particles and steel substrate.
- Zn corrosion promotes loss of electrical contact between Zn particles, diminishes both Zn active area, and its galvanic effectiveness.
- For long-term protection, Zn corrosion products should seal the coating structure and maintained electrical continuity.
- Zn coatings must meet A-A-59745 (CID)

Products Evaluated

Name	Characteristics
Zinc Clad IV	Solvent-based with low VOC concentration (2.8 lb/gal) and 85% by weight of Zn dust pigment in dry film. DFT is 3-5 mils. ***Time to recoat: 4 hrs at 77 °F.***
Zinc Clad XI	Water-based inorganic Zn silicate with no VOC and 90% by weight of Zn in the dry film. DFT is 2-4 mils. ***Time to recoat: 2 hrs at 77 °F.***
N-5751M2	Solvent-based moisture cure with low VOC concentration (2.8 lb/gal) and 90% by weight of Zn in the dry film. DFT is 2 mils. ***Time to recoat: 8 hrs at 77 °F.***
Intershield 300V	Aluminum-rich epoxy with <2.8 lb/gal VOC concentration. DFT is 5.9 mils. ***Time to recoat: 7 hrs at 77 °F.***
Epoxzen	Organic epoxy with low VOC concentration (3.5 lb/gal) and 90% Zn in the dry film. DFT is 4 mils. ***Time to recoat: 1-2 hrs at 77 °F***.
Zinga	Organic epoxy primer with low VOC concentration (~3.9 lb/gal) and 96% Zn in the dry film. DFT is 2 mils. ***Time to recoat: 2 hrs at 77 °F.***

Galvanized steel and a wash primer, consisting of zinc phosphate conversion coat in accordance to the DOD-P-15328 used as a control.

Specimen Preparation

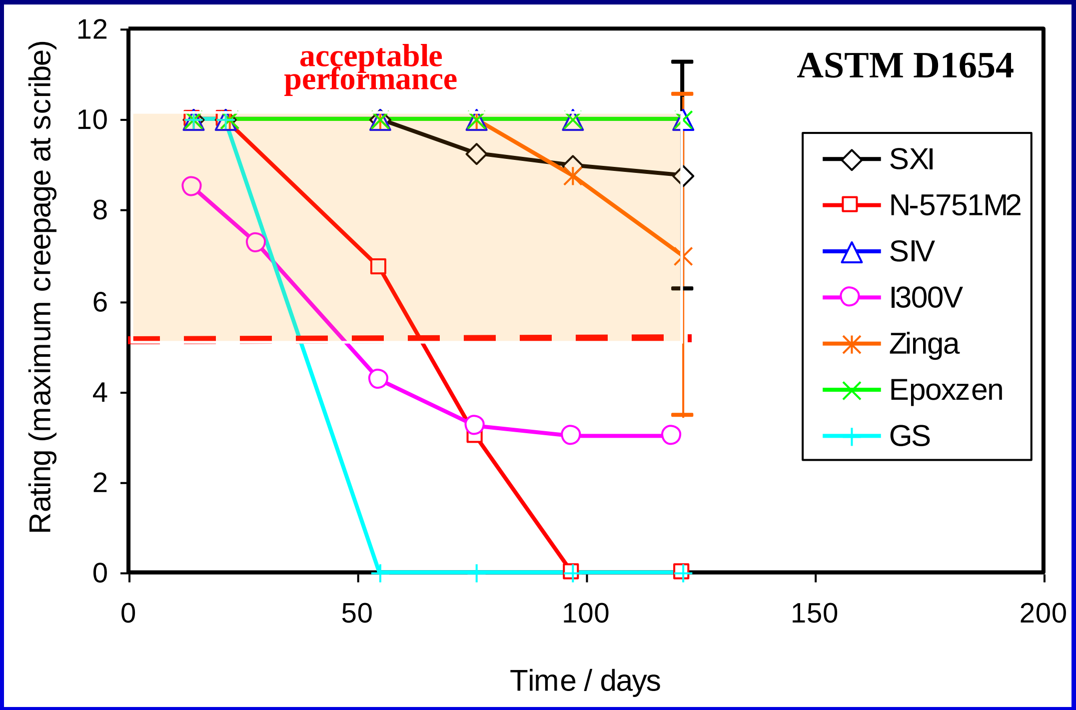
- Initially sandblasted 1018 carbon steel.
- Zn-rich coating applied according to manufacturer's instructions.
- CARC primer (MIL-P-53022II at ~1 mil DFT).
- CARC topcoat (MIL-DTL-53039B and MIL-DTL-64159II at ~2 mils DFT).
- Scribed and unscribed surfaces.

Corrosion Assessment

Atmospheric exposure tests: GM 9540P for 120 days. Corrosion assessment in accordance with ASTM D1654 and D714.

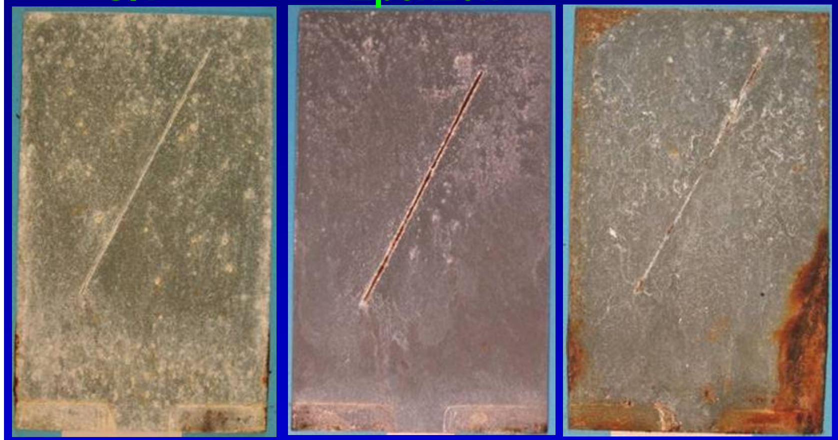
Immersion tests: Open circuit potential, galvanic protection/corrosion, and, electrochemical techniques.

Results – Atmospheric Exposure: ZRC only



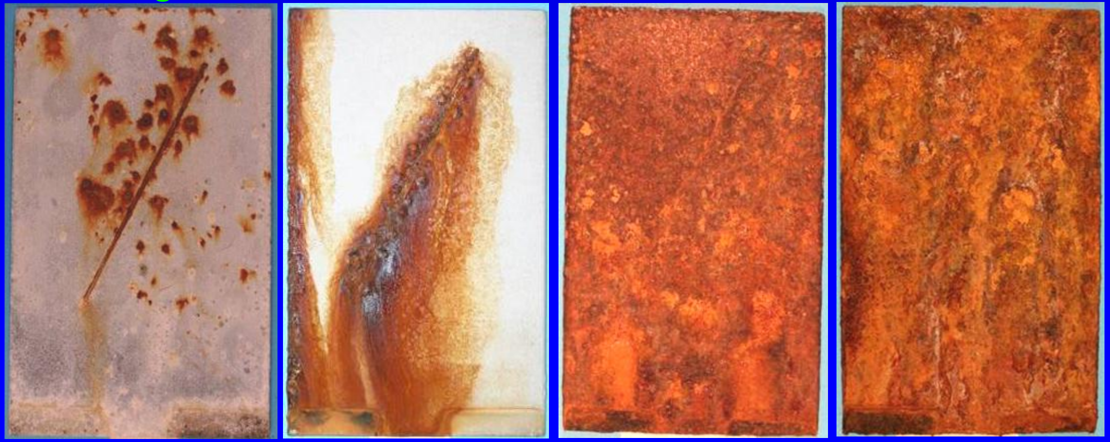
GM 9540P – Top Rated Coatings

SIV Epoxzen SXI



GM 9540P – Low Rated Coatings

Zinga I300V N-5751M2 Galvanized steel

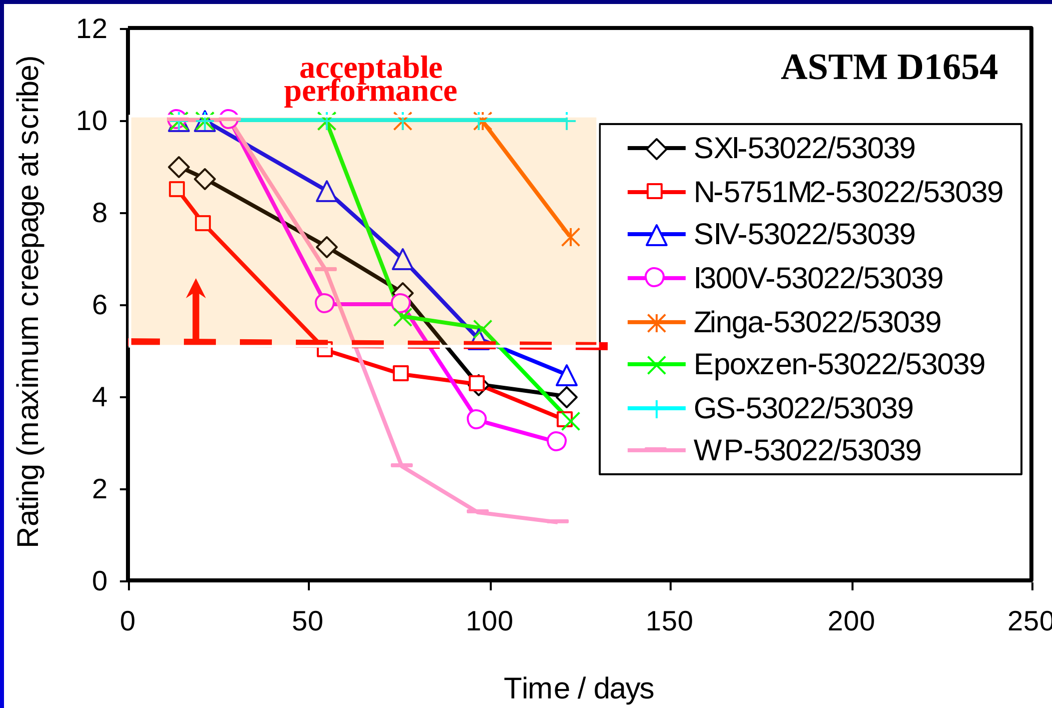


According to TACOM rating system

- Stage 0: none
- Stage 1: SIV, SXI, and Epoxzen
- Stage 2: Zinga and I300V
- Stage 3: N-5751M2 and Galvanized steel

The prevalent failure mode for most of the panels was blistering.

Results – Atmospheric Exposure ZRC-52022/53039II



GM 9540P – Top Rated Coatings

Galvanized steel (stage 1)

Zinga (stage 1)

GM 9540P – Low Rated Coatings

Standard Dev.	
SXI	0.8
N-5751M2	0.6
SIV	0.6
I300V	0.8
Zinga	2.9
Epoxzen	1.3
GS	0
WP	0.5

SIV (stage 2)

SXI (stage 2)

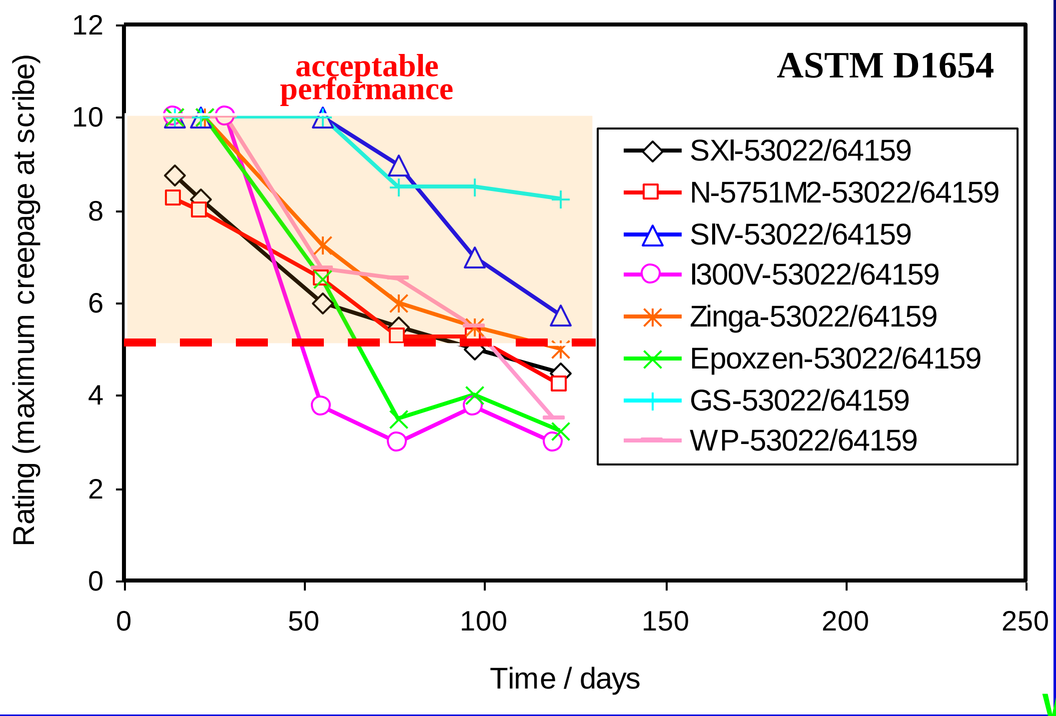
Wash Primer (stage 2)

I300V (stage 2)

N-5751M2 (stage 2)

Epoxzen (stage 2)

Results – Atmospheric Exposure ZRC-52022/64159II



GM 9540P – Top Rated Coatings

Galvanized steel (stage 1)

SIV (stage 1)

Zinga (stage 1)

GM 9540P – Low Rated Coatings

Standard Dev.	
SXI	0.6
N-5751M2	0.5
SIV	0.5
I300V	0.8
Zinga	0
Epoxzen	0.5
GS	2.1
WP	1.7

SXI (stage 2)

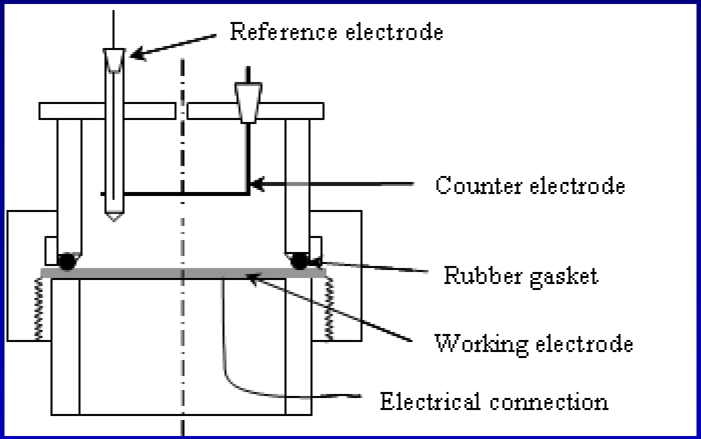
N-5751M2 (stage 2)

Wash Primer (stage 2)

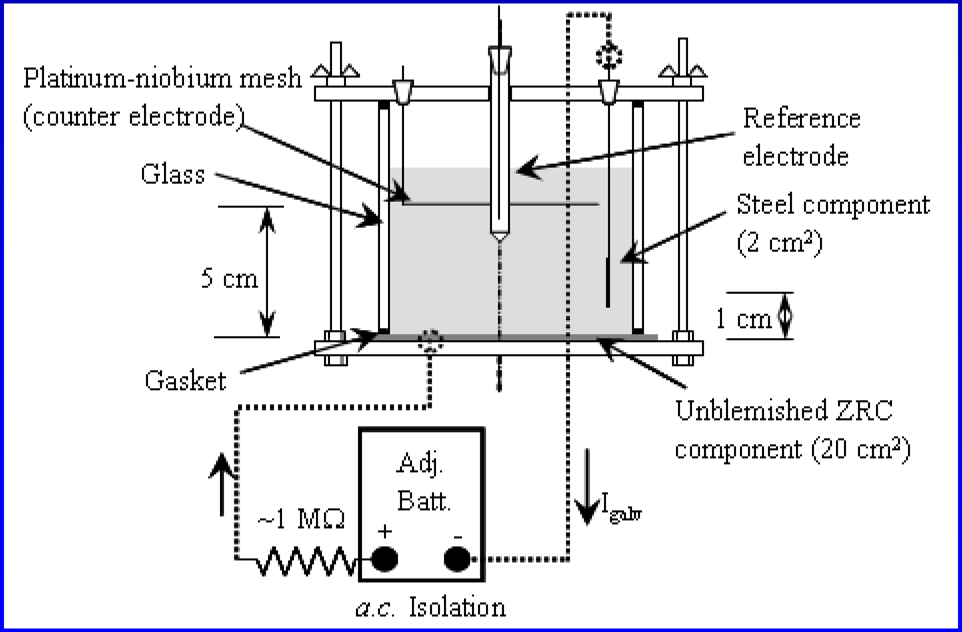
Epoxzen (stage 2)

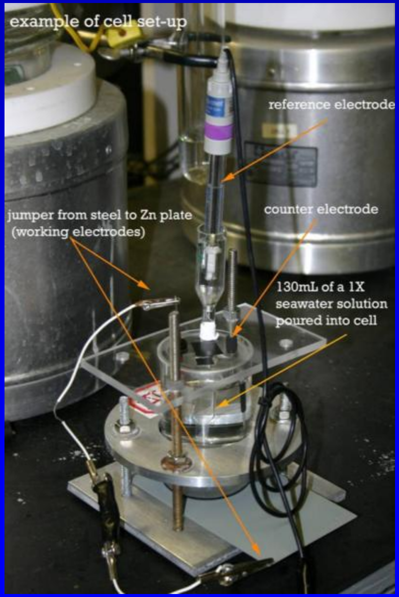
I300V (stage 2)

Results – Immersion Tests
Test Cell Arrangements



Specimen area: 95 cm^2
Scribe size: 3 cm by 0.2 cm
Naturally aerated system
Exposure time: 80 days
Simulated seawater
Solution volume: 500 cm^3
Solution temperature: 21-24˚C

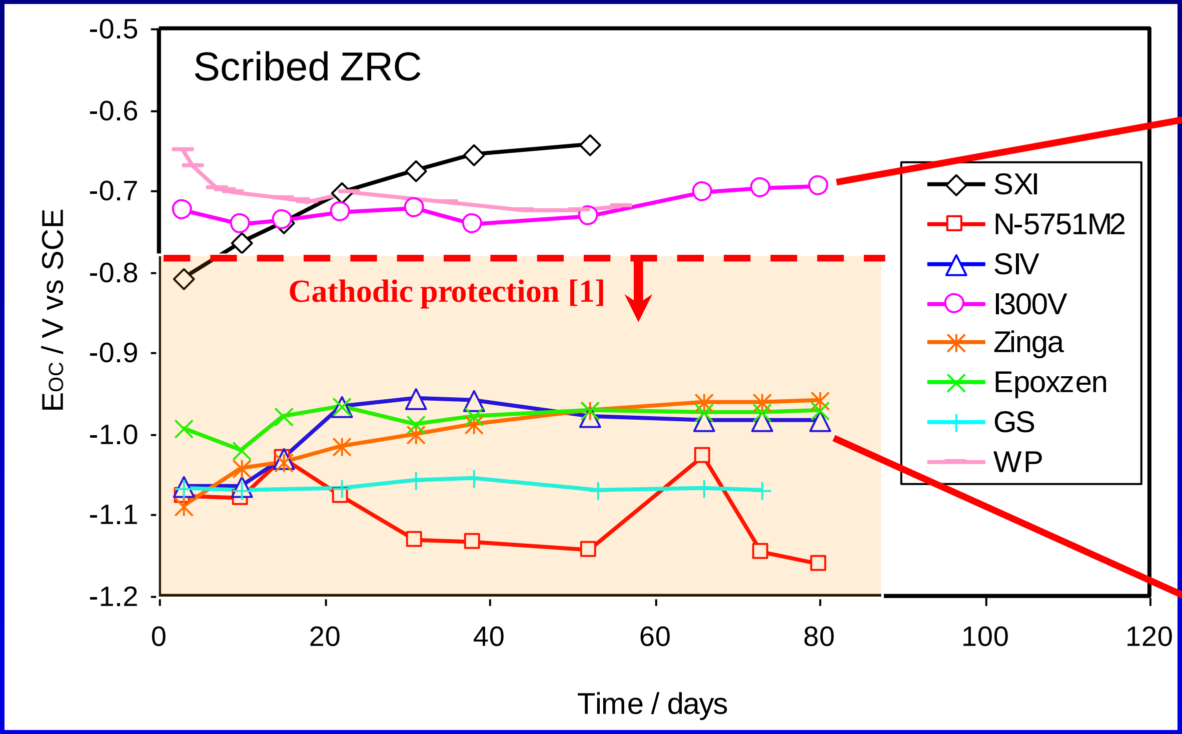


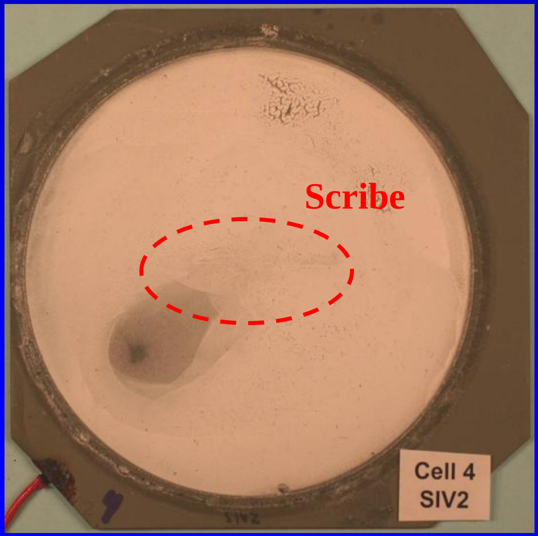


EIS and galvanic corrosion cell
Naturally aerated system
Exposure time: 75 days
Simulated seawater
Solution volume: 120 cm^3
Solution temperature: 21-24˚C

- Steel component: 320-grit surface finish, back side covered.
- ZRC/bare steel always connected except during EIS tests.
- Current sign: positive when ZRC is the anode

Results – Immersion Tests
Open Circuit Potentials

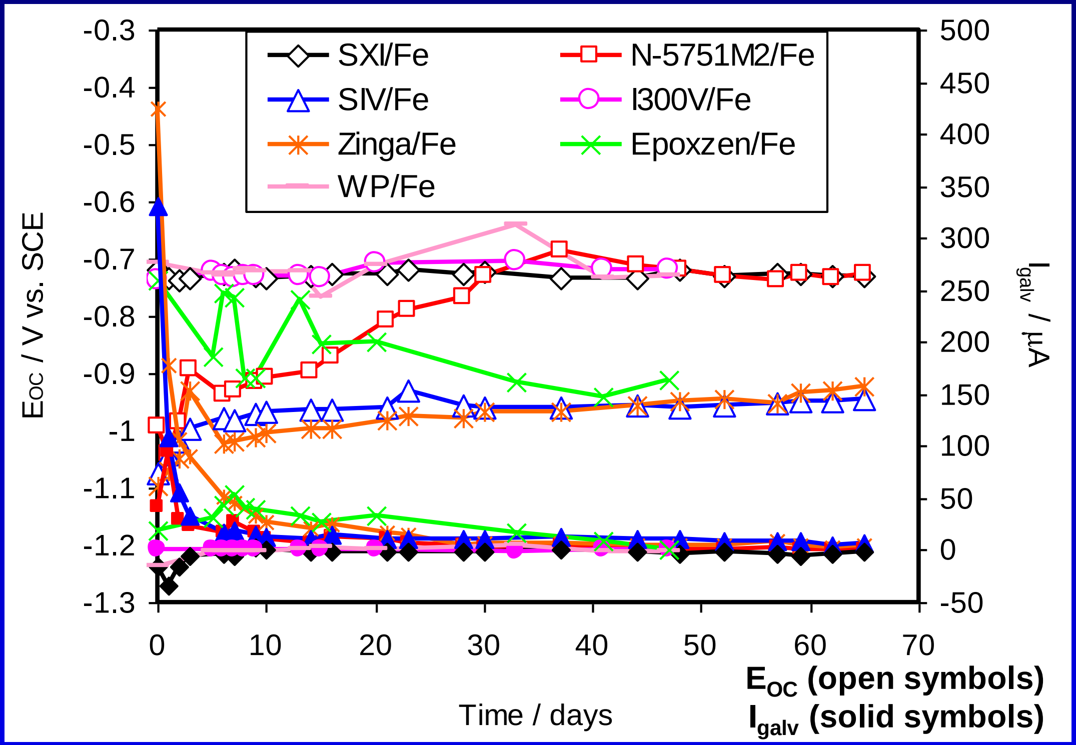


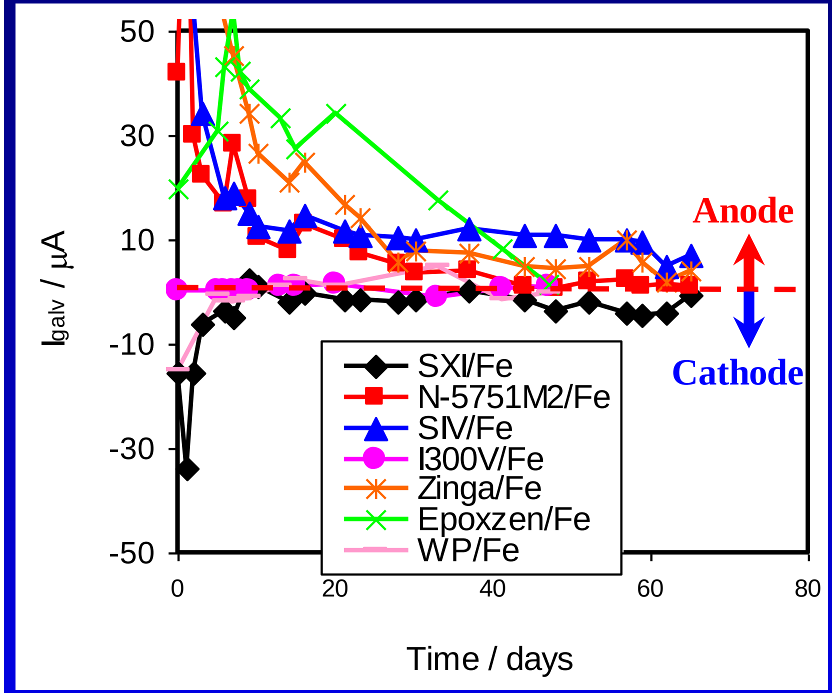


- E_{OC} of sacrificial coatings ~ E_{OC} of plain steel would not yield sufficient galvanic protection.
- Scribed I300V and WP panels had red rust at the scribe and no corrosion elsewhere.
- The other ZRC panels showed no red rust at the scribe consistent with E_{OC} trends.

1. Uhlig, Revie, Corrosion and Corrosion Control, 3rd Ed. (New York, NY: John Wiley and Sons, 1985).

Results – Immersion Tests
Galvanic Current Measurements

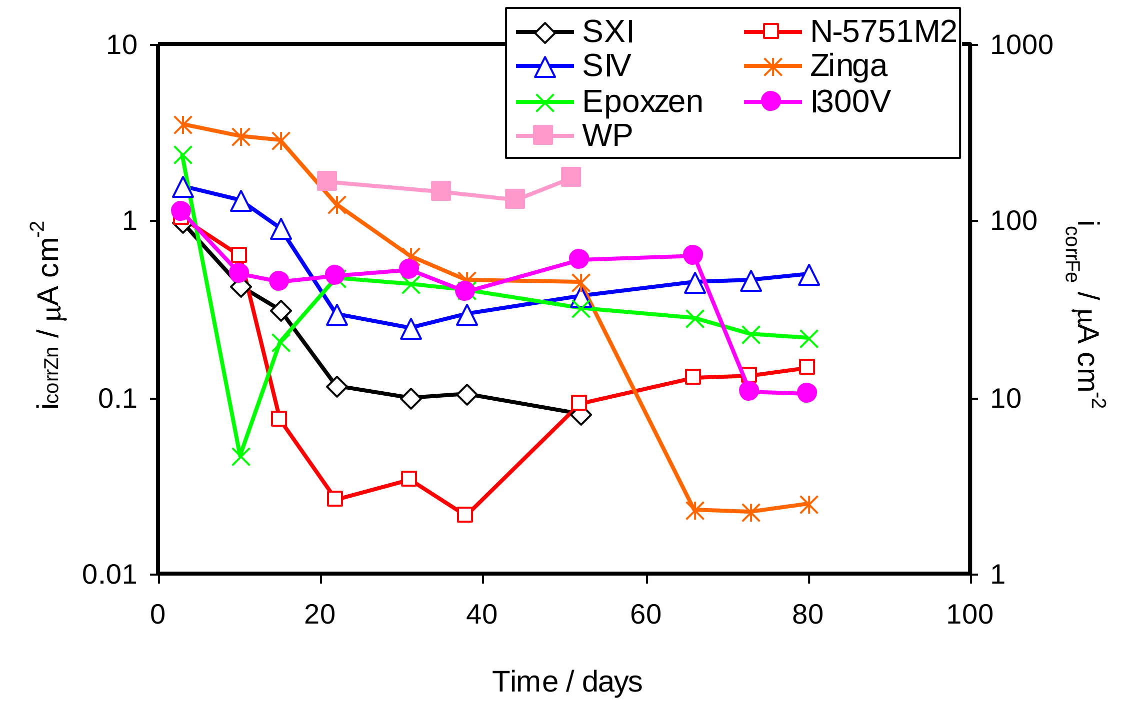




- The steel was always net cathodes except for the SXI, I300V. and WP, which showed transient anodic-cathodic behavior.
- The ZRC surface showed white discoloration except for the I300V and WP coatings.
- The steel components showed red rust formation, inconsequential for the case of the Zinga/Fe and SIV/Fe assemblies, and more prominent for the other assemblies. The appearance of red rust in the N-5751M2/Fe, WP/Fe, I300V/Fe, and SXI/Fe assemblies were in agreement with positive E_{OC} excursions, indicative of limited cathodic protection by the ZRC.

Results – Immersion Tests
Corrosion Rates

i_{corrFe} (solid symbols) and i_{corrZn} (open symbols) for the scribed ZRC panels



- I300V and WP showed initially large corrosion rates of the exposed steel, consistent with observation of corrosion deposits at the scribe. Corrosion rates for the ZRC were low (<1 µA/cm^{-2}) by the end of exposure, except for the I300V and WP (coating in passive state with extremely low corrosion rates).

Conclusions I – Atmospheric Exposure

ZRC only

- SIV, Epoxzen, and SXI have acceptable corrosion ratings (>5.0) per ASTM D1654 (no blisters, minor red rust formation at the scribe and white rust elsewhere).
- The remaining coatings showed corrosion ratings <5.0 with medium-dense blisters and extensive formation of red rust over the entire surface.

ZRC + 53022-53039II

- Acceptable ratings (5.0) were noted for galvanized steel and Zinga coating. Corrosion localized at the scribe with nearly intact coating elsewhere.
- The remaining coatings showed ratings <5.0 with red rust corrosion at the scribe, edges and medium-dense blisters surrounding the scribe.

ZRC + 53022-64159II

- Acceptable ratings (>5.0) were noted for galvanized steel, SIV, and Zinga coatings.
- The remaining coatings showed ratings <5.0 with red rust corrosion at the scribe, edges and medium-dense blisters surrounding the scribe.

Conclusions II – Immersion Tests

- E_{OC} ~ -700/-750 mV for I300V, WP, and SXI scribed panels, indicative of limited sacrificial ability by the coating (formation of red rust at the scribe) and E_{OC} ~-1 V for the remaining scribed panels (steel surface remained free of corrosion and the ZRC showed signs of active corrosion).
- Galvanic currents were anodic for the N-5751M2, SIV, Epoxzen, and Zinga ZRC. Only the galvanic currents delivered by the SIV and Zinga ZRC were enough to prevent steel rust formation. The SXI, I300V, and WP ZRC showed transient anodic-cathodic behavior (extensive steel rusting).
- Corrosion rates of the exposed steel at the scribe for the I300V and WP panels were initially large (>120 μA/cm^2) in keeping with the formation of corrosion products over the steel. The corrosion rates of the steel for the remaining scribed ZRC panels were expected to be negligible due to the steel cathodic polarization to potential levels where the Fe/Fe^{+2} reaction is near equilibrium at the low Fe^{+2} ion concentration levels of the solutions.
- Corrosion rates of the ZRC surrounding the scribe ranged from 0.05 μA/cm^2 (Zinga) to 0.5 μA/cm^2 (SIV). The I300V and WP coating in the scribed panels did not show signs of corrosion distress, suggesting that the coating acted solely as a physical barrier.

Rust Converter Evaluation

Objective

- Evaluate corrosion prevention efficiency of different rust converter formulations.

Test Expectations

- Best rust converter corrosion performance to be used where sandblasting is not appropriate.

Introduction

- Abrasive blasting procedure offers the best level of oxide removal.
- Rust converters are chemical formulations useful in passivating rusted steel surfaces.
- Not clear are the mechanisms of corrosion protection by rust converters.
- Factors affecting oxide conversion: optimum phosphoric acid at ~15-33% wt., phosphoric and tannic acids, optimum conversion takes place from 3 to 12 months, thickness of oxide layer and its barrier characteristics.

Rust Converters Evaluated

1. Gempler's (water-based, tannic acid)
2. Loctite rust treatment (polymeric-based, barium sulfate)
3. Total Solutions (water-based, tannic acid)
4. Phoscote (phosphoric acid – current USMC product)
5. VpCI CorrVerter (combined rust converter and primer)
6. Corroseal (water-based, tannic acid with primer)
7. Gem Rust Killer (under test)

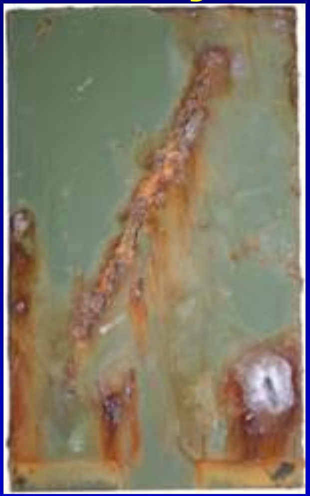
Specimen Preparation

- Multiple 1018 carbon steel specimens (3”x5”X0.08”) pre-corroded for 2-5 days in GM 9540P chamber (oxide layer thickness ~0.03”).
- Specimens cleaned according to manufacturer’s instructions (oxide layer thickness after cleaning ~0.02”).
- Rust converter applied using a brush per manufacturer’s instructions.
- Primer (MIL-P-0053022 II at ~1 mil DFT) – (most rust converters required oil-based primers).
- CARC topcoat (MIL-DTL-0064159 II at ~2 mils DFT).
- Scribed and unscribed specimens.

Results – Atmospheric Exposure

50-day exposure – scribed specimens

Corroseal



CorrVerter

Gempler's

Loctite

Phoscote

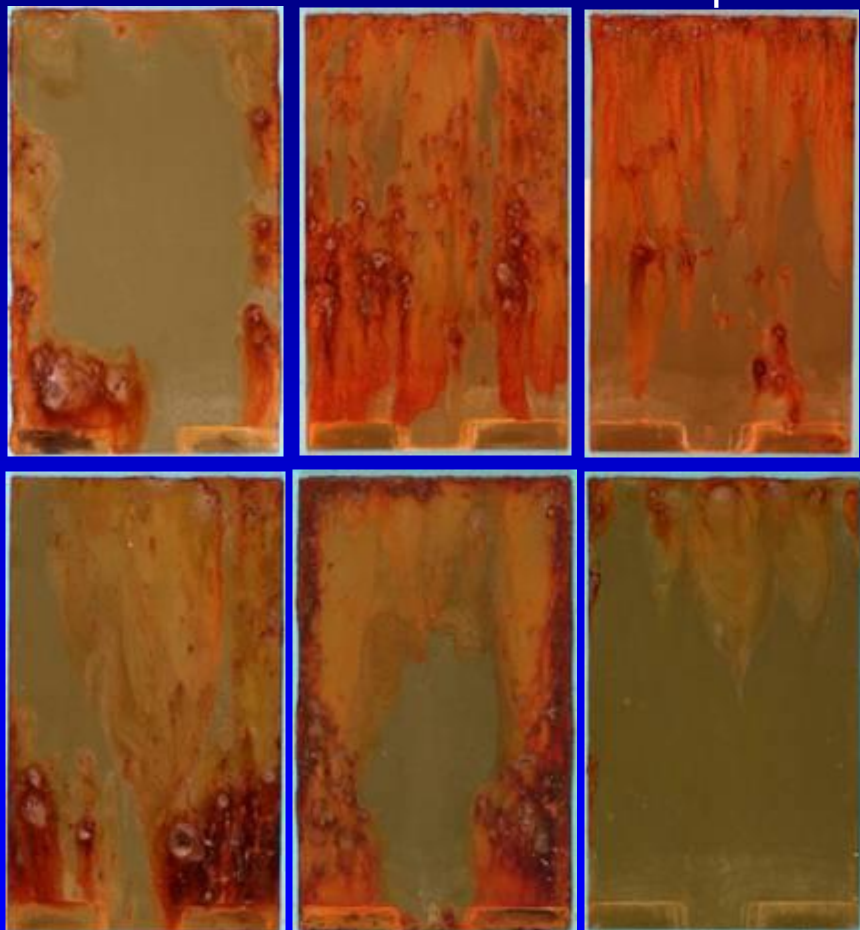
Total Solutions

Major corrosion damage in all specimens.
Corrosion started at the scribe, and propagated under coating, causing blisters.
Paint delamination at the scribe.
Rust converters not appropriate for damaged coatings.

Results – Atmospheric Exposure

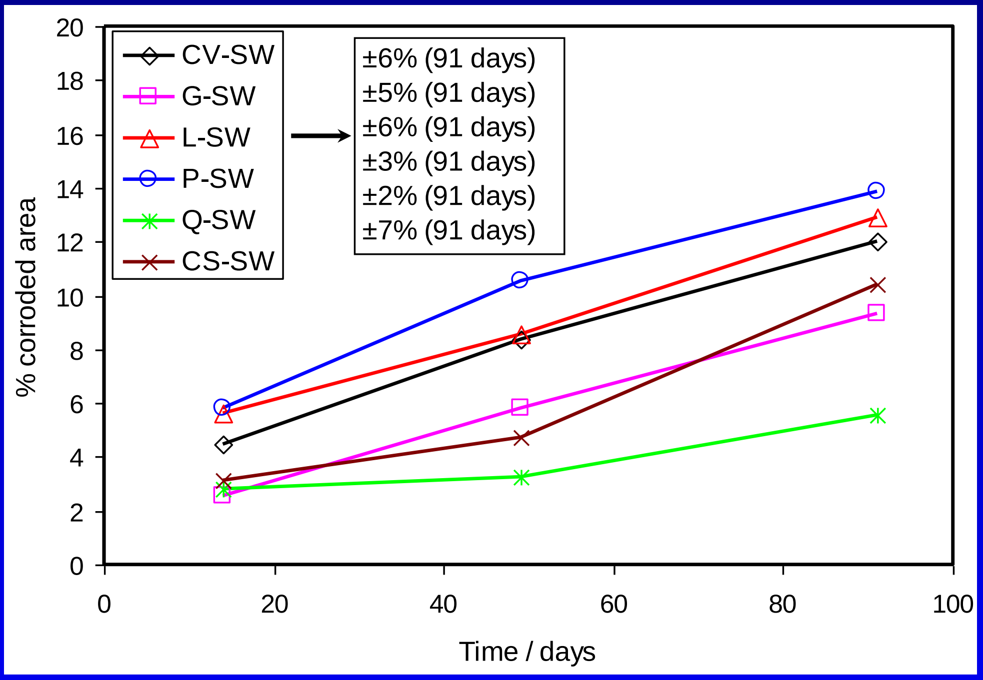
91-day exposure – unscribed specimens

Corroseal CorrVerter Gempler's



Loctite Phoscote Total Solutions

Average of multiple specimens



Blisters and pinholes in all specimens. Best performer: Total Solutions (water-based, tannic acid).

Conclusions

Scribed specimens

- Extended corrosion damage in all specimens.
- Corrosion started at the scribe, and propagated under coating, causing blisters.
- Paint delamination at the scribe.
- Rust converters appeared not to be appropriate for damaged coatings.

Unscribed specimens

- Blisters and pinholes in all specimens.
- Best performer: Total Solutions.

Acknowledgements

- USMC Corrosion Prevention and Control Office (Matt Koch)