Fluorescent Coatings for Corrosion Detection in Steel and Aluminum Alloys

H.G. Wheat and G. Liu
Mechanical Engineering Department
Texas Materials Institute
University of Texas at Austin
Austin, TX 78712

The inherent corrosion properties of metallic structures can be enhanced or preserved by coating with a metallic material or with a nonmetallic material.

The ideal situation would be to have a “smart coating” or even a “smart structure”.

Such coatings or structures would be able to “sense” external stimuli, environments or conditions and then respond.

BACKGROUND

Several coating principles that are relevant to corrosion sensing include:

- **Paint systems with color-changing compounds that respond to pH changes associated with corrosion processes;**
- **Coating compounds that exhibit non-fluorescent to fluorescent states as a result of oxidation or other interactions with metal ions;**
- **The incorporation of color dyes into the coating in the form of dye-filled micro (or nano) capsules that release these dyes when the coating is damaged; and**
- **Piezoelectric thin films that exhibit electrical changes as a result of mechanical deformation.**

BACKGROUND

Water droplet experiment: (A gel containing phenolphthalein and potassium ferricyanide is placed on a piece of steel.
Phenolphthalein develops a reddish or pink color in the presence of hydroxyl ions and potassium ferricyanide develops a blue color upon reaction with ferrous ions.
Oxygen from the air is more accessible to the periphery of the drop and a pink color forms around the edges of the drop.
A blue color forms near the center of the drop where there is less access to oxygen.

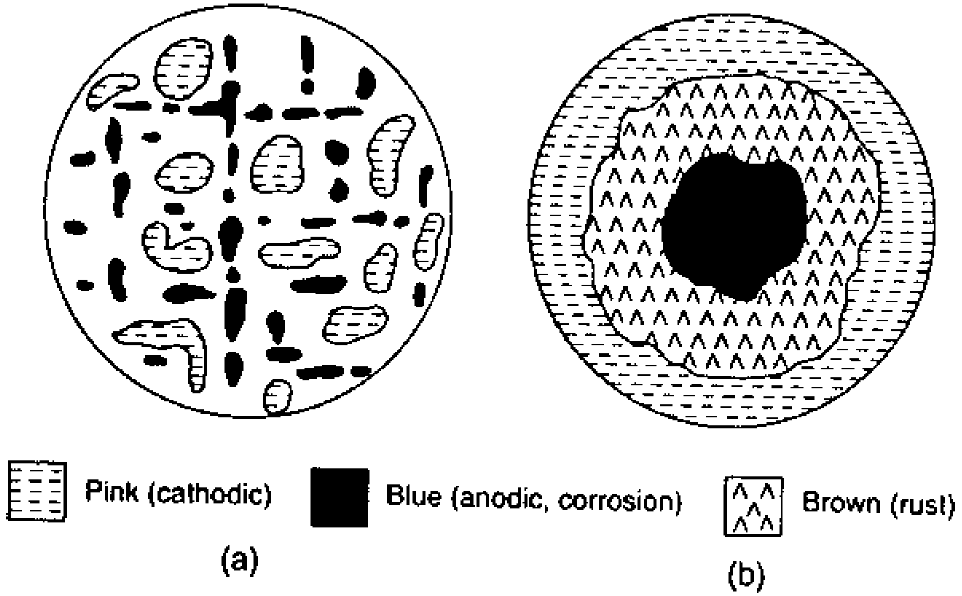


Figure 1. Initial (a) and final (b) distribution of anode and cathode in a water drop on a horizontal iron surface. (*From U.R. Evans*, An Introduction to Metallic Corrosion, *Arnold, London, p. 36,1981.)*

BACKGROUND

Some Forms of Coating Assessment

Water or saltwater immersion
ASTM B 117 Salt fog
EIS
Scribed Specimens
Rust creepage

INTRODUCTION

The present investigation makes use of coating compounds that exhibit non-fluorescent to fluorescent states as a result of oxidation or other interactions with metal ions.

Smart Materials for Corrosion Sensing and Detection in Aluminum Alloys

Several fluorescent compounds have been incorporated into coatings.

Fluorescein, morin and columbia blue, and coumarin derivatives have been used .

EXPERIMENTAL PROCEDURE

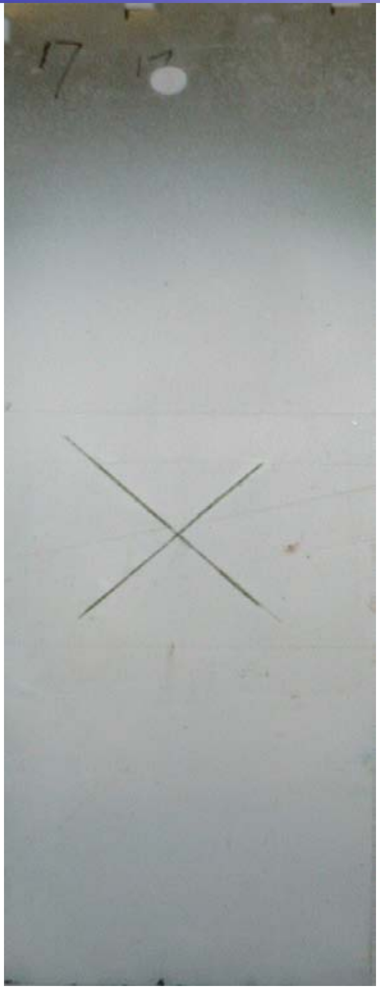
Several sets of large and small specimens were used; each set contained several specimens.

For each set, large coupons of 2024 aluminum and 1018 steel, measuring 25.4 cm long , 7.6 cm wide and 1 mm thick, were prepared for exposure to 3.5 wt% NaCl. Small coupons were cut from the large coupons and measured approximately 18 mm in diameter.

Coupons had a variety of coating layers such as primer plus topcoat, primer plus indicator, primer plus indicator plus topcoat, primer plus topcoat plus indicator, and pre-corroded specimens containing primer and/or topcoat plus indicator .

The specimens were subjected to a number of types of tests, but the major focus was cyclical exposure followed by observations using natural and UV light.

EXPERIMENTAL PROCEDURE

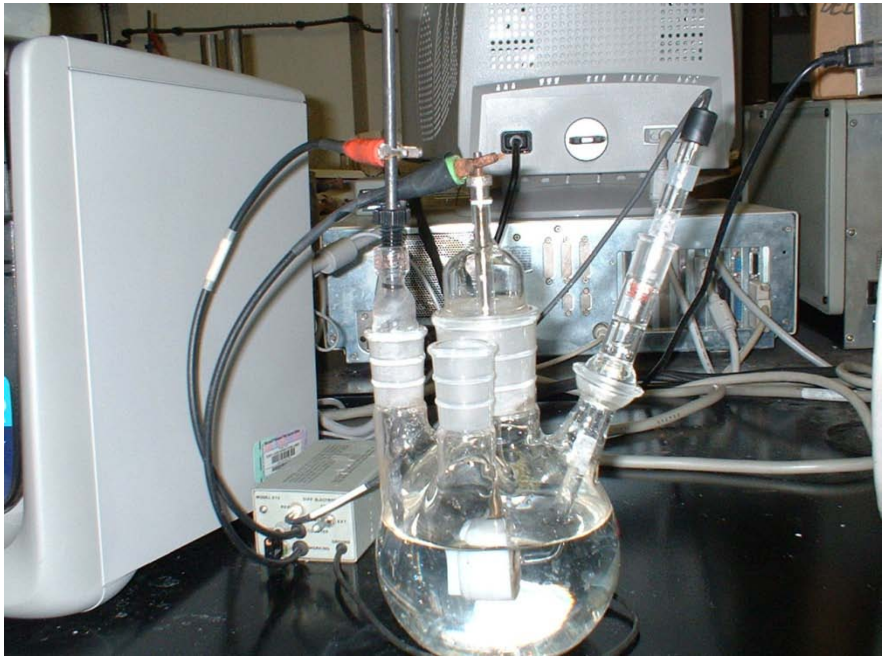


a. Photograph of one of the scribed specimens (large coupons) b. 2024 Al coupons in tank for modified salt fog exposure.

EXPERIMENTAL PROCEDURE

Sets of small circular coupons

Small circular coupons were also exposed to a 3.5 % NaCl solution.



The setup for electrochemical testing using EIS

EXPERIMENTAL PROCEDURE

Other components of the test setup included the Fluorescent Corrosion Indicator (FCI) paint scanner system.

Prototype FCI Paint Scanner and PC

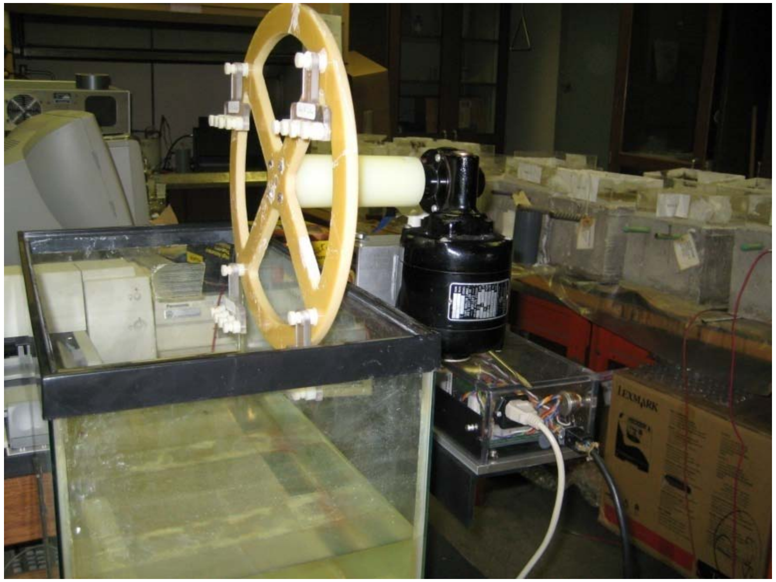
EXPERIMENTAL PROCEDURE

The paint scanner contained a high-energy UV source for illumination of the paint,
a high speed digital camera with a UV blocking filter to record the fluorescent image, and
a coupon fixture to hold the coupon under test in the same position for each fluorescent image scan.

The system scanned and recorded an image to detect the change in the fluorescent indicator level as a function of the corrosion beneath the paint.

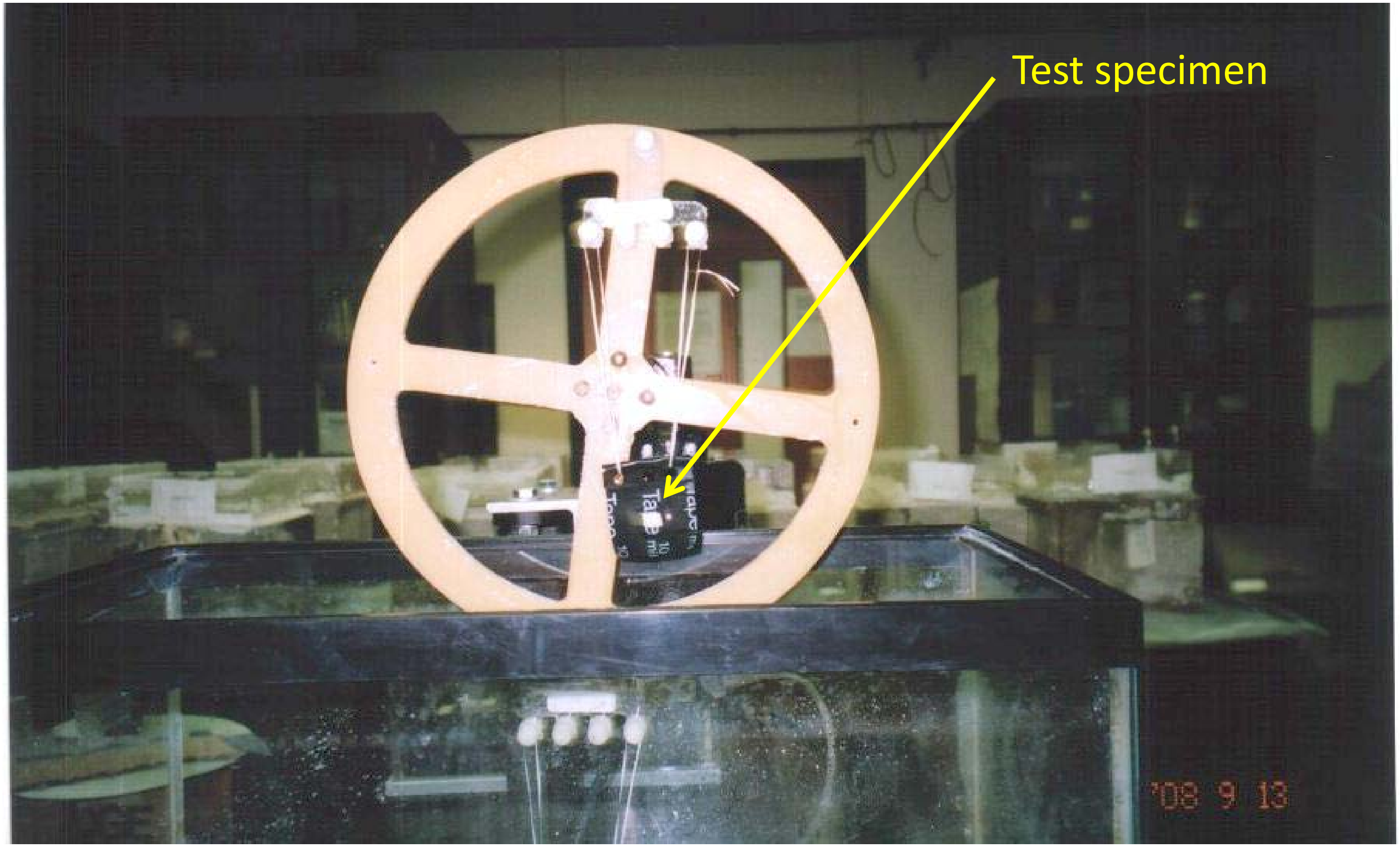
Prototype FCI Paint Scanner Internal View

EXPERIMENTAL PROCEDURE

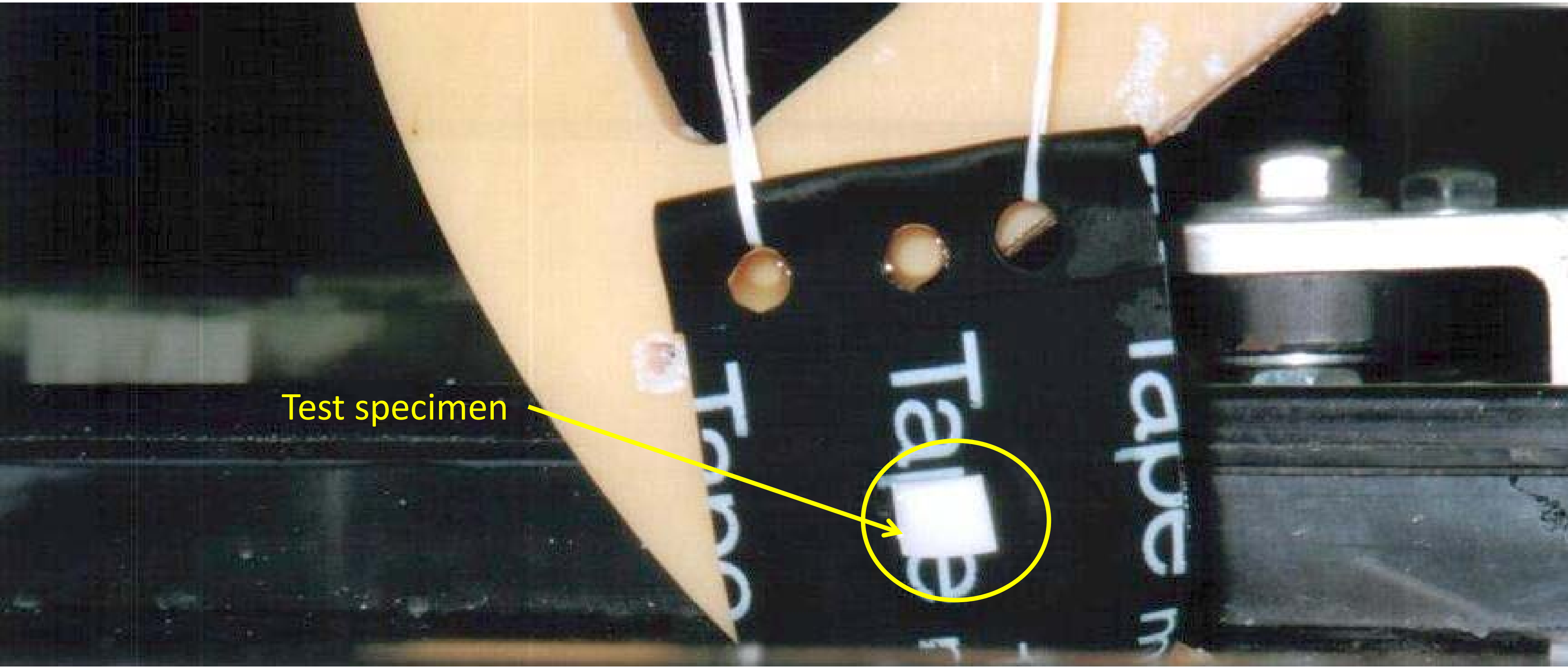


Cylical Testing 1-End view of corrosion wheel and test chamber

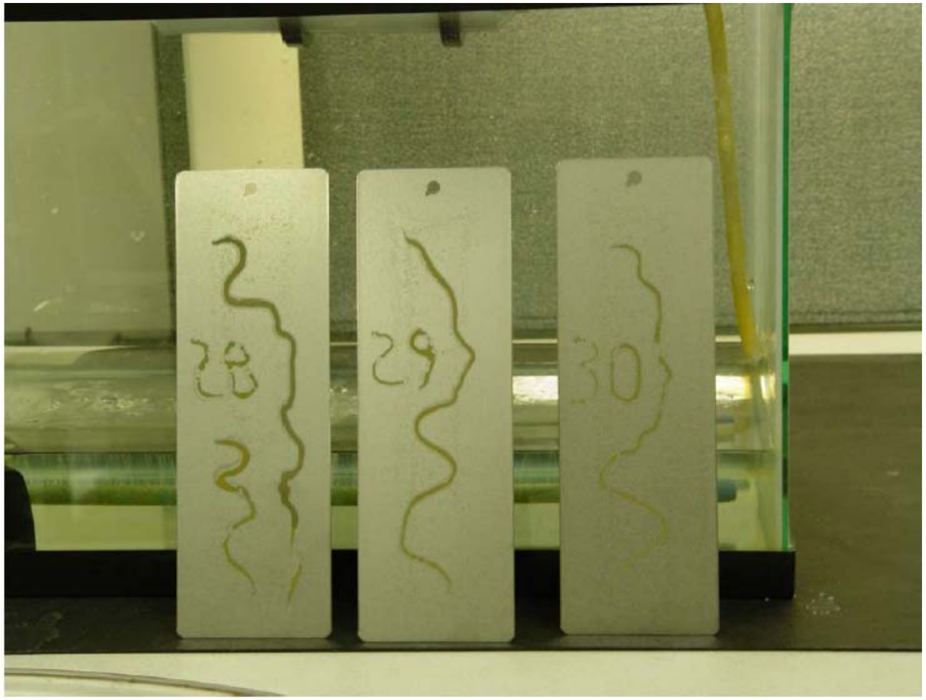
FRONT VIEW OF CORROSION WHEEL



CLOSE UP VIEW OF TEST SPECIMEN

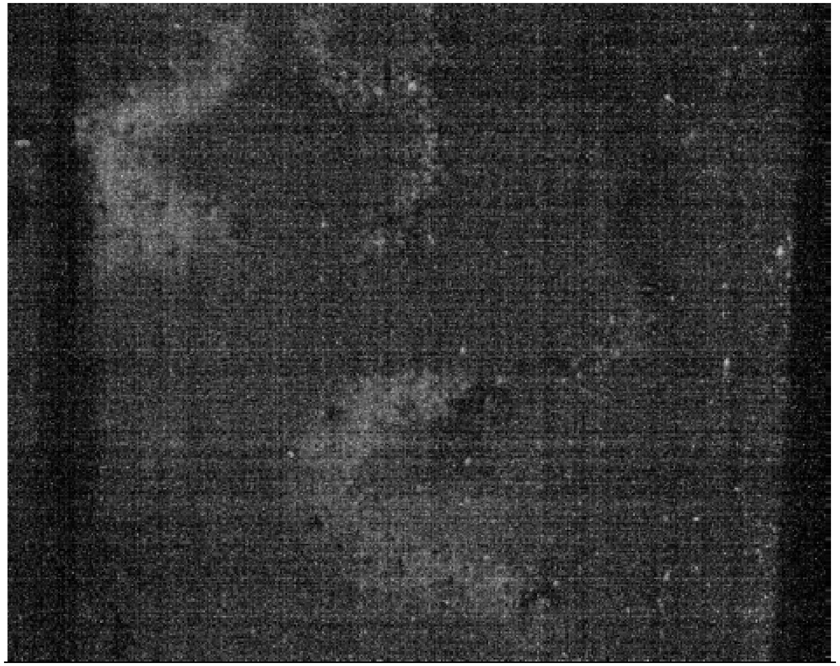


RESULTS



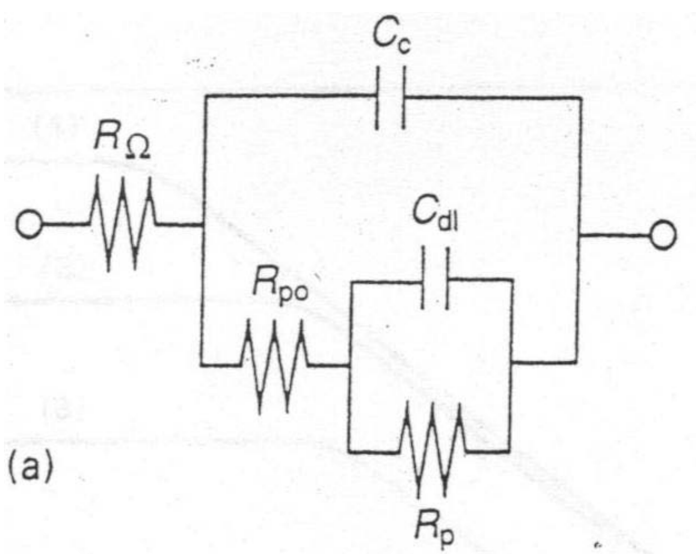
Coupons 28, 29, and 30 showing the "pre-rusted" patterns created by placing water drops on the surface of the bare steel metal before painting the coupons with topcoat with and without indicator. (SPEC, 2005)

RESULTS

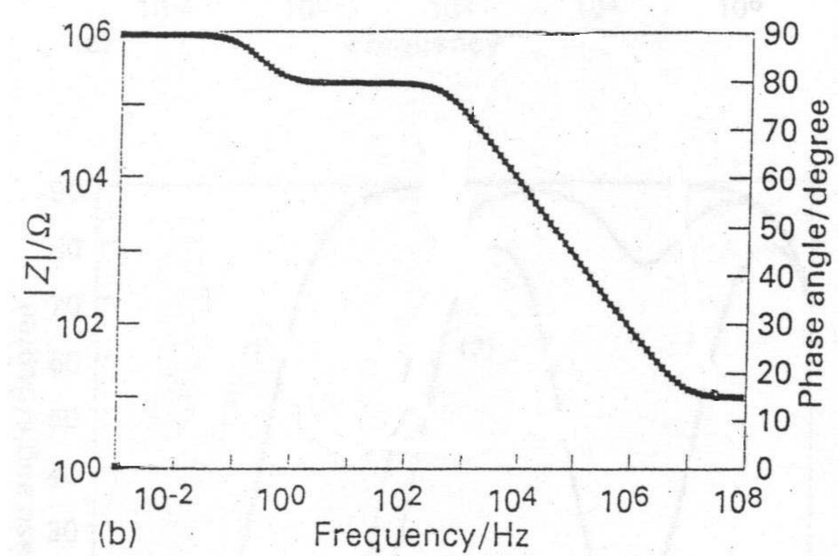


Coupon 29 pre-rusted pattern with topcoat paint layer with indicator in the topcoat showing strong fluorescence response (SPEC, 2005)

Model and Theoretical Impedance Spectra

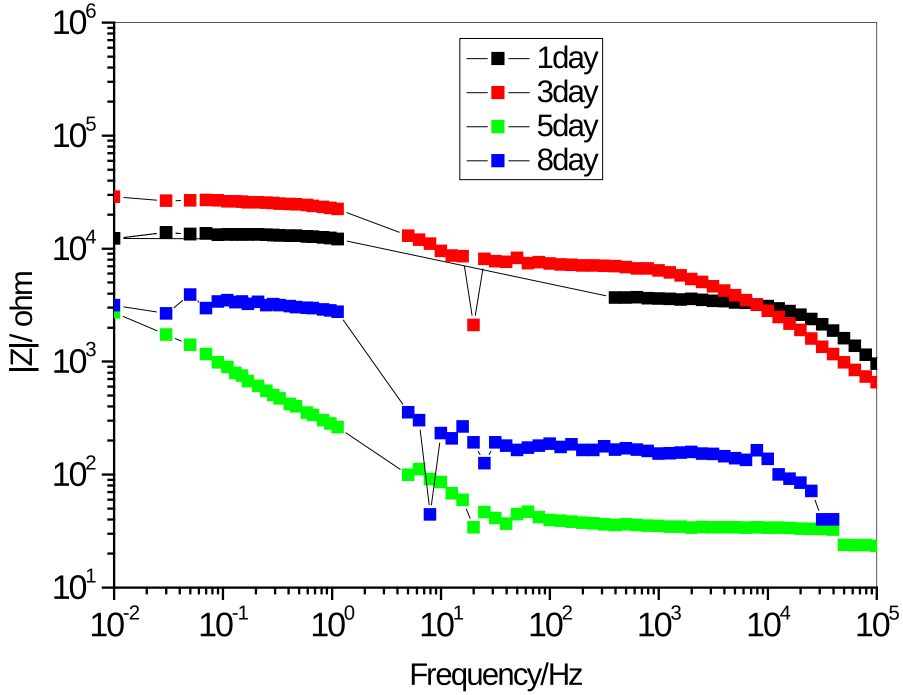


Model for the impedance of the polymer coated metal (Mansfeld, 1995)



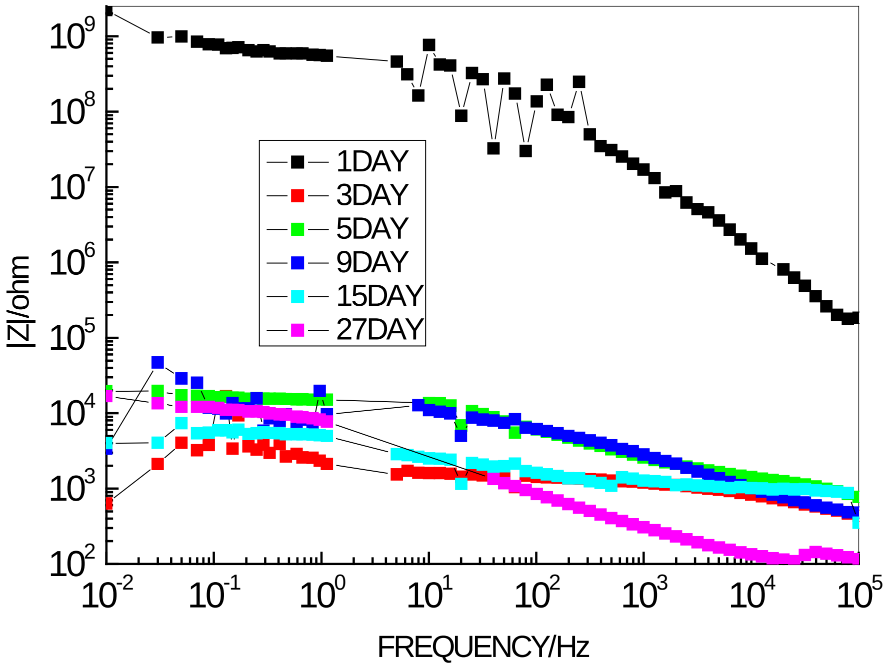
Theoretical impedance spectra for a degraded polymer coating based on (Mansfeld, 1995)

RESULTS



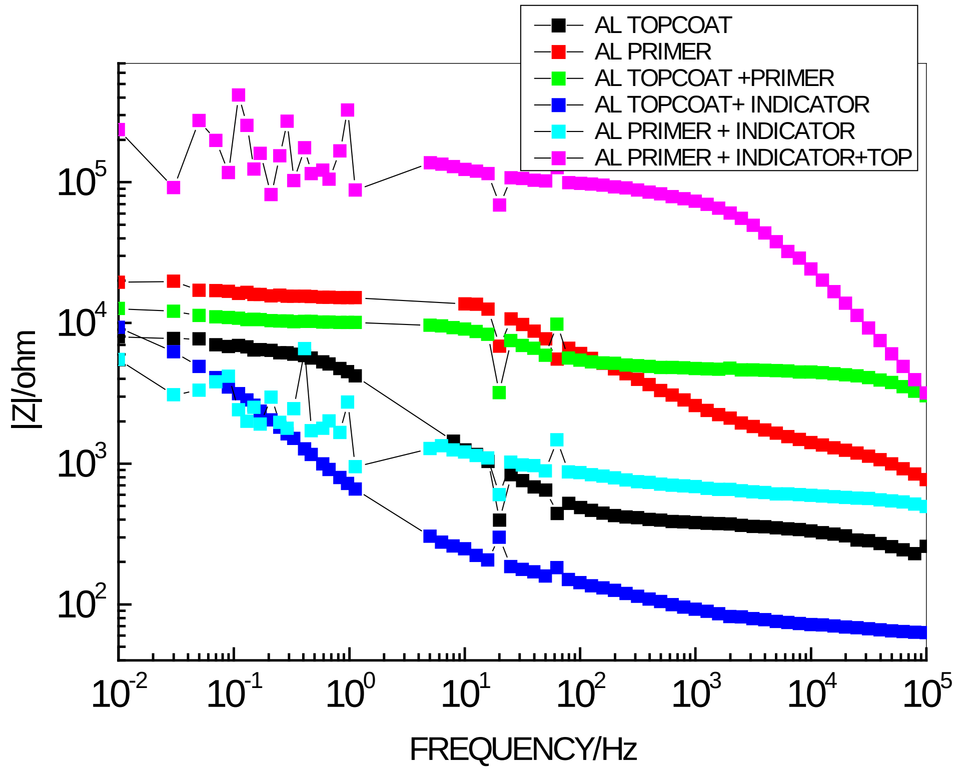
Bode impedance plots for the 2024 aluminum (Metal plus Topcoat) immersed in 3.5% NaCl

RESULTS



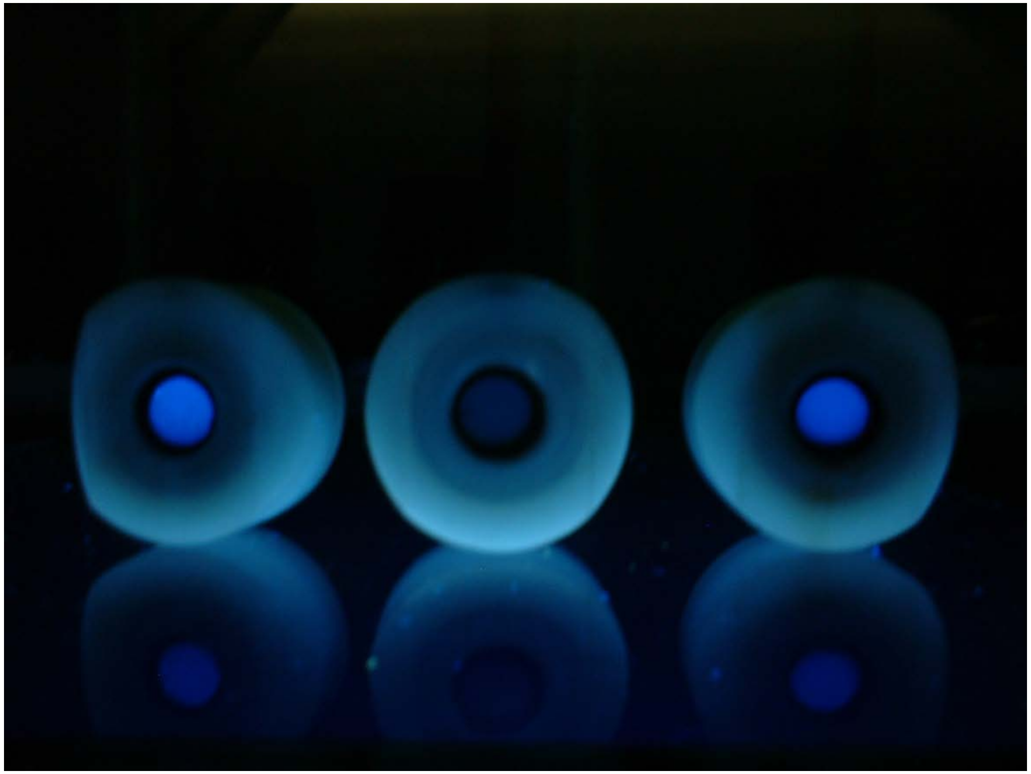
Bode impedance plot for the 2024 aluminum (Metal plus Primer) immersed in 3.5% NaCl

RESULTS



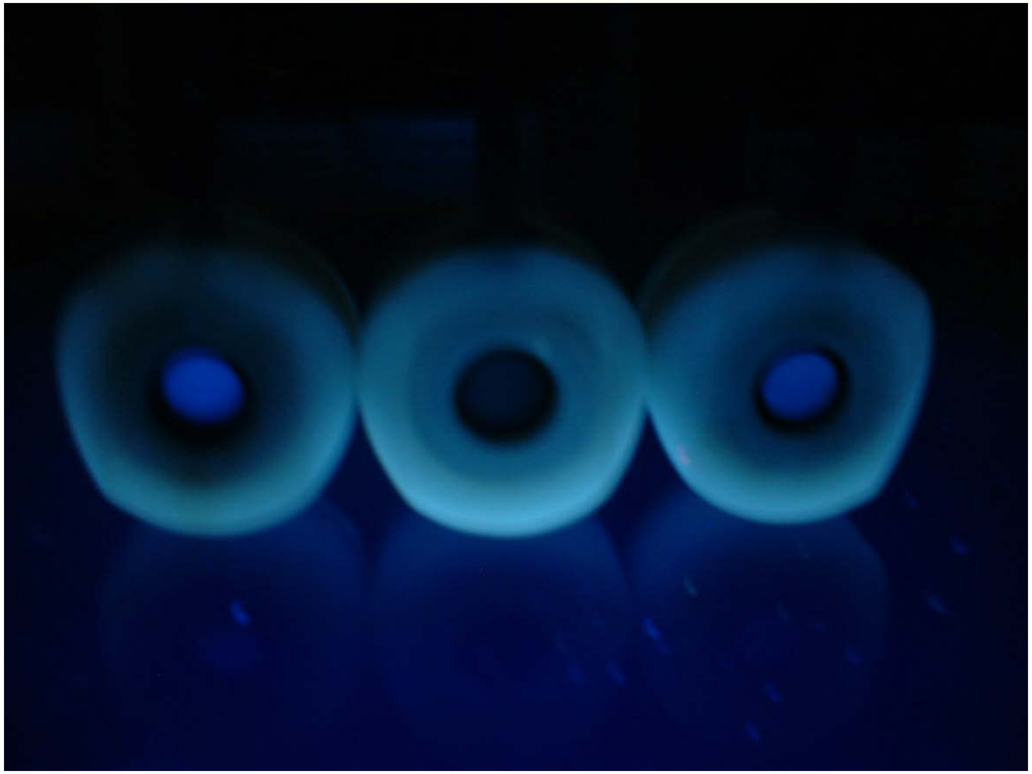
Bode impedance plot of 2024 aluminum with different coating combinations immersed in 3.5% NaCl solution for 5 days

RESULTS



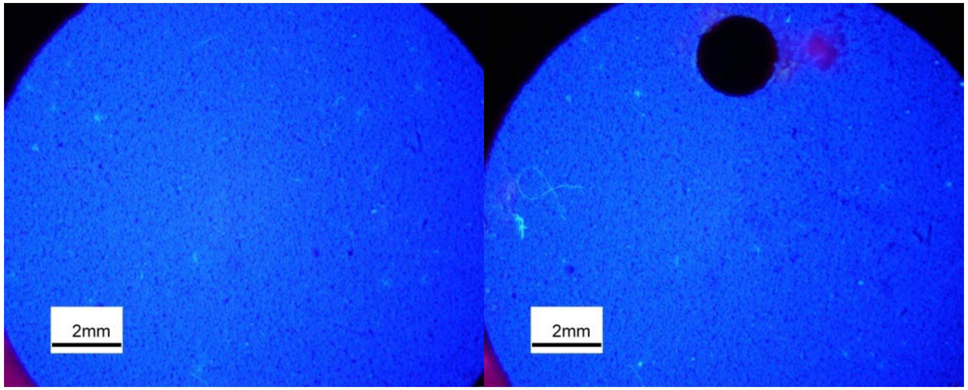
2024 Al, Before exposure; Center specimen contained no indicator

RESULTS



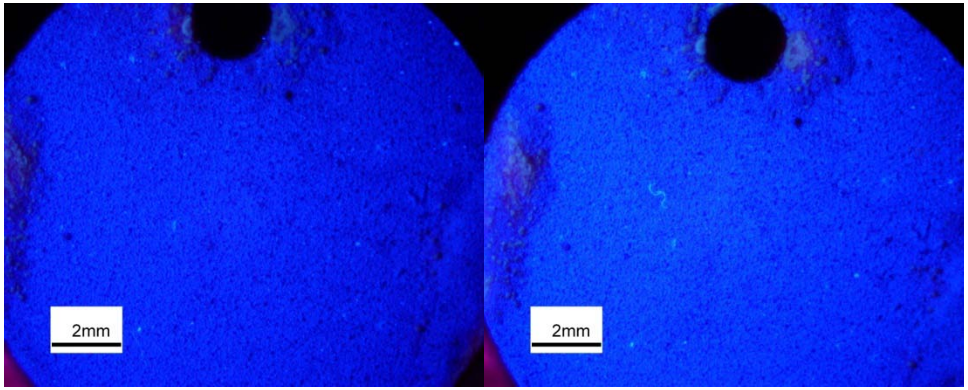
2024 Al, After corrosion; Center specimen Contained no indicator

RESULTS- Corrosion wheel



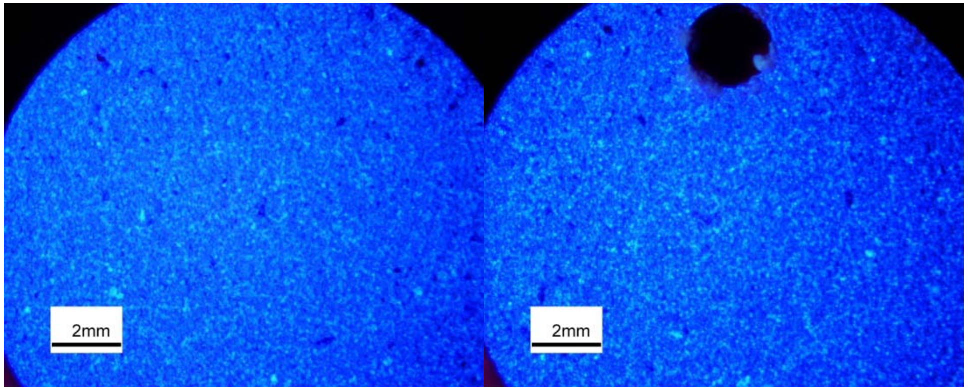
Al plus primer plus indicator (a) before exposure (b) after 1 day

RESULTS- Corrosion wheel



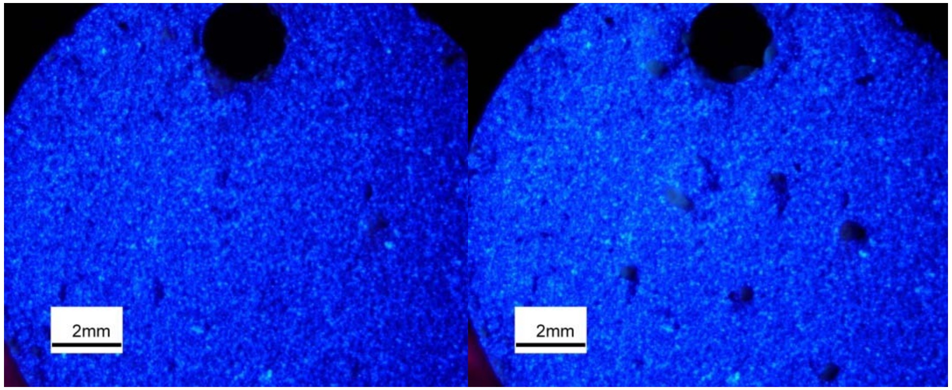
2024 Al plus primer plus indicator (a) after 4 days (b) after 6 days

RESULTS- Corrosion wheel



Al plus topcoat plus indicator (a) before exposure (b) after 1 day

RESULTS- Corrosion wheel



Al plus topcoat plus indicator (a) after 4 days (b) after 6 days

CONCLUSIONS

- **A fluorescent corrosion indicator system and a corrosion wheel have been used to study paint primer and overcoat coatings on 2024 aluminum and 1018 steel specimens.**

  All of this is in an effort to develop smart coatings that could be used on metallic structures for aircraft, offshore, etc.

  The goal is to develop a system that has the ability to reveal corrosion under specially prepared coatings before any visible damage has appeared on the surface of the coating itself.

- **Preliminary testing on aluminum alloy and steel specimens demonstrated that the indicator could be detected through certain topcoat layer thicknesses. However, optimization of the primer/topcoat system is needed.**

  There is also a strong correlation with corrosion under the painted surfaces, especially for large aluminum specimens.

CONCLUSIONS

- Complementary work using EIS provided independent information on corrosion behavior as a function of time and exposure. It will assist in the optimization of the primer/topcoat systems.

  It will also provide insight into the mechanism by which corrosion (or corrosion reduction) takes place.

- The long-range plan is to use a hand-held device to reveal corrosion under specially prepared coatings before any visible damage has appeared on the surface.

ACKNOWLEDGMENTS

The authors are grateful to Systems & Processes Engineering Corporation (SPEC) for partial funding of this investigation.