Natural exposure and cyclic corrosion testing for the assessment of the performance of powder-coated steel

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Introduction

For applications, such as **civil infrastructures**, **automotive**, **agricultural or marine equipment** specific powder coatings are formulated to protect the metal surface from a relatively harsh environment.

Introduction

Nowadays, materials specifications, require that coatings need to provide **long-lasting protection**. (between one to several decades)

When the **service lifetime** of the coating is extensive, the challenges of **Corrosion Testing** increases significantly because of the long periods of time required to obtain a reliable performance information.

Broadly, It has been accepted that **natural exposure** is the most reliable method for the assessing long-term performances.

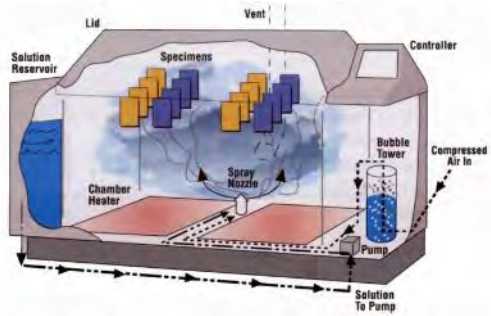
To reduce **long natural exposure testing times**, some **Accelerated Corrosion Tests** have been developed. (First Salt Spray test – 1914)

Introduction

Accelerated Corrosion Tests

The principle is based on the assumption that: the exposure in a significantly **more aggressive environment** provides in a relatively **short time** an indication of the long term behaviour in a less aggressive environment.

Associated Issues with principle of accelerated corrosion testing



- The fixed laboratory conditions are not exactly the same as the service conditions, hence the failure mechanisms would be different.
- The failure mechanisms can be accelerated such as they act on a substantially shorter timescale than in service, but the increment of a stress factor is unlike to have a linear response, hence the degradation mechanism would fluctuate in different type of responses.
- Variations of a single degradation factor could speed up one process and retard another, having an influence in the overall degradation process.

Natural exposure and cyclic corrosion testing for the assessment of the performance of powder-coated steel

Aims

To Gain understanding of the fundamental characteristics of the results obtained from Natural Exposure Test, and to develop a criteria for determining what can be considered a sufficient test duration.

To identify the relationship between the results of a standard accelerated cyclic corrosion test ISO 20340 and the natural exposure test results.

Experimental Methodology

Samples and Sample Preparation

Materials:

Substrate: Cold rolled mild steel panels

Coatings: 26 Powder coating systems selected on the AkzoNobel's current market offer

Sample Preparation

1. The powder coatings systems were applied electrostatically onto the steel panels.
2. Curing procedures were followed according to the recipe of each system.
3. The coated panels were scribed with an elcometer scriber for the natural exposure test and with a milling machine for the cyclic test.

Experimental Methodology

Individual Coating systems and Coating Classes

The coating systems were divided by their chemistry in different coating classes.

Four classes of coatings were identified:

i) Polyester based -- PS
ii) Polyester-epoxy based (Hybrid) -- HY
iii) Epoxy based -- EP
iv) Epoxy based with zinc-rich primer -- ZN

Coating thickness were dependent of the number of layers present in each system. The values were from 90 um to 250 um

Experimental Methodology

Natural Exposure Testing

Three samples of each powder coating system were exposed for 4 years (Location Site: Florida-USA).

The specimens were mounted unbacked on a aluminium exposure rack, and the coated samples with scribe line side facing the sun.

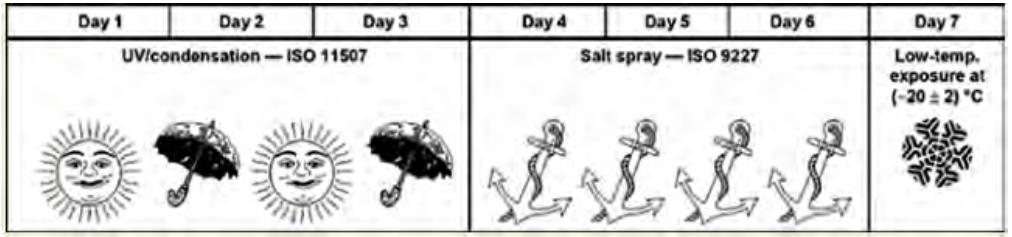
Every year, three samples of each panel were collected for the evaluation of corrosion propagation.

Experimental Methodology

Cyclic Corrosion Test ISO 20340

The ISO 20340 test involves the cyclic exposure to 3 days under UV and condensation conditions according to ISO 11507, followed by 3 days exposure in salt spray, according to ISO 9227, and followed by 1 day exposure to freezing temperatures.

- **UV/Condensation step**: Alternating periods of 4 hours exposure to UV at 60ºC and 4 hours exposure to condensation at 50ºC .
- **Salt Spray step**: continuous exposure to 5%wt NaCl solution fog, pH 6.5 -7.2 at 35ºC.
- **Freeze temperature step:** rinse in deionised water, excess of water cleaned with cloth wipe, and exposure to -20ºC in air.

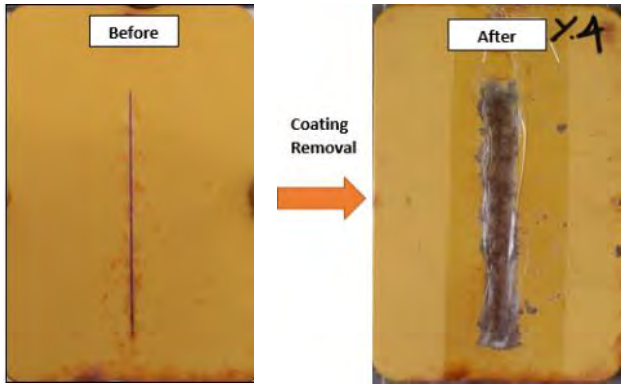


The panels were exposed to two nominally identical cyclic tests for **four and six months.** Three samples of each panel were collected after the tests for the individual evaluation of corrosion propagation

Experimental Methodology

Corrosion Propagation Measurements

1. Coating Removal



Mechanical removal of the coating

2. Image Segmentation

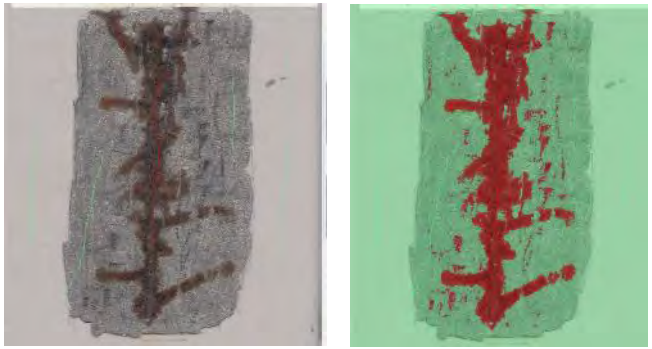


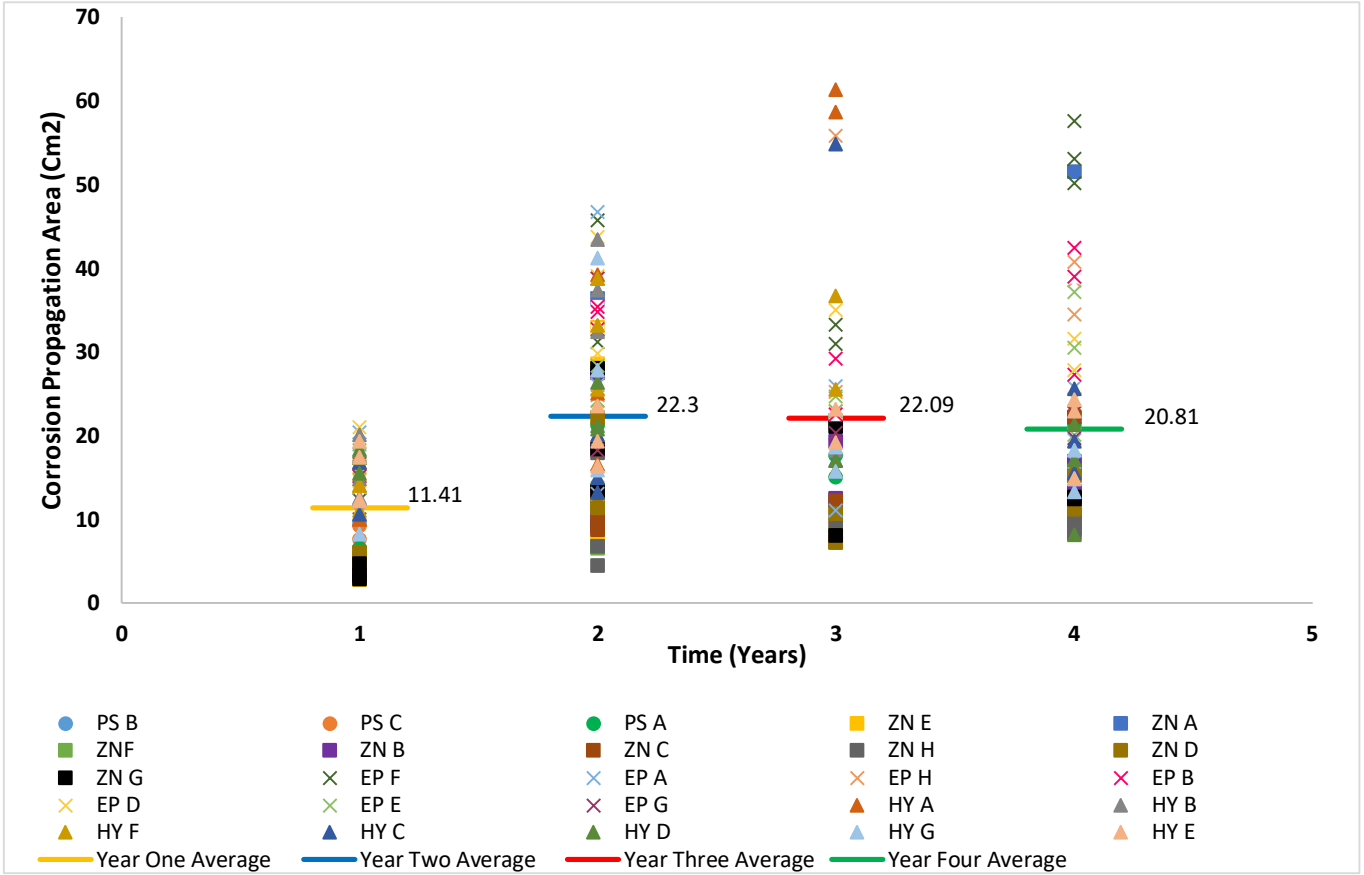
Image-J software.
separation of the different materials in the image

3. Corroded Area Calculation

Image-J software.
Binary colour image for corroded area calculation

Results

Natural Exposure Test



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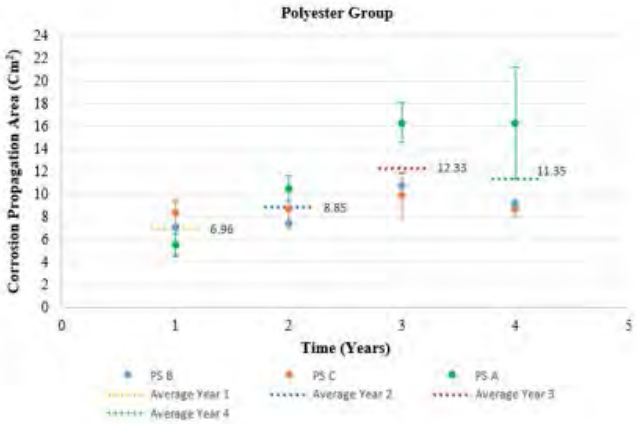
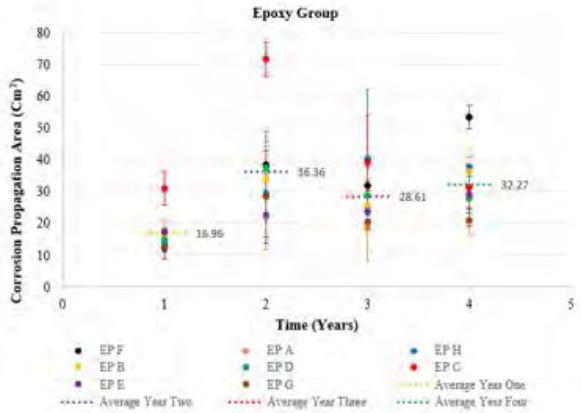
Corrosion Kinetics

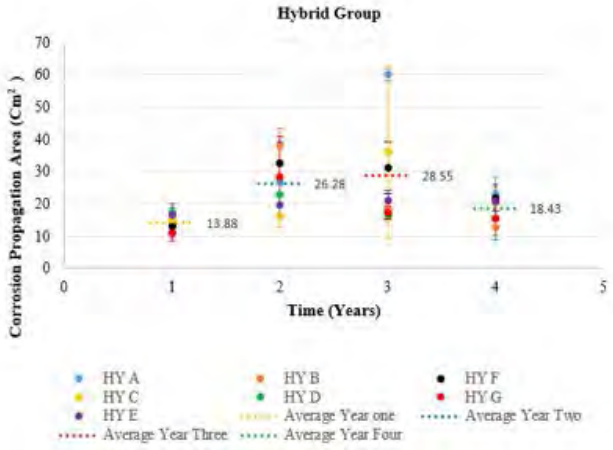
on average, the corroded area **increases significantly during the first and second year,** with values of the second year being approximately double than the values on the first year, but **it remains essentially constant after three and four years.**

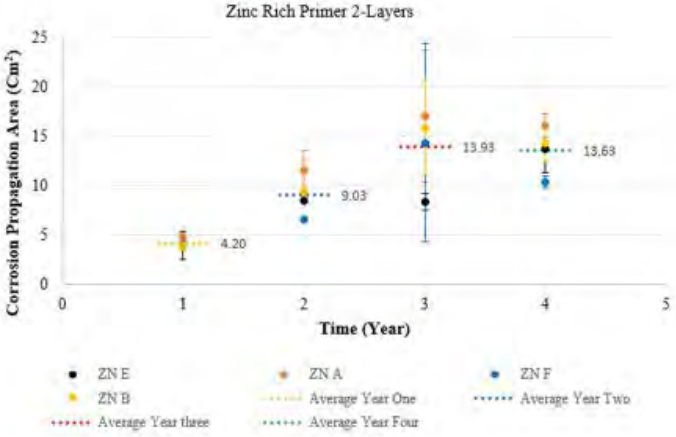
Results

Natural Exposure Test









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Corrosion Kinetics

The overall trend of corrosion kinetics observed before is actually repeated when grouping the systems in coating classes

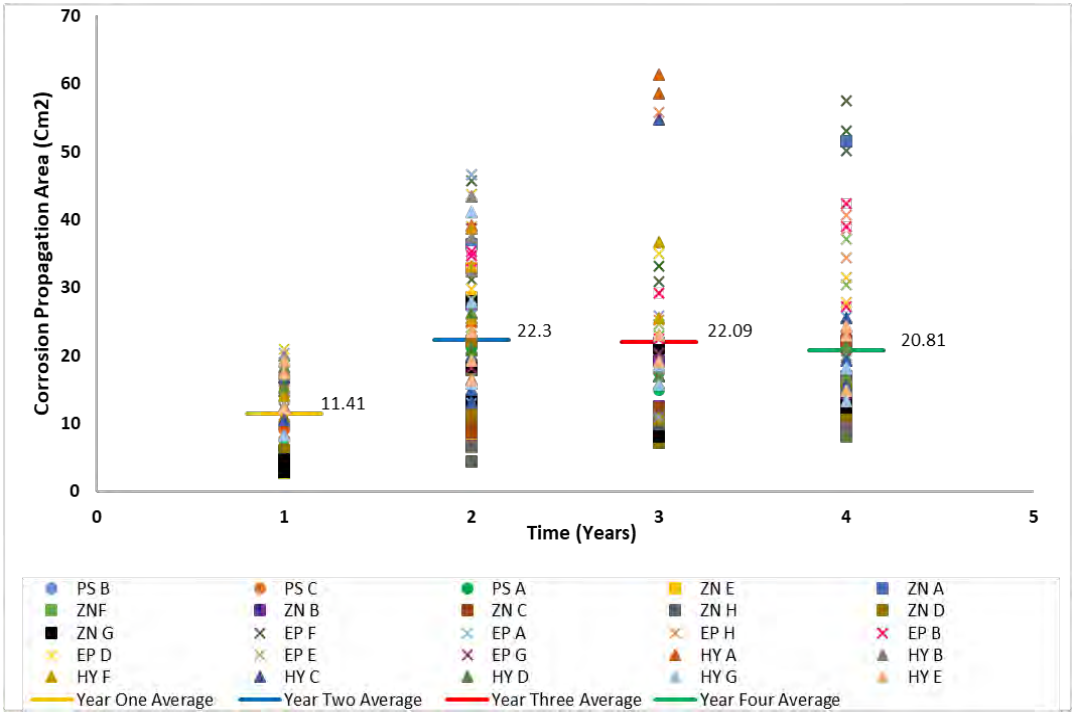
Inconsistencies

The occasional area decreases observed are due to variation in performance within nominally identical specimens, and it is an issue often observed in any corrosion test

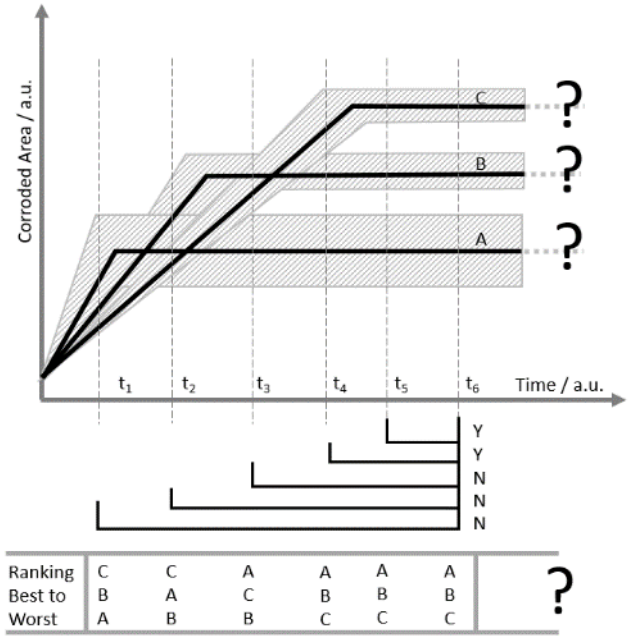
Results

Natural Exposure Test

corrosion area propagation kinetics



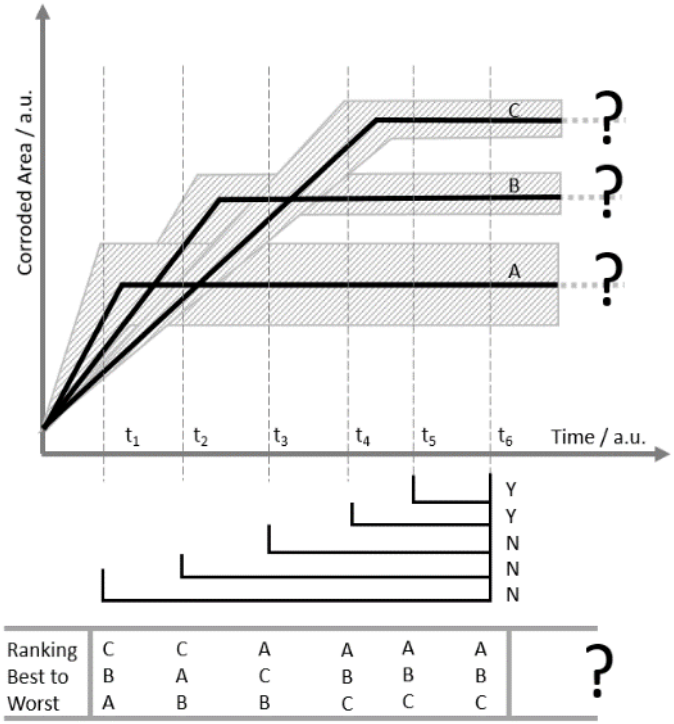
Kinetics Schematic



Results

Natural Exposure Test

How to characterize a coating system?



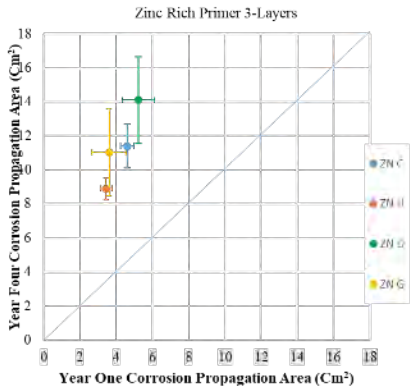
By Analysing:

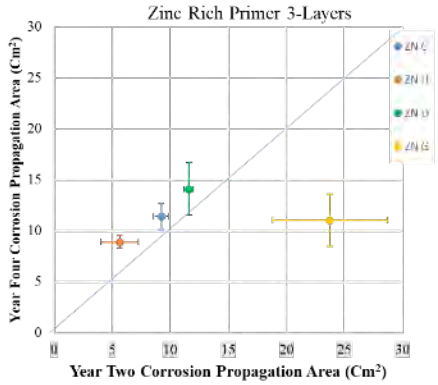
- The rate of corrosion propagation area during the initial stages
- The plateau value at long exposure times
- The intrinsic variability between specimens obtained under nominally identical condition in relation to the actual average value of corrosion propagation area.

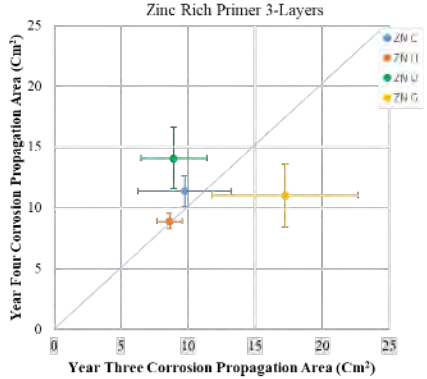
Results

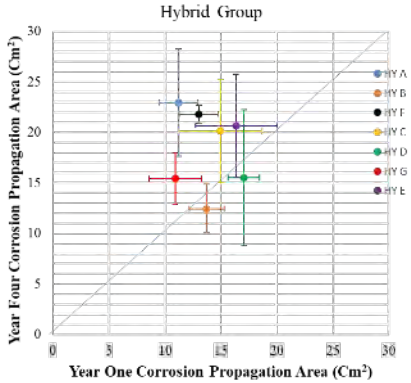
Natural Exposure Test

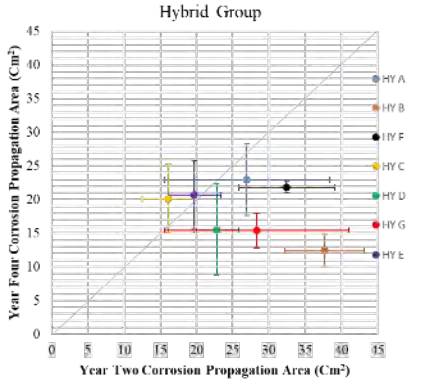
Enough Time of Natural exposure test?

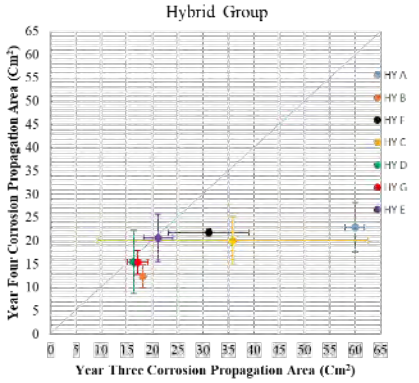












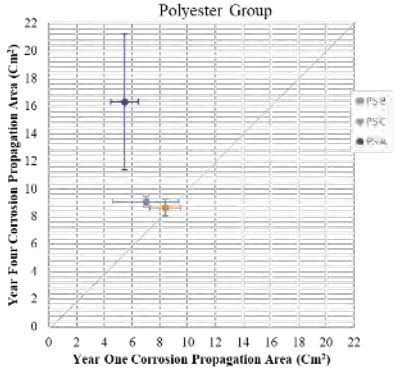
Analysis of the actual data of Natural exposure

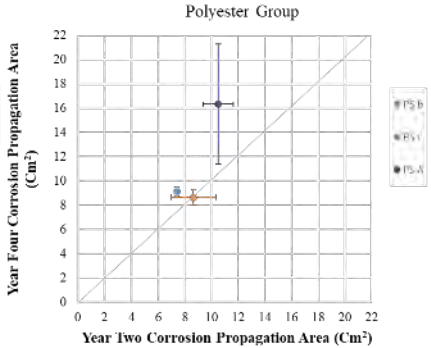
The points very rarely align on a straight line above the 45 degrees line, indicating that the ranking between specimens is not consistent after three or four years of testing.

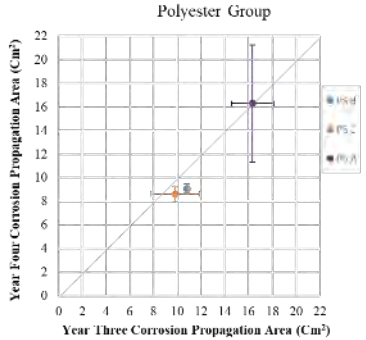
Results

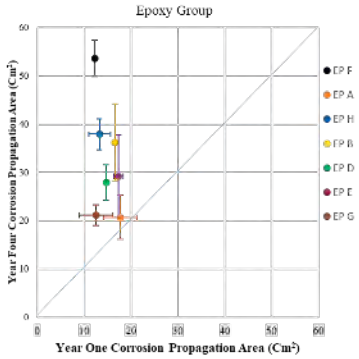
Natural Exposure Test

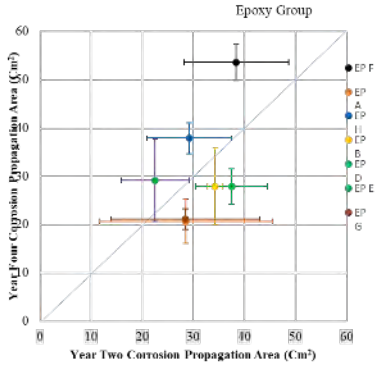
When to stop a Natural exposure test?

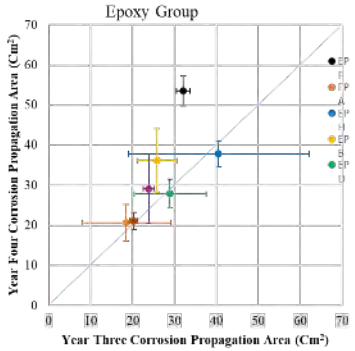












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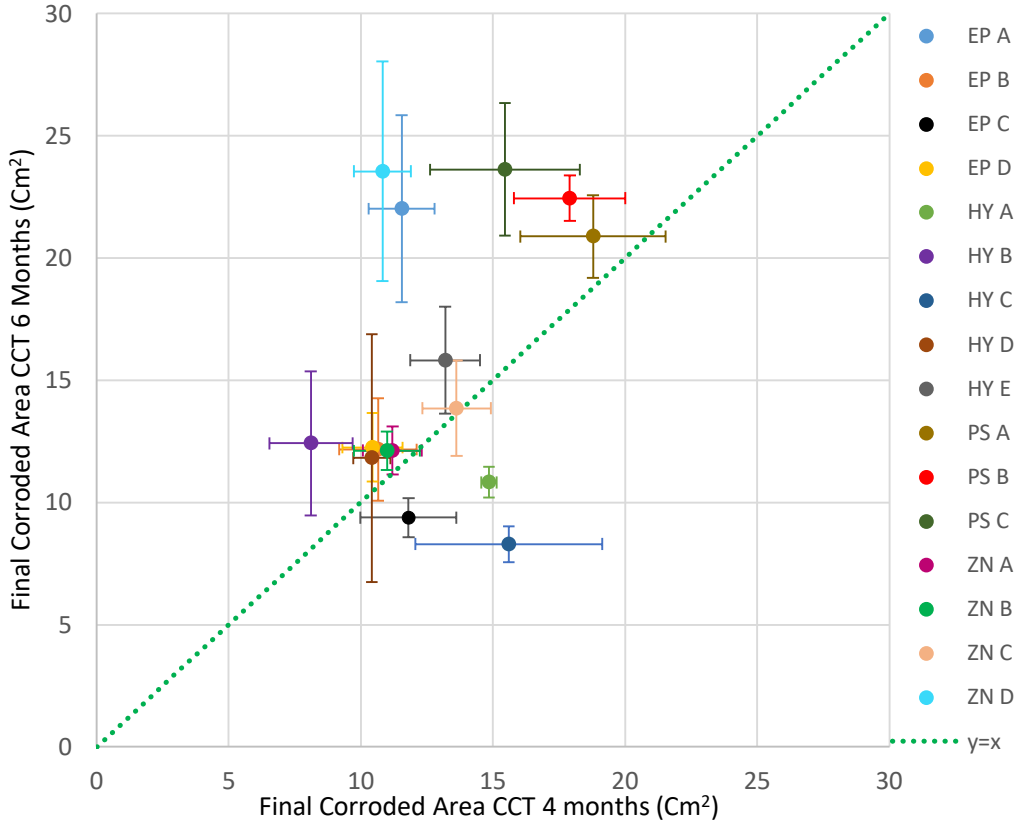
Analysis of the actual data of Natural exposure

The points very rarely align on a straight line above the 45 degrees line, indicating that the ranking between specimens is not consistent after three or four years of testing.

Results

Cyclic Corrosion Test ISO 20340

Test Reproducibility



What is expected?

The points should all fall above the 45 degrees line, because each system should in principle corrode more during six months exposure than during four months exposure under the same conditions.

What Happened?

The points fell above the 45 degrees line, except for 3 systems. This means the test is relatively consistent.

Sample variability Influence

The overall ranking is not perfectly maintained. This indicates that the variability between specimens is significant with respect to the effect of extra two months of exposure, which is the difference between the four and six month's tests.

Results

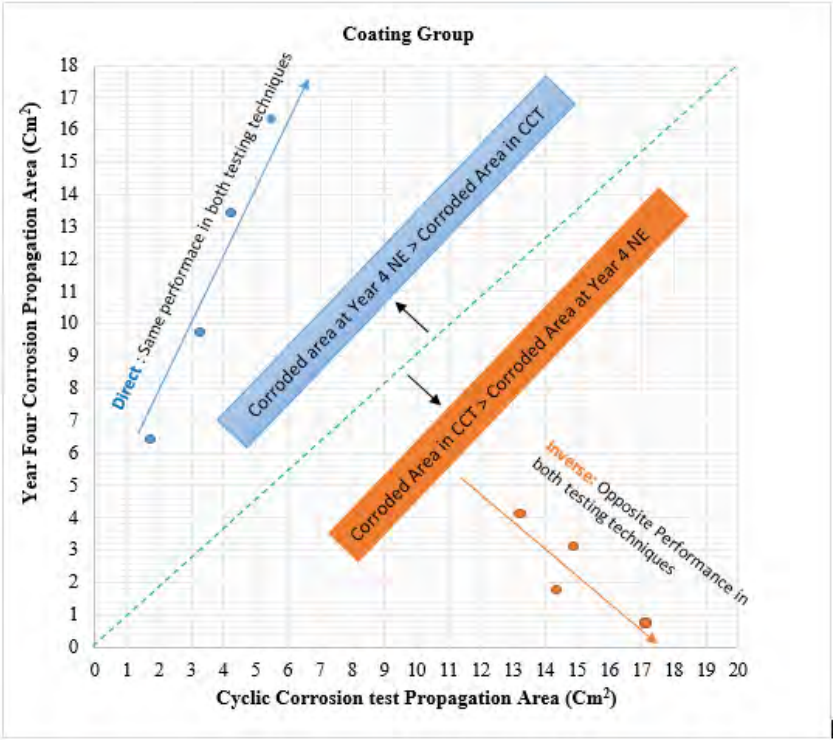
Natural Exposure and ISO 20340

Correlation Plots

- Correlation plots were made between the natural exposure test results and the ISO 20340 test results.

- The graphs represented: Corroded area after 6 and 4 months after ISO 20340 as function of the corroded area after 4 years of natural exposure

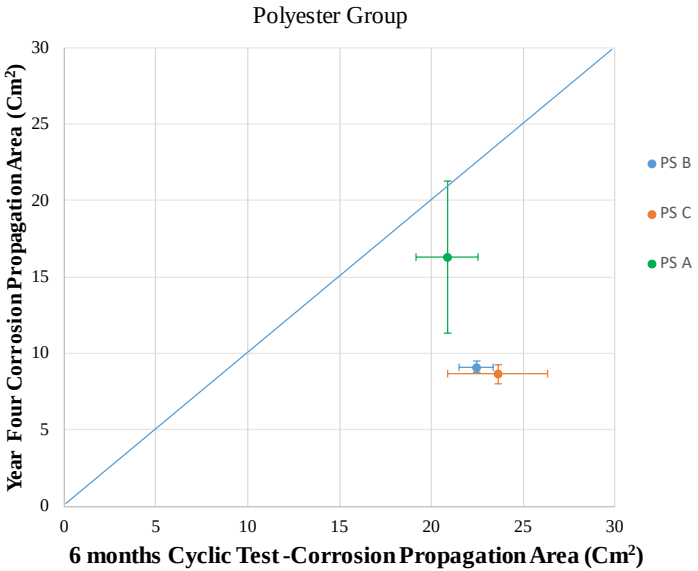
- 45 degrees line plotted to differentiate which test has been more aggressive

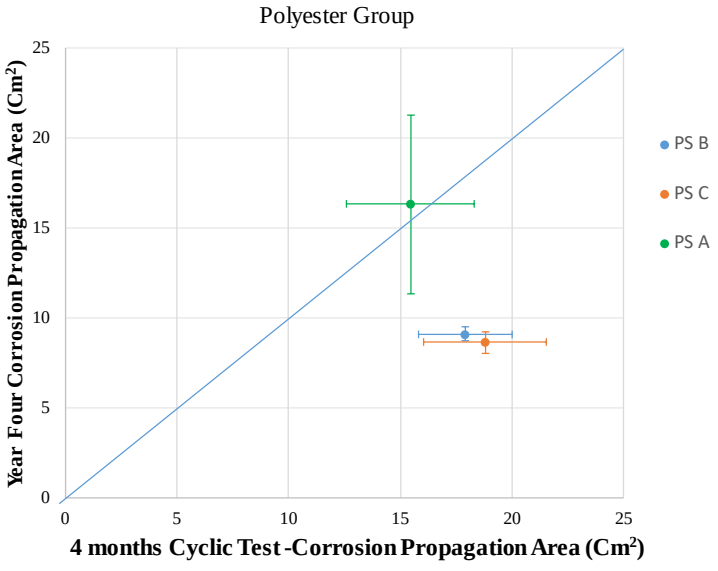


Results

Natural Exposure and ISO 20340

Correlation Plots





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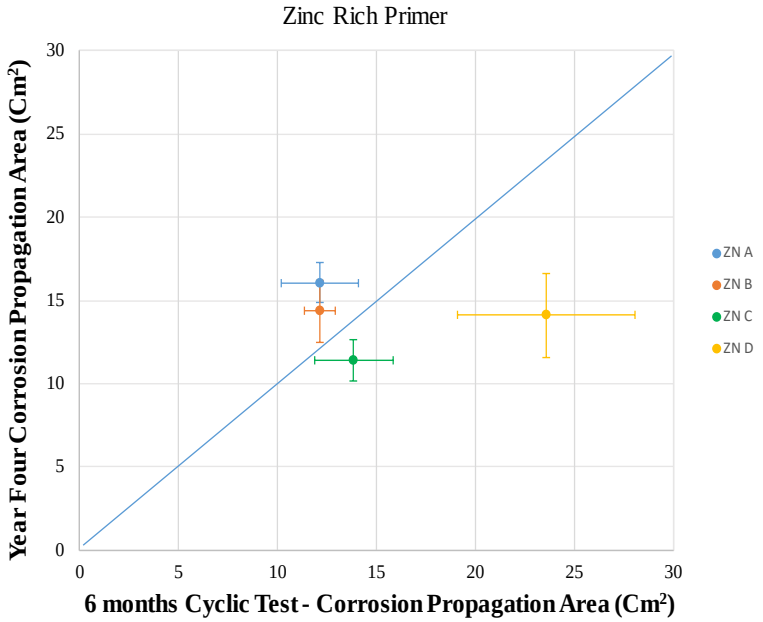

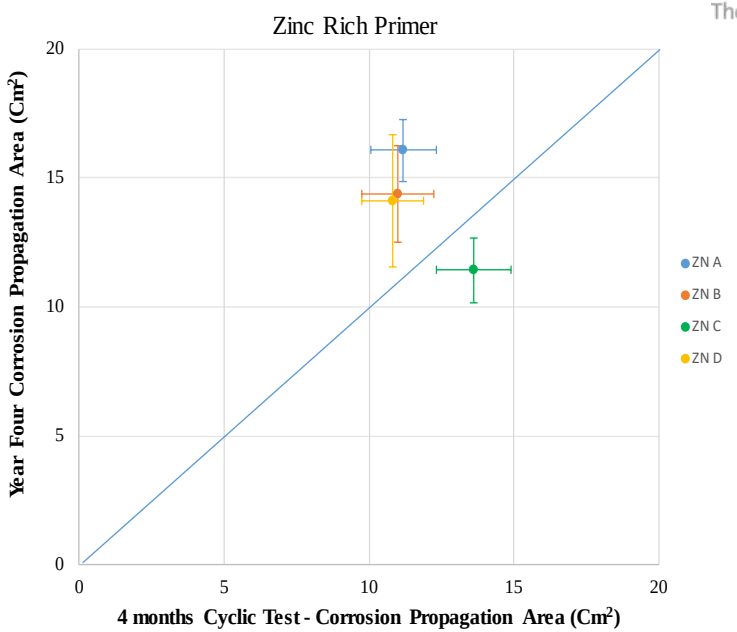

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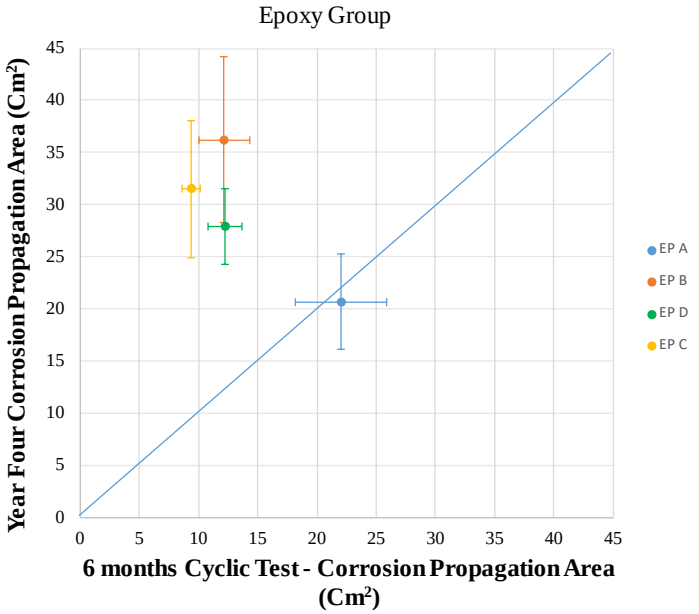

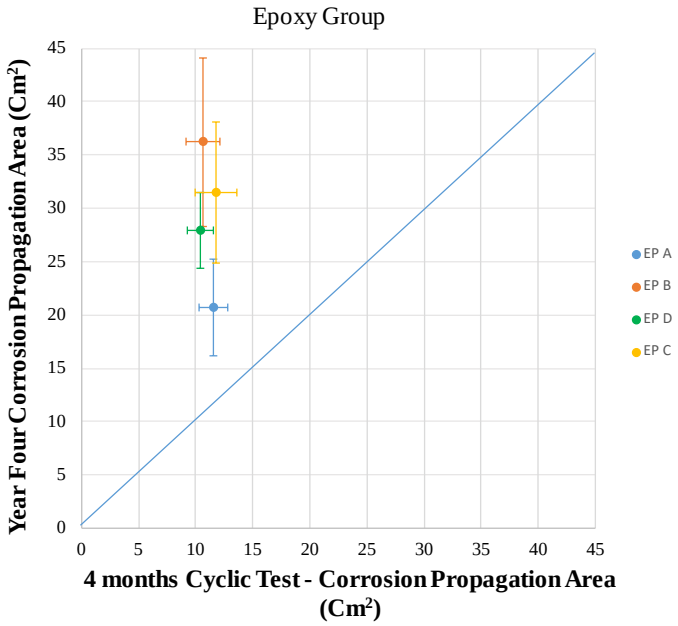

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Natural Exposure and ISO 20340

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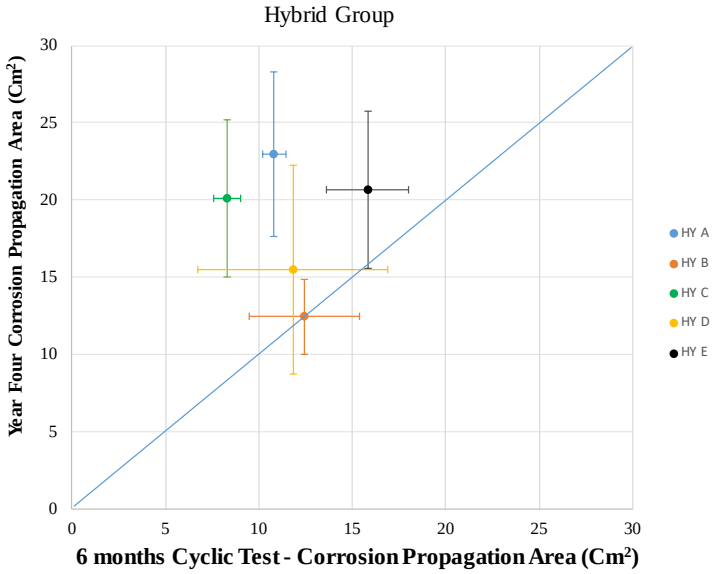

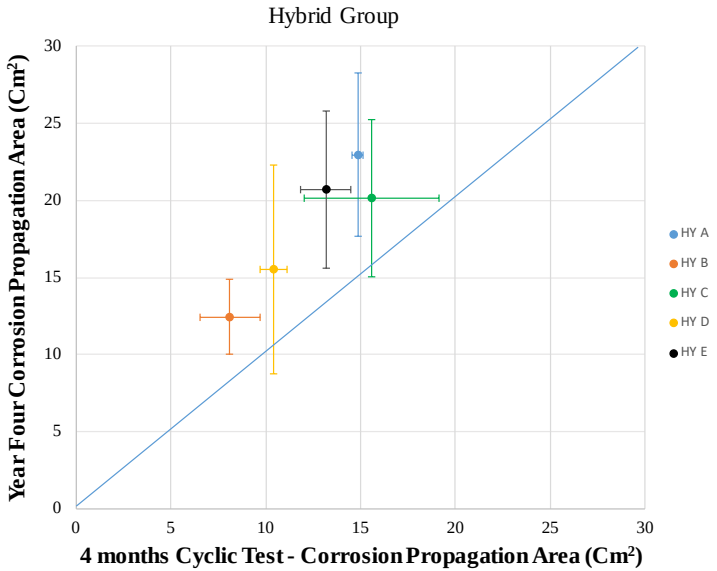

Natural Exposure and ISO 20340

Correlation Plots

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General observations in the correlation plots:

- In most cases, four years of natural exposure induce more corrosion than both four and six months of ISO 20340 cyclic testing.
- Polyester coatings suffer more from ISO 20340 test that from natural exposure.
- Inverse correlation tends to be observed between cyclic and natural exposure. This observation indicates that specimens that perform better during ISO 20340 testing perform worse during natural exposure and vice versa.
- Hybrid group, an apparent correlation is observed between four months tests and four year of natural exposure. (Probably more accidental)

Conclusions

- Corrosion propagation during natural exposure is characterized by an initial increase in the corrosion area followed by a period where the corroded area grows very slowly. As a direct consequence, the relative ranking of the coating systems varies significantly as a function of test time.

- Identification of the correlation between test results at shorter time and test result obtained at longer time, once the ranking has stabilized, might be a method to establish minimum test duration for natural exposure.

- Correlation between natural exposure results and cyclic ISO 20340 test results seems not to exist, and for most classes of coatings, a better performance in one test is associated with a worst performance in the other.

Acknowledgment

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Thanks For The Attention