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Dye Containing Coatings for Corrosion Sensing Applications

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UNIVERSITY OF LEICESTER

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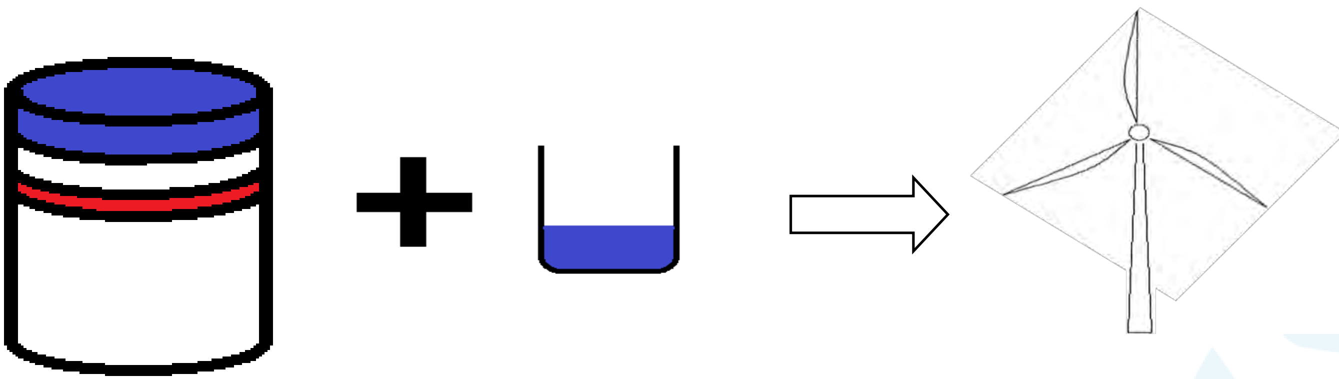
Contents

Concept

"Develop a corrosion sensing organic coating, via the incorporation of pH active chromophores (pH sensitive dyes), for use in offshore atmospheric environments (wind turbine towers)."

Coating System + ph-sensitive dyes



Coating

ph-sensitive dye

pH sensitive intelligent coating on wind turbine tower structure

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad O_2 + 2H_2O \rightarrow 4OH^{-} + 4e^{-}$$

$$\underset{\text{(Original colour)}}{Chromo + nOH^{-}} \rightarrow \underset{\text{(Different colour)}}{Chromo^{-n} + nH_2O}$$

Intended Impact

- Increased awareness of corrosion before significant metal loss has occurred.
  - Therefore reduce repairs and downtime, while increasing safety.

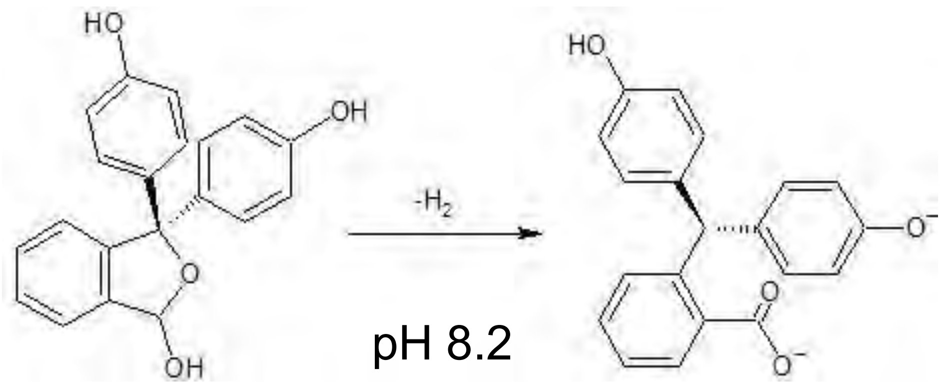
Experimental Method

- 3 Stages
  1. Check compatibility pH sensitive dye and coating combinations – glass substrate
  2. Check coating + dye combinations activity in hydroxide environment – glass substrate
  3. Check coating + dye combination activity in a corrosive environment (synthetic seawater) – steel substrate

pH Sensitive Dyes - candidates

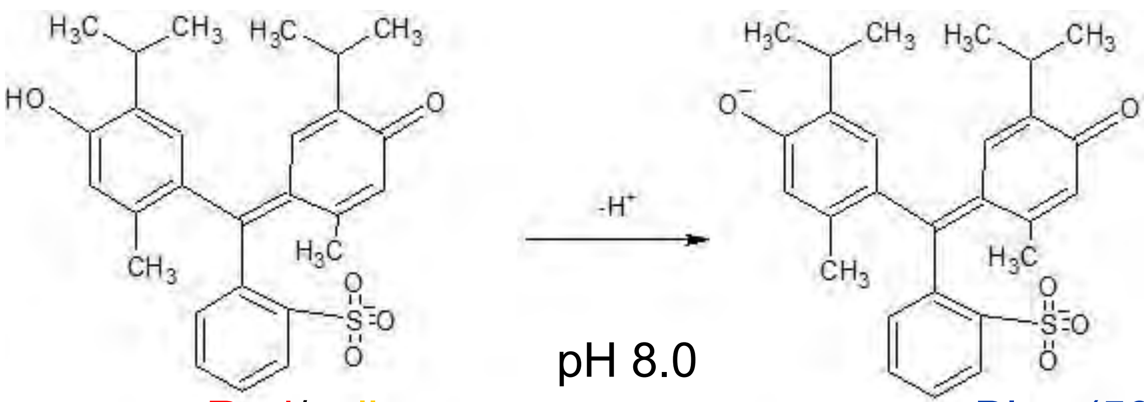
Approximate corrosion reaction $2Fe + O_2 + 2H_2O \longrightarrow 2Fe(OH)_2$

Phenolphthalein



Colourless $\xrightarrow{\text{pH 8.2}}$ Pink (552 nm)

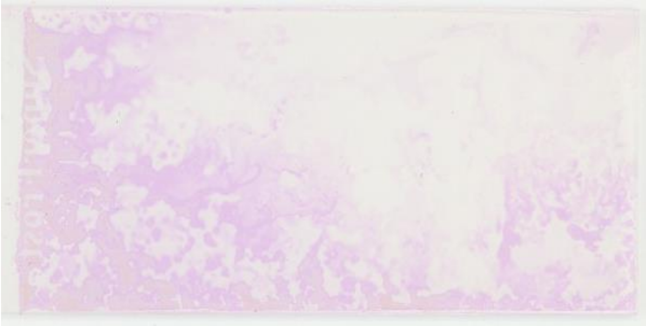
Thymol Blue



Red/yellow $\xrightarrow{\text{pH 8.0}}$ Blue (594 nm)

- Commercial Polymer Coatings
  - Liquid epoxy - Intergard 410 (International Paints Ltd)
    - – brush applied – air cured (24 hour full cure)
    - White pigments
  - Powder epoxy - PipeClad 2000 (Sherwin Williams Ltd)
    - – Electrostatically powder spray – oven cured 232°C (3.5 mins)
    - Green pigments
  - Powder polyester – Interpon A4742 (AkzoNobel Ltd)
    - – Electrostatically powder spray – oven cured 180°C (13 mins)
    - No pigments
  - Electrostatic powder spraying was carried out using a dual-voltage powder coating system (model #11676, Eastwood Ltd)
    - 8 psi at 15kV excitation
    - Aluminium backing was used for electrostatic powder spraying to glass

Results - Glass Substrates - Liquid Epoxy Paint



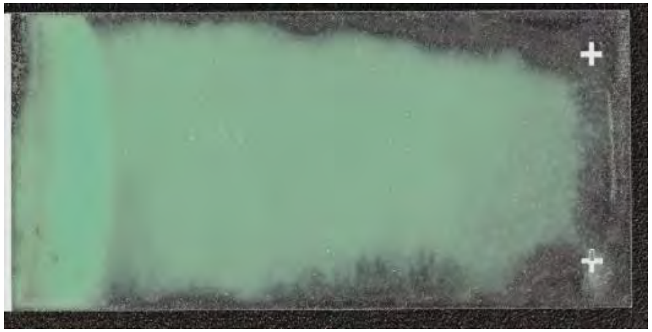
Phenolphthalein

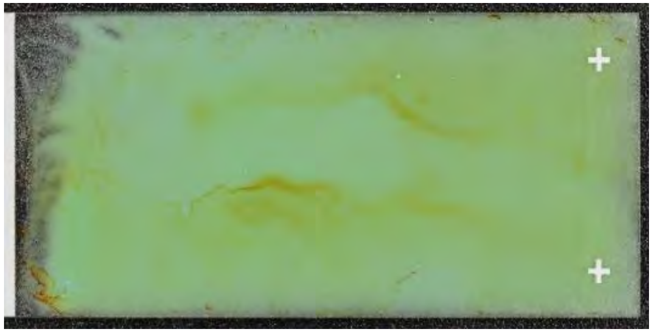
Thymol Blue

- Intergard 410 – International Paint Ltd
- Two pack liquid epoxy
  - Part 1: Base – (mixture Bisphenol A & Epichlorohydrin)
  - Part 2: Hardener (mixture of Triamines)
  - Brush applied

- Colour change observed

Glass Substrates – Epoxy Powder Coating


Phenolphthalein


Thymol Blue

- PipeClad 2000 – Sherwin-Williams Ltd
- Epoxy powder (also known as FBE)
  - Electrostatic powder spray
  - Heat cured (oven 232°C)
- No dye colour change observed

Glass Substrates – Polyester Powder Coating

Phenolphthalein

Thymol Blue

- Interpon A4742 – AkzoNobel Ltd
- Polyester powder
  - Electrostatic powder spray
  - Heat cured (oven 180 °C)
- No dye colour change observed

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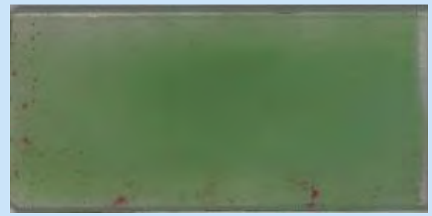
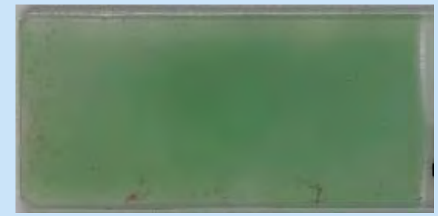
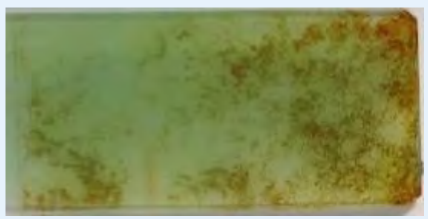
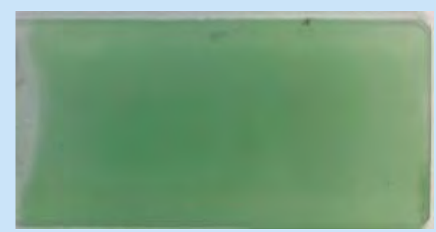
Glass Substrates – Dye Activation

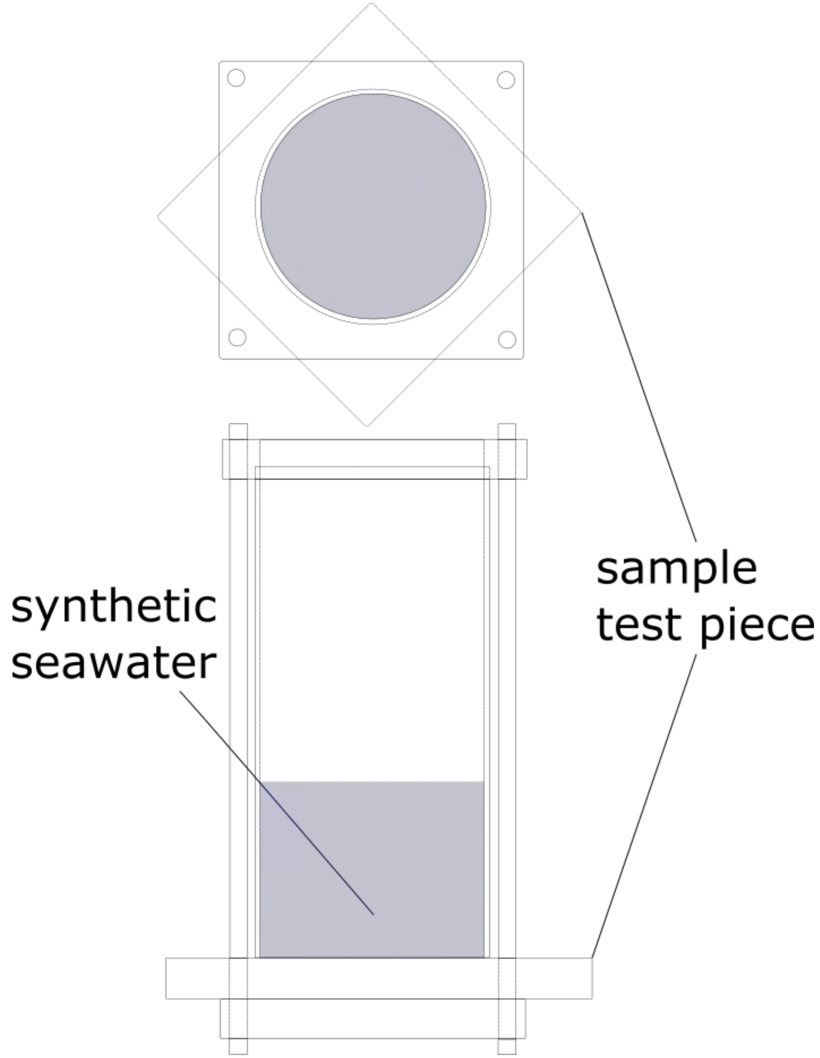
- Dye & epoxy powder coated slides immersed in 0.1M NaOH for 35 days

CCM	Start (Day 0)	Day of colour change	End
phph		 Day 2	 Day 35
TB		 Day 2	 Day 35
CTRL		N/A	

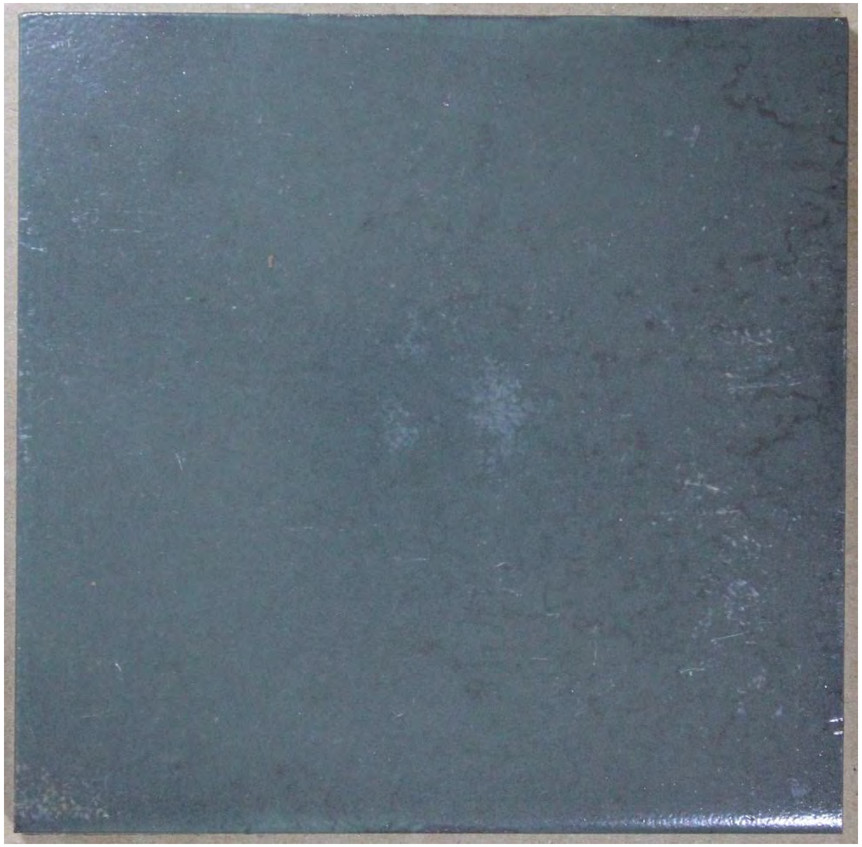
- Dye & polyester powder coated slides immersed in 0.1M NaOH for 35 days

CCM	Start (Day 0)	Day of colour change	End
phph		 Day 2	 Day 35
TB		 Day 2	 Day 24
CTRL		N/A	

Steel Exposure Test Setup

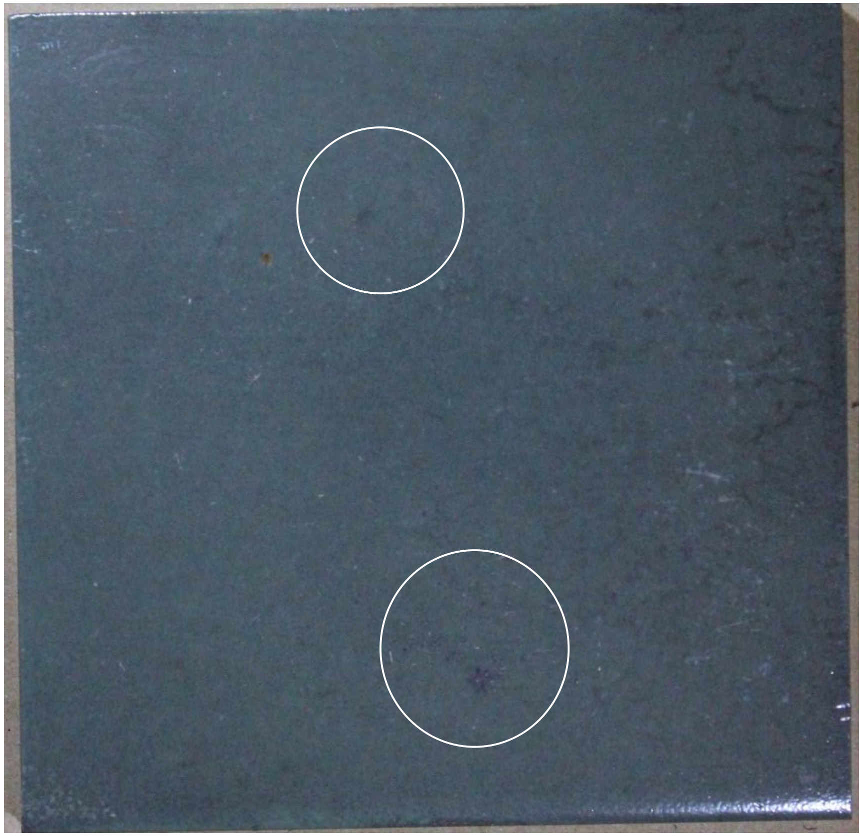


- phph & epoxy powder coated S355 steel immersed in synthetic seawater ASTM D1141 – Day 0 (start)



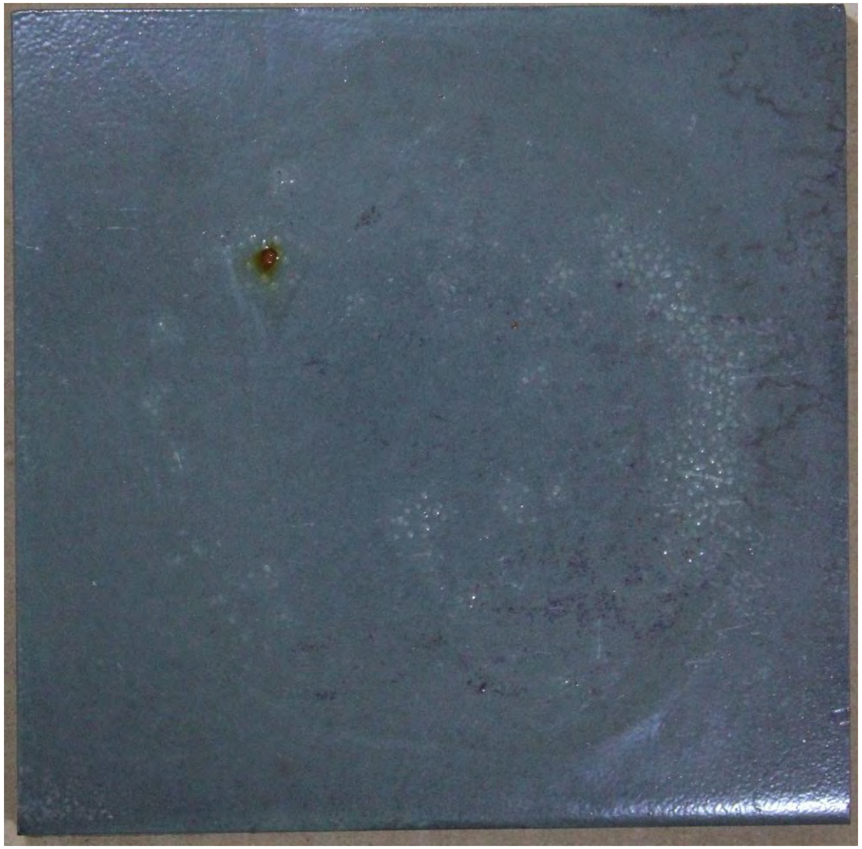
- phph has no colour beneath the coating
- Some deposits of the dye are visible

- phph & epoxy powder coated S355 steel immersed in synthetic seawater ASTM D1141 - Day 7



- Some phph colour change is observable near some coating defects
  - Colourless to pink (beneath green)
- However observation is difficult with pink phph and green epoxy coating

- phph & epoxy powder coated S355 steel
  - Day 35 (end)

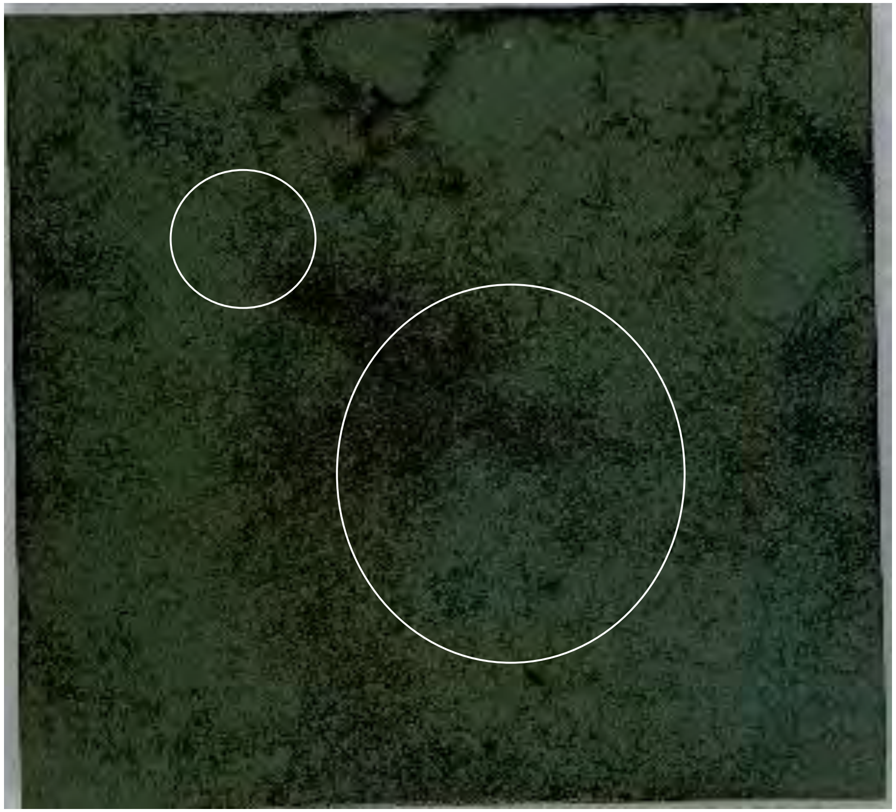


- Location of corrosion readily observable.
  - Pink colour remains observable however is difficult due to green epoxy
- Polymer blistering is also visible

- TB & epoxy powder coated S355 steel
  - Day 0 (start)

- Inactivated TB beneath epoxy powder post cure is brown/black on bare steel

- TB & epoxy powder coated S355 steel
  - Day 7



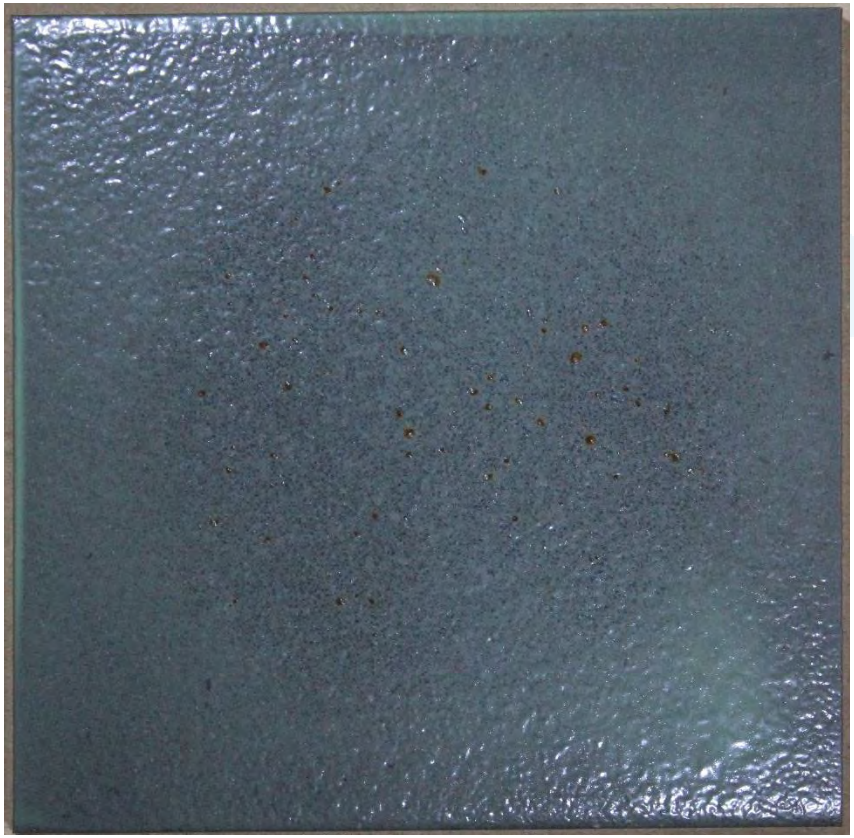
- Start to see TB colour change
  - brown to blue
- No patches of corrosion are observable

- TB & epoxy powder coated S355 steel
  - Day 35 (end)

- Strong TB colour change observable throughout the exposed area.
- Patches of corrosion are observable
- Calcareous deposits are observable

- Control - epoxy powder coated S355 steel
  - Day 0 (start)

Day 35 (end)



- phph & polyester powder coated steel
  - Day 0 (start)

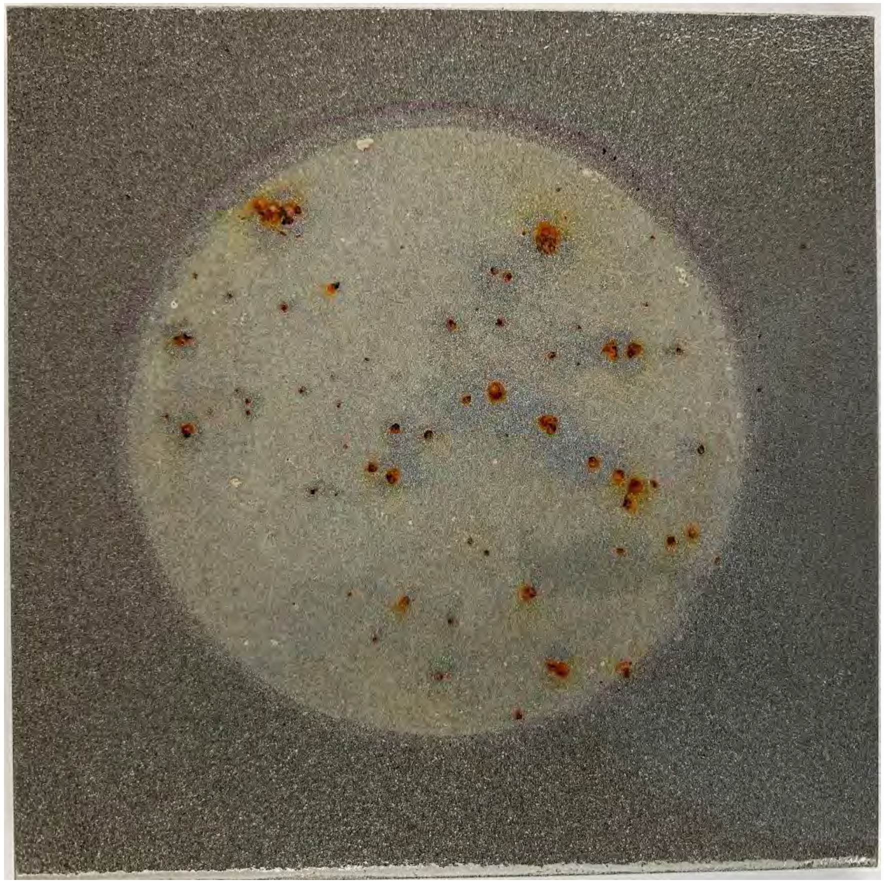
- phph is not visible beneath colourless polyester

Evaluation on Metallic Substrates – S355

- phph & polyester powder coated steel
  - Day 4

- Pink colour is observable on the exposed area.
- A few corrosion patches are observable.

- phph & polyester powder coated steel
  - Day 35



- Some pink colour observable on the exposed area however are it is obscured by calcareous deposits
- Patches of corrosion are observable and numerous

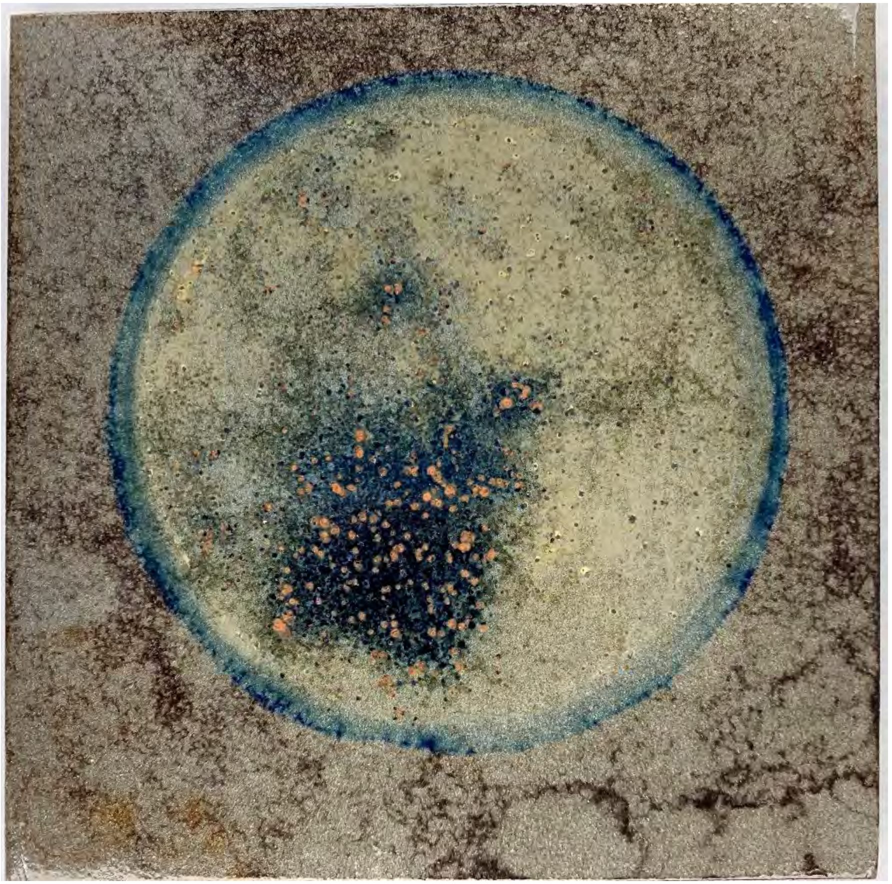
- TB & polyester powder coated steel
  - Day 0 (start)

- TB is black/brown beneath the polyester coating before exposure.

- TB & polyester powder coated steel
  - Day 4

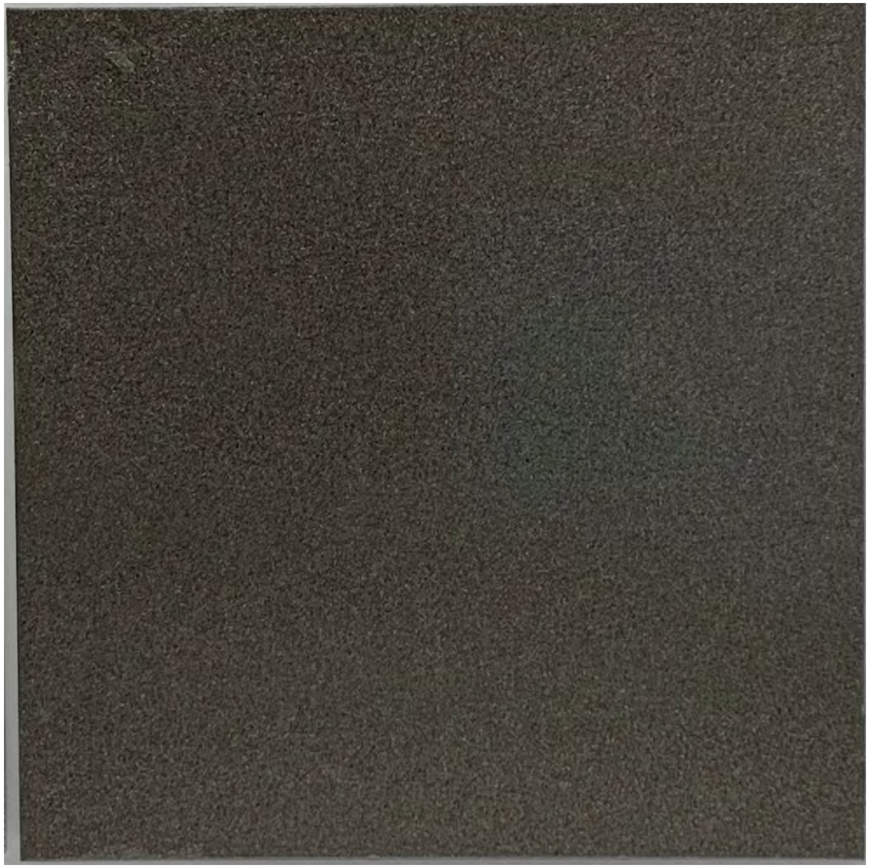
- Blue colour from TB is now observable.

- TB & polyester powder coated steel
  - Day 35

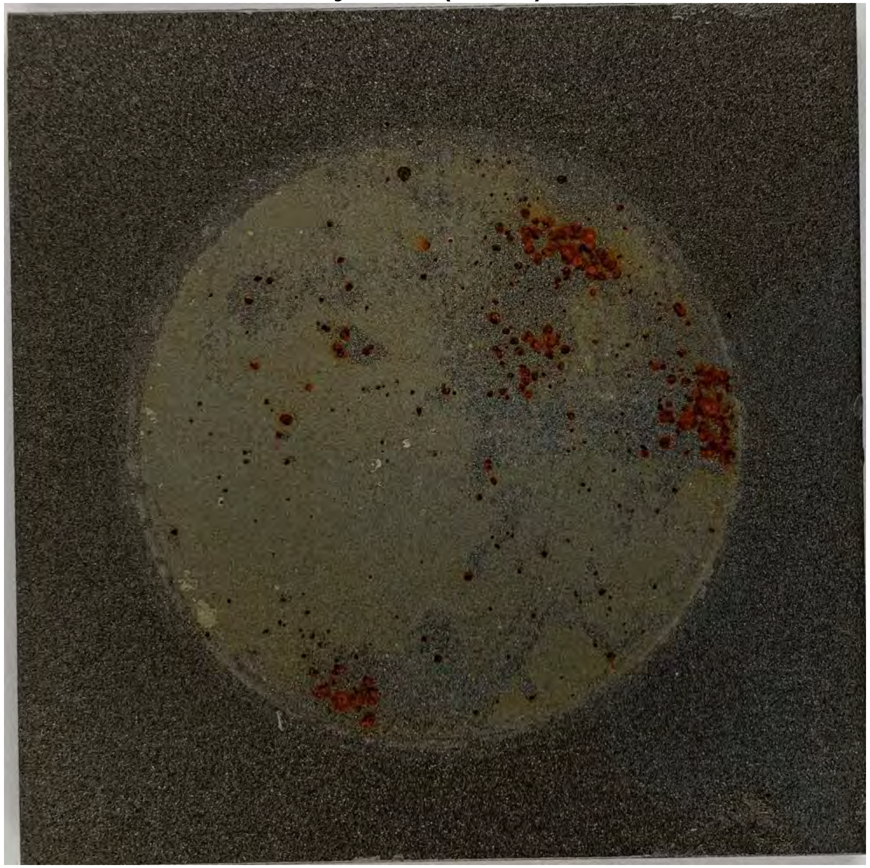


- Strong blue colour observable throughout the exposed area.
- Patches of corrosion are observable and numerous.
- Calcareous deposits are also observable throughout the exposed area.

- Control - polyester powder coated S355 steel
  - Day 0 (start)



Day 35 (end)



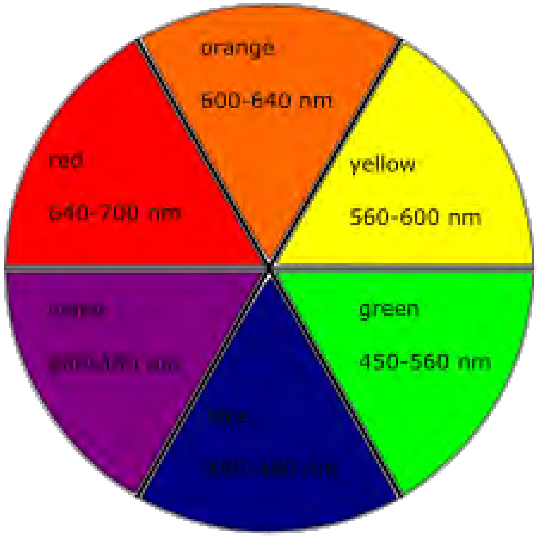
Discussion – Glass Samples

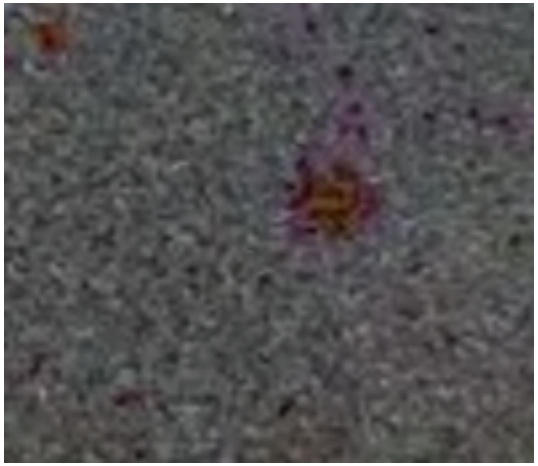
- Glass samples – liquid epoxy
  - Amine catalyst produces hydroxide ions in water

    $R_2NR + H_2O \rightarrow R_2NRH^+ + OH^-$
  - Increases local pH during curing
  - Activates pH colour change of dyes
- Glass samples – epoxy powder and polyester powders
  - Heat cured therefore no [OH^-] required for cure
  - Dyes activation only observed once cured slides are exposed to a source of [OH^-]

Discussion – Steel Samples - phph

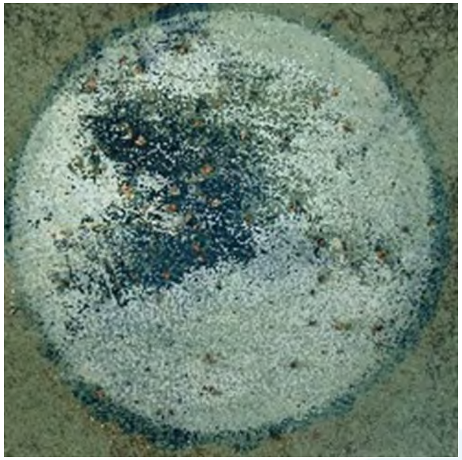
- phph & epoxy powder system on steel
  - Difficulty in observing pink on against green epoxy
    - Green is complimentary to red (pink)

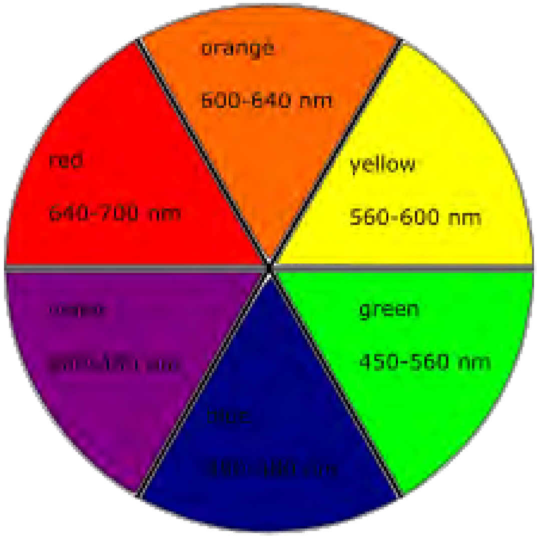




- Phph & polyester powder system on steel
  - Colour change more recognizable, however still difficult to spot next too corrosion product

- TB & epoxy powder system on steel
  - easier to observe blue against green epoxy
    - Green is not complimentary to blue





- TB & polyester powder system on steel
  - Highly observable blue against colourless polyester.

Conclusions

- Liquid epoxy paints are not compatible with pH sensitive dyes
  - Owing to $[OH^-]$ containing catalyst/hardener.
- Epoxy powders can be used to coat steel substrates pre-coated in pH-sensitive dyes.
  - Heat cured therefore do not produce $[OH^-]$
- Polyester powders can be used to coat steel substrates pre-coated in pH-sensitive dyes.
  - Heat cured therefore do not produce $[OH^-]$
- Corrosion sensing performance can be observed on steel samples immersed in seawater for both polyester and epoxy powders with pH sensitive dyes.
  - Thymol Blue samples are more easily observed than phenolphthalein.

Acknowledgements

Thanks for listening.

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