# C21.2022 - Prediction and Prevention of Bridge Performance Degradation due to Corrosion, Material Loss, and Microstructural Changes

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## Objective

- To perform a comparative study on general corrosion properties of low alloy steels A7, A36 and A588 and to produce a model predicting the corrosion performance of a bridge.
- Bridges in US share ~37% of the total annual cost of corrosion [4].
- More than 50% of the bridges in Connecticut were estimated to be in fair or poor in condition by the Department of Transportation [4].

## Background

- A7 steel was used for bridge construction till 1960s. One major limitation of A7 is that it is corrosive and mechanically not robust [1,4].
- A7 was replaced by A36 in 1967 due to its better mechanical properties [2,4].
- A588 is developed very recently with better corrosive properties.

**Table:** Compositions of A7, A36 and A588 [1-3]

| Steel | C | Mn | Si | Cr | Cu | Mo | Ni | P | S | V |
|---|---|---|---|---|---|---|---|---|---|---|
| A7 | - | - | - | - | 0.18 Min | - | - | 0.075 Max | 0.063 Max | - |
| A36 | 0.26 Max | - | 0.4 Max | - | 0.2 Max | - | - | 0.04 Max | 0.05 Max | - |
| A588 | 0.2 Max | 0.5 - 1.35 | 0.15 - 0.65 | 0.4 - 0.7 | 0.2 - 0.5 | 0.1 Max | 0.5 Max | 0.03 Max | 0.03 Max | 0.01-0.1 |

- Bridges in marine environments will undergo corrosion due to humidity, chlorides, sulfides, temperature etc.
- De-icing salt, and the salt present in the air will enhance the corrosion by providing the Chloride ion.

## Methods

- **Wet-dry cycle testing**

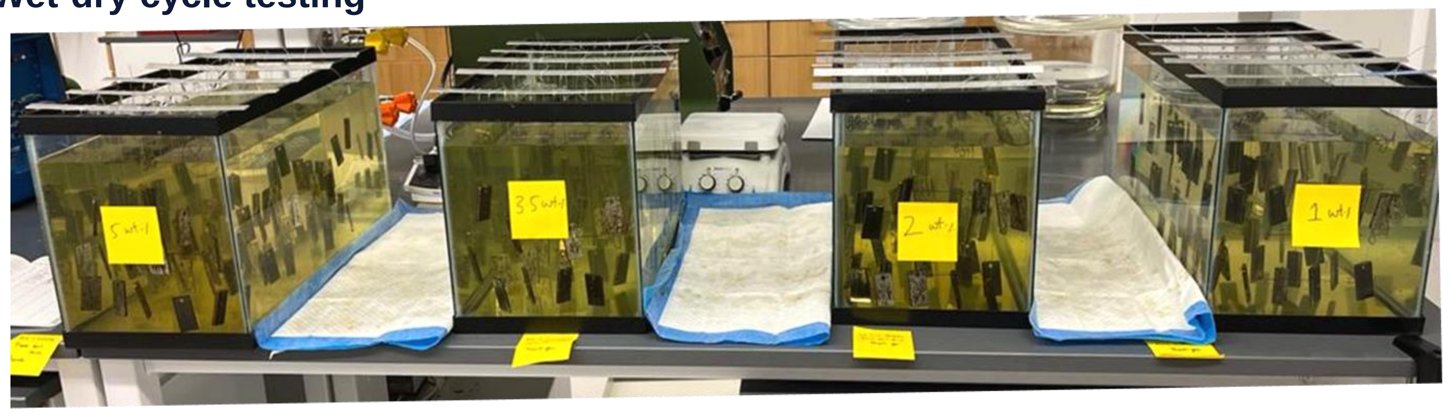


**Fig.** Wet-Dry cycle test setup

| Parameters | Levels/Conditions |
|---|---|
| Total wet-dry cycles | 400 ( each cycle - 15 min wetting and 1 hour drying) |
| Surface conditions (2) | Oxidized(As-received) and Polished |
| Salt concentrations (4) | 1, 2, 3.5, 5 wt.% |
| Batches of samples collected (10) | 25, 50, 75, 100, 150, 200, 250, 300, 350, 400 cycles |
| Each sample dimensions | 50 mm×25 mm×4.76 mm |

- **Photographing the samples**
- All the samples were photographed on both sides using Nikon- 5000 DSLR camera for the surface comparison.

**X-Ray Diffraction (XRD)**

- To confirm the phases present in the corrosion products.
- Parameters used: 2θ range: 10˚-65˚, Speed: 5˚/min Step size: 0.02˚/step [45 kV and 200 mA]
- The relative intensities were compared to find growth of the oxide products
- Bragg-Brentano method was used for powder diffraction with XRF reduction.

**Scanning electron microscopy (SEM)**

- To compare (i) surface morphology and (ii) sizes of the various features of the products.
- Images were collected in the magnification range of 500x to 50,000x.

## Results

**Comparison of sample surfaces (400 cycles) using photographs**

- A7 Polished

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%

**Morphologies of corrosion products**

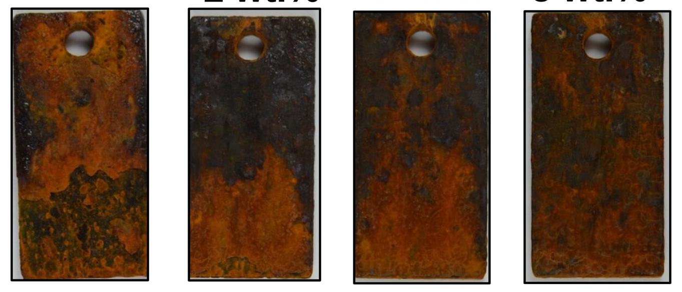
| Product | Morphology |
|---|---|
| Magnetite | Small cotton ball, dense plate |
| α-FeOOH | Cotton ball, Fine whisker |
| β-FeOOH | Big cotton ball, thick dendrite |
| γ-FeOOH | Flake or fine plate |

- A36 Oxidized

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%

A36 Polished

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%



- A588 Oxidized

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%

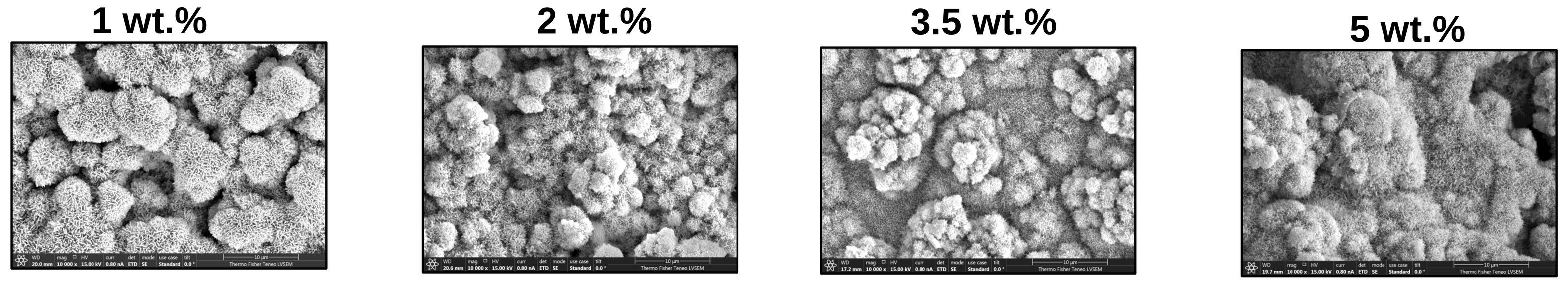
A588 Polished

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%

**Comparison of morphology of corrosion products using SEM (10,000 x)**

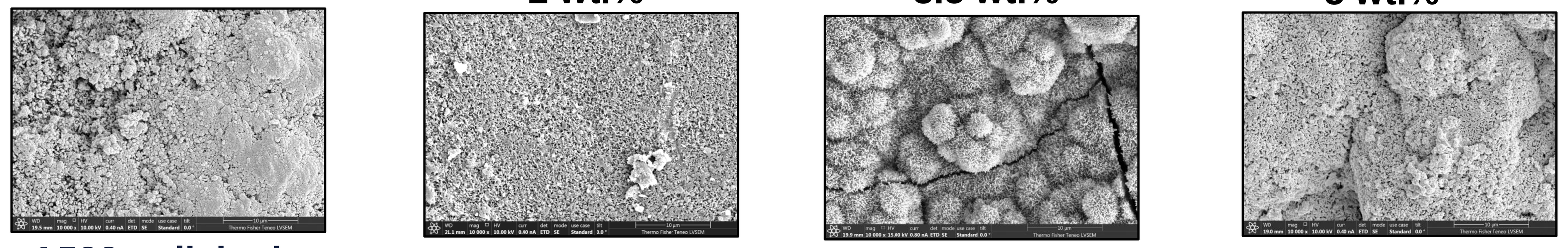
- A7 Polished

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%



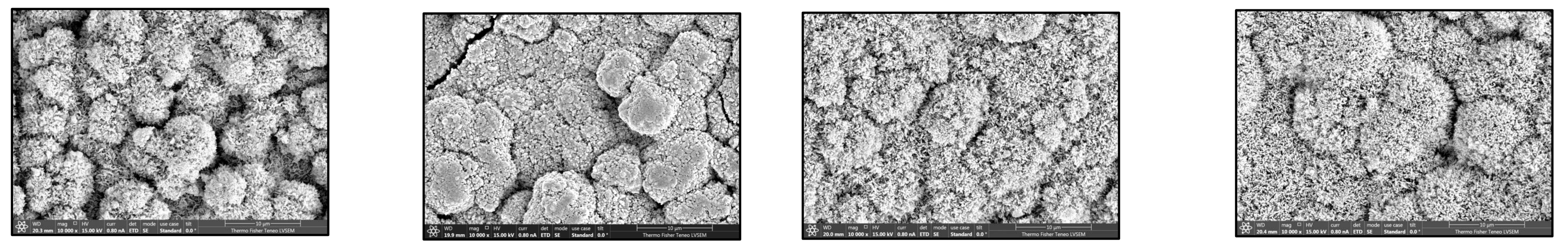
- A36 Polished

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%



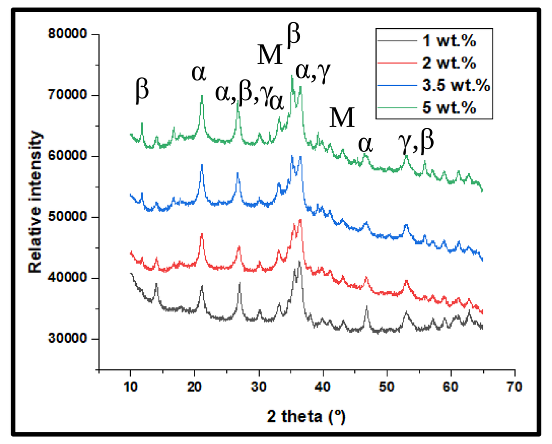
- A588 polished

1 wt.% 2 wt.% 3.5 wt.% 5 wt.%

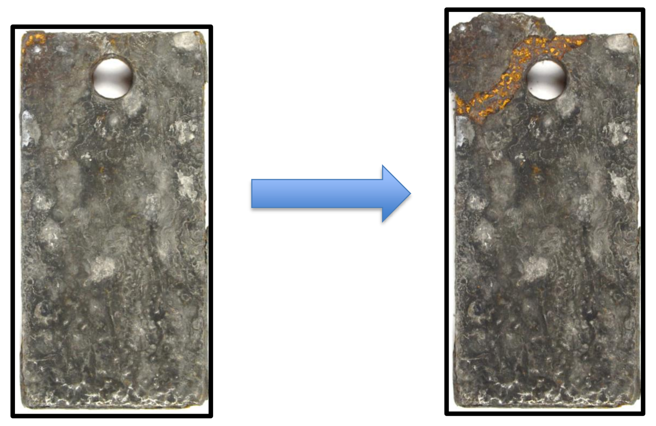


**XRD**

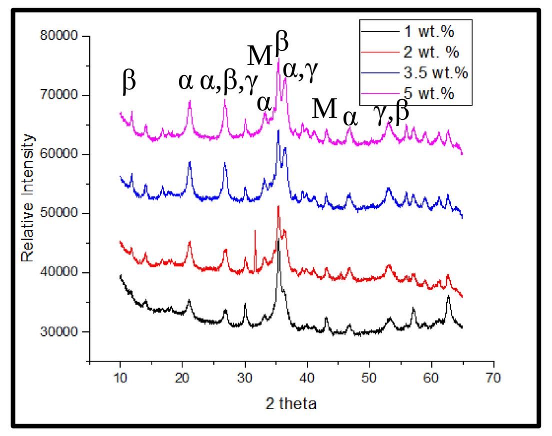
- A7 Polished



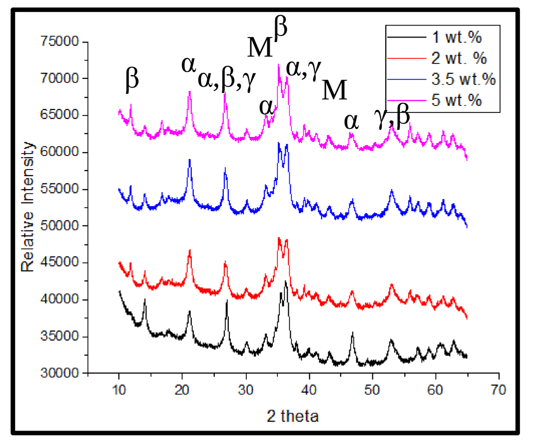
Corrosion layers due to beta phase formation



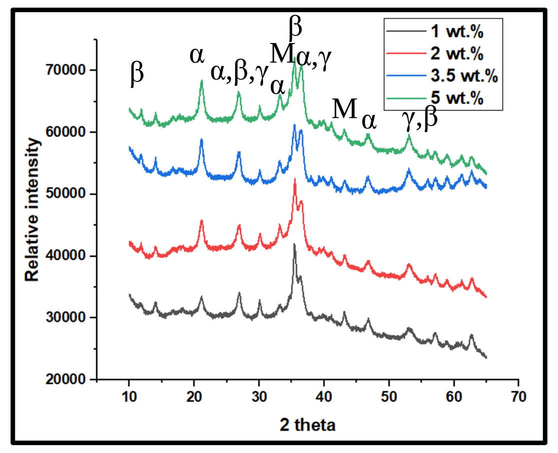
A 36 Oxidized



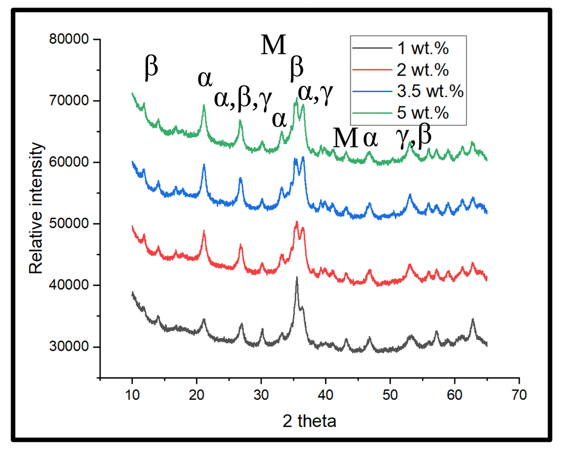
A36 Polished



A588 Oxidized



A 588 polished



## Conclusions

- α, β-Phases increase with NaCl%
- Less Magnetite formation compared to field collected samples
- Morphology: Formation of α, β-FeOOH and Magnetite can be seen
- **Effect of geometry:**
  - Edges and corners have more magnetite
  - Interior regions contain high α-FeOOH

## Ongoing Work

- Electrochemical studies (OCP, PDP and EIS)
- Characterization of cross section:
  - Study of phase fraction
  - Study of morphology in the interior layers

## Sources


1. ASTM International. (1952). A7-52T. ASTM
2. ASTM International. (2019a). A36/A36M-19. ASTM International, 1–3
3. ASTM International. (2019b). A588/A588M-19. ASTM, 1–3
4. Predicting of Galvanic Corrosion in Legacy Bridges: Plain Carbon Steel and Weathering Steel, Dissertation by D. Kim, 2023



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