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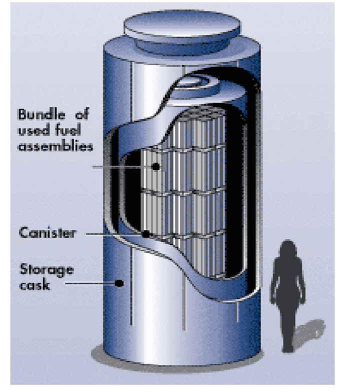
Applications of Coatings for the Mitigation and Repair of Stress Corrosion Cracking on Spent Nuclear Fuel Canisters

Introduction

There are currently 81 Independent Spent Fuel Storage Installations located across the United States, many of which are in coastal regions near marine environments [5]. Over time, dust containing sea-salt aerosols accumulate on the surface of stainless steel (SS) spent nuclear fuel (SNF) canisters, and research investigating stress corrosion cracking (SCC) has demonstrated that salt deliquesce can lead to the formation of a surficial corrosive brine as the canister cools. While the mechanisms behind SCC are being actively studied, there are currently no implemented prevention, mitigation, or repair techniques, therefore inspiring this research, and the need to develop and evaluate the use of mechanically robust, corrosion-resistant coatings for the prevention, mitigation, or repair of possible SCC.



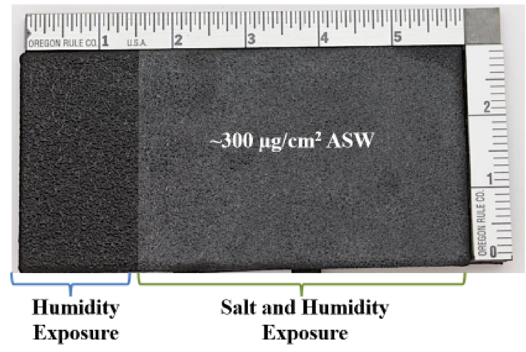
Methodology

3" x 6" 304L austenitic SS coupons were coated with each coating.

Coating Type	Coating Manufacturer	Variant	Details
Polymeric	OPM-21	01	PEKK resin powder coat
		02	Solution cast Sulfonated PEKK
	WHRD-21	01	Polyurea-polyimide resin
		02	Polyurea-polyimide resin
		03	Phenolic infused polyurea resin
Organic/ Inorganic Hybrid Ceramic	FC-21	01	Single-part modified polyurethane macromolecule with quasi-ceramic structure
	LUNA-21	01	2-part silica-ceramic with polyurethane linker
		02	2-part silica-ceramic with polyurethane linker on Zn-rich primer
		03	2-part silica-ceramic with polyurethane linker
		04	2-part silica-ceramic with polyurethane linker on Zn-rich primer
		05	Commercial Zn-rich primer

Atmospheric Exposures

3/4 of each coupon was salt coated with artificial sea salt and then exposed to 76% relative humidity (RH) at 40ºC for 0, 30 and 90 days, to mimic accelerated exposure conditions.



Adhesion Tests

Adhesion tests were performed using ASTM D4541-17 [1]. Prior to adhesion testing, the coupons were rinsed with DI water to remove salt, and plasma cleaned. A DeFelsko PosiTest AT-A hydraulic pull-off tester and 10 mm aluminum dollies were used in conjunction with Loctite EA 1C and Araldite 2011 epoxies to perform pull-off tests. Each epoxy was used to adhere three dollies onto the surface (two in the salt coated area and one in the control area), all of which were cured at 40ºC for 48 hours.

Scratch Tests

Scratch resistance tests were performed using ASTM D7027-13 [2]. Two scratches, each with a force up to 25N were performed on each coupon over a 10mm distance using a 200-micron radius diamond stylus. When damage did not occur, 50N was then applied over 10mm.

Results

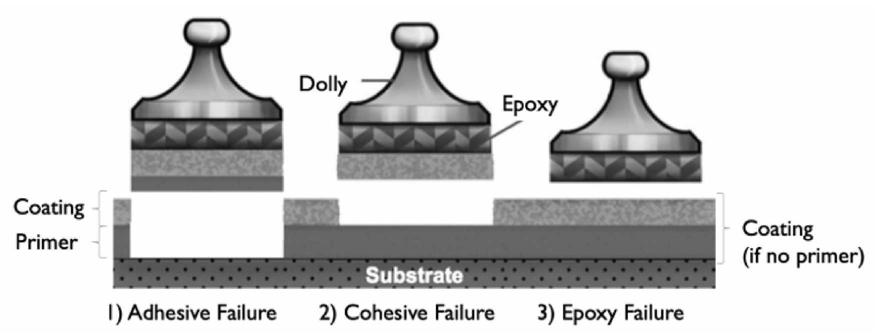


Figure 1. Adhesion failure types. [3]

Figure 2. Exhibited failure during adhesion testing following 90-day exposure to salt and humidity.

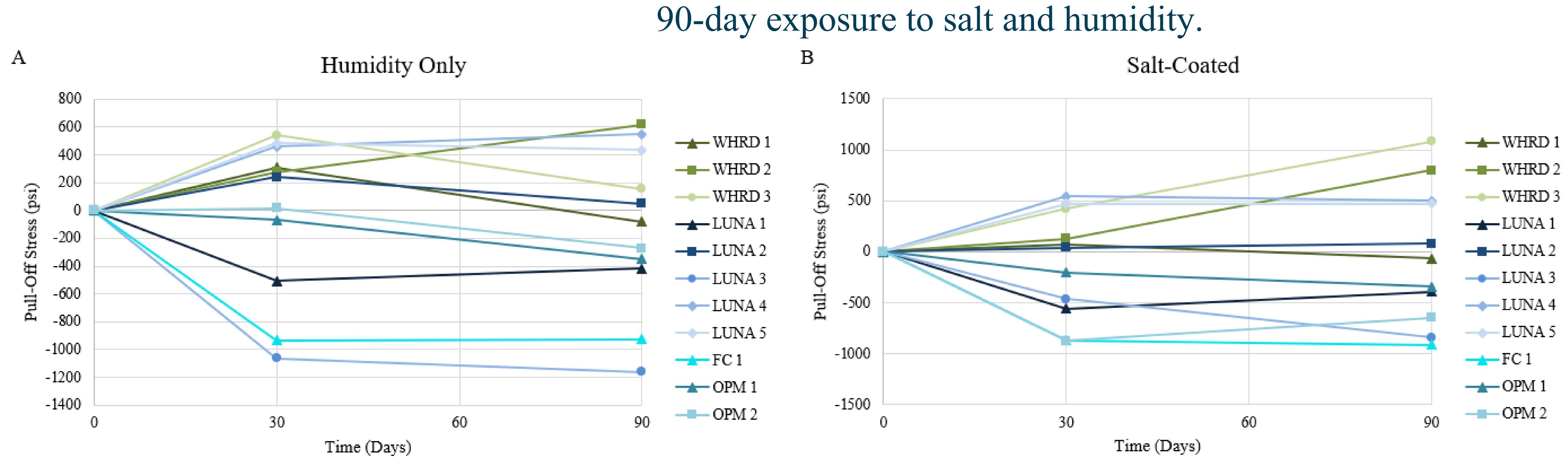


Figure 3. Difference in pull-off stress values from baseline data as a function of time exposed to humidity only and humidity with salt, respectively (A,B).

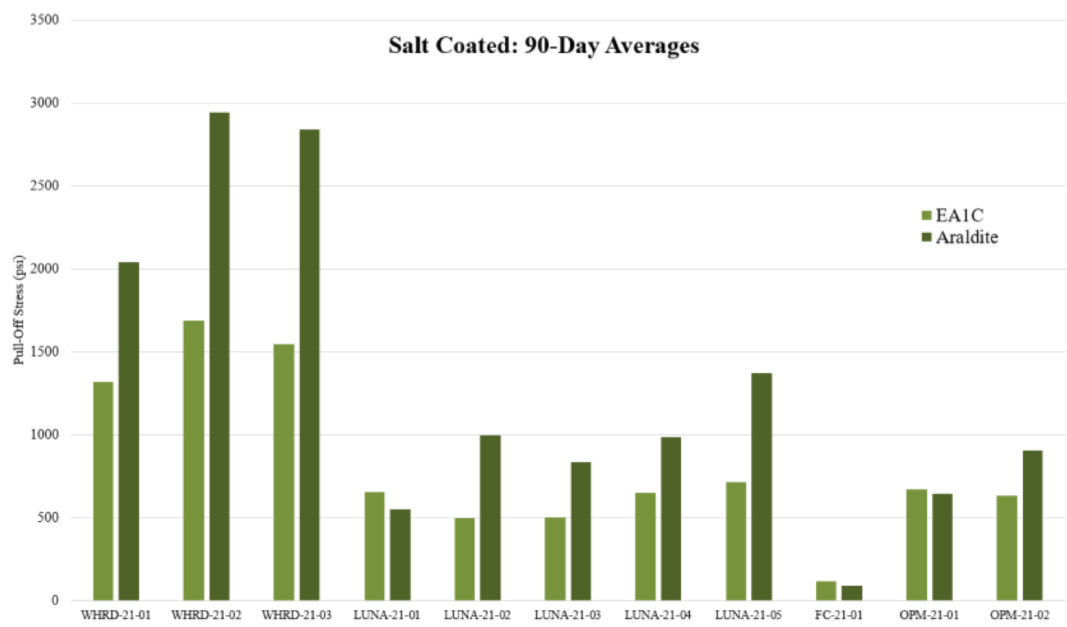


Figure 4. Pull-off stresses following 90-day exposure to humidity with salt, comparing EA 1C and Araldite epoxy performance.

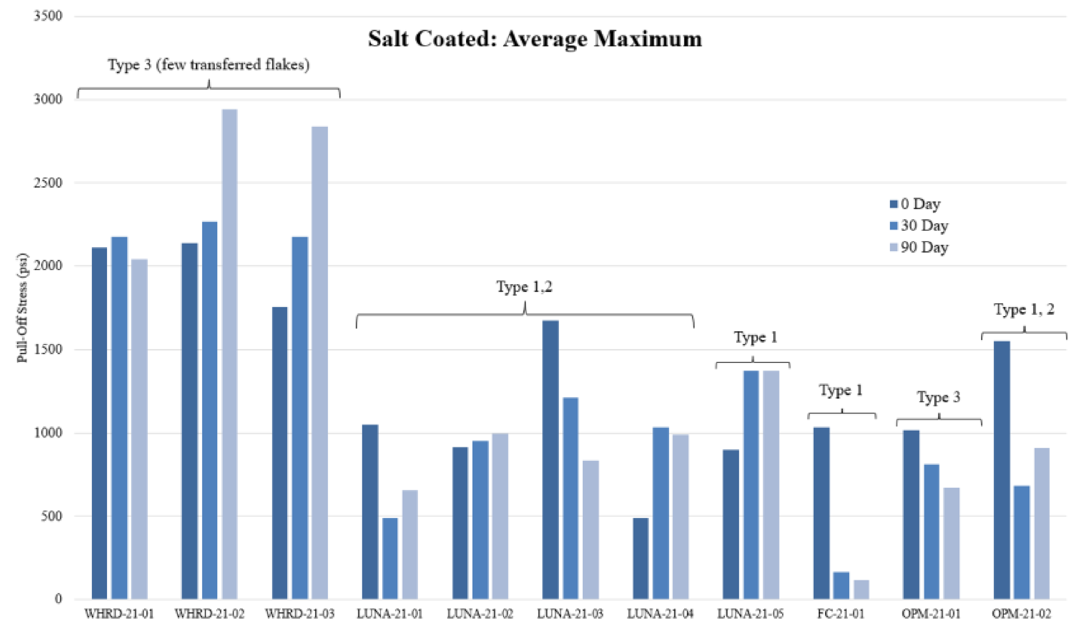


Figure 5. Maximum pull-off stresses (Araldite or EA 1C) obtained following 0, 30, and 90-days of exposure to humidity and salt.

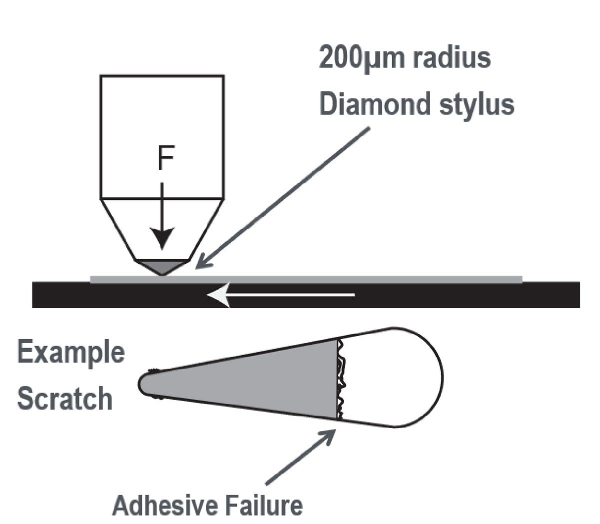


Figure 6. Scratch testing schematic.

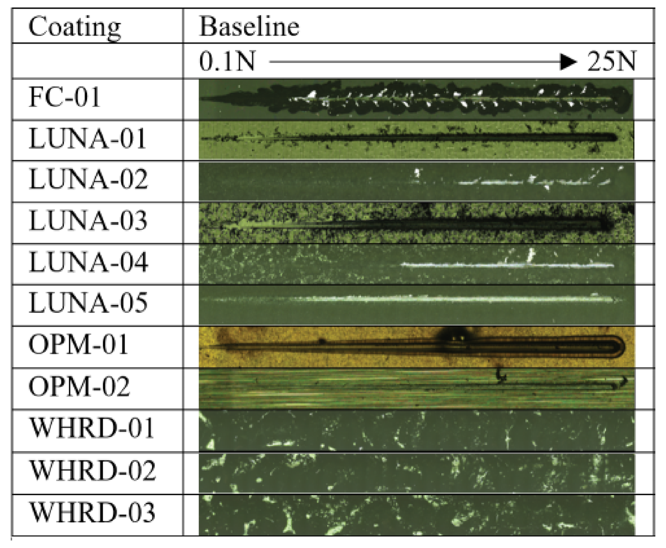


Figure 7. Optical images following scratch testing.

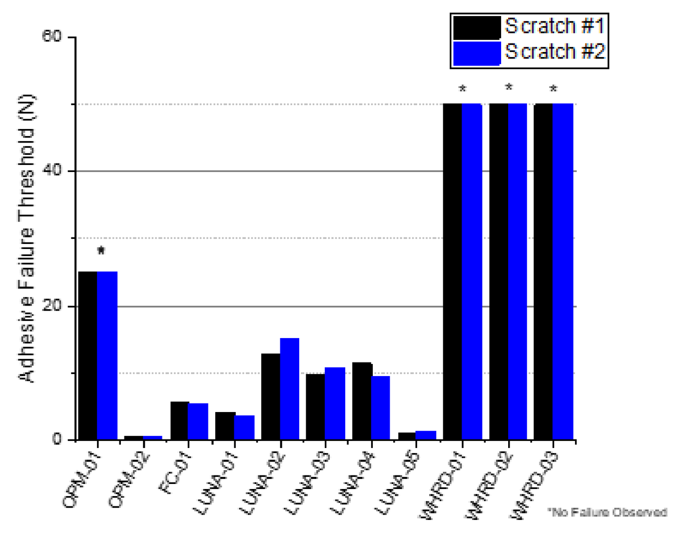


Figure 8. Adhesive failure threshold.

Discussion

Coating	Adhesion Test Failure Type	Scratch Test Failure Threshold (25N)
FC-21-01	Type 1	Fail
WHRD-21-01	Type 3 – few transferred coating flakes	Pass
WHRD-21-02	Type 3 – few transferred coating flakes	Pass
WHRD-21-03	Type 3 – few transferred coating flakes	Pass
OPM-21-01	Type 3	Pass
OPM-21-02	Type 2,3 – Cohesive failure on occasion	Fail
LUNA-21-01	Type 2	Fail
LUNA-21-02	Type 1, 2 - Partial failure to substrate on occasion	Fail
LUNA-21-03	Type 2	Fail
LUNA-21-04	Type 1, 2 - Partial failure to substrate on occasion	Fail
LUNA-21-05	Type 1	Fail

- **Adhesion Tests**
  - Araldite 2011 epoxy outperformed Loctite EA 1C by 48% on average and will be used here after.
  - Plasma cleaning was necessary to improve epoxy coating adhesion.
  - Zinc-rich primers reduced coating adhesion to the metal surface.
  - High pull-off forces obtained following salt and humidity exposure are not attributable to improved coating strength, but rather the bond interaction between the epoxy and coatings.
- **Scratch Tests**
  - Luna-21-05 experienced delamination in the area between two scratches, indicating slight mechanical damage to a Zn-rich primer may result in delamination of a large portion of the coating.
  - Ductility of the OPM-21-02 coating allowed it to flow out of contact during scratching, but complete adhesive failure was not detected.
- **Preliminary Results**
  - Polymeric coatings generally outperformed hybrid ceramic coatings.
  - WHRD-21-01,02,03 and OPM-21-01 are the most promising coatings for canister application.

Acknowledgments

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