Evaluation of the Effectiveness of Salt Neutralizers for Washing Snow and Ice Equipment

Project Number: PS-2013-19

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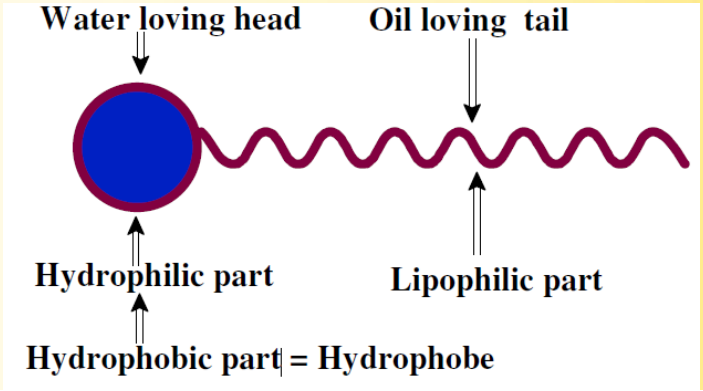
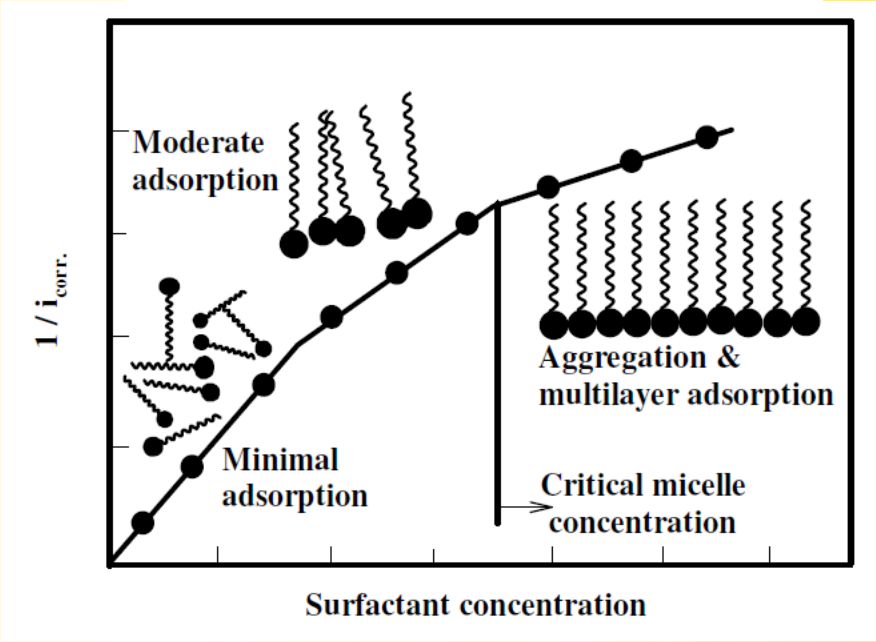
Research Need

- US loses over $220 billion on corrosion annually
  - 15% is avoidable
- Deicers corrode winter maintenance vehicles
  - $1500/ton in damages
- Soap and water may not be enough to clean vehicles
- Potential solutions:
  - Coatings
  - Salt neutralizers

Overview of Salt Neutralizers

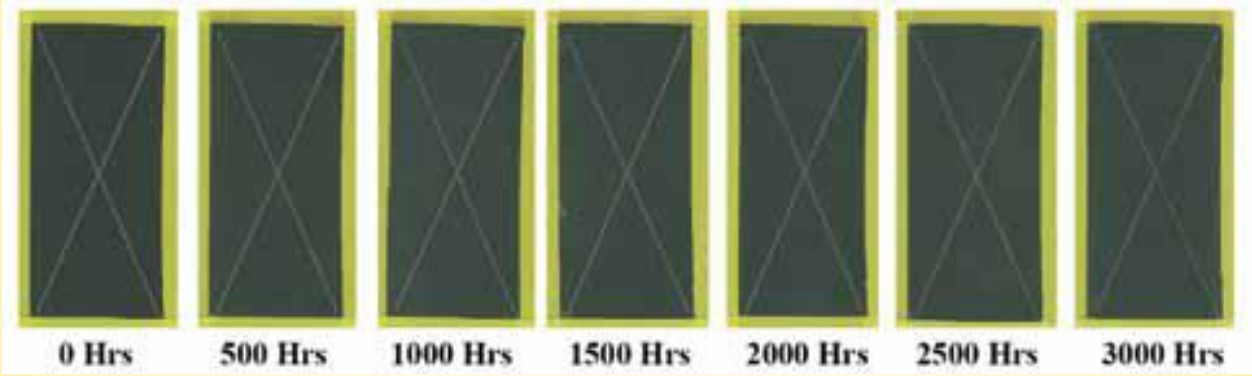
- Salt neutralizers contain two main components
  - Cleaning Agent
    - Typically an acid (hydrochloric, sulfamic)
    - Acid can be corrosive to the metal
  - Corrosion Inhibitor
    - Typically a surfactant
    - Protects surface during/after cleaning





Protective Coatings Reduce Corrosion

A



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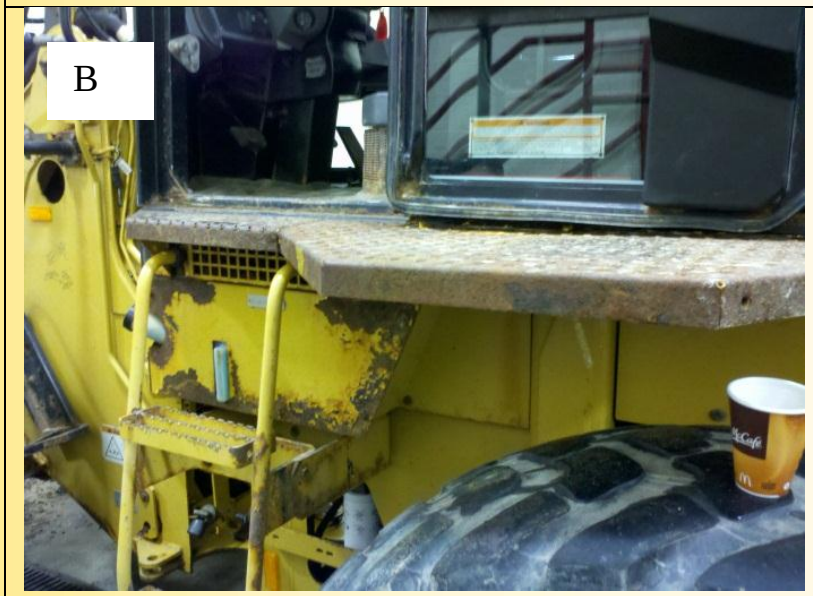


Objectives of the Project Focus on Different Corrosion Prevention Alternatives

- Objective 1 -Perform a thorough literature search on the effectiveness of salt neutralizers on bare metal and coated surfaces as reported by other state DOTs,
- Objective 2 -Assess selected, commercially-available salt neutralizer products in removing salt residue and preventing corrosion bare metal, electrical connections, and coated metal surfaces on the laboratory scale and in-field on ODOT equipment,
- Objective 3 -Perform a cost-benefit analysis of the top-performing salt neutralizing product on all tested surfaces, and
- Objective 4 -Propose a deployment strategy for the salt neutralizing product consistent with current ODOT practices.

Our Research Plan Will Compare Effectiveness of Coating and Neutralizers

- Task One: Evaluation of Available Data and Reports on the Effectiveness of Salt Neutralizers and Coatings
  - Survey sent out to ODOT districts
- Task Two: Data Collection
  - Laboratory Experiments
- Task Three: Benefit to Cost Analysis Using Commercially Available Salt Neutralizers

Anticipated Results

- Anticipated Result One – Summary and evaluation of existing salt neutralizer data with and without protective coatings,
- Anticipated Result Two – Ranking of commercially available salt neutralizers based on corrosion rate with and without protective coatings,
- Anticipated Result Three – Cost-benefit analysis for winter season 2012-2013, and
- Anticipated Result Four – Recommended washing strategy using salt neutralizers consistent with ODOT Maintenance and Administration Manual 900 (Snow and Ice Control).

Online Survey Results Show 62% of 49 Respondents Use Salt Neutralizers

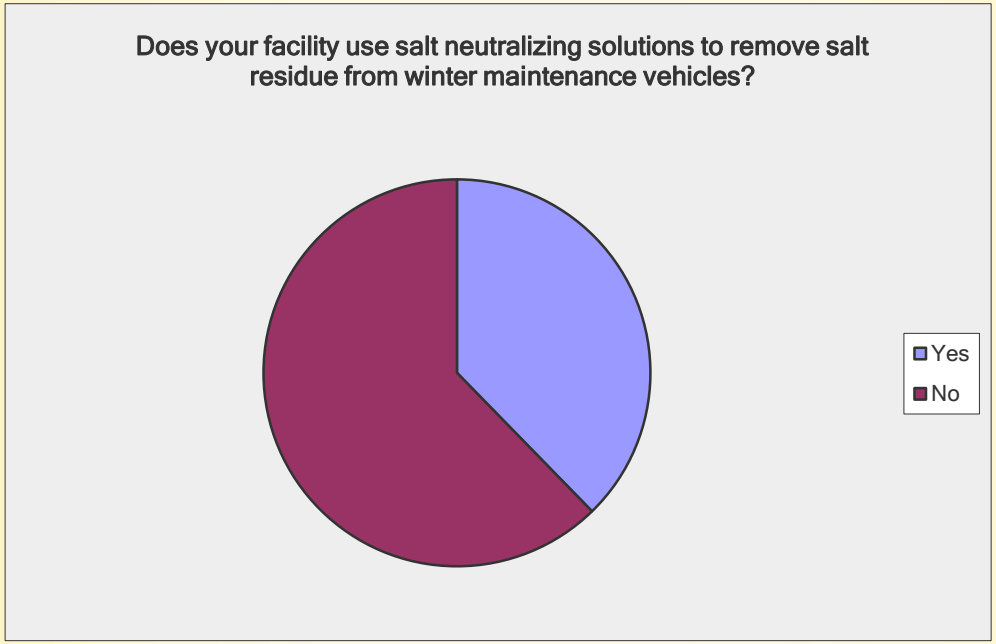


Table 2: Rating of effectiveness of salt neutralizers					
Answer Options	Very effective	Effective	Slightly effective	Not Sure	Response Count
	1	10	3	6	20

Online Survey Results Show That Majority of Respondents Cited Cost for Discontinued Use of Neutralizer

Table 3: Reasons for discounted use of salt neutralizer		
Answer Options	Response Percent	Response Count
Cost	80.0%	4
Ineffective	20.0%	1
Time constraints	40.0%	2
Other (please specify)		3
answered question		5
skipped question		48

Online Survey Results Show 36% of 49 Respondents Use Coatings to Prevent Corrosion

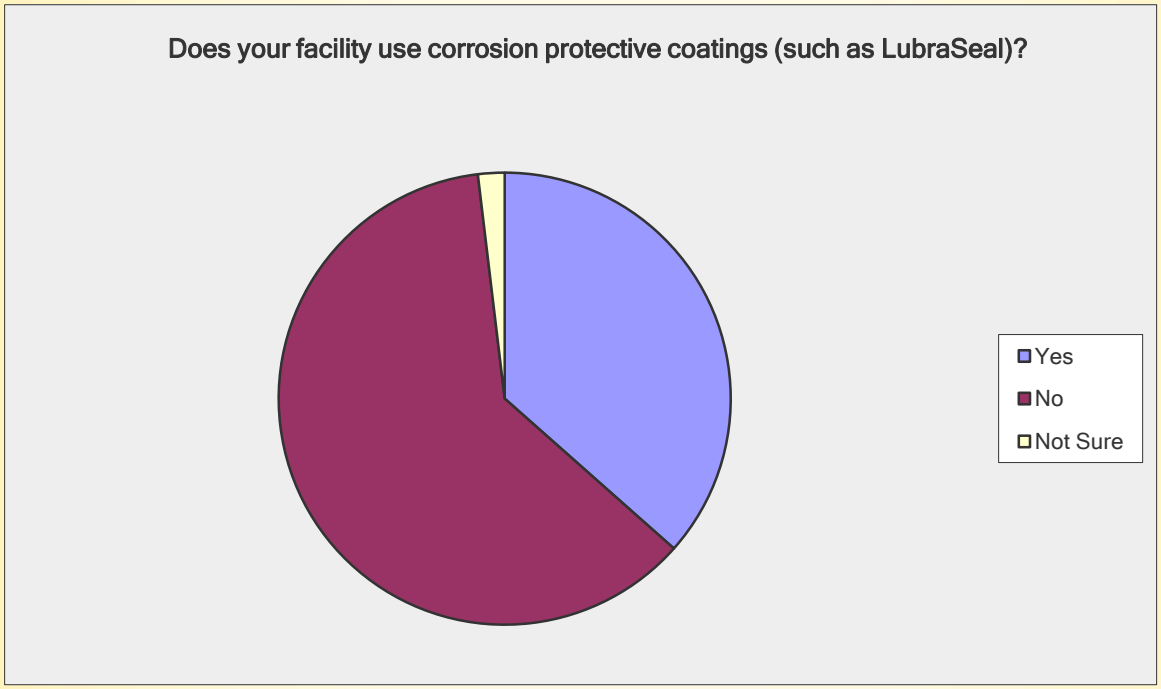
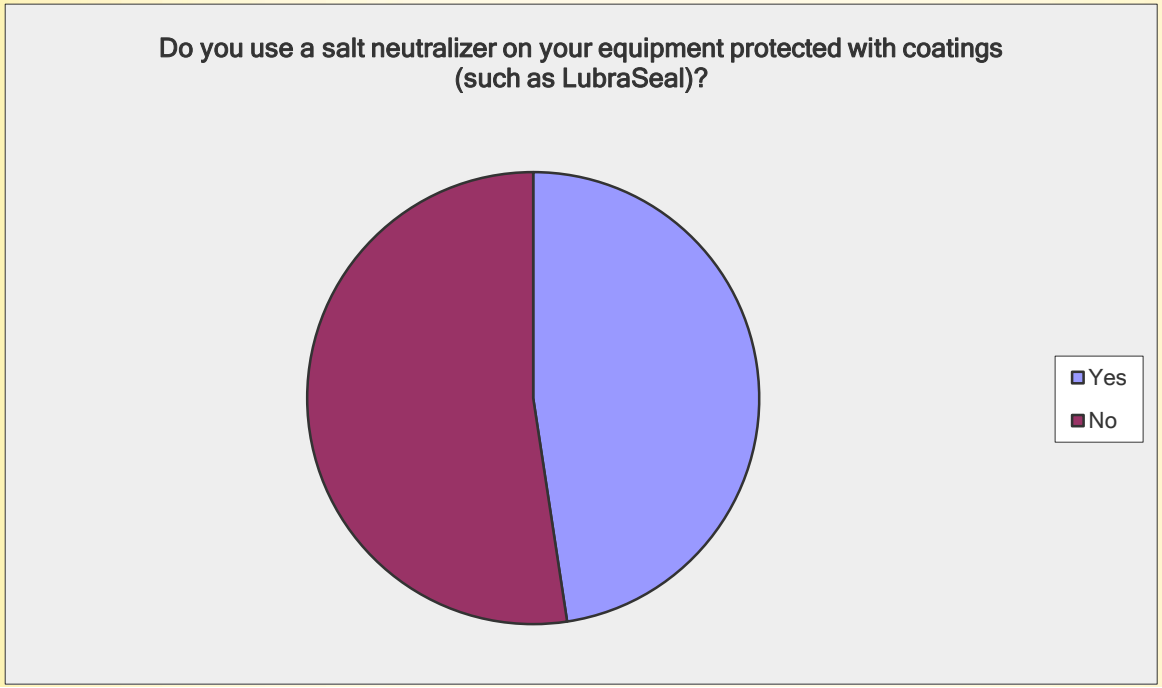


Table 4: Rating of effectiveness of coatings at preventing corrosion					
Answer Options	Very effective	Effective	Slightly effective	Not Sure	Response Count
	2	9	6	3	20

Online Survey Results Show 48% of Respondents Use Coatings and Salt Neutralizer to Prevent Corrosion

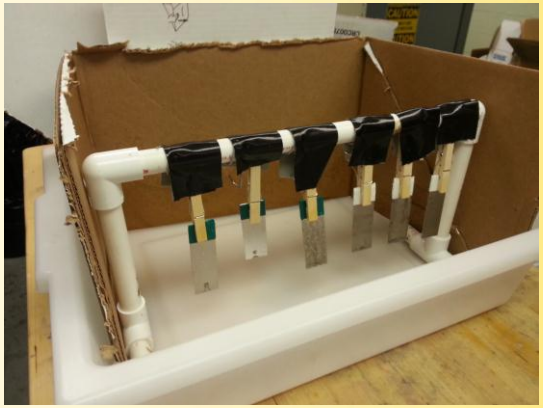


Do you use a salt neutralizer on your equipment protected with coatings (such as LubraSeal)?		
Answer Options	Response Percent	Response Count
Yes	47.6%	10
No	52.4%	11
	answered question	21
	skipped question	32

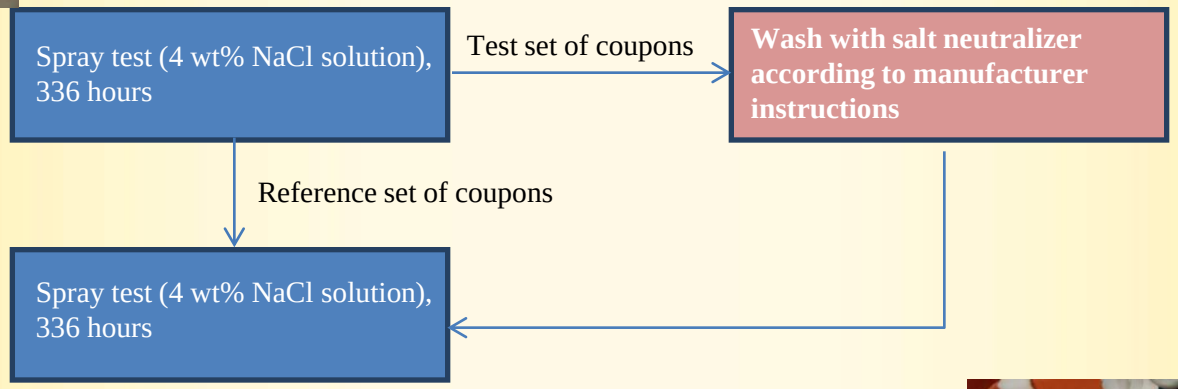
Online Survey Aided in Selection of Salt Neutralizers and Coatings

Salt Neutralizer	Strong Acid Cleaner	Recommended Washing Concentration (vol. %)
BioKleen	Proprietary	3
ConSALT	Hydrochloric Acid	10
Eastwood	Sulfamic Acid	5
Neutro-wash	Sulfamic Acid	11
Saltaway	Proprietary	10
Winter Rinse	Sulfamic Acid	4

ASTM B-117 Procedure Conducted at Light Curable Coatings (Berea)

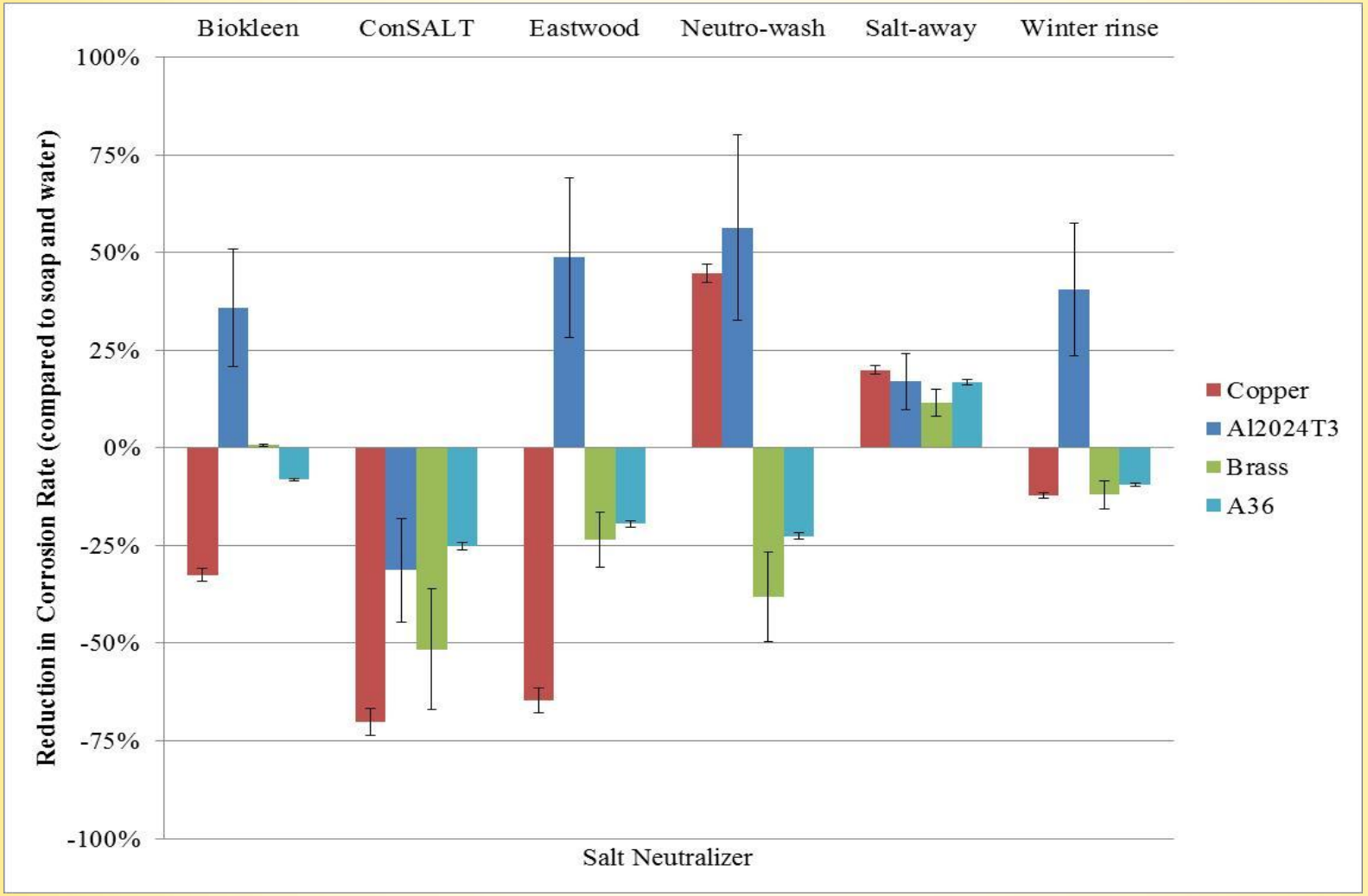


Modified ASTM B-117 Test Procedure



$$Corrosion\ Rate = \frac{K \times W}{A \times T \times D}$$

Results Indicate that Effectiveness of Neutralizers is Alloy Specific



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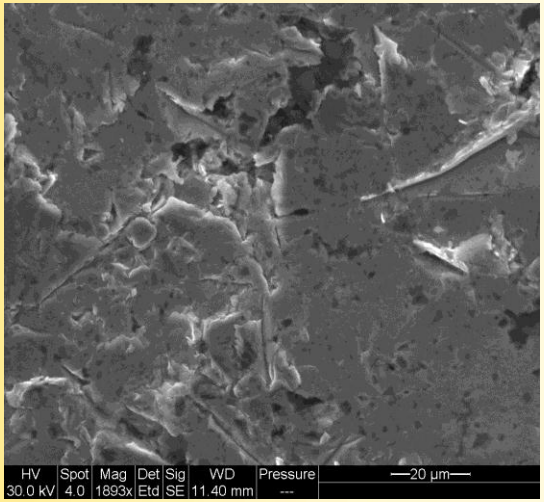
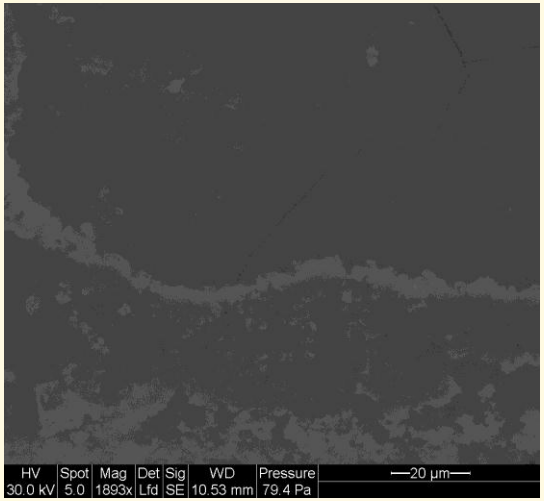
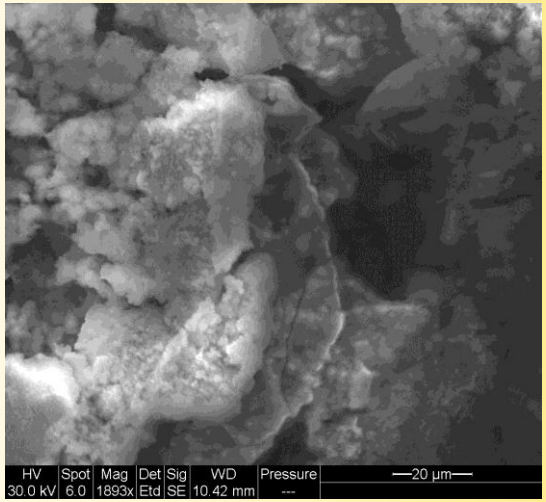
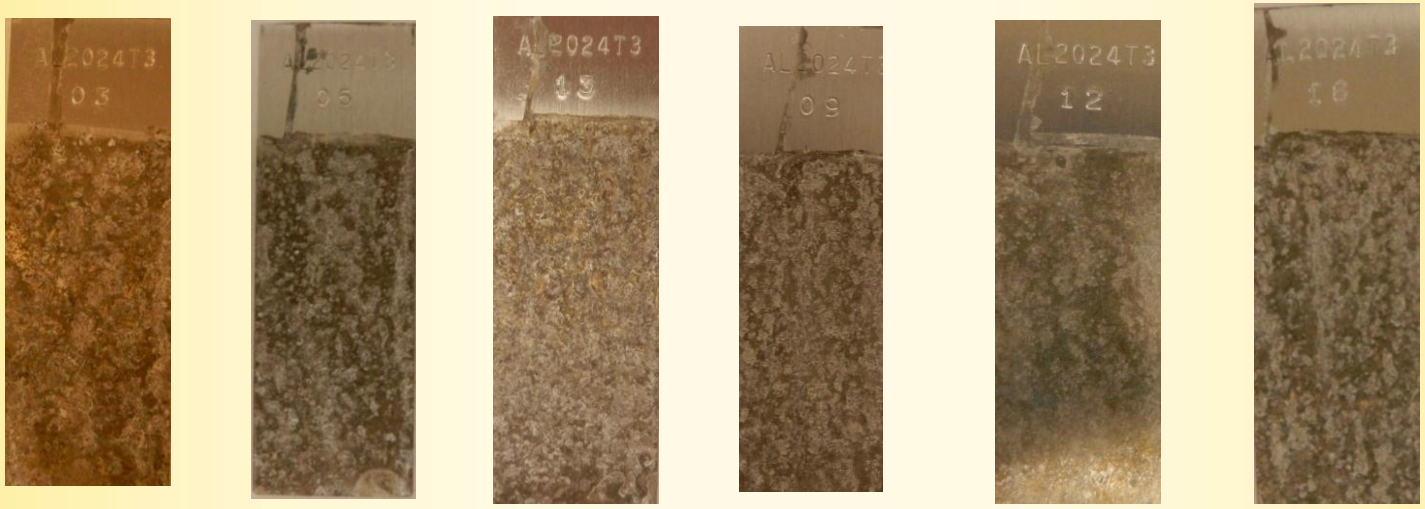




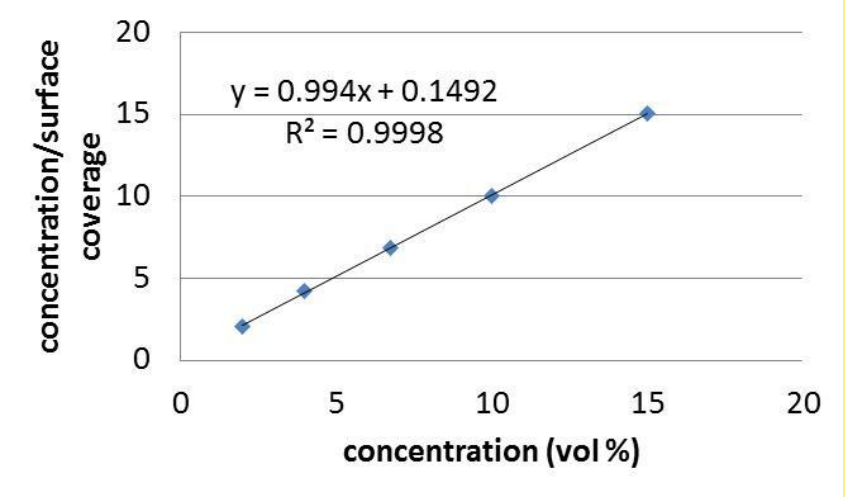




Interaction of Salt Neutralizer at Metal Surface is Important to Corrosion Protection

- Electrochemical polarization experiments were conducted to determine corrosion current at various wash concentrations
- Can determine surface coverage and effective adsorption constant for each neutralizer

$$\theta = 1 - \left(\frac{I_{inhib}}{I_{uninhib}}\right) \qquad \frac{C_i}{\theta} = \frac{1}{K_{eff}} + C_i$$



Neutralizer with Larger K_{eff} Values Typically Showed Reduced Corrosion Rate

Salt Neutralizer	A36	Aluminum (2024T3)	Copper	Brass
	Effective Adsorption Constant (vol %)	Effective Adsorption Constant (vol %)	Effective Adsorption Constant (vol %)	Effective Adsorption Constant (vol %)
BioKleen	7	0.4	0.2	0.9
ConSALT	3	-	24	0.1
Eastwood	1	3	0.6	0.4
Neutro-wash	1	3	9	0.5
Salt-away	7	1.5	18	2
Winter Rinse	0.6	1	10	0.2

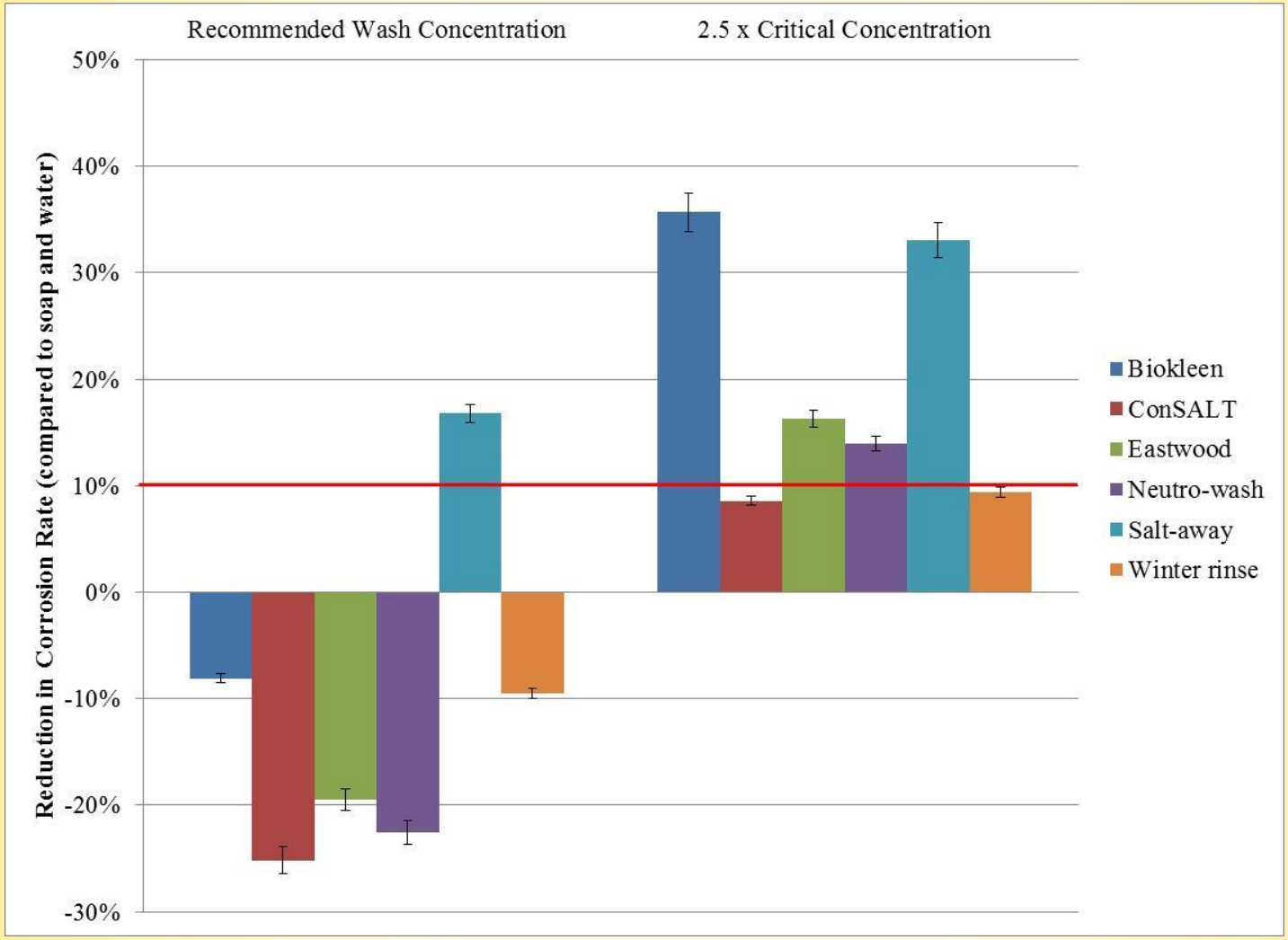
- Aluminum K_{eff} values greater than one (on average), five of six neutralizers reduced corrosion on aluminum
- Copper and A36 have high K_{eff} values, still performed poorly in accelerated corrosion testing

Results Indicate that Effectiveness of Neutralizers is Concentration Specific

Salt Neutralizer	Critical Wash Concentration (vol. %)	Surfactant Surface Coverage (θ)	Manufacturer's Wash Concentration (vol. %)	Surfactant Surface Coverage (θ)	2.5 x Critical Wash Concentration (vol. %)	Surfactant Surface Coverage (θ)
BioKleen	3	0.95	3	0.95	16	0.99
ConSALT	14	0.93	10	0.92	35	0.99
Eastwood	4.5	0.83	5	0.83	12	0.90
Neutro-wash	5	0.83	11	0.91	13	0.91
Salt-away	3	0.91	10	0.92	9.8	0.92
Winter Rinse	4	0.76	4	0.76	10	0.88

- Salt neutralizers used above their critical micelle concentration were more effective at preventing corrosion
- At increased concentration, surface coverage increases

Results Indicate that Effectiveness of Neutralizers is Concentration Specific



Overview of Results from Bare Metal Testing

- On all bare metal surfaces tested at manufacturer-recommended wash concentration, only Salt-Away reduced or had minimal impact on the corrosion rate compared to soap and water
- Many of the commercial neutralizer solutions actually increased the rate of corrosion, especially for carbon steel (A36) and copper, two metals of particular concern to ODOT.
- Increasing the neutralizer dose to a value greater than that recommended by the manufacturer made all of the neutralizers effective at reducing the corrosion rate on carbon steel. However, this will significantly reduce the cost-effectiveness of neutralizer application.

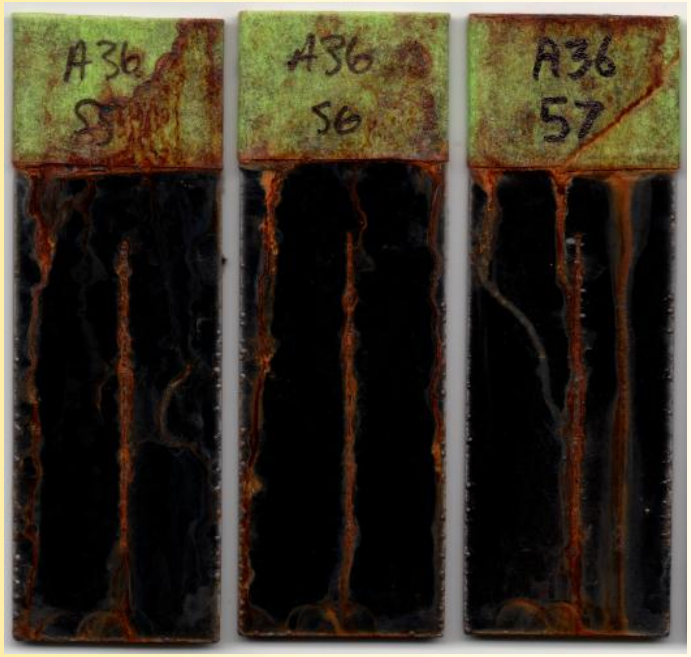
Laboratory Experiments Were Then Conducted on Coated Metal Samples

- Accelerated corrosion testing was conducted using three top performing salt neutralizers determined bare metal testing
- Accelerated corrosion tested was performed on scribed (7 days) and unscribed (14 days) metal samples
- Performance of the coating was evaluated using Electrochemical Impedance Spectroscopy

	Hardness	Adhesion				
		A36	AL2024T3	AL5086	304	410
LubraSeal	9B	5B	5B	5B	5B	5B
Light-curable Coating	9H	4B	1B	2B	1B	4B
OEM paint	B	4B	-	-	-	-

Creep Rate Was Used to Determine Effectiveness of Neutralizer

- Measure amount of rust from the scribe at the center of the coupon
- Determine coating rating



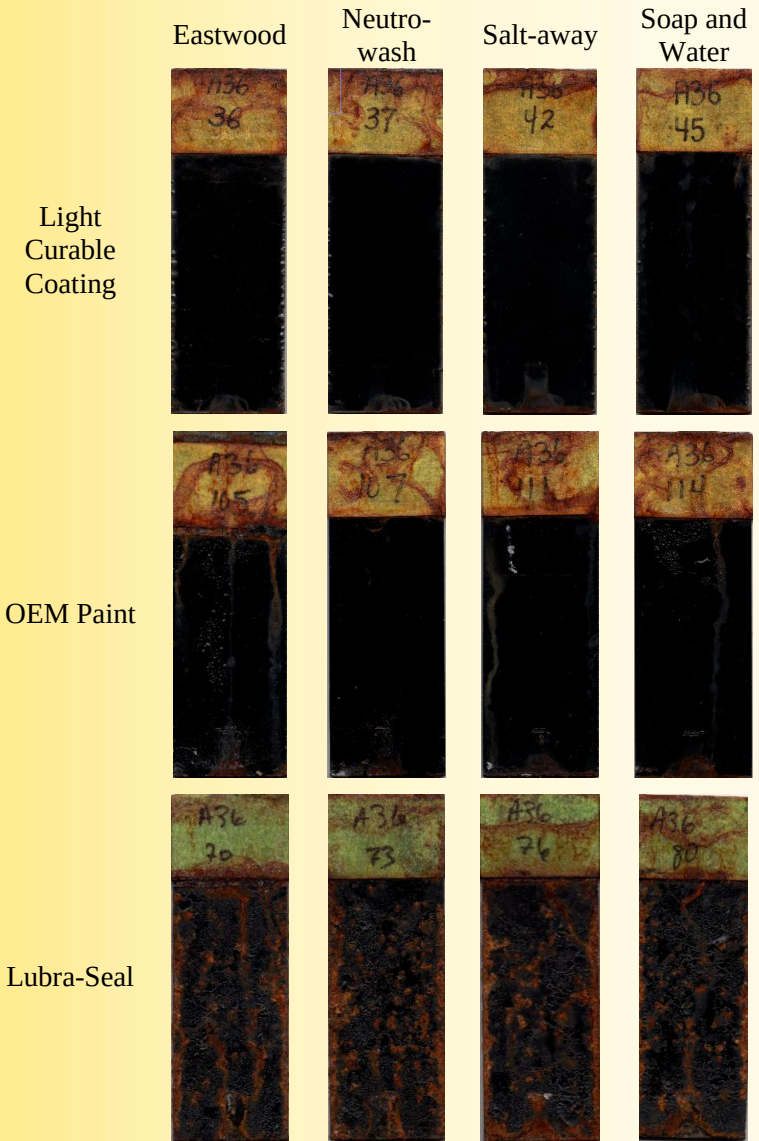
Representative Mean Creepage from Scribe (mm)	Coating Rating
Zero	10
Over 0 to 0.5	9
Over 0.5 to 1.0	8
Over 1.0 to 2.0	7
Over 2.0 to 3.0	6
Over 3.0 to 5.0	5
Over 5.0 to 7.0	4
Over 7.0 to 10.0	3
Over 10.0 to 13.	2
Over 13.0 to 16.0	1
Over 16.0	0

Results Indicate that Neutralizers Do Not Reduce Corrosion for Most Coated Metals

- Creep rate was insignificant for aluminum and stainless steel
- Salt neutralizers do not decrease creep rate for LubraSeal and OEM paint
- Salt-away and Eastwood decreased creep rate by 28% and 34%, respectively, on LCC

		Creep (mm)	Coating Rating	Corrosion Inhibition (%)
LubraSeal	Eastwood	1.21 ±0.04	7	N/A
	Neutro-wash	1.10±0.24	7	N/A
	Salt-away	1.15±0.31	7	N/A
	Soap and Water	1.22±0.29	7	N/A
	Water only	1.15±0.19	7	N/A
Light-curable Coating	Eastwood	0.70±0.10	8	34%
	Neutro-wash	1.22±0.38	7	-15%
	Salt-away	0.76±0.06	8	28%
	Soap and Water	1.06±0.36	7	N/A
	Water only	0.83±0.17	8	N/A
OEM Paint	Eastwood	1.06±0.04	7	N/A
	Neutro-wash	1.08±0.23	7	N/A
	Salt-away	1.09±0.19	7	N/A
	Soap and Water	1.03±0.25	7	N/A
	Water only	1.32±0.16	7	N/A

Coating Failure Was Used to Determine Effectiveness of Neutralizer on Unscribed Samples



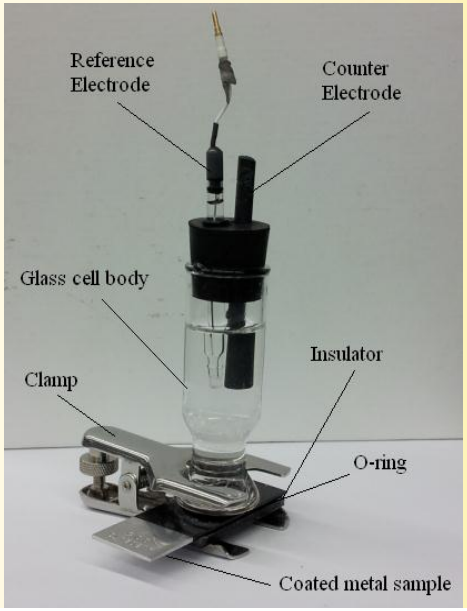
Area Failed (%)	Coating Rating
No failure	10
0 to 1	9
2 to 3	8
4 to 6	7
7 to 10	6
11 to 20	5
21 to 30	4
31 to 40	3
41 to 55	2
56 to 75	1
Over 75	0

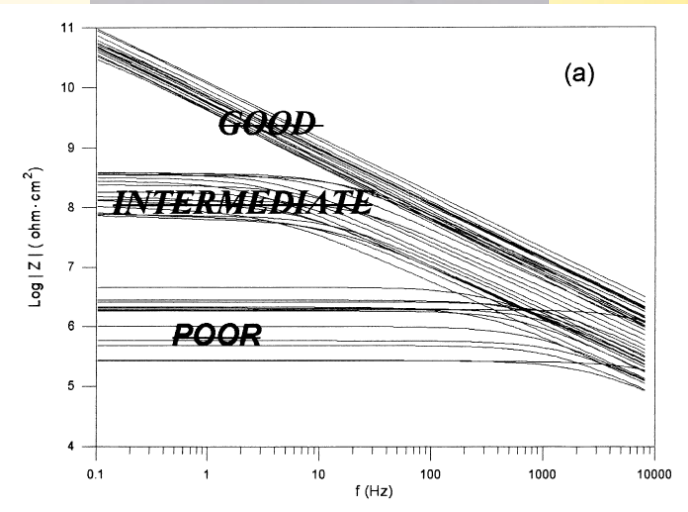
LCC Samples Have Highest Coating Rating; Salt-away and Eastwood Reduce Coating Failure

		Mild Steel (A36)	Aluminum (2024T3)	Aluminum (5086)	Stainless Steel (304L)	Stainless Steel (410)
Lubra Seal	Eastwood	1	9	9	9	7
	Neutro-wash	2	8	8	8	6
	Salt-away	4	7	8	9	6
	Soap and Water	3	7	7	7	5
	Water	2	7	7	7	6
LCC	Eastwood	8	9	9	9	8
	Neutro-wash	8	9	9	9	8
	Salt-away	8	9	9	10	8
	Soap and Water	7	9	9	10	7
	Water	8	10	10	9	9
OEM Paint	Eastwood	4	-	-	-	-
	Neutro-wash	2	-	-	-	-
	Salt-away	2	-	-	-	-
	Soap and Water	4	-	-	-	-
	Water	2	-	-	-	-

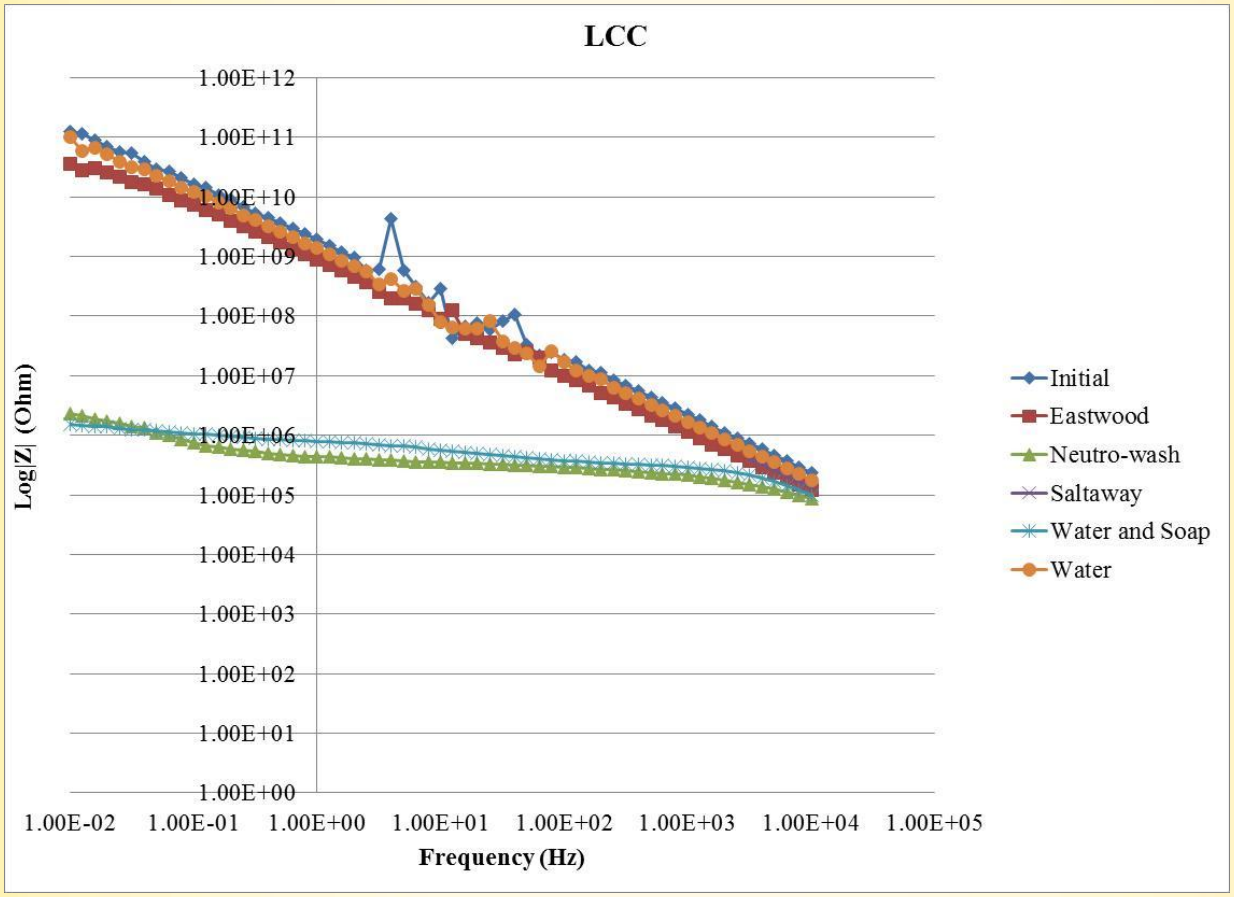
Visual Inspection Does Not Show What is Happening at Metal-Coating Interface

- Electrical Impedance Spectroscopy (EIS) used to determine protective ability of coating
- Pore resistance is determined, shows amount of water uptake
- Decrease in pore resistance shows that water have entered coating
- Salt neutralizers that maintain or increase pore resistance are effective at preventing corrosion



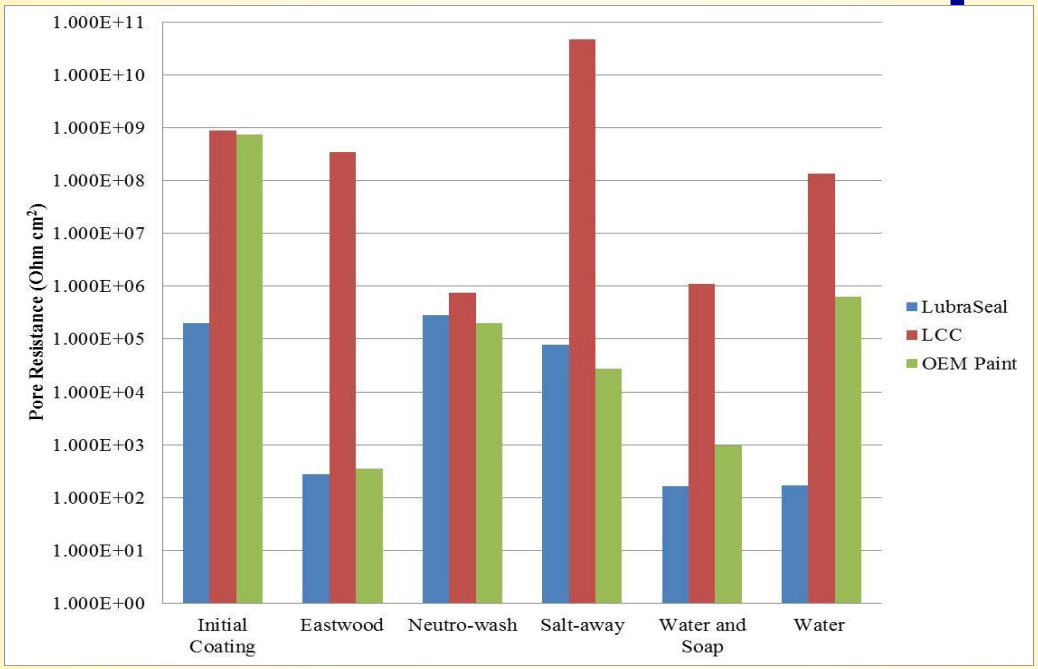


After 14 Days of Salt Exposure, Salt-away and Eastwood Maintain Coating Performance for LCC on A36



Example of EIS data, corresponds to visual inspection

EIS Results Indicate that LCC coatings are Maintained After Salt Exposure



	Pore Resistance (Ohm cm^2)		
	LubraSeal	LCC	OEM Paint
Initial Coating	2.02×10^5	8.93×10^8	7.41×10^8
Eastwood	2.81×10^2	3.44×10^8	3.52×10^2
Neutro-wash	2.87×10^5	7.50×10^5	2.03×10^3
Salt-away	7.86×10^4	4.70×10^{10}	2.78×10^4
Water and Soap	1.65×10^2	1.10×10^6	9.86×10^2
Water	1.70×10^2	1.33×10^8	$26. \times 10^5$

Overview of Results from Coated Metal Testing

- The ability of coatings to prevent corrosion on coated samples is alloy and wash specific. All carbon steel scribed samples without neutralizer application exhibited corrosion.
- Statistically, neutralizer application did not inhibit corrosion on the majority of carbon steel scribed samples. However, the average creep rates for Salt-away and Eastwood were better than soap and water on LCC coated metal coupons.
- These results were corroborated with EIS testing that indicates that Salt-away and Eastwood increase corrosion protection on carbon steel samples coated with LCC.
- EIS testing was used to validate visual inspection. Testing indicated that although some coatings did not appear corroded or blistered during visual inspection, there was indeed a breakdown in corrosion protection occurring at the metal surface.

A Cost-Benefit Analysis Was Carried Out on Three Top-Performing Neutralizers

Cost Factor	Units	Description
1. Neutralizer solution	$/gallon	Concentrated solution
2. Dilution ratio	%	Volume dilution percentage (neutralizer solution/total mixed volume)
3. Neutralizer volume used per wash event	gallons	Volume of actual water and neutralizer applied to truck
4. Number of trucks at facility	trucks	Trucks washed with neutralizer

Following Equations Were Used to Determine Costs

$$Neutralizer\ cost\ per\ truck\ per\ wash\ event$$

$$= \$XX/gallon * XX\ dilution\ ratio\ (as\ a\ decimal)\ * \frac{XX\ gallons}{1\ wash}$$

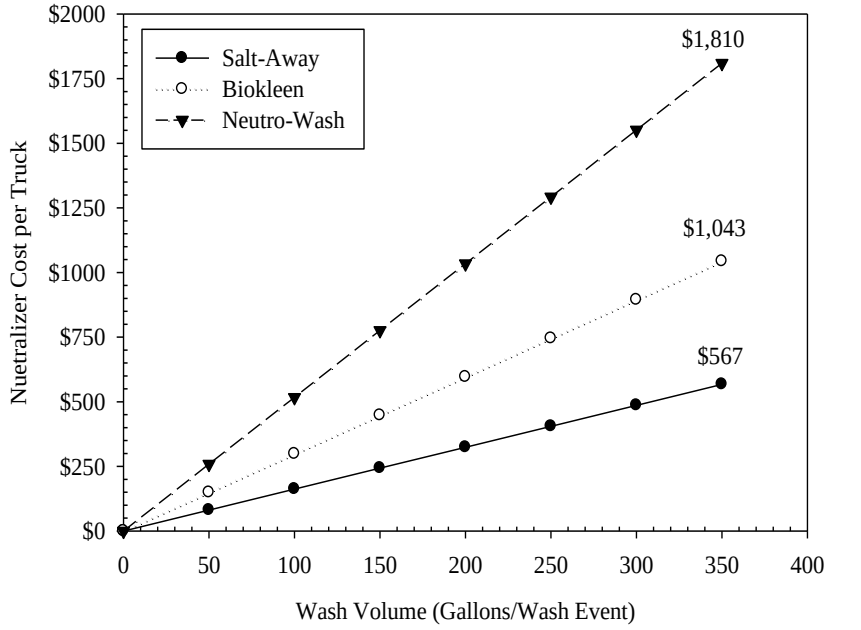
$$Neutralizer\ cost\ per\ facility\ per\ winter\ season$$

$$= NCWE\ * Trucks\ at\ facility * Total\ \#\ of\ wash\ events$$

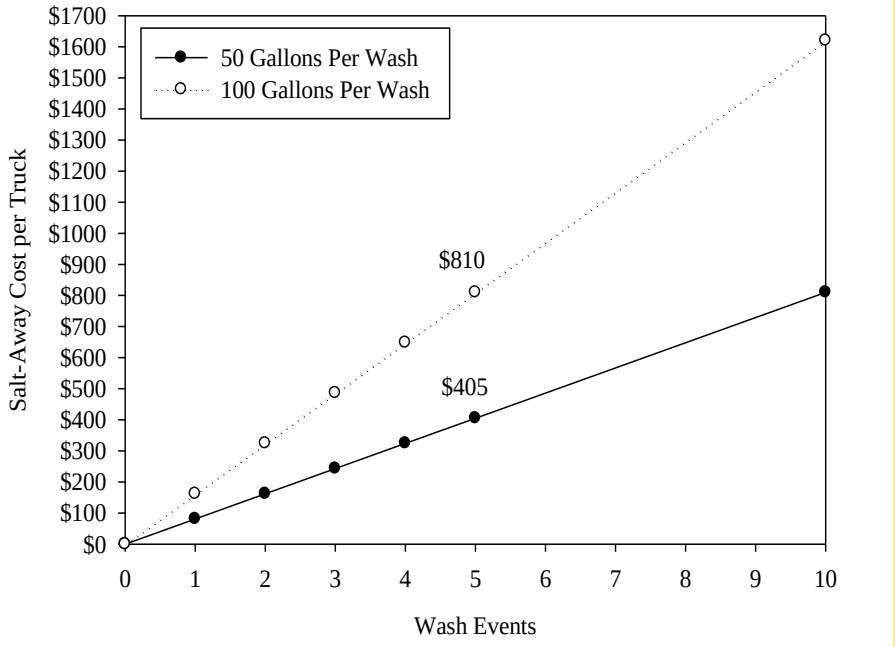
$$Annualized\ Capital\ Costs = Capital\ Costs * \left[\frac{i}{((1+i)^n) - 1}\right] + i$$

Neutralizer	Conc. Solution Cost ($/gallon)	"Modified" Dilution Ratio (Volume %)	Usable Solution Cost ($/gallon)	A36 Steel Corrosion Rate Reduction (%)
Salt-Away	$16.15	10.00	$1.62	32%
Neutro-Wash	$36.95	14.00	$5.17	14%
Eastwood	$30.00	12.00	$3.60	16%

Salt-away is Most Cost Effective of Top Performing Neutralizers



Neutralizer cost per truck as a function of neutralizer and wash volume per wash event



Salt-away cost per truck as a function of wash events and wash volume per event

Neutralizer Application Can Increase the Useful Life of the Truck by 6 Months to 1 Year

	Tandem Truck EUAC	6 Months Extension (# Wash Events)	12 Months Extension (# Wash Events)
8 Years	$23,445.49	9	18
10 Years	$19,932.85	6	12
12 Years	$17,626.28	5	9

Cost-benefit analysis (cost-benefit net zero) for estimating the number of 100 gallon Salt-Away usable solution wash events (rounded to whole number) per truck per year as a function of truck replacement cycle useful life extension assumptions.

Note: Based on tandem truck capital cost $140,000, 7% discount rate, and EUAC is the Equivalent Uniform Annual Cost.

Overview of Cost-Benefit Analysis

- The cost to thoroughly wash a single truck is significant and can vary by more than 300% depending on the neutralizer product. For the top performing the neutralizer cost for a full 350 gallon wash per truck would be $567 for Salt-Away, $1,043 for BioKleen, and $1,810 for Neutro-Wash.
- If Salt-Away neutralizer is applied at a reduced volume (50 gallons or 100 gallons per truck wash) and neutralizer is applied for five wash events per winter season, the total cost per year to wash the truck is $405 at 50 gallons per wash or $810 at 100 gallons per wash (Figure 5-2).
- Assuming replacement cost of ODOT tandem truck is ~$140,000 ($125,000 single axle) and the neutralizer solution can increase the useful life of the truck by 6 months to 1 year, washing the trucks with Salt-Away 5 to 18 times per year is cost-effective. The benefits could be even greater if the maintenance costs associated with wiring etc. are also reduced.

Recommendations for Implementation: General Use of Neutralizer Products

1. For garages using any of the neutralizer solutions tested, they should be used above the recommended minimum concentration (vol. %).
2. Lab results support Salt-Away™ as the most effective salt neutralizer wash for reducing corrosion of bare metal and coated surfaces. Based on this, a preliminary cost analysis, and if a neutralizer solution is selected to be applied, we recommend Salt-Away.
3. Field testing of corrosion behavior of metal surfaces utilizing standardized washing procedures and equipment is needed to confirm the effectiveness of salt neutralizers.
4. Review and data mining of maintenance records for prioritizing preventative maintenance actions for protecting metal surfaces.

Recommendations for Implementation: General Use of Coatings

1. Overall, LCC™ is the most effective coating for corrosion protection. This is based on its performance on all metal surfaces tested.
2. For garages that prefer to use LubraSeal, the thickness of the coating should exceed 1 mil.
3. Statistically, neutralizer application did not inhibit corrosion on coated samples. However, the average creep rates for Salt-away and Eastwood were better than soap and water on LCC coated metal coupons.
4. Field testing of corrosion behavior and durability of coated-metal surfaces.

Questions?