

Field-to-Lab Correlation of De-Icing Salt–Driven Corrosion in Automotive Materials under Subarctic Exposure



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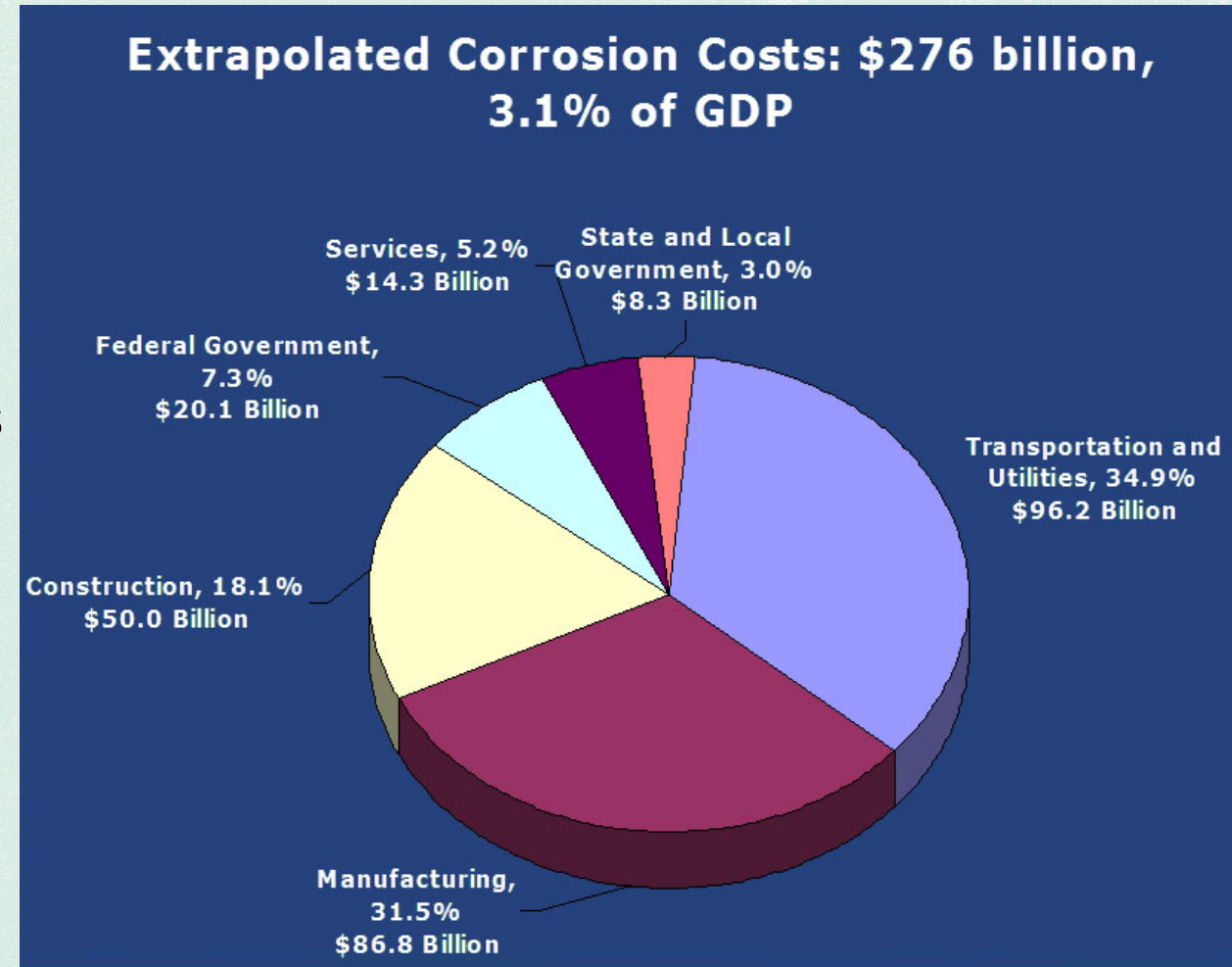
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This material is based upon work supported by the Rivian Automotive LLC., and the University of Alaska Anchorage ConocoPhillips Arctic Science & Engineering Endowment

Introduction

Cost of Corrosion*

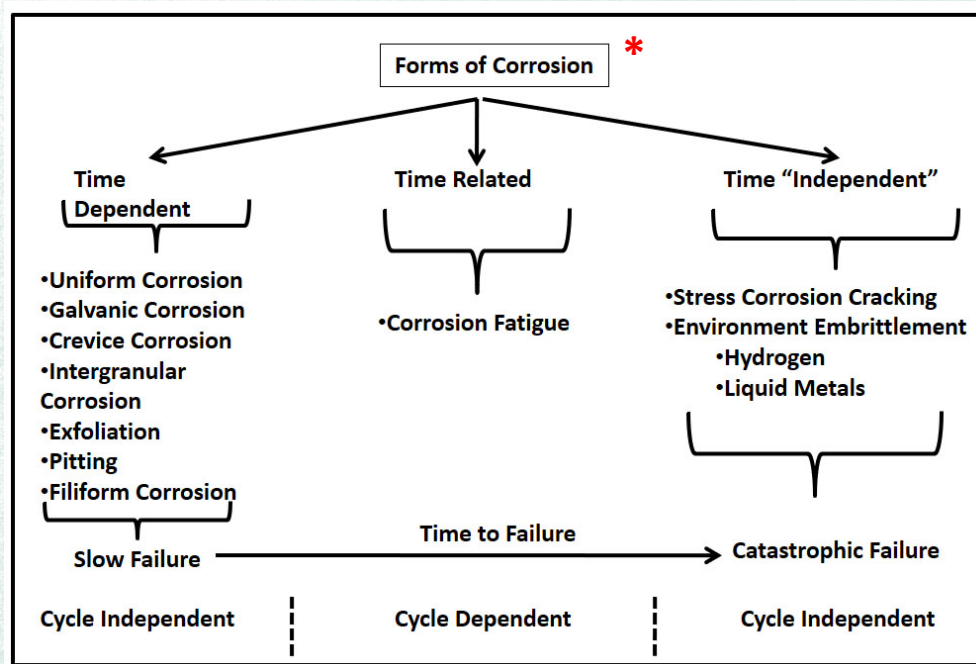
- Corrosion continues to be a major problem and losses due to corrosion are estimated to cost the United States approximately 3 to 4% of their gross domestic product (GDP)
- Functionally, the integrity and longevity of structures, tools, and equipment can be compromised, leading to unexpected failures that could result in safety hazards.
- Moreover, the environmental fallout of corroded structures can introduce toxins and pollutants into ecosystems.
- It is of great importance to study the limits of chemical and electrochemical stability of metal alloys for corrosion prevention, detection, and mitigation under extreme conditions, including arctic climates.



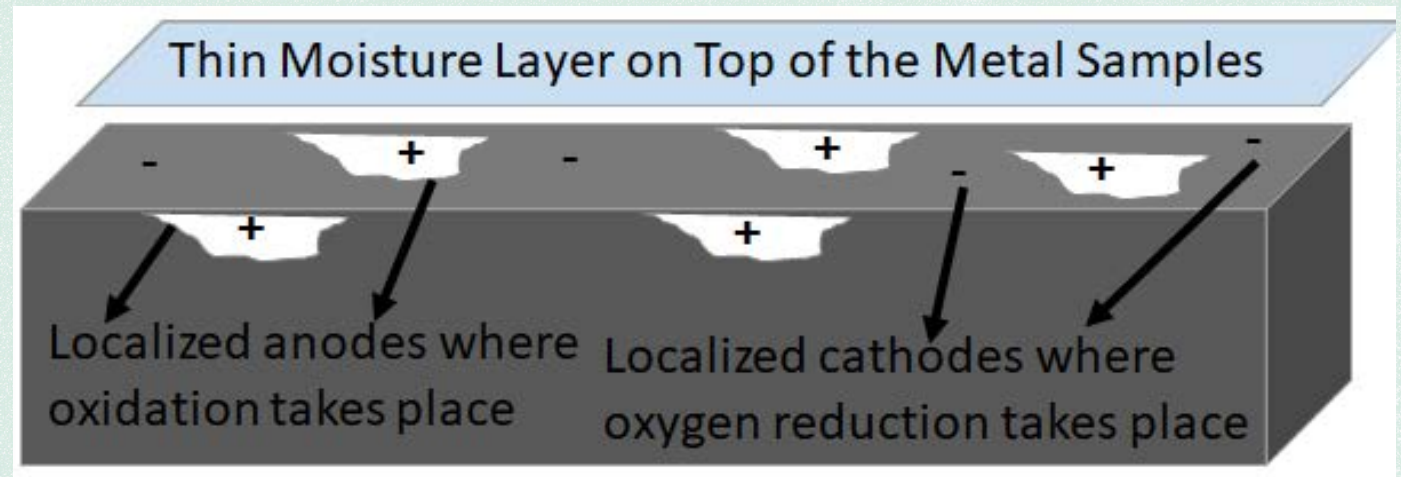
*"Corrosion Costs and Preventive Strategies in the United States" PUBLICATION NO. FHWA-RD-01-156

Atmospheric Corrosion

- Atmospheric corrosion is an important form of corrosion because many structures and systems are used in natural environments.
- Atmospheric corrosion is a complex process, which involves chemical, electrochemical, and physical changes to the metal exposed.



For atmospheric corrosion, the electrolyte is a thin layer of moisture (not completely immersed in solution) and the corrosion occurs at the metal/electrolyte interface when exposed to meteorological or environmental factors.



Automotive Corrosion

- Corrosion of automotive materials in cold regions is significantly accelerated by the combined effects of de-icing salts, environmental exposure, and mechanical damage mechanisms.
- While laboratory-based accelerated corrosion tests have advanced significantly in recent decades, field exposure is the best benchmark.
- Among the most aggressive natural environments for corrosion, coastal and high-humidity regions are well known
- However, northern climates such as Alaska present cold cycles, deicing salt usage, and seasonal changes that make them especially relevant for the evaluation of automotive materials and protective coatings used in vehicle structures.

Background

- While previous research has characterized salt-induced corrosion in temperate climates, very few studies have examined how exposure orientation interacts with de-icing practices in sub-Arctic regions.
- Deicers include sodium chloride (NaCl), potassium chloride (KCl), calcium chloride (CaCl_2) in any combination, but NaCl is most commonly used as it is low-cost and readily available.
- The eutectic point or the freezing point of de-icing salts can be lowered to $-50^\circ\text{C}/-58^\circ\text{F}$, melting the ice/snow layer on top of metal samples.
- This phenomenon keeps metal samples moist for much longer periods, thus increasing the Time of Wetness (TOW).

Background

- In Alaska, the US Department of Transportation (DoT) sprays ~23% of NaCl brine solution during the winter months.
- 5% CaCl_2 brine is also added periodically when the winter temperature is nearing $-18\text{ }^{\circ}\text{C}/0^{\circ}\text{F}$.
- The winter maintenance program includes both brine spray and stones/gravel/sands, and there is no consistency between what is used on the state highways, municipal roads, and private parking lots.



**Gravel soaked with
23.5% Sodium Chloride
brine solution**



Sprayed onto the road



**Automobile Underbody
Corrosion**



Approach and Objectives

- The exposure of automobile surfaces was simulated by deploying coupons on test racks equipped with weather sensors at 0° and 90 ° exposure angles.
- To simulate the corrosive effects of de-icing salts during the winter months, half of the coupons were periodically sprayed with a 23% NaCl brine solution, while the other half were installed as is.
- To evaluate the effects of exposure angles, the relative TOW was recorded at both angles.
- Additional weather parameters recorded include the air temperature, relative humidity, and rainfall.
- Preliminary experiments were conducted inside an accelerated chamber to characterize different surface roughness using various sandblasting media

Experimental Procedure



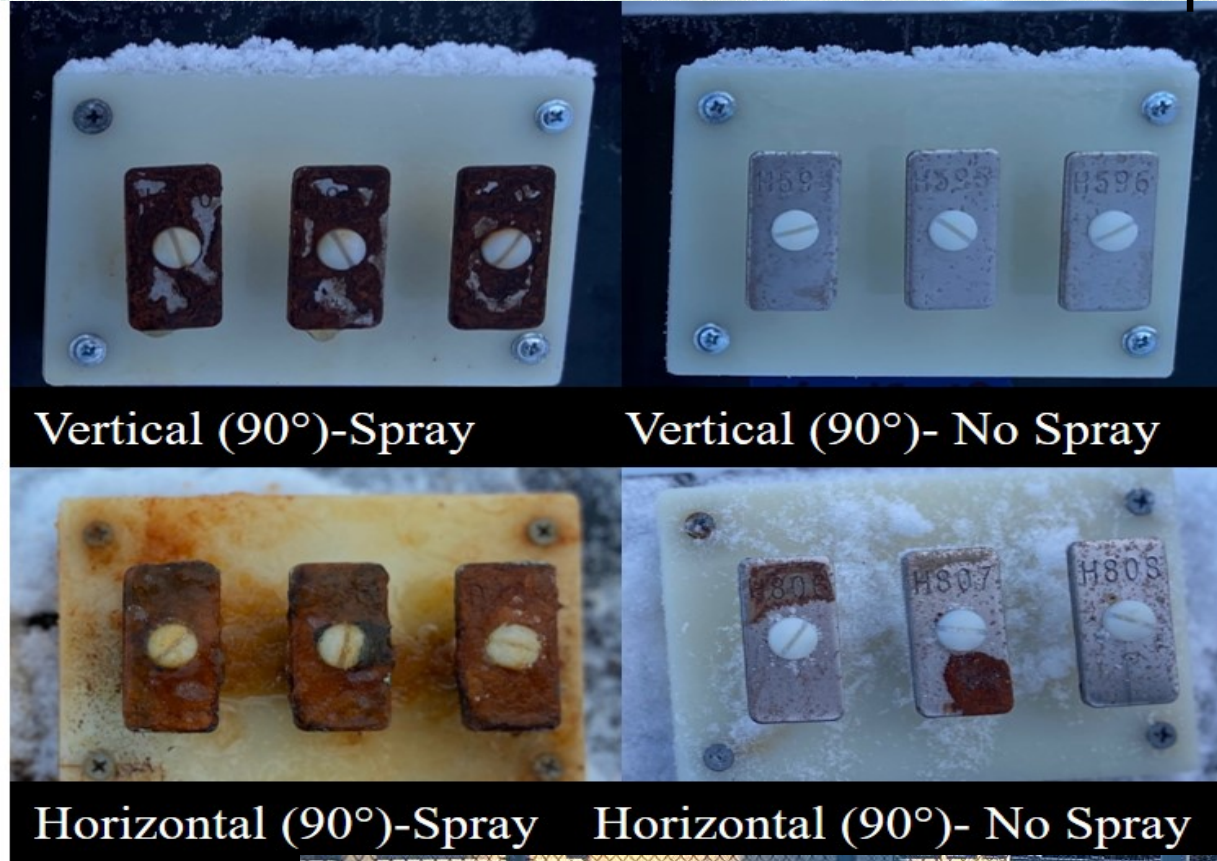
Anchorage experiences prolonged subfreezing temperatures and consistent snowfall throughout the winter months, creating conditions that necessitate the use of de-icing salt-treated gravel for ice control

Exposure Periods		
Set	Dates	Days
Set 1: 1 st 6-month Period (first year cycle)	12/01/2022 – 06/01/2023	183
Set 2: 2 nd 6-month Period (first year cycle)	06/01/2023 – 12/01/2023	184
Set 3: 1 st 12-month period (first year cycle)	12/01/2022 – 12/01/2023	366
Set 4: 1 st 6-month Period (second year cycle)	12/12/2023 – 06/13/2024	184
Set 5: 2 nd 6-month Period (second year cycle)	06/13/2024 – 12/10/2024	181
Set 6: 2 nd 12-month period (second year cycle)	12/12/2023 – 12/10/2024	364

The 6-month intervals captured seasonal transitions to compare cold-season (salt-intensive) and warm-season (minimal salt use) corrosion behavior

Experimental Procedure

Outdoor-mounted low-carbon steel coupons



STUDY OVERVIEW

-  Cold-region field exposure in Alaska with deicing salts
-  0° (Horizontal) vs 90° (Vertical) exposure angles
-  23% NaCl brine spray vs. no spray
-  6-month and 12-month exposure periods

Each coupon was chemically cleaned according to ASTM G1 “Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.”



Results and Discussion

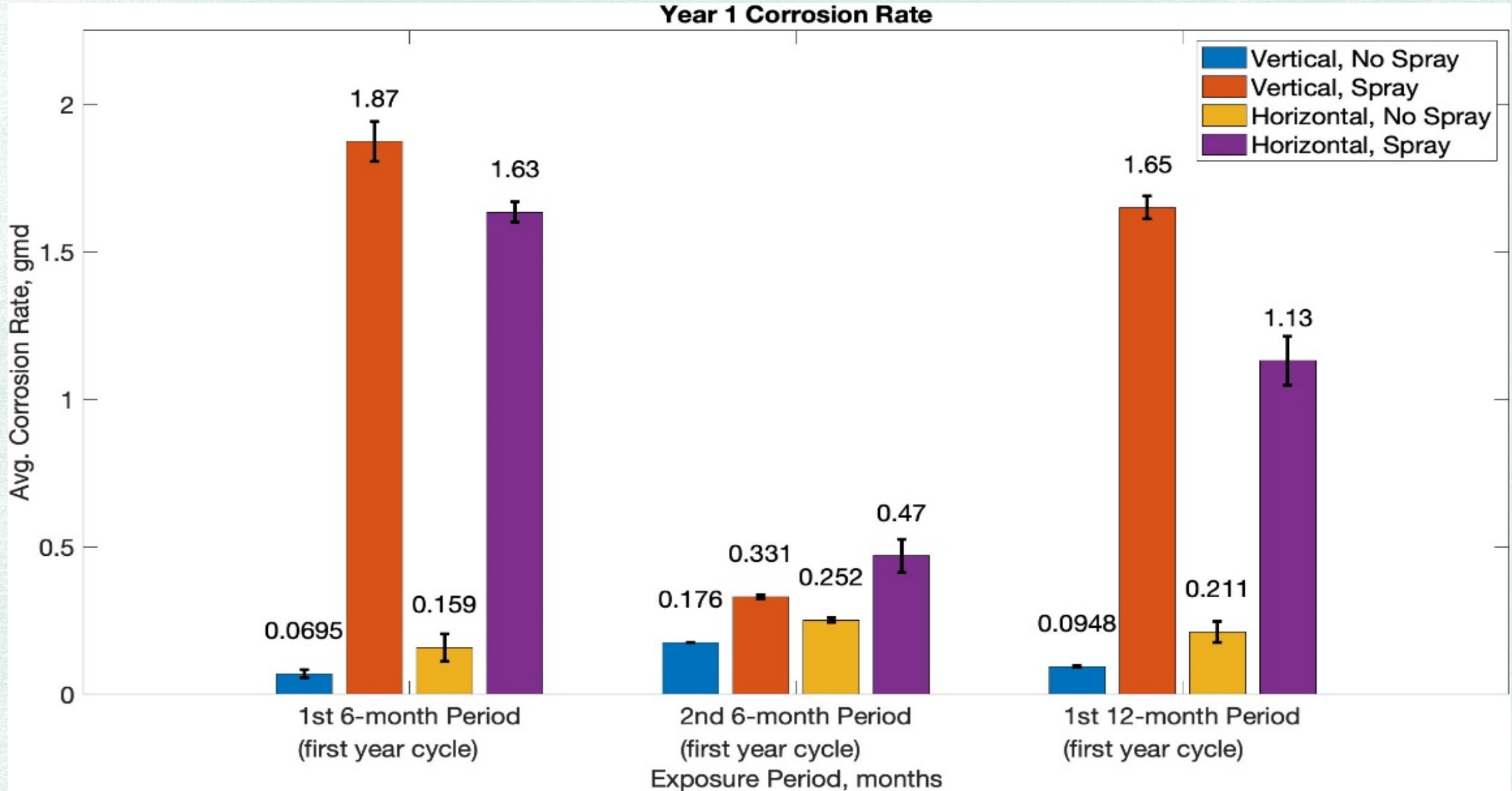
Weather Data

Set	Avg. Air Temp. [°C]*	Avg. RH [%]	TOW [%]		Rainfall [in]*
			0°	90°	
Set 1: 1 st 6-month Period (first year cycle)	-0.38	72.2	34.27	8.75	1.78
Set 2: 2 nd 6-month Period (first year cycle)	8.25	81.00	48.79	38.37	19.48
Set 3: 1 st 12-month period (first year cycle)	4.57	77.25	41.55	23.60	21.26
Set 4: 1 st 6-month Period (second year cycle)	-1.61	75.36	49.86	28.05	5.00
Set 5: 2 nd 6-month Period (second year cycle)	7.02	79.91	54.10	37.65	12.45
Set 6: 12-month period (second year cycle)	2.65	77.64	52.03	32.88	17.45

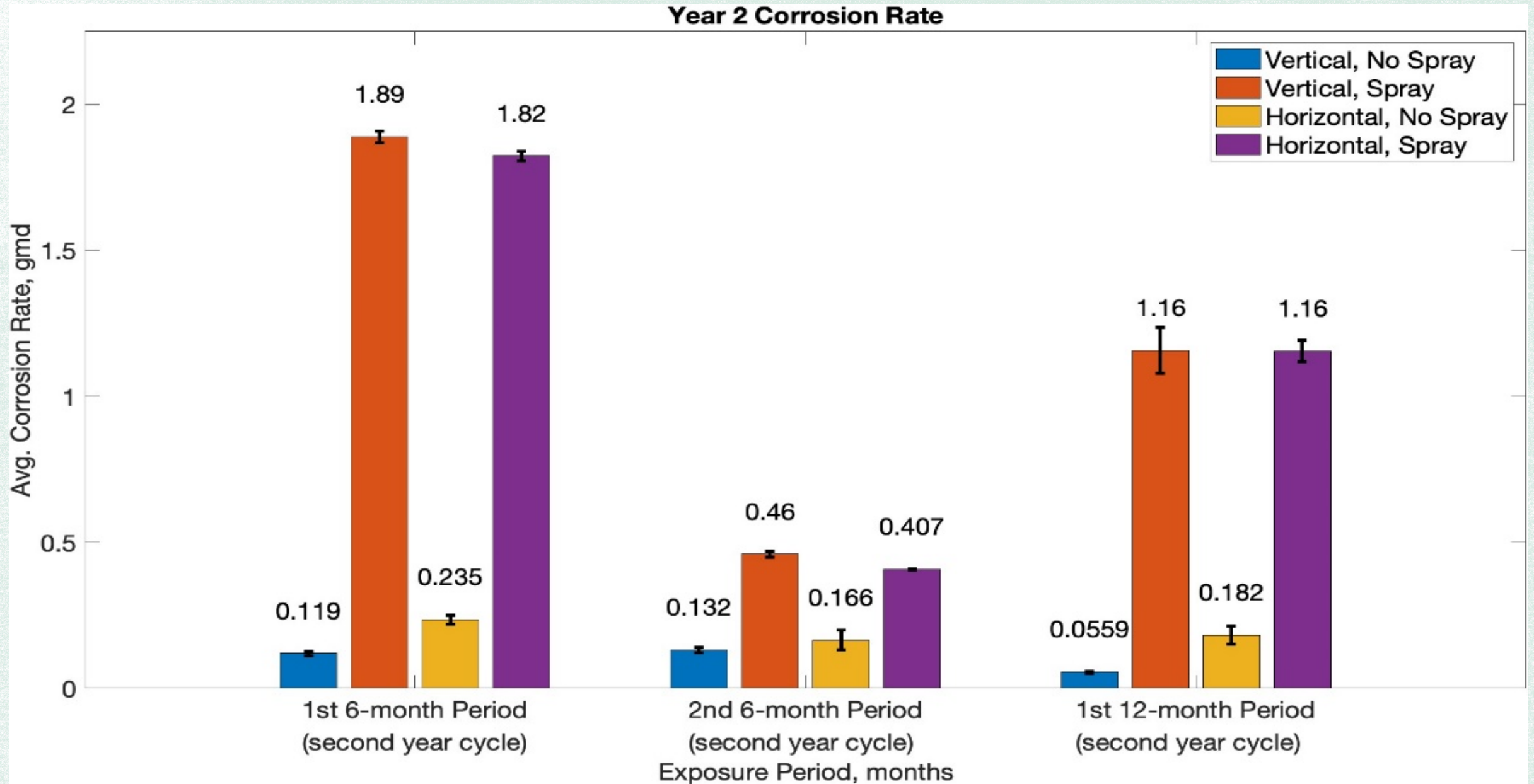
- The air temperature reflects the seasonal variability of Alaska's cold, sub-Arctic environment.
- Two sensors were deployed at 0° and 90° exposure angles to accurately assess corrosion susceptibility.
- The TOW was found to inversely correlate with the exposure angle.
 - The metal coupons exposed at a 0° angle resulted in a higher TOW than those exposed at a 90° angle.
 - There is a positive correlation between air temperature, relative humidity, and TOW.

- Rainfall and precipitation have multifaceted, opposite effects on atmospheric corrosion - washing away corrosive agents on the one hand, while introducing corrosive ions through wet deposition on the other hand.

Results and Discussion



Results and Discussion



Results and Discussion

- Higher corrosion rates were observed during the exposure period, which aligned with the winter months, particularly on coupons subjected to the salt spray treatment, highlighting its significant impact on corrosion.
- The carbon steel coupons exposed at a 90° angle experienced the highest corrosion rates during the winter periods.
- This is contrary to the expectations that horizontally exposed coupons would experience higher corrosion rates due to an increase in surface moisture retention.
- This unexpected trend can be attributed to snow and ice accumulation on the coupons exposed at a 0° angle during the winter months.

Results and Discussion

- With minimal snow incidents and minimal salt spray applied during the summer months, differences in corrosion rates can be attributed to relative humidity and surface wetness.
- During these exposure periods, the coupons exposed at the 0° angle experience higher corrosion rates, indicating that the angle of exposure plays a complex and season-dependent role in corrosion susceptibility.

Corrosion Damage as a Function of Surface Roughness

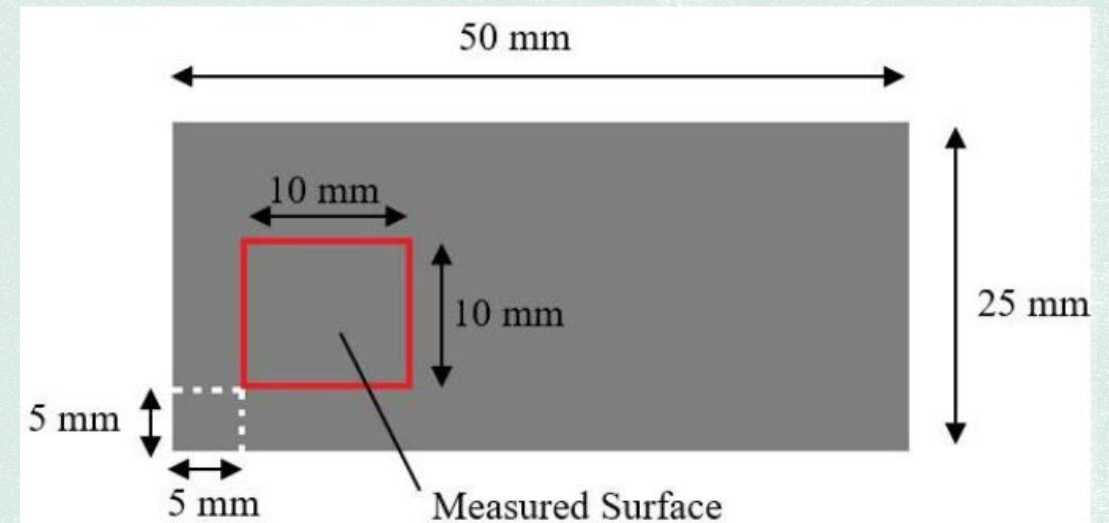
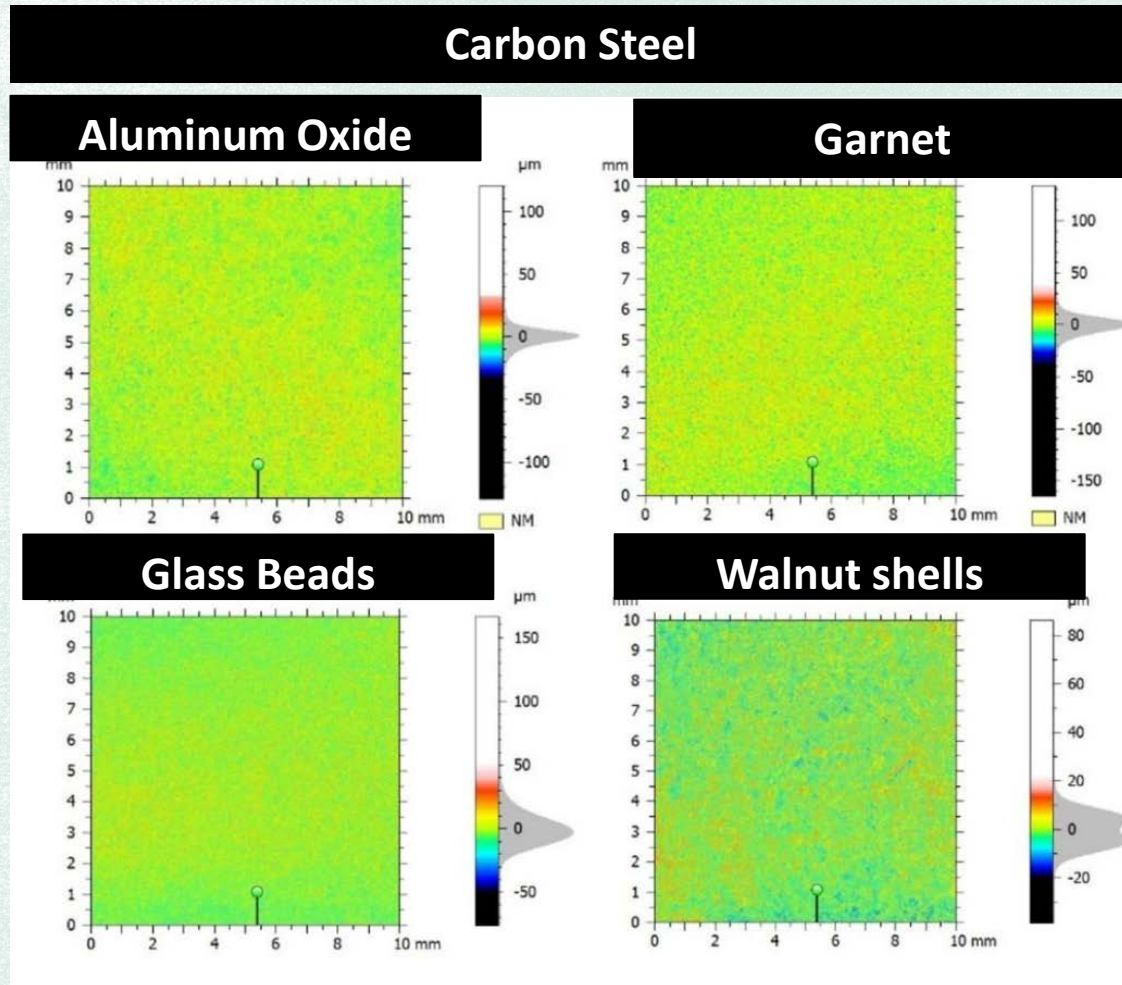
The main goal of this proposal is to quantify the corrosion damage to the automobile underbody caused by de-icing salt-induced stone/gravel impingement.

The specific objectives are:

1. Characterize different surface roughness using various sandblasting mediums
2. Expose metal samples with various surface roughness to different chloride solutions in the accelerated corrosion chambers under controlled parameters
3. Deploy metal samples with various surface roughness to the automobile underbody to evaluate corrosion damage in real-time conditions
4. Characterization of Corrosion Products and Correlation Studies:

Surface Analysis using Profilometry

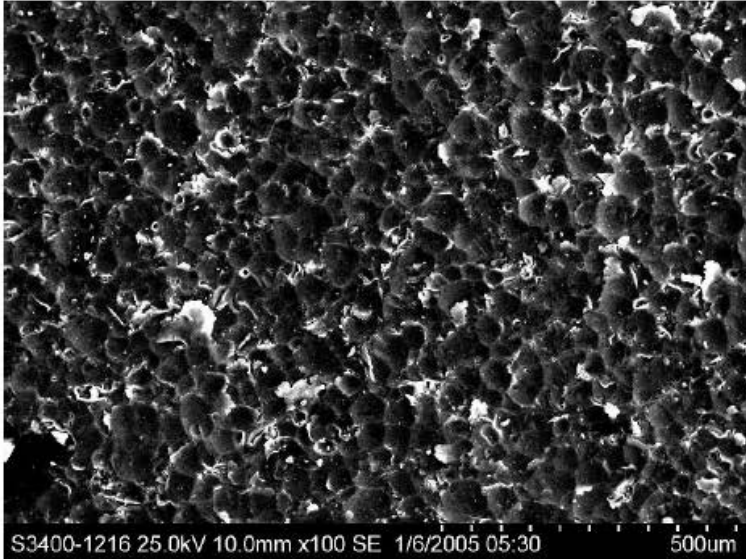
- Prepare aluminum and carbon steel samples with different surface roughness.
- Sandblasted using Aluminum oxide, Garnet, Glass beads, and Walnut shells (representing softer, rounded particles) to emulate gravel impact.



Order of Surface roughness for both Steel and Aluminum (from rough to smoother surface):

Garnet>Aluminum Oxide>Glass Beads>Walnut shells

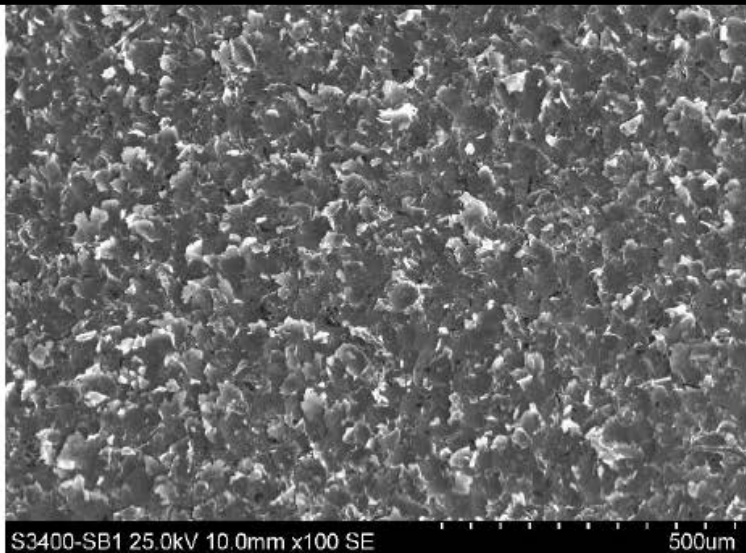
Surface Analysis using SEM/EDXA



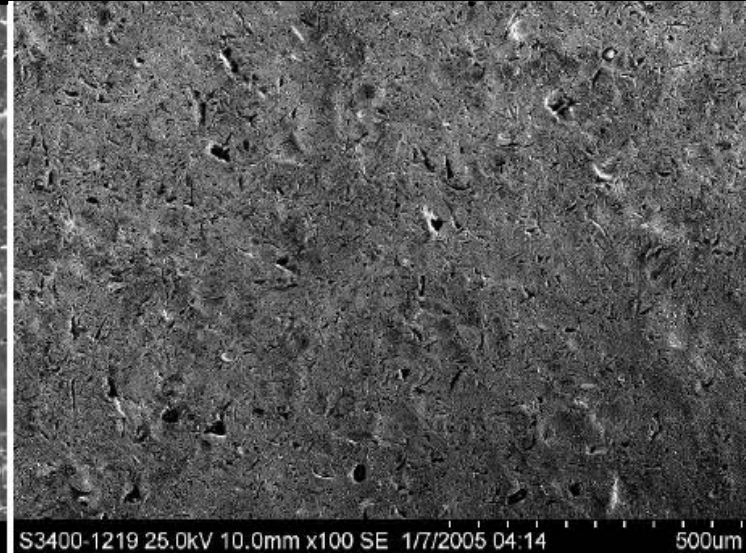
Aluminum-Glass Beads



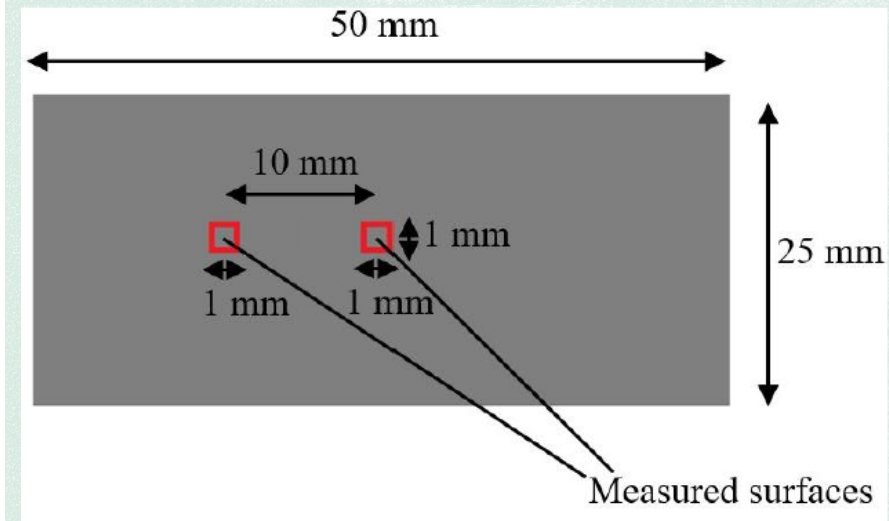
Aluminum-Walnut Shells



Steel-Glass Beads

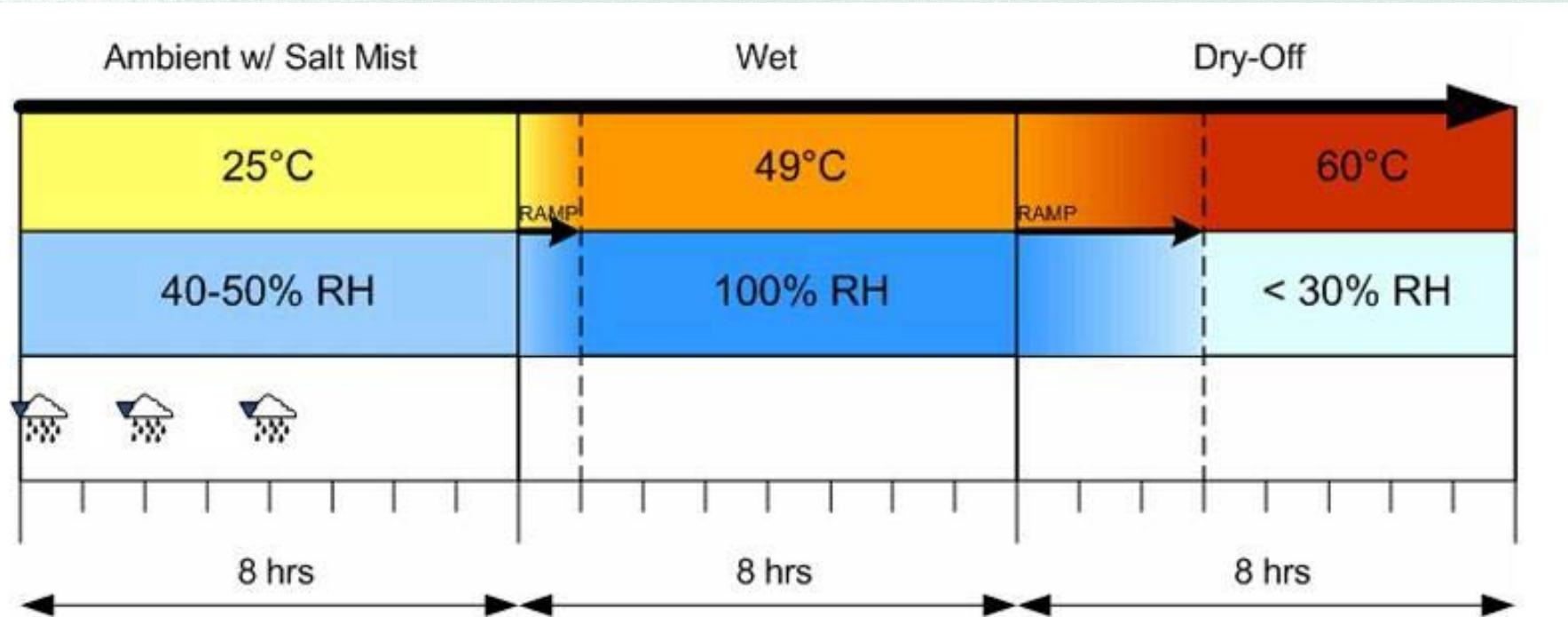


Steel-Walnut Shells

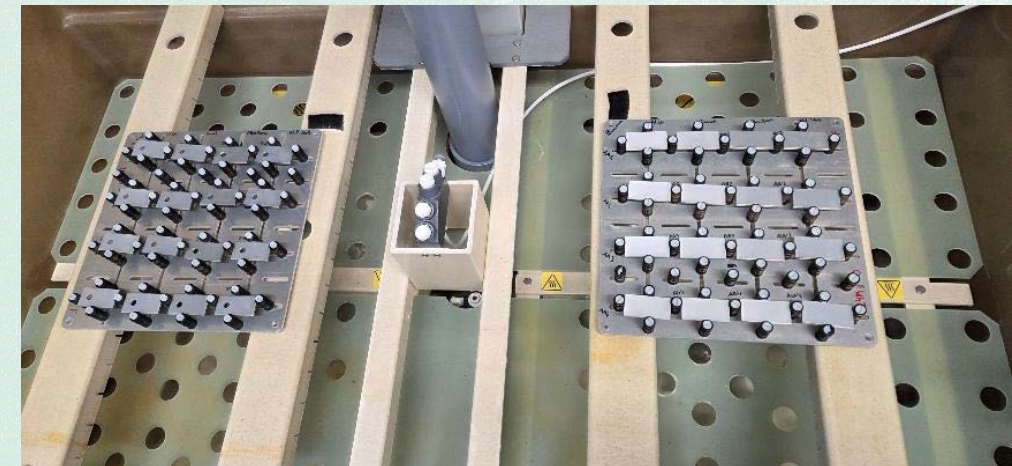


Experimental Procedure

Modified GM9540P Cycle



- Conducted 2 cycles, and each cycle had 3 brine (23.5%) sprays

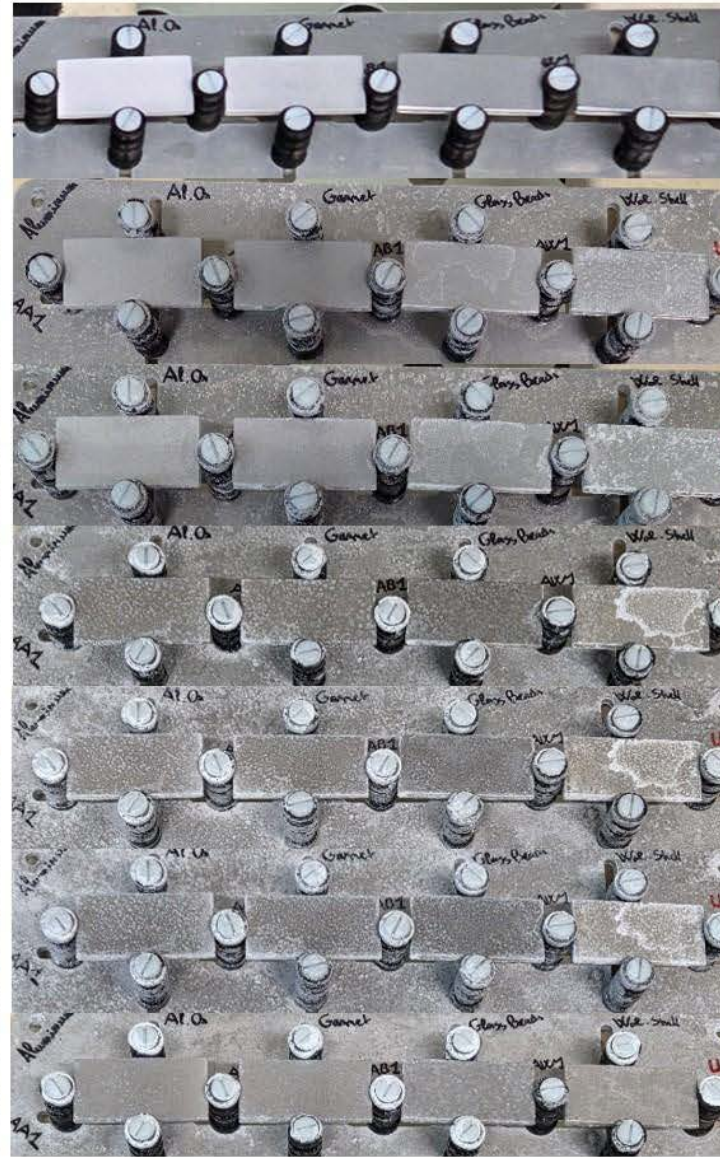


Experimental Procedure

Carbon steel



Aluminum



Time

Cycle 1 – 00h00

First spray

Cycle 1 – 02h00

Second spray

Cycle 1 – 04h00

Third spray

Cycle 2 – 00h00

First spray

Cycle 2 – 02h00

Second spray

Cycle 2 – 04h00

Third spray

Cycle 2 – 24h00

End of exposure

Results and Discussion



SG4



SG3



SW4



SW3



AG4



AG3



AW4



AW3



SA4



SA3



SB4



SB3



AA4



AA3



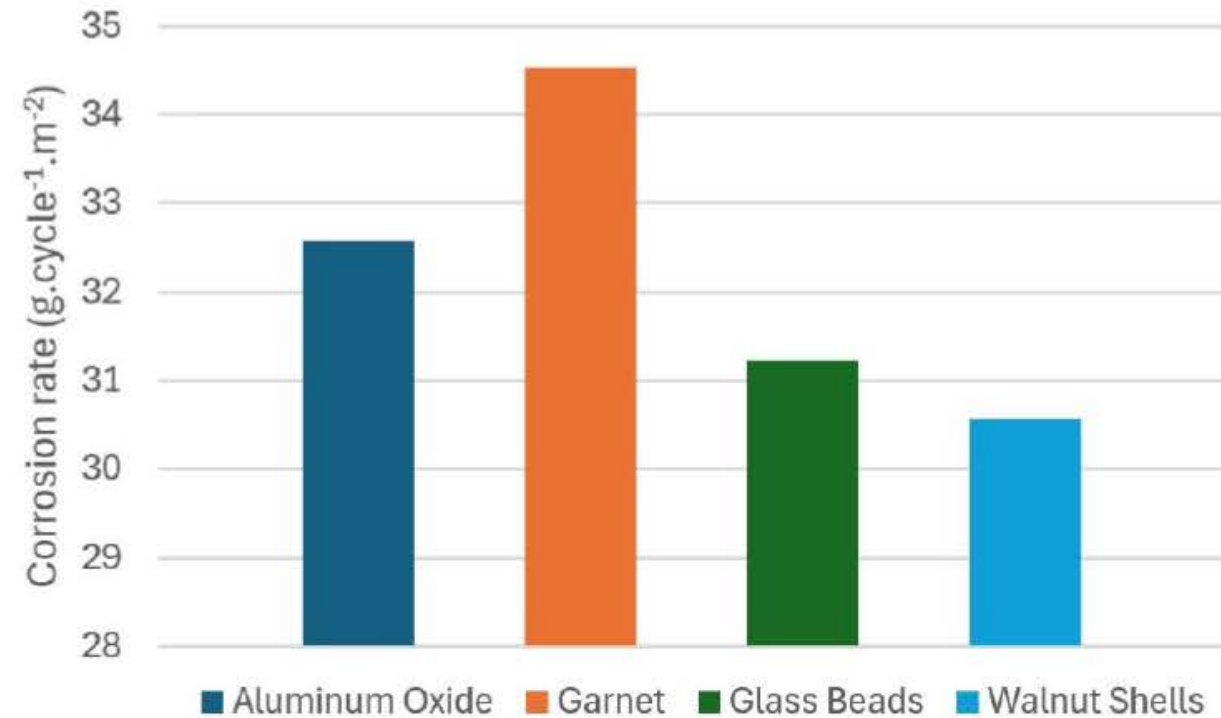
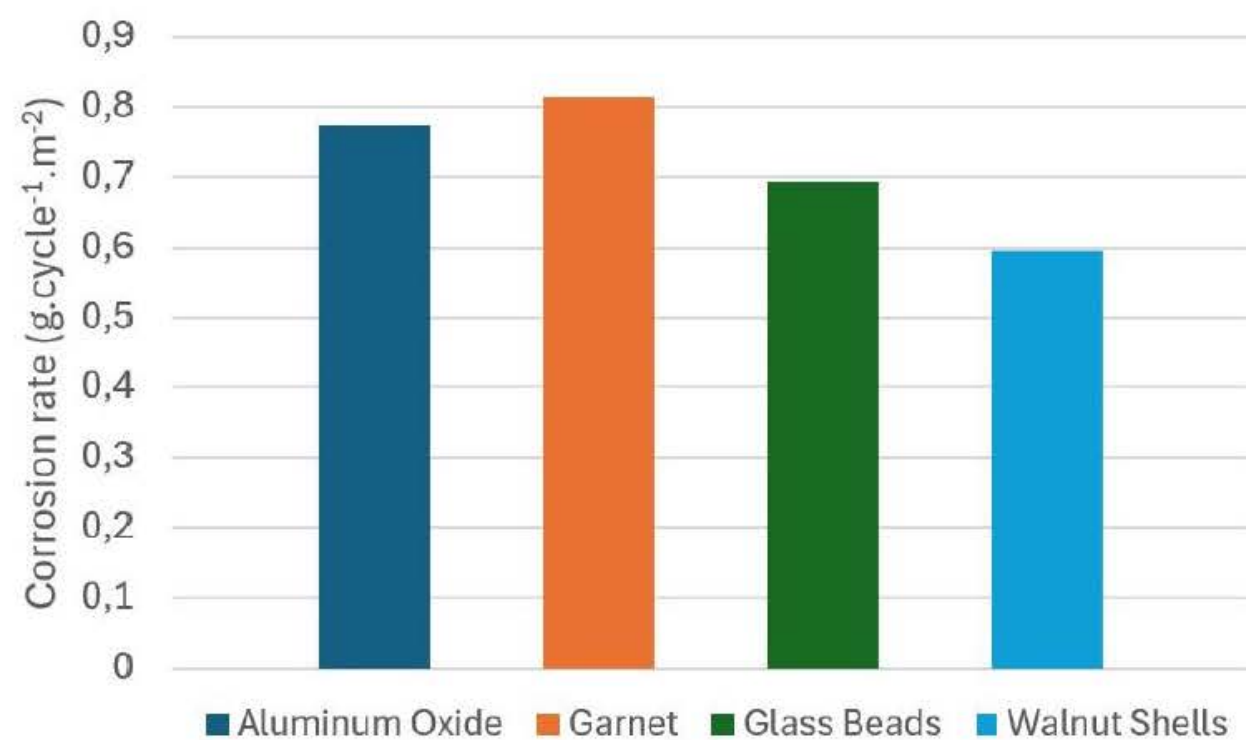
AB4



AB3

Results and Discussion

Corrosion Rate in Grams per Meter Squared per Cycle after Chemical Cleaning



- Garnet sandblasting media causes the most corrosion, followed by Aluminum Oxide, then Glass Beads, and then Walnut Shells.**

Conclusion

- Results indicate that corrosion behavior is strongly dependent on exposure orientation and seasonal effects.
- Variations in surface roughness significantly influenced corrosion initiation and propagation, with rougher surfaces exhibiting higher susceptibility.
- This work establishes a pathway to improve correlation between field exposure data and laboratory testing, enabling more reliable prediction of automotive material performance in cold-region environments.

Conclusion



Key takeaway



- De-icing salts, moisture, and mechanical damage severely accelerate corrosion of automotive materials in cold regions.
- Field conditions are complex and difficult to replicate in the lab.



Acknowledgements

- The author would like to acknowledge the Alaska Department of Transportation for providing information and brine solution for these experiments.
- The author is also grateful to various undergraduate and graduate students who worked on this project
- This material is based upon work supported by the Rivian Automotive LLC., and the University of Alaska Anchorage ConocoPhillips Arctic Science & Engineering Endowment.

Questions???

Thank You!



YOUR IMPACT.



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