Introducing the Corrosion Accelerated Test with Controlled Humidity (CATCH) for aluminum materials in automotive applications

Q-Lab Corporation

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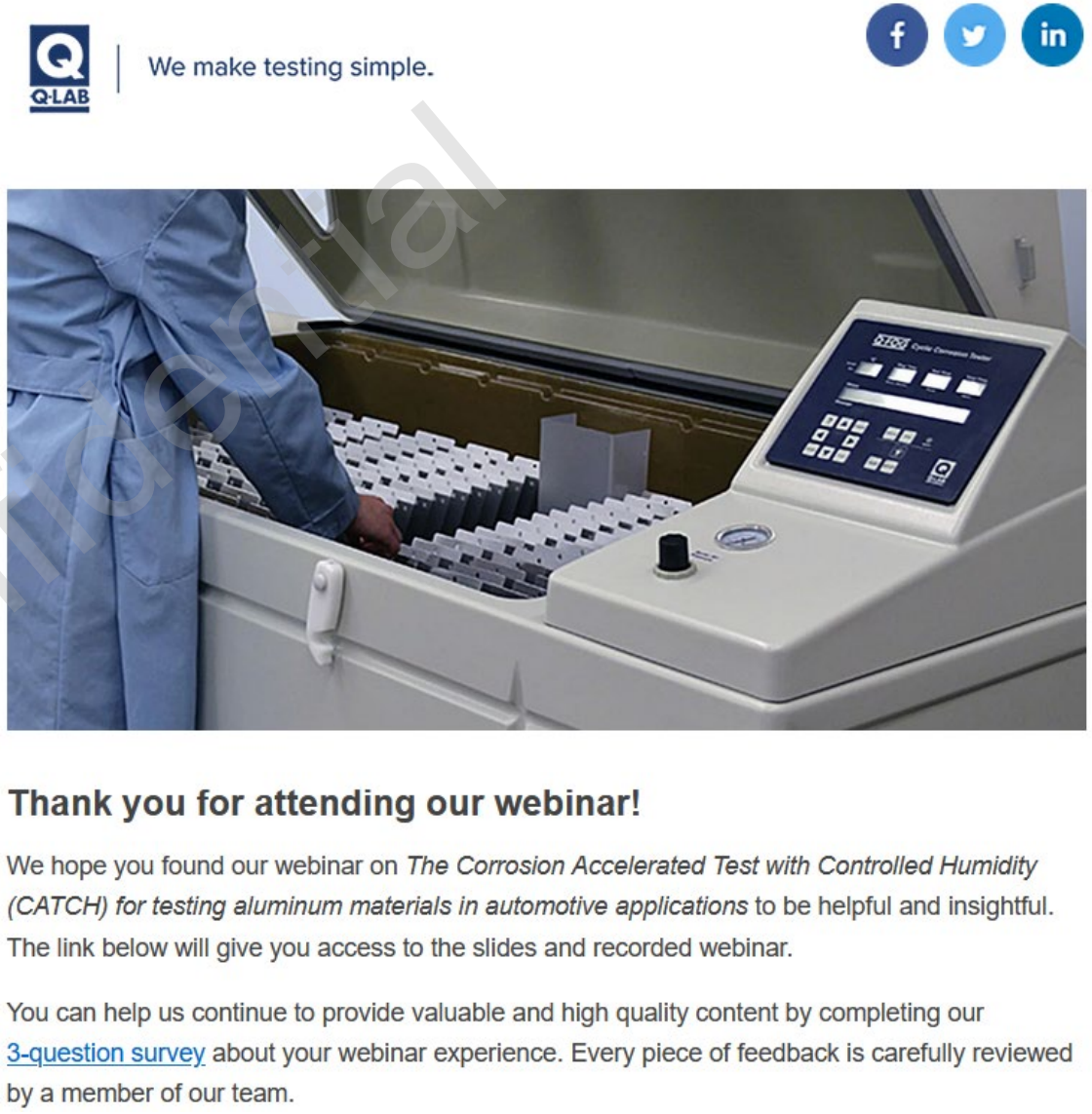


Q-Lab's Corrosion Webinar Series

- Today is the third of our three-part webinar series on **corrosion.**
- Our upcoming and archived webinars, including corrosion parts 1 and 2, are hosted at: q-lab.com/webinars

Date	Topic
03 Mar	Introduction to Atmospheric Corrosion
10 Mar	Relative Humidity and Wet/Dry Transitions in Salt Spray Corrosion Tests
17 Mar	The Corrosion Accelerated Test with Controlled Humidity (CATCH)

Content

- Background and participants
- Specimens & Evaluations
- Steel Substrate Results
- Second Study—Aluminum Subtrates

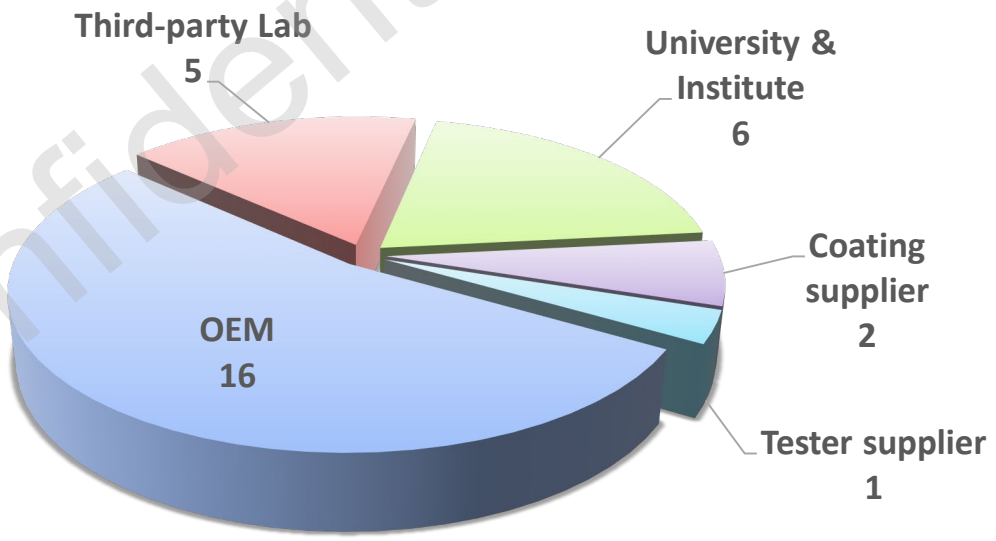
Background

SAE China (CSAE) began a project in 2016 to develop a new corrosion test method for domestic manufacturers

- Reduce redundant testing within domestic market
- Observe best practices from global OEM testing
- Test could be used for validation and QC
- Method development would start with steel substrates

Participants

Q-Lab China (Lead Company)	Chery Auto - Shanghai
FAW	FAW - Tianjin
Changan Auto	Guanzhi Auto
BYD Auto	Institute of Metal Research, CAS
Dongfeng Auto	Hainan Institute
Jianghuai Auto	725 Institute
FAW-VW	59 Institute
Shenlong Auto	SGS - Shanghai
Shanghai Auto	CTI - Shanghai
Nanjing Auto	Intertek - Shanghai
Guangzhou Auto	Emtek - Suzhou
Changan Ford	Shanghai Hanhai
PATAC	AkzoNobel - Shanghai
Wuhu Kaiyi Auto	Kmtehx - Shanghai
Wuhan University of Science & Technology	University of Science & Technology Beijing



Types of Accelerated Tests

Accelerated Test Type	Result	Test Time	Results compared to	Research? Development? Certification?
Quality Control	Pass / fail	• Defined • Short	Material specification	Certification & Research
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification	Certification & Development
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)	Development
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)	Development & Warranty Contracts

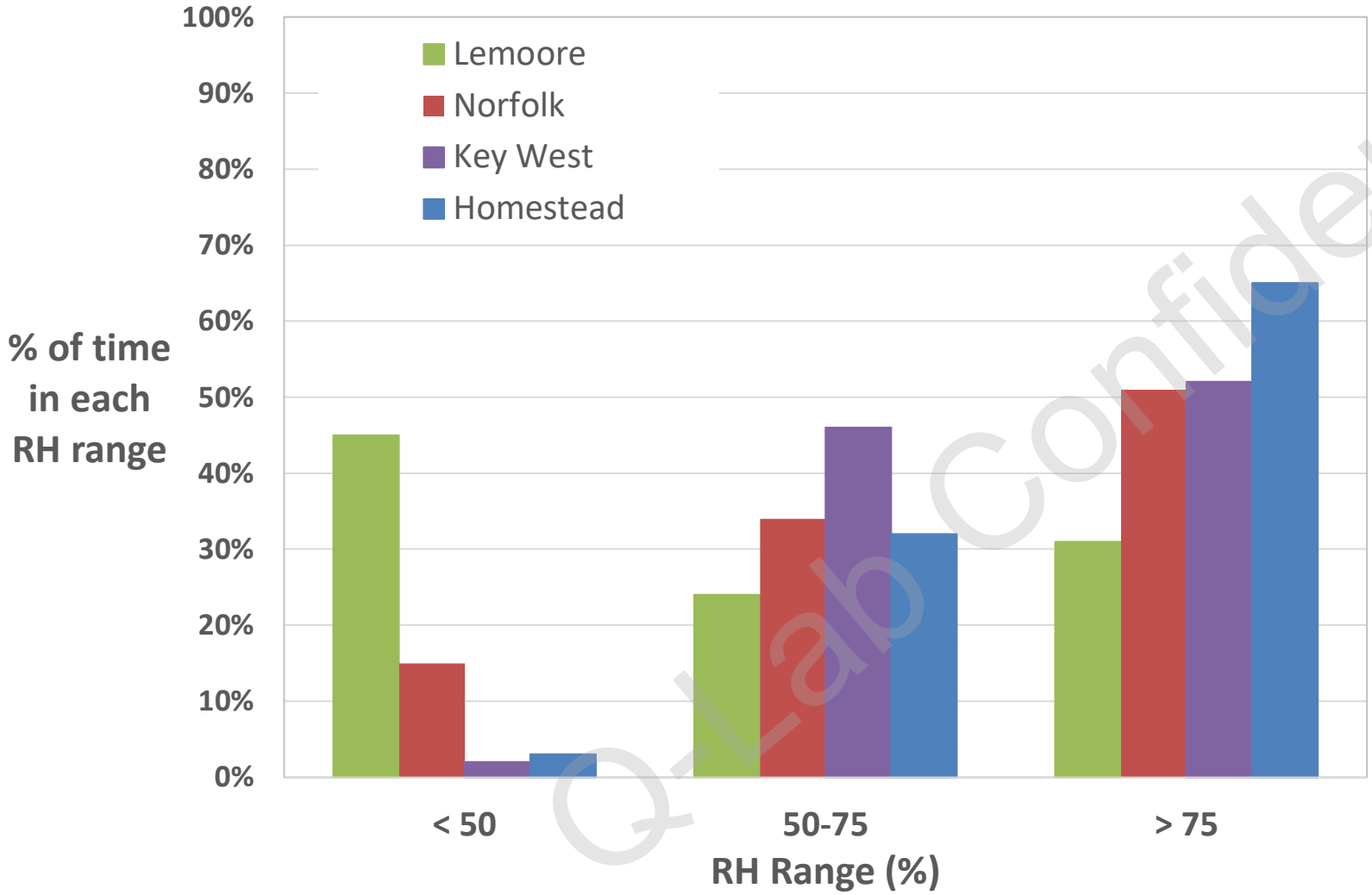
Technical Background

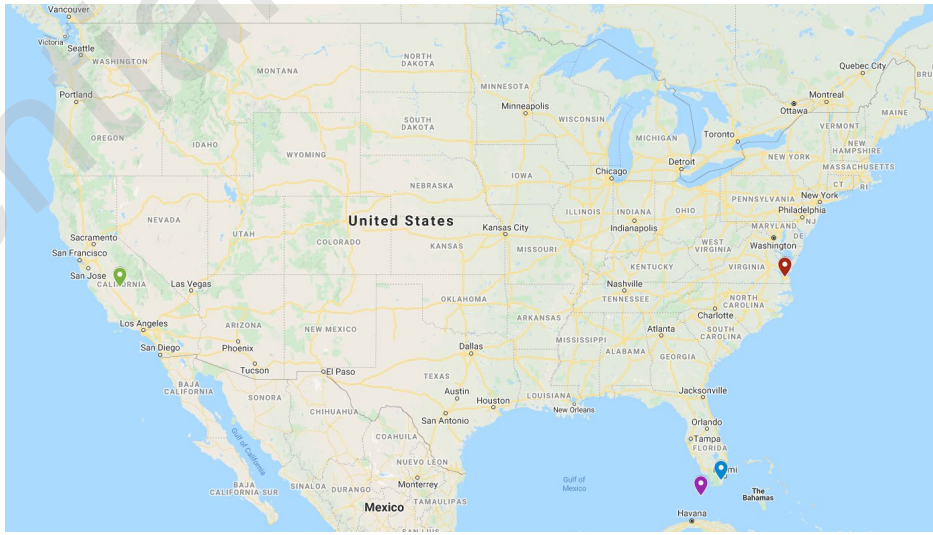
- Relative humidity control is key to laboratory repeatability
  - It's also a key driver for corrosion
  - Different RH levels can produce different corrosion mechanisms
- During last 10-15 years, automotive methods with precise RH control have become popular

Relative Humidity and Corrosion

Condition	RH Range	Result
Dry	**≤ 50%**	Very little corrosion from NaCl
Electrolytic cells around salt crystals; film formation as RH increases	**50-76%**	• AL-Steel galvanic couple broken Both metals in galvanic couples can corrosion in this RH range
Uniform Electrolytic Film formation	**≥76%**	• **Al corrosion** in galvanic couple with steel

RH Conditions in the Natural Environment





Summary of Environmental Conditions of First Generation Cyclic Automotive Standards

Cycle	Solution	Spray Type	RH < 50%	50%≤RH<76%	RH ≥76%
ISO 11997-1 Cycle A	NaCl 5.0% pH = 7	Fog	48%	3%	49%
VW PV1210	NaCl 5.0% pH = 7	Fog	9%*	7%	85%

Summary of Environmental Conditions in Modern Automotive Corrosion Standards

Cycle	Solution	Spray Type	RH < 55%	55%≤RH<76%	RH≥76%
Ford L-467 Volvo ACT2	NaCl 0.5% pH uncontrolled	Shower	0%	**66%**	34%
GMW 14872	NaCl 0.9% **$CaCl_2$ 0.1%** $NaHCO_3$ 0.075% pH uncontrolled	Shower	47% (22% below RH30%)	**15% (40% of cycle 30%-76% RH)**	38%
Renault D17 2028 (ECC1)	NaCl 1.0% pH =4.0 (H_2SO_4)	Fog	8%	**62%**	30%
VDA 233-102	NaCl 5.0% pH neutral	Fog	23%	**17%**	60%
Volvo ACT 1	NaCl 1.0% pH =4.2 (H_2SO_4)	Shower	33%	**15%**	52%
CATCH	NaCl 1.0% pH =4.0-4.2 (H_2SO_4)	Shower	19%	**33%**	48%

Test Methods & Specimens

Steel Substrate Study

- ASTM B117
- ISO 11997-1 Cycle A
- GMW 14872
- Ford L-467
- VW PV1210
- Outdoor multiple sites (natural)
- Outdoor 2 sites (salt spray enhanced)
- CATCH

- 5000 specimens total
- Substrate
  - CRS (various OEM specifications)
  - Galvanized sheets
- Pretreatment
  - 6 Types
- Primer
  - 3 types or omitted
- Basecoat/clearcoat (several varieties)

OR

- 1k water based, solvent based, powder

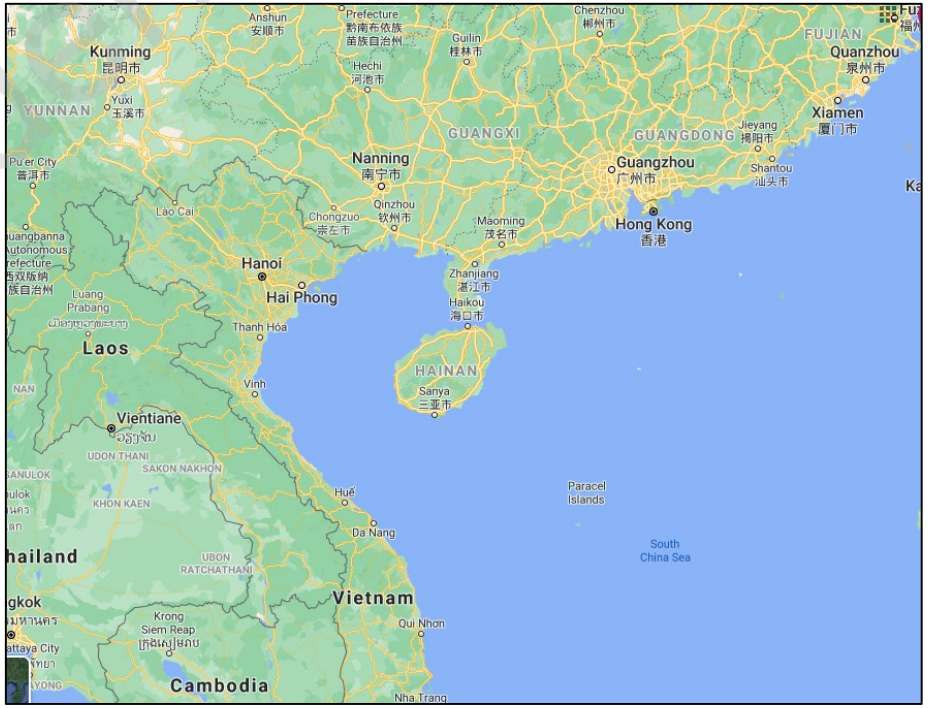
Test Methods Evaluated

Test Method	ASTM B117	ISO 11997-1 Cycle A	GMW 14872	Ford L-467	PV 1210	CATCH
Total test duration	2016h 84 Days	2016h 84 Days	72 cycles 72 Days	72 cycles 72 days (no weekends)	60 cycles 84 Days (include weekends)	72 cycles 72 days

Outdoor Tests

Xiamen, China

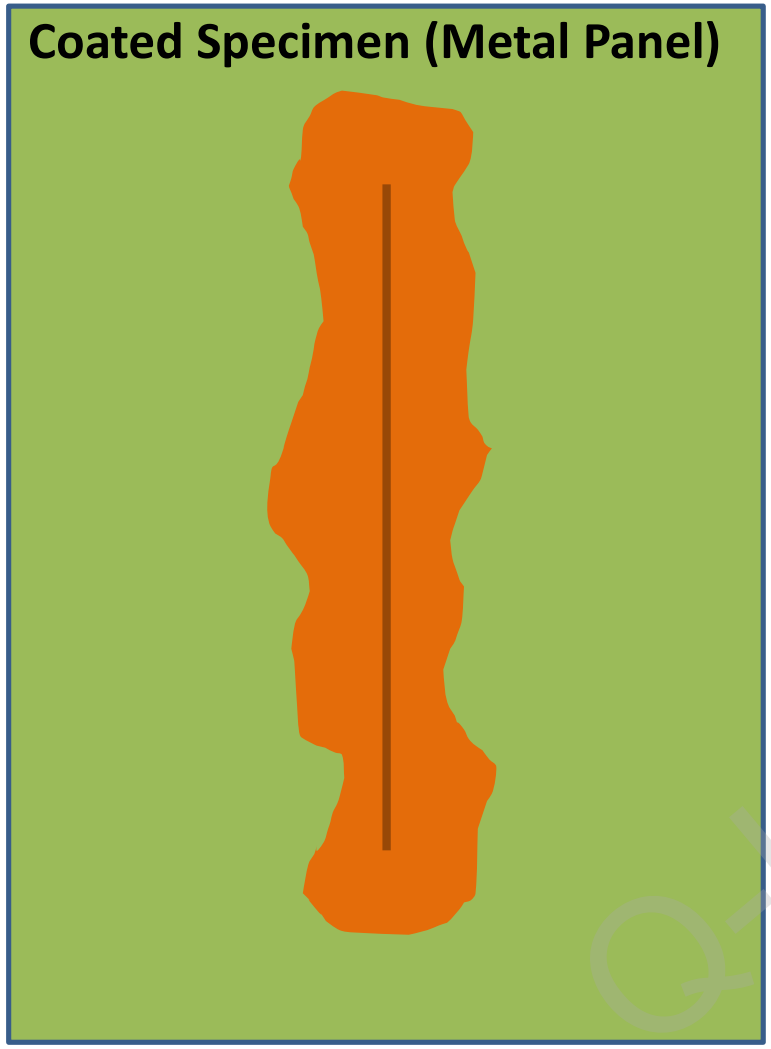
- Oceanfront Racks
- 12 months natural exposure



Hainan Island, China

- 12 months, natural
- 21 months, natural
- 12 months, salt spray enhanced

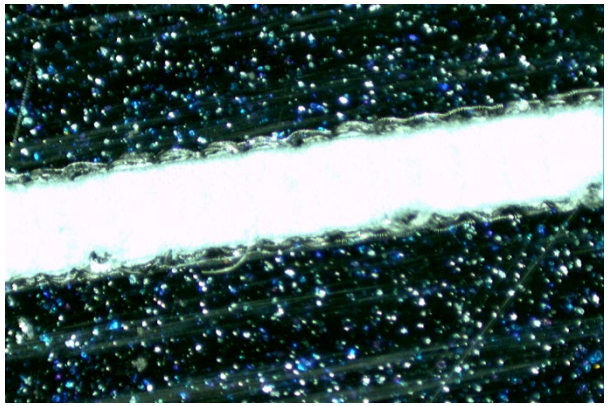
Corrosion Along a Scribe



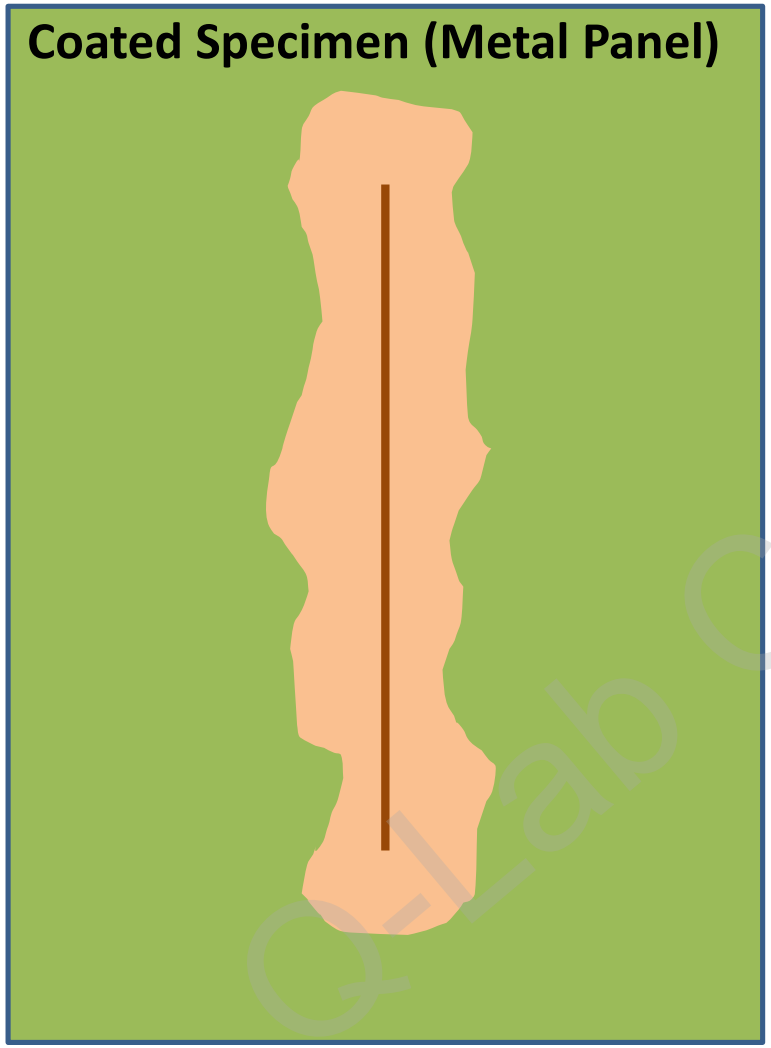
Scribing Tool

Scribe (cut) through the coating to the metal substrate

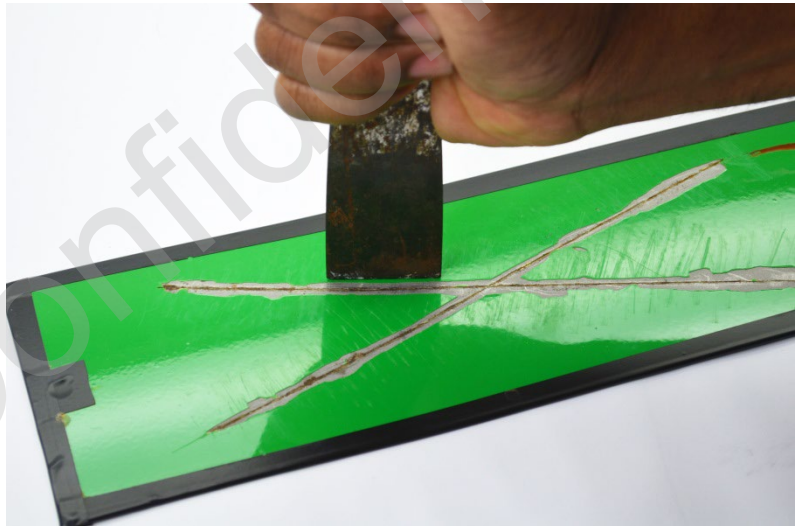
Expose the panel and allow corrosion to “creep” from the scribe



Corrosion Along a Scribe

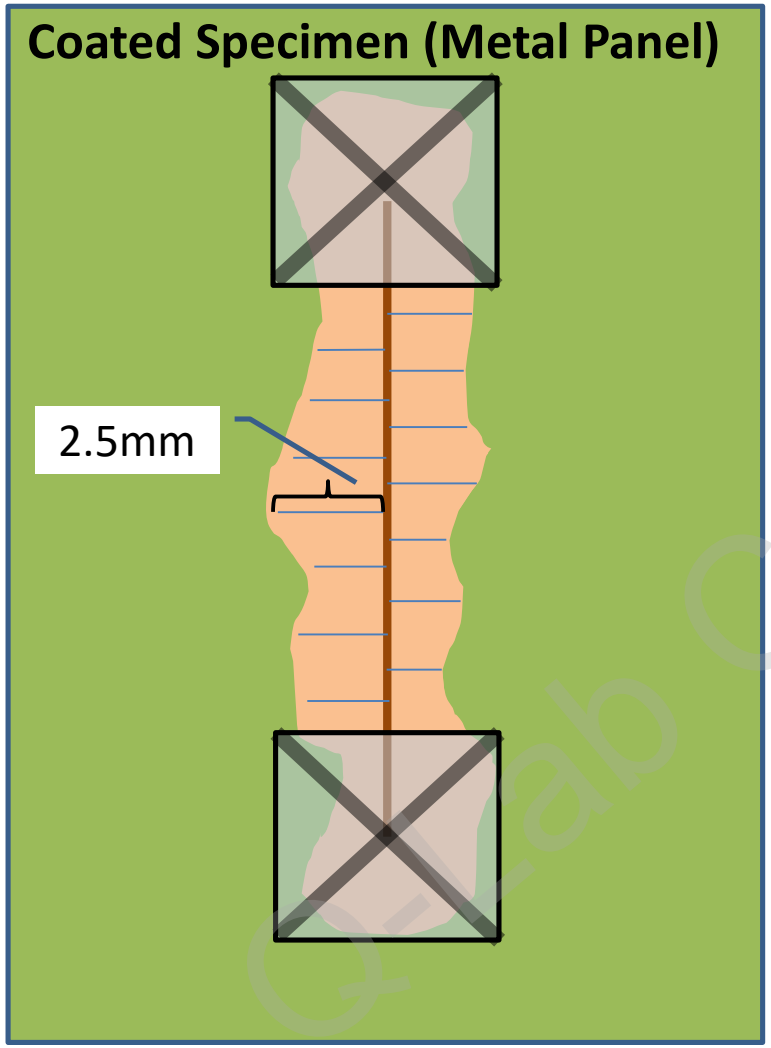


Remove rust “scab” with dull blade



Now the panel is ready for evaluation

Corrosion Along a Scribe



Ignore corrosion areas near ends of scribe (approximately 6-12 mm)

Create grid lines (minimum of 6) from scribe perpendicular to edge of corroded areas— transparency can be placed over panel for this purpose

Measure distance between scribe and edge of corrosion

Paint removed due to loss of adhesion is a separate measurement

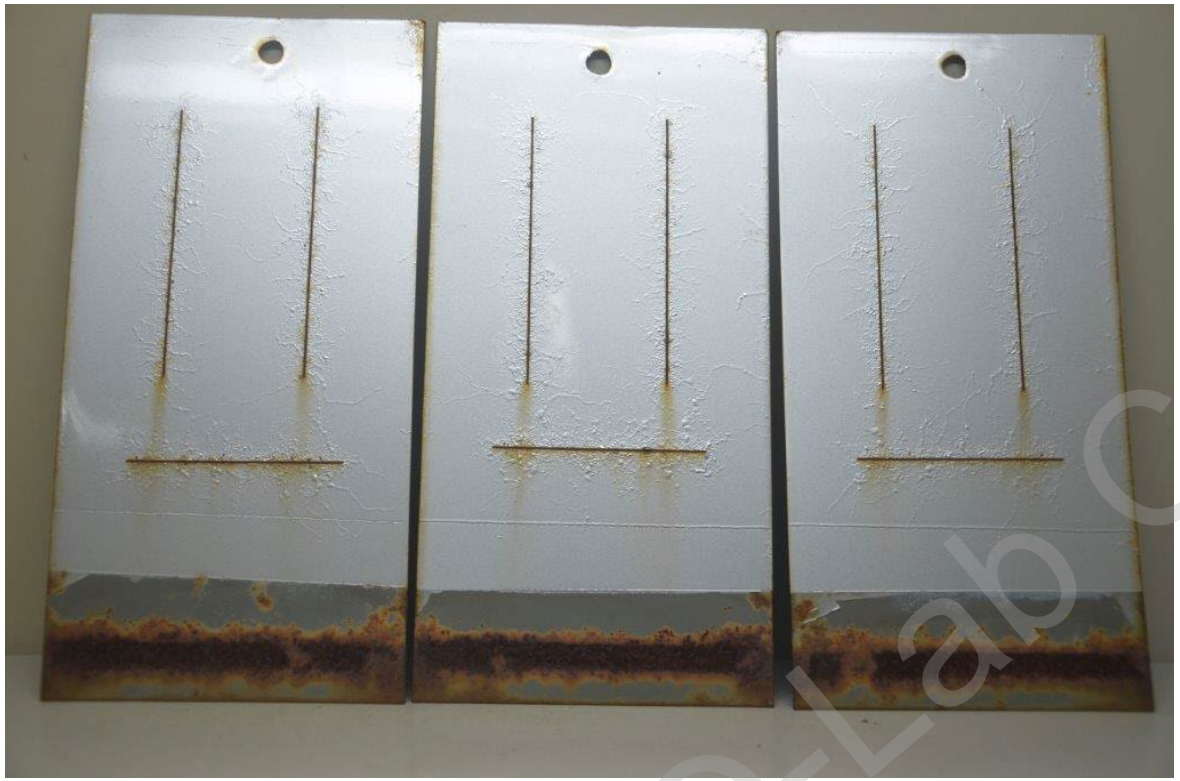
Corrosion creep

Vs

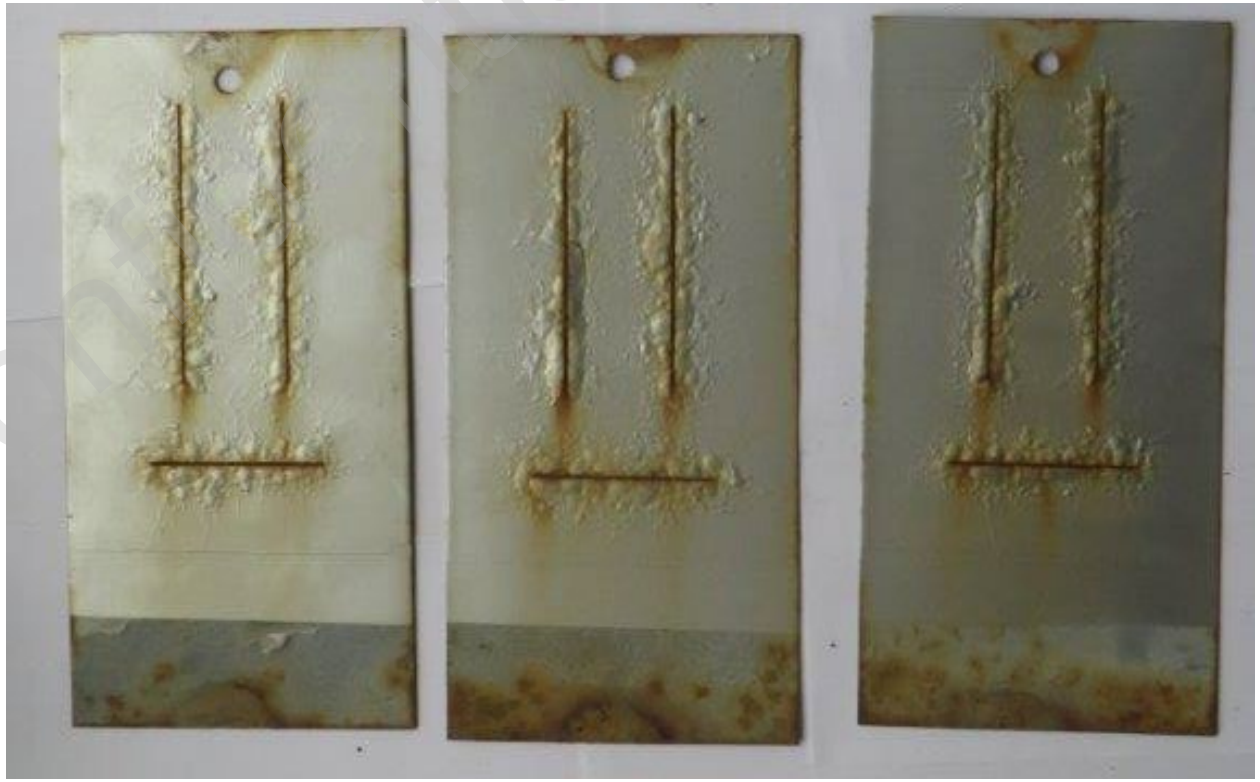
Loss of adhesion (cathodic delamination)

In this study, delamination data from laboratory tests correlated best to outdoor data

Filiform Corrosion on Steel Panels

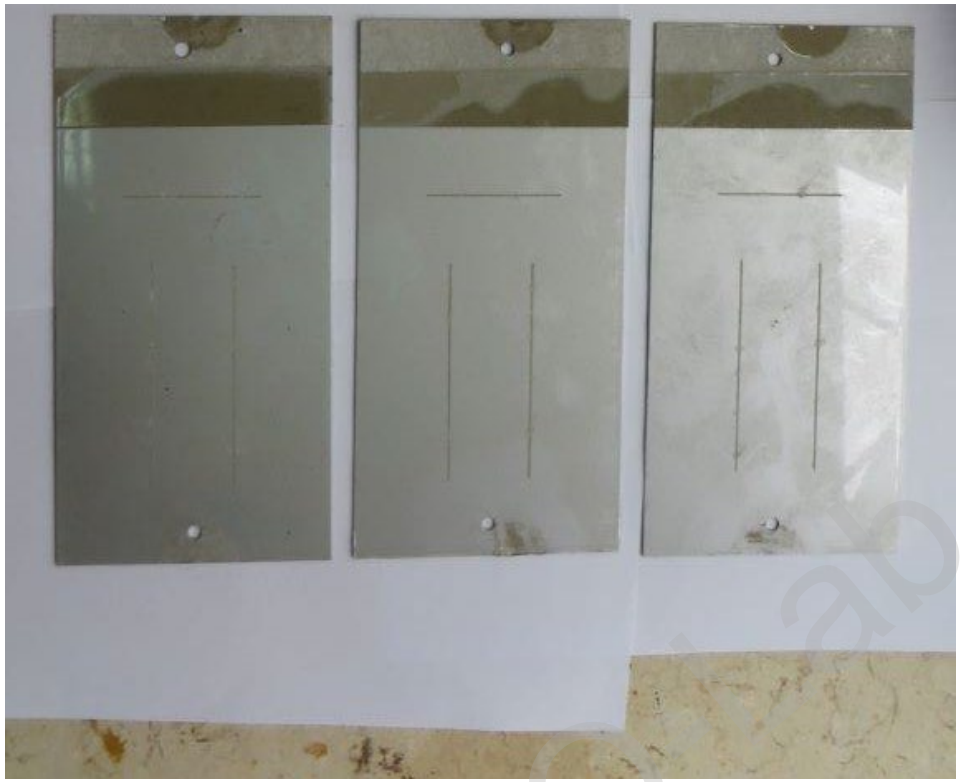


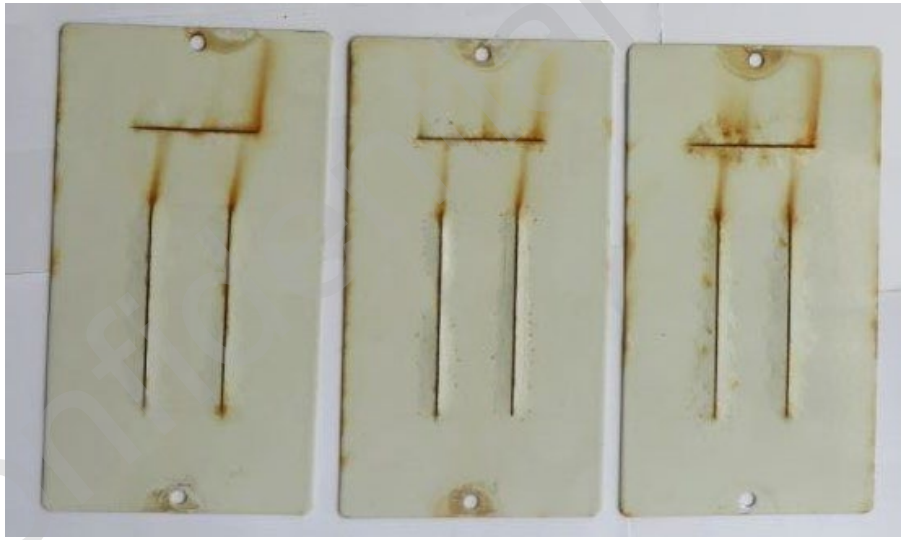
Subtropical Site (not near ocean)



Oceanfront Site

Wide Range of Durability

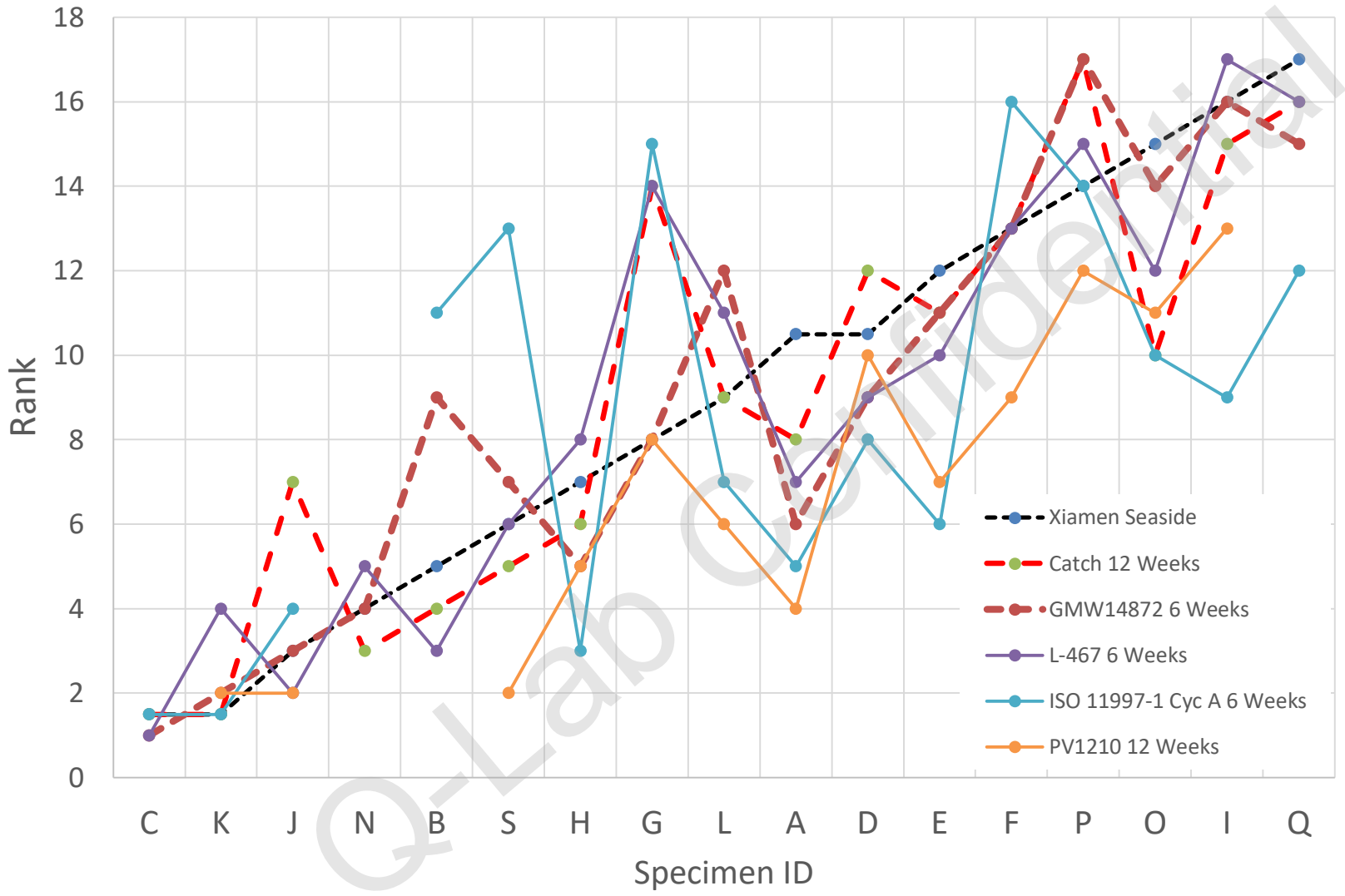




Spearman Rank—Laboratory versus Outdoor Tests

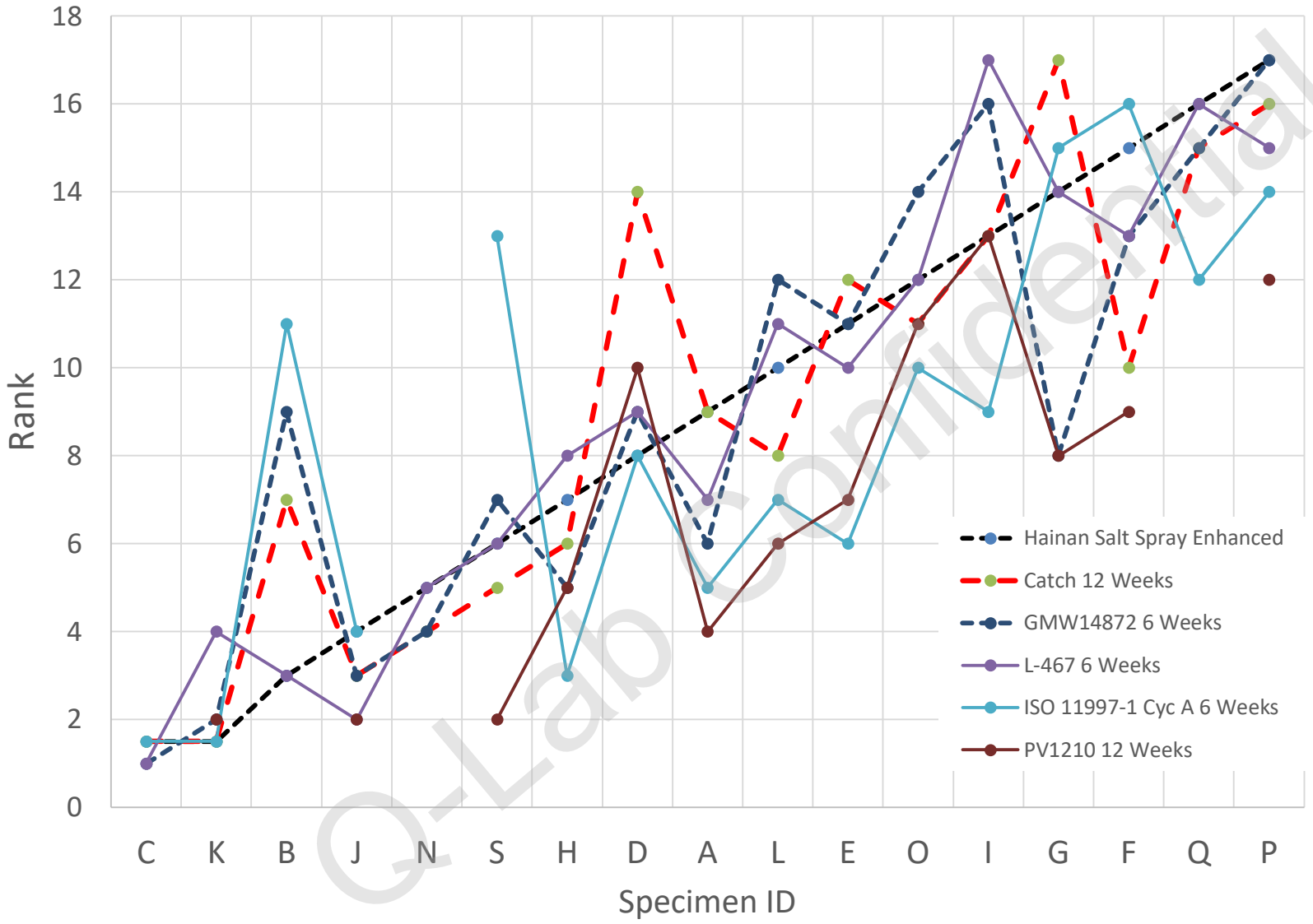
Laboratory Test	CATCH		GMW14872		L-467		ISO 11997-1 Cyc A		PV1210
Outdoor Test	6 Weeks	12 Weeks	6 Weeks	12 Weeks	6 Weeks	12 Weeks	6 Weeks	12 Weeks	12 Weeks
Hainan, 12 months	0.82	0.83	0.82	0.72	0.90	0.85	0.45	0.61	0.58
Hainan, 21 months	0.83	0.83	0.77	0.72	0.87	0.84	0.39	0.55	0.53
Hainan salt spray enhanced, 12 months	0.81	0.84	0.84	0.76	0.90	0.83	0.53	0.71	0.65
Xiamen (seaside), 12 months	0.79	0.89	0.82	0.67	0.95	0.94	0.71	0.78	0.66

Rank Order Compared to Xiamen Seaside Exposure



Dotted black line represents the rank orders of specimens in the reference test, the Xiamen natural seaside exposure in this case.

Rank Order Compared to Hainan Salt Spray Enhanced Outdoor



Dotted black line represents the rank orders of specimens in the reference test, the Hainan salt spray enhanced natural exposure in this case.

Second Study—Aluminum Substrates

- Automotive lightweighting efforts
- In the market there was no clear standard for aluminum body panels
- Conduct comparison tests between laboratory and outdoor methods in order to achieve:
  - Verification of corrosion resistance of aluminum alloy coatings
  - Performance verification of coatings developed and applied to aluminum alloy substrates
  - Quality control of anti-corrosion performance for aluminum alloy coating

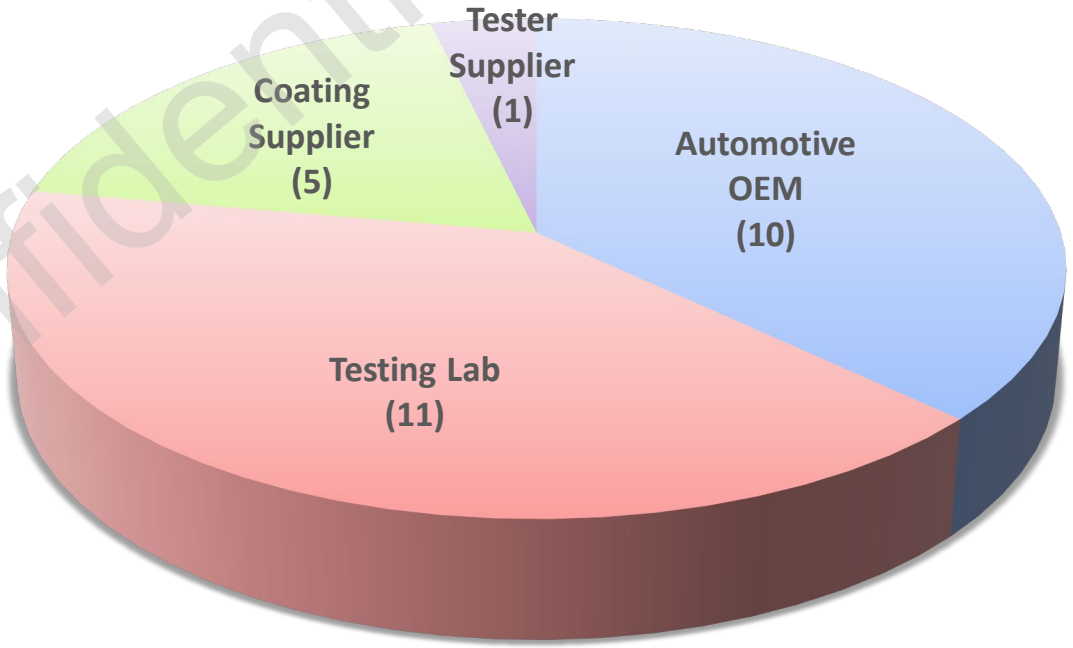
Participants in This Study

Lead company: JAC Auto

Participant companies:

- Q-Lab China
- Zhongtai Auto
- Beijing Benz
- AkzoNobel
- Weikai Lab
- Meixin Lab
- Hainan automotive research institute
- Liaoning Zhongwang
- BYD Auto
- Xince Lab
- CTI Lab
- Nannan aluminum processing
- Empirechem
- ……

Total: 27 participants



Comparison test

- Two rounds of tests
  - First goal to achieve acceptable correlation to outdoor tests and pass/fail QC results with good agreement
  - Second round: Can we speed up the test?

Test specimens

- 53 different specimens, 1033 panels
- The difference of the specimens:
  - Substrate: 5000 series, 6000 series, profiles
  - Pre-processing: silane, phosphating, zirconium
  - Electrophoretic coating: 3 types
  - Finish: 2 types

Corrosion test methods

Test method	CASS	AASS	Filiform	CATCH*	Outdoor - Spray salt water	Road enhanced corrosion
Reference standard	**ISO 9227**	**ISO 9227**	**SAE J2635**	**T/CSAE 71**	**ASTM D6675**	**QC/T 732**
Salt solution, pH value and deposition rate	sodium chloride: 50g/L copper chloride dehydrate: 0.26g/L pH = 3.1~3.3 1 ~ 2mL/h @80cm2	sodium chloride: 50g/L pH = 3.1~3.3 1 ~ 2mL/h @80cm2	Same as CASS	1% sodium chloride pH = 4.0 39 ~ 79mL/h @80cm^2 (16min/day)	sodium chloride: 50g/L, twice per week	sodium chloride: 50g/L
Temperature and RH	50 °C	35 °C	6 hours CASS + 60 °C, 85%RH, Wind speed: 6-24 m/min	-	-	-
Total test duration	240 h	1980 h	6 h CASS + 672 h	2980 h	12 month	120 days

*CATCH： Corrosion Acceleration Test with Controlled Humidity

CATCH test method

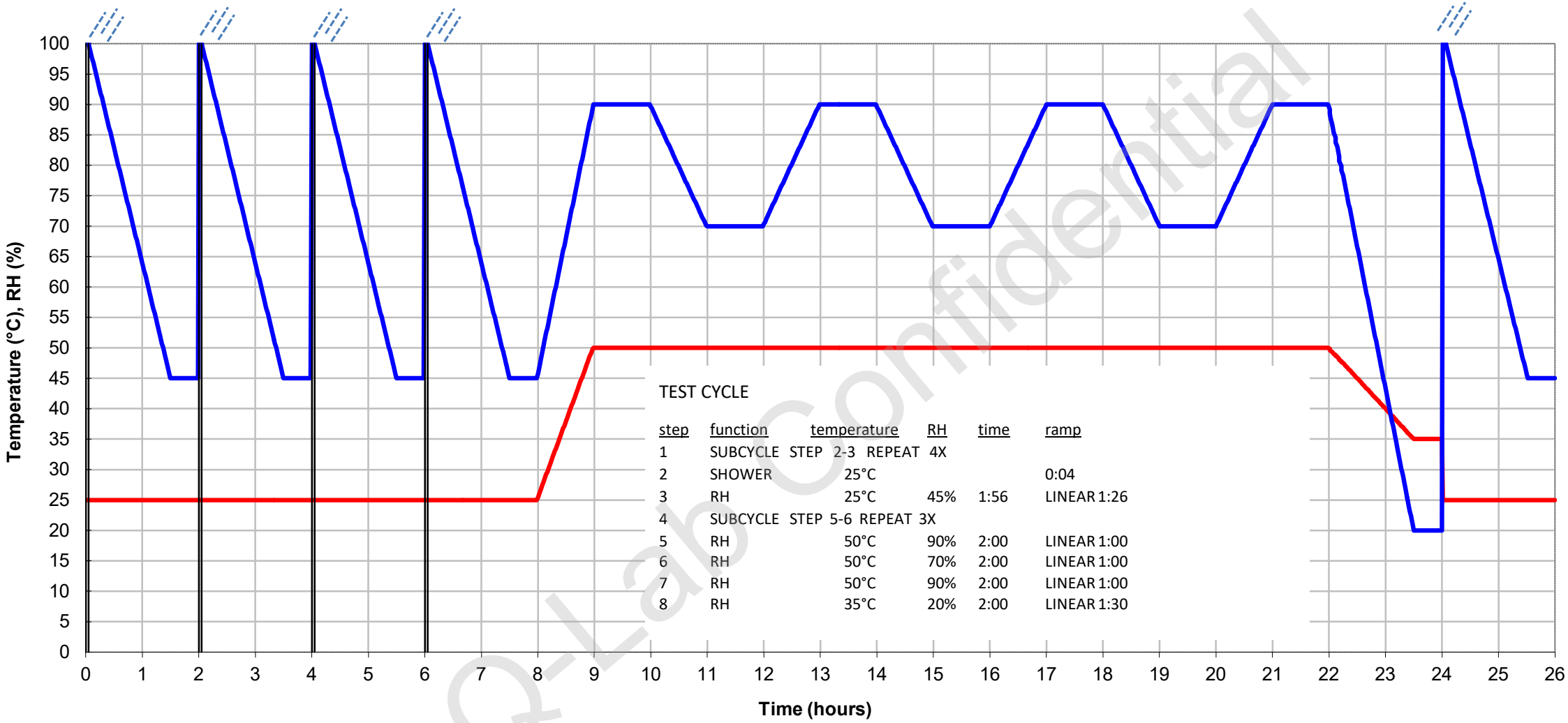
Step	Function	Chamber air temp (℃)	RH (%)	Step time (hh:mm)	Ramp	Ramp time (hh:mm)
1	Subcycle: repeat steps 2-3 4x					
2	Shower	25		0:04		
3	RH	25	45	1:56	Linear	1:26
4	Subcycle: repeat steps 5-6 3x					
5	RH	50	90	2:00	Linear	1:00
6	RH	50	70	2:00	Linear	1:00
7	RH	50	90	2:00	Linear	1:00
8	RH	35	20	2:00	Linear	1:30
9	Final step – go to step 1					

Note: solution: Sodium Chloride (NaCl): 1%, pH = 4.0,
Shower deposition: 39 ml ~ 79 ml @ 80 cm^2。

Color Code
Chamber Temperature
Chamber Relative Humidity

CATCH Cycle

Test Solution:
1% NaCl, pH = 4.0 or 3.0 by addition of sulfuric acid (H_2SO_4), 0.5M



TEST CYCLE

step	function	temperature	RH	time	ramp
1	SUBCYCLE STEP 2-3 REPEAT 4X				
2	SHOWER	25°C			0:04
3	RH	25°C	45%	1:56	LINEAR 1:26
4	SUBCYCLE STEP 5-6 REPEAT 3X				
5	RH	50°C	90%	2:00	LINEAR 1:00
6	RH	50°C	70%	2:00	LINEAR 1:00
7	RH	50°C	90%	2:00	LINEAR 1:00
8	RH	35°C	20%	2:00	LINEAR 1:30

Q-FOG CRH cyclic corrosion chamber

Outdoor accelerated corrosion

Spray salt water

Typical corrosion morphology of aluminum alloy composite coating

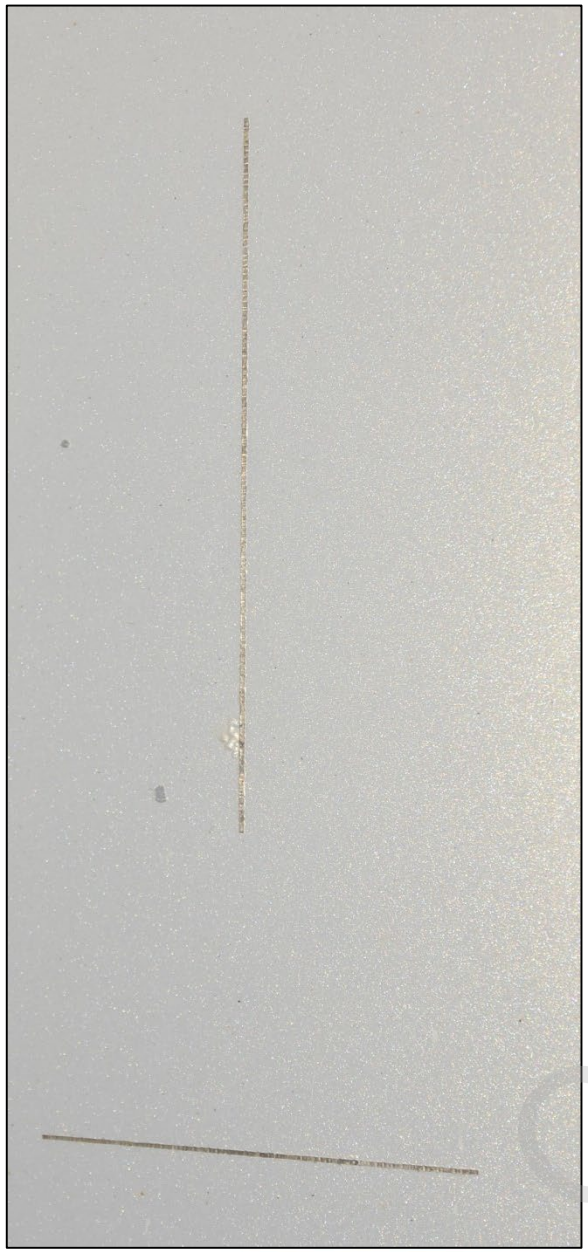
Type	Description
A	Filiform corrosion—individual filaments
B	Filiform corrosion -- Multiple filaments which form a network and spread out from the scribed line
C	Single or multiple corrosion blisters from the scribed line
D	Other forms of corrosion, usually a combination of the above three types

Filiform Corrosion

Test specimen – spray salt water

Outdoor accelerated corrosion

Road-enhanced corrosion

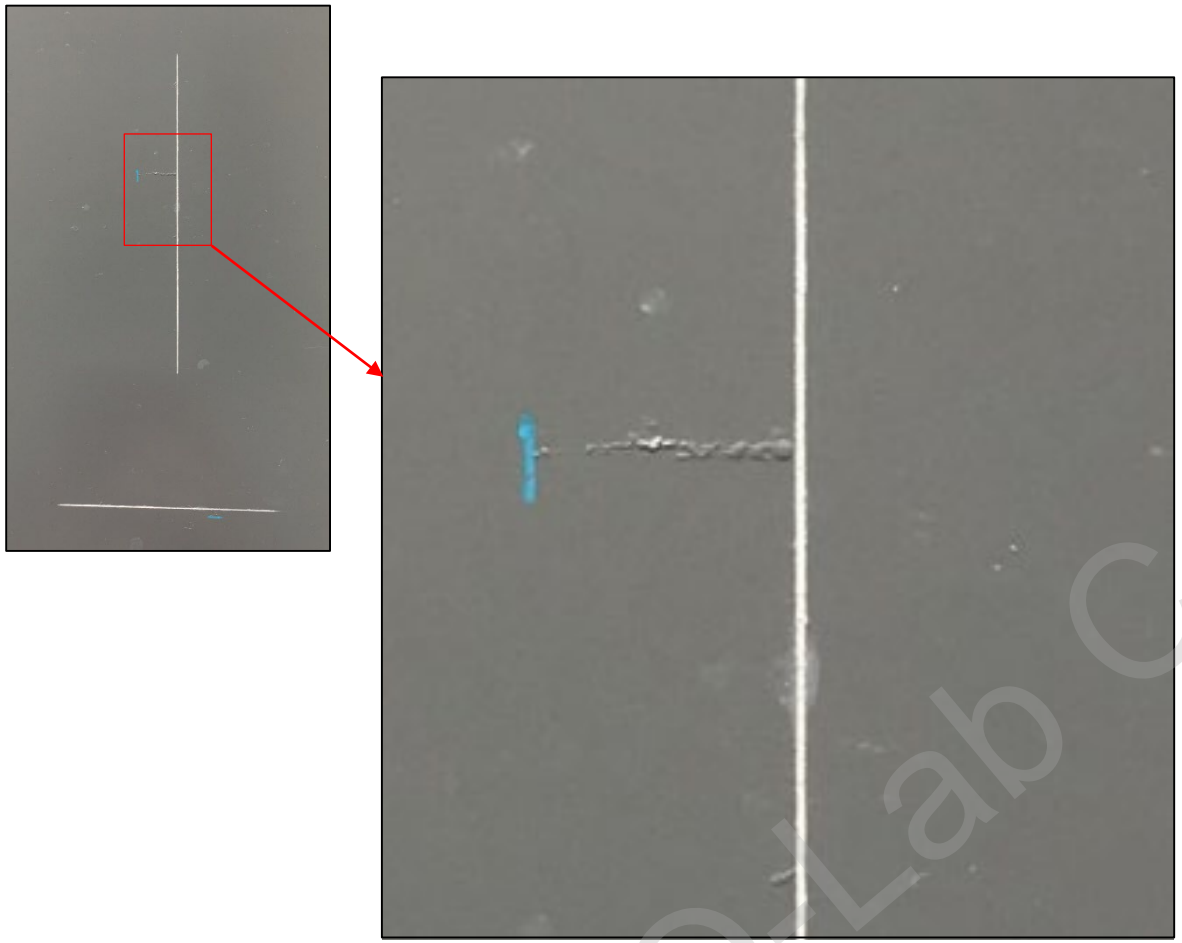


Road-Enhanced Corrosion

Test specimen

Good performer

Corrosion Morphologies A&B



Corrosion morphology – Type A

Corrosion morphology – Type B

Corrosion Morphologies C&D

Corrosion morphology – Type C

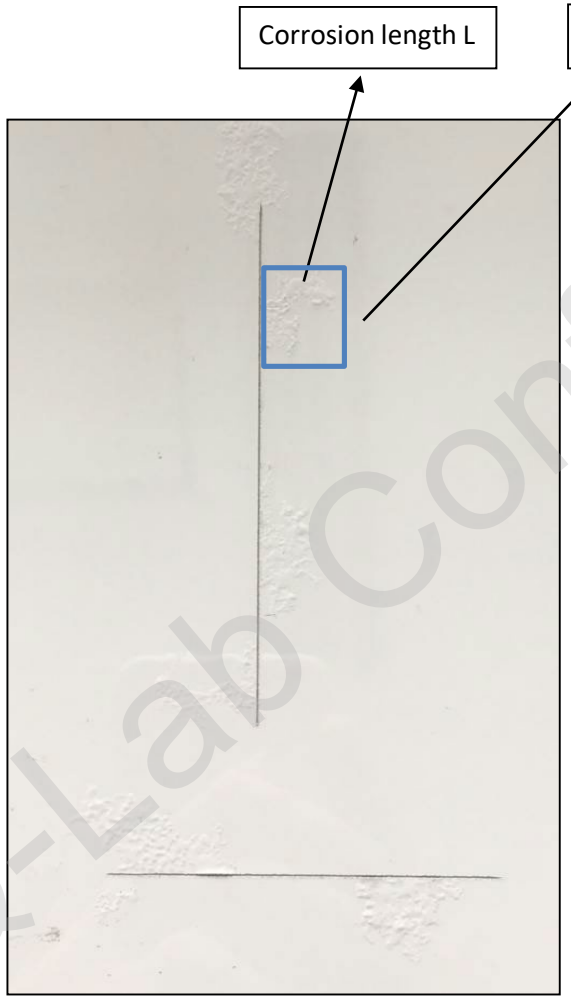
Corrosion morphology – Type D

Test results

- One set of specimens tested by road enhanced corrosion
  - 120 cycles (120 days)
  - Compared with lab accelerated corrosion test methods

- A different set exposed to salt spray enhanced natural test
  - 12 months
  - Compared with lab accelerated corrosion test methods

Test results



Calculate the corrosion area:
Corrosion area = L * W

Manually or using photography and CAD software

First round test

Example Test results – corrosion area

Specimen no.	Road enhanced corrosion	CASS	AASS	Filiform	CATCH
12	0	9.83	1.89	2.00	0.50
24	0	4.90	2.23	0.50	0.00
5	0.4	42.30	14.25	3.50	1.00
2	0.5	18.90	7.75	0.00	1.00
14	1	157.70	7.00	5.00	1.50
18	1.4	79.55	3.75	4.50	11.00
16	1.5	59.80	18.33	7.50	13.50
20	3.5	44.50	5.25	3.00	10.50
23	14.25	62.40	15.50	325.00	29.00
21	28.85	59.50	9.50	7.00	17.00

Note: the unit of corrosion area is mm^2

Example Test results – corrosion area

Specimen no.	Spray salt water	CASS	AASS	Filiform	CATCH
35	0.00	3.27	0.00	2.50	0.00
45	10.67	31.57	12.00	9.38	2.33
44	20.00	28.00	10.58	5.12	4.67
50	31.00	33.20	8.25	17.73	9.33
47	73.67	65.93	171.08	10.32	108.67
46	53.67	356.00	392.33	35.87	102.00
42	133.00	362.53	2104.58	193.95	194.33
41	718.33	1507.67	3554.25	30.13	516.33
37	1750.67	615.00	2698.00	5.17	316.33

Note: the unit of corrosion area is mm^2

Correlation

- Comparison of pass/fail results
  - True pass and fail results, chamber versus outdoor tests
  - False pass and fail results, chamber versus outdoor tests

- Spearman Rank Correlation Coefficient
  - Pearson correlation inappropriate due to non-linearity of dataset (2-3 orders of magnitude between best and worst performers)
  - Complete data and subsets examined

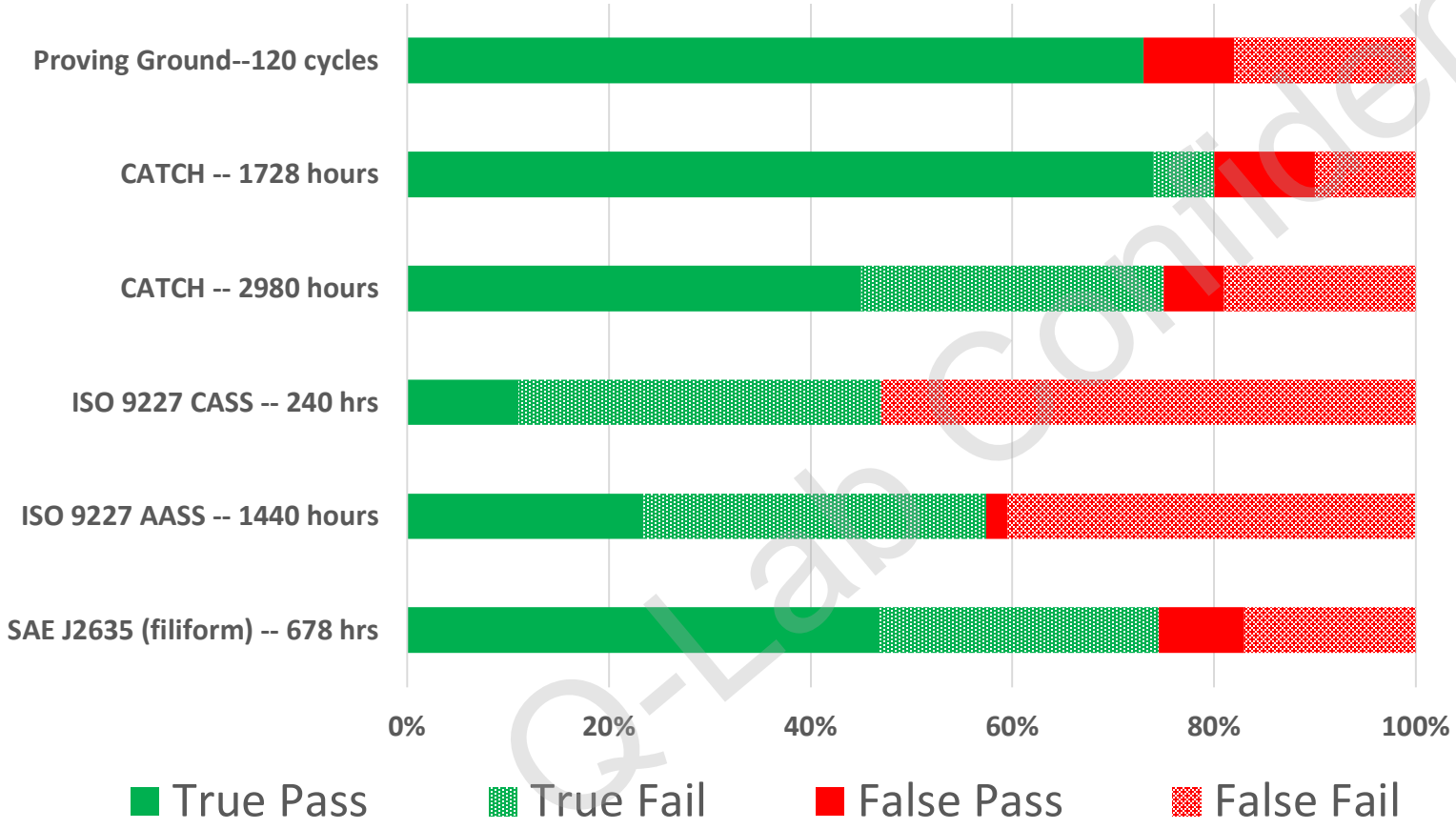
Spearman Rank

Test Method	Correlation vs Outdoor Salt Spray	Correlation vs Proving Ground
Outdoor Salt Spray	1.0	0.58
Proving Ground	0.58	1.0
CATCH 1728 hours	0.71	0.56
CATCH 2980 hours	0.79	0.52
CASS (ISO 9227) 240 hours	0.69	0.30
AASS (ISO 9227) 1440 hours	0.66	0.07
SAE J26353 (filiform) 678 hours	0.48	0.05

CATCH is best, but why not use simpler and faster CASS and AASS tests?

Pass/Fail Correlation

Pass/Fail Compared to Salt Accelerated Outdoor



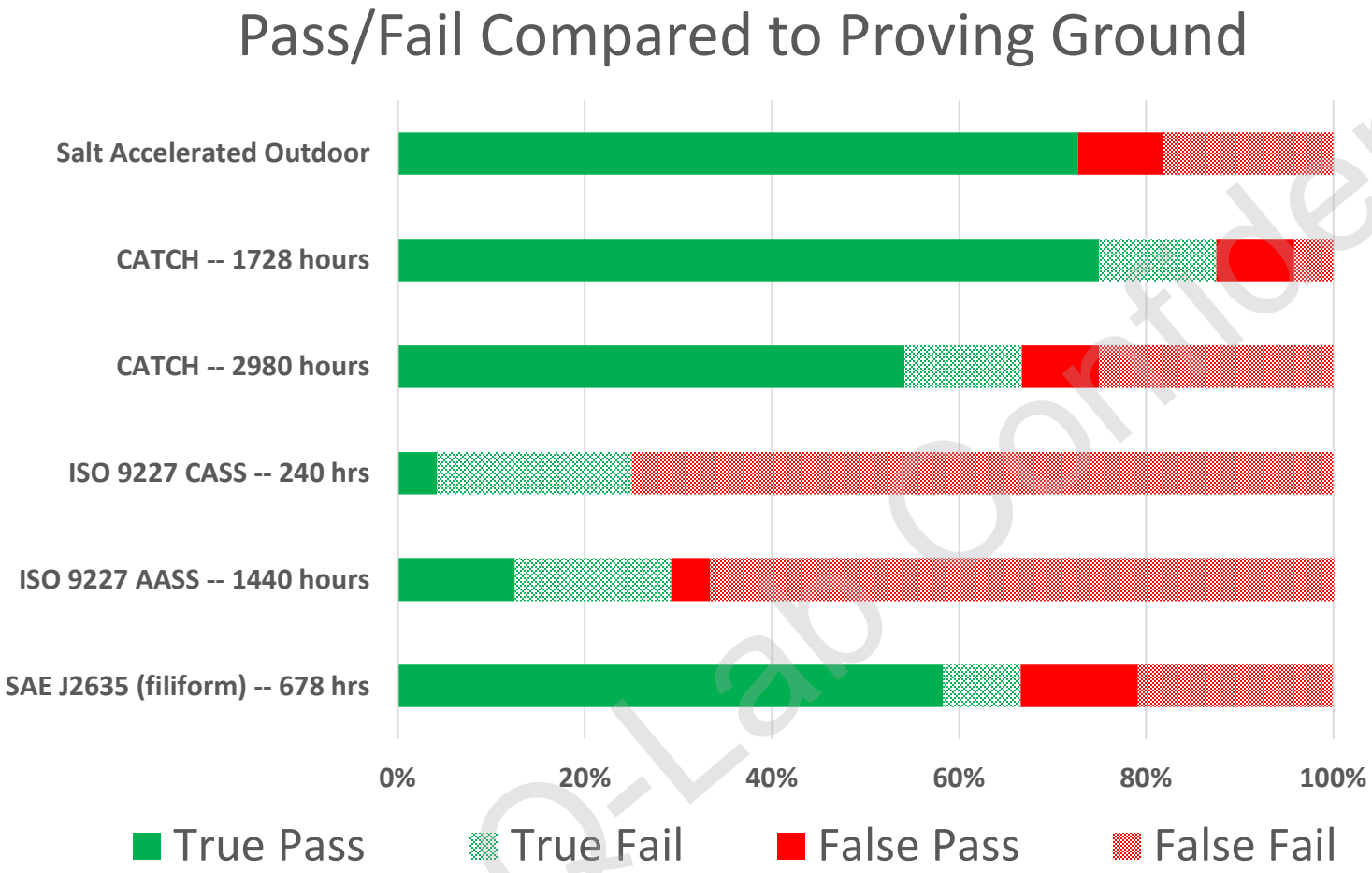
Green means agreement between outdoor test and chamber test

Red means that outdoor test and chamber test do not give same pass/fail results

Solid colors refer to specimens that passed the chamber test

Textured colors refer to specimens that failed the chamber test

Pass/Fail Correlation



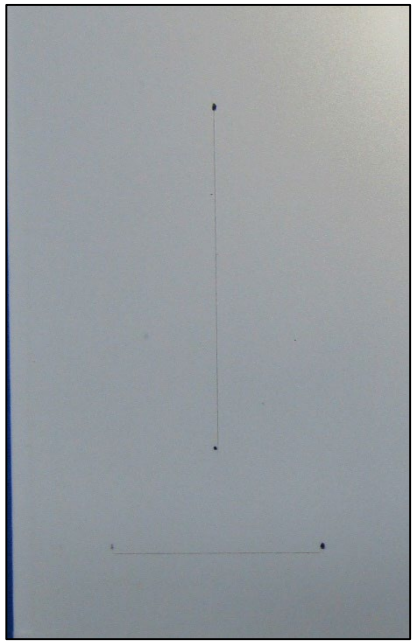
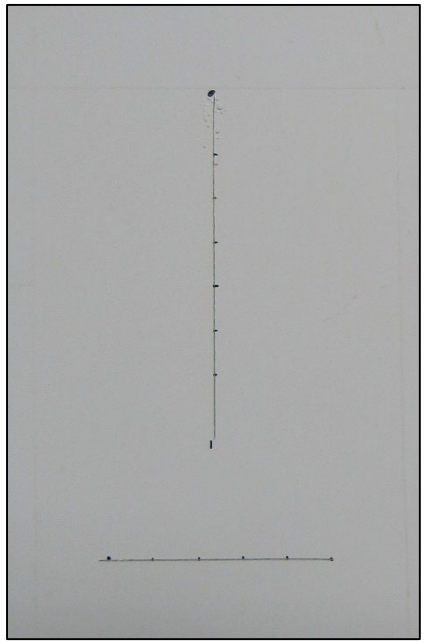
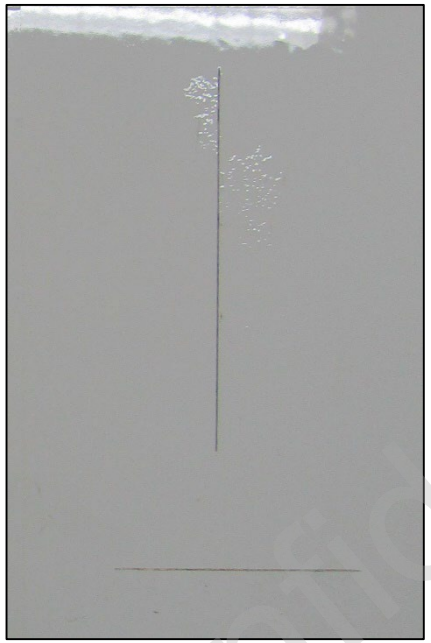
Green means agreement between outdoor test and chamber test

Red means that outdoor test and chamber test do not give same pass/fail results

Solid colors refer to specimens that passed the chamber test

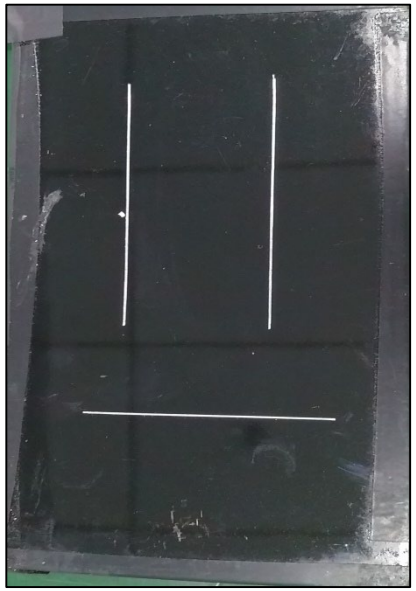
Textured colors refer to specimens that failed the chamber test

CATCH results

Aluminum panels:
CATCH - 2980 h

(from left to right:
good, middle, bad)

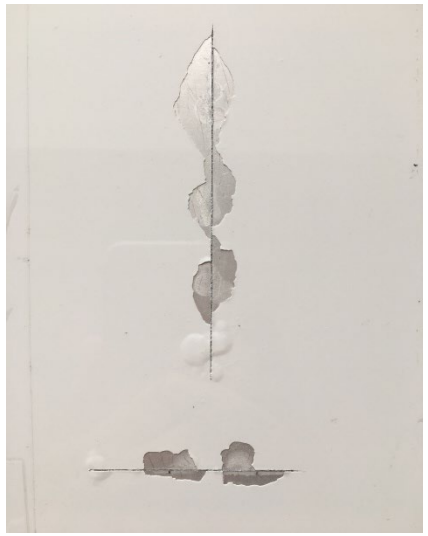
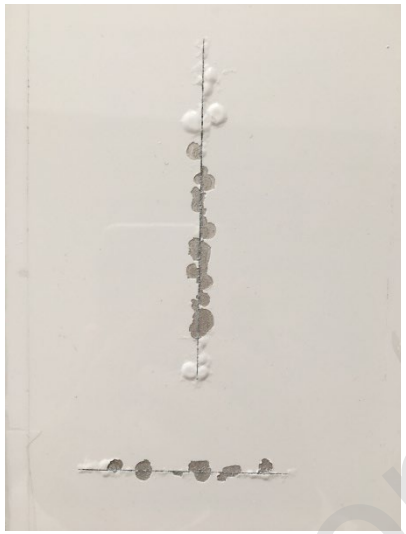
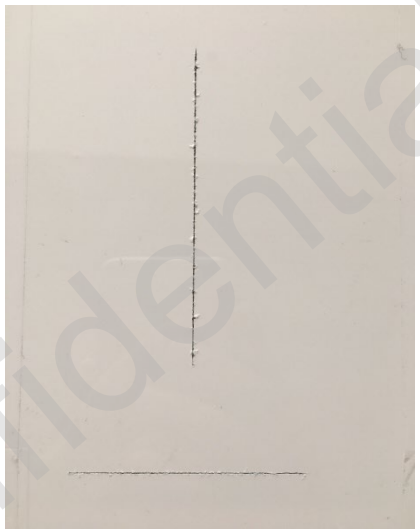


Steel panels:
CATCH - 1728 h

(from left to right:
good, middle, bad)

Corrosion morphology comparison

Specimen 41 | **Specimen 46** | **Specimen 44**

CASS
240 hours



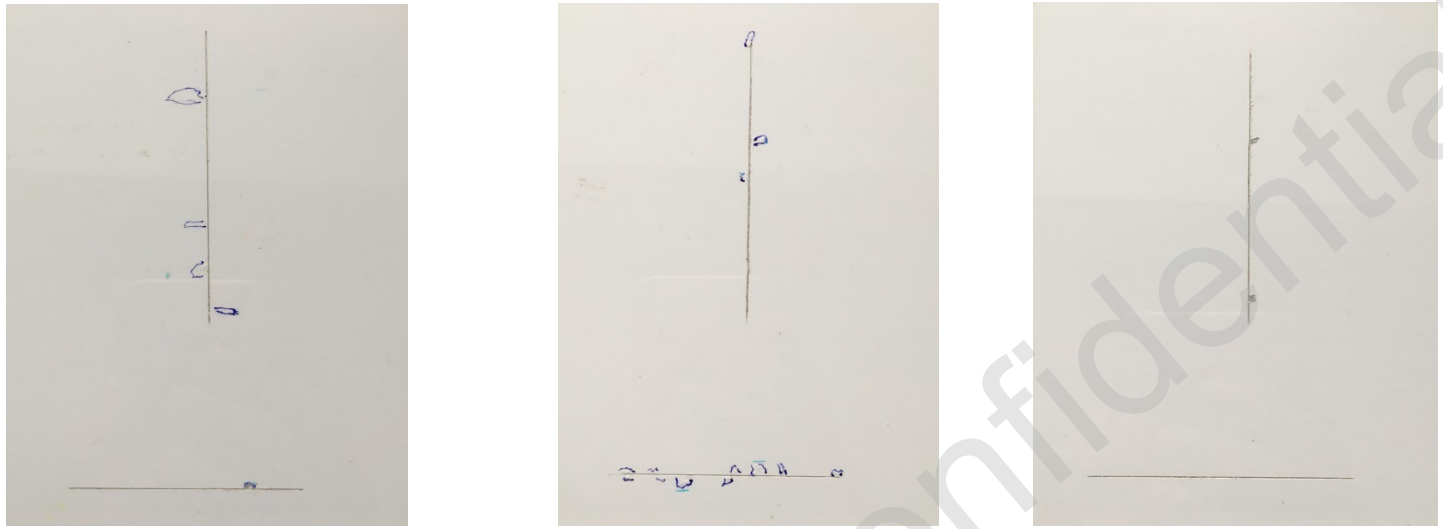
Spray salt water
12 months

Corrosion morphology comparison

Specimen 41	Specimen 46	Specimen 44	
			**AASS 1980 hours**
			**Spray salt water 12 months**

Corrosion morphology comparison

Specimen 41 **Specimen 46** **Specimen 44**

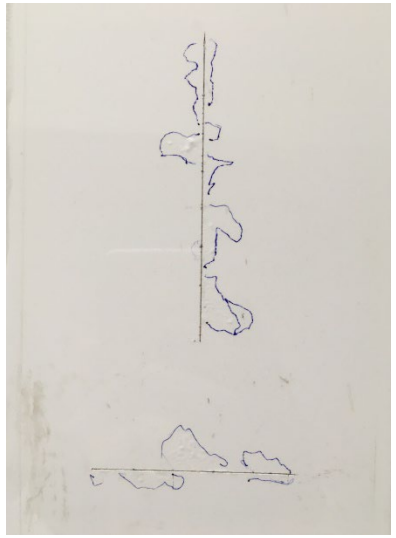
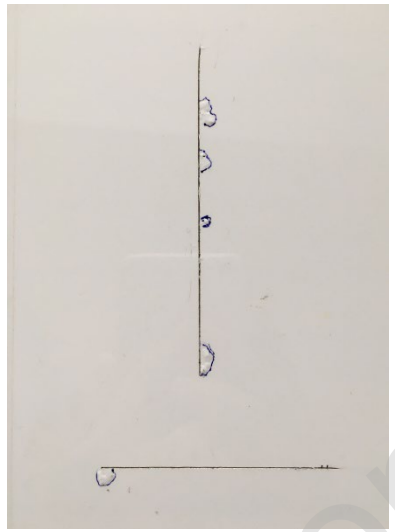


Filiform
678 hours

Spray salt water
12 months

Corrosion morphology comparison

Specimen 41 | **Specimen 46** | **Specimen 44**


CATCH
2980 hours



Spray salt water
12 months

Summary of first round test

- From the test results of CATCH, we can see that the anti-corrosion performance of aluminum panels is better than that of steel panels.
- CATCH test method produces similar corrosion morphology to outdoor spray salt water, and the correlation is good
- The anti-corrosion performance of coated aluminum panels is closely related to electrophoresis, surface treatment and substrate, but not finish type.
- The corrosion morphology of aluminum panels is quite different from that of steel panels. Evaluation method of aluminum panels is calculating corrosion area.
- “Protection is adhesion”, it is recommended to use pressure cooker adhesion test as a pre-screening tool.

Analysis of first round test results

- There are differences of corrosion morphology between different test methods
- CATCH test method is consistent with the test design
- CATCH test method delivers similar corrosion morphology with outdoor spray salt water, and the correlation is good
- CATCH test method has good correlation with road enhanced corrosion, too

Pressure Cooker as Screening Tool

Test Method	Time (hours)	Correlation vs Outdoor Salt Spray	Correlation vs Proving Ground
Outdoor Salt Spray		1.0	0.56
Proving Ground		0.56	1.0
CATCH	**1728**	**0.70**	**0.55**
CATCH	2980	0.65	0.50
CASS (ISO 9227)	240	0.52	0.30
AASS (ISO 9227)	1440	0.45	0.08
SAE J26353 (filiform)	678	0.29	0.04

- 1 hour screening test eliminates worst performers and reduces need for the other screening tests
- With remaining specimens, Spearman values remain high for CATCH but decrease for other methods

Second round test

- The correlation between CATCH and outdoor spray salt water, road enhanced corrosion is good, but the CATCH test method is slow
  - CATCH 1728 h (2.4 months) or 2980h (4.1 months)
  - Outdoor spray salt water 12 months
- CASS, AASS, and J2635 tests suggest reduction of pH to accelerate corrosion (3.0 instead of 4.0)

CATCH pH3.0 vs. CATCH pH4.0

pH	3.0					4.0		
Time (hours)	336	600	864	1296	1728	864	1296	1728
A	0.00	0.45	0.72	1.67	2.65	0.13	0.65	0.99
B	0.00	0.05	0.16	0.29	0.49	0.00	0.00	0.00
C	0.00	0.50	1.11	1.60	2.49	0.00	0.00	0.06
D	0.00	0.09	0.18	0.20	0.80	0.00	0.00	0.00
E	0.17	0.23	0.59	0.98	1.56	0.17	0.35	0.56
F	0.43	0.72	0.98	1.05	2.22	0.21	0.50	0.88
G	1.18	1.63	1.92	2.40	4.11	0.50	0.98	1.76
H	2.67	7.48	9.51	14.55	20.77	2.53	4.84	6.76
I	0.00	0.59	0.92	1.43	3.24	0.00	0.26	0.29
J	0.72	1.66	2.88	5.30	7.80	0.48	0.79	1.02
Total	5.17	13.40	18.99	29.45	46.12	4.02	8.39	12.33

Note: the unit of corrosion area is mm^2

CATCH pH3.0 vs. CATCH pH4.0

- The corrosion area of CATCH pH3.0 600h matches CATCH pH4.0 at 1728h
- The correlation coefficient between CATCH pH3.0 600h and CATCH pH4.0 1728h is 0.87

CATCH 3.0 Correlation

Spearman Rank Coefficient	CATCH 3.0 - 600h	CATCH 3.0 - 864h	CATCH 3.0 - 1296h	CATCH 3.0 - 1728h
Proving Ground	0.73	0.72	0.82	0.8
CATCH 4.0 1728 hrs	0.87	0.77	0.84	0.84

Conclusion

- SAE China published CATCH 3.0 as a new standard: **T/CSAE 130-2020**
- 672 hours exposure recommended
- 1 hour “pressure cooker” test for pre-screening

Thank you!

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21 Apr	ASTM D7869: Modern Weathering Test Protocol for Transportation Coatings
28 Apr	Light Stability Testing of Home and Personal Care Products
05 May	Importance of water delivery in accelerated weathering testing
12 May	Correlation in Accelerated Weathering Testing