Corrosion Accelerated Test with Controlled Humidity (CATCH)
控制湿度腐蚀加速试验

Testing for aluminum materials in automotive applications
汽车用铝材的测试

Sunny Sun | 孙杏蕾

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Content 内容

- Background and participants 背景介绍与参与单位
- Specimens & evaluations 试样与评估
- Steel substrate results 钢基材试验结果
- Aluminum substrate results 铝基材试验结果
- Acid-accelerated testing 酸加速试验

Background 背景

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

SAE中国于2016年开始研发一种新的腐蚀试验方法

- Reduce redundant testing within domestic market 减少冗余测试
- Observe best practices from global OEM testing 关注全球OEM测试的最佳实践
- Develop test that could be used for validation and QC 试验可用于验证和质量控制
- Start method development focusing on **steel substrates** 方法开发从**钢基材**开始

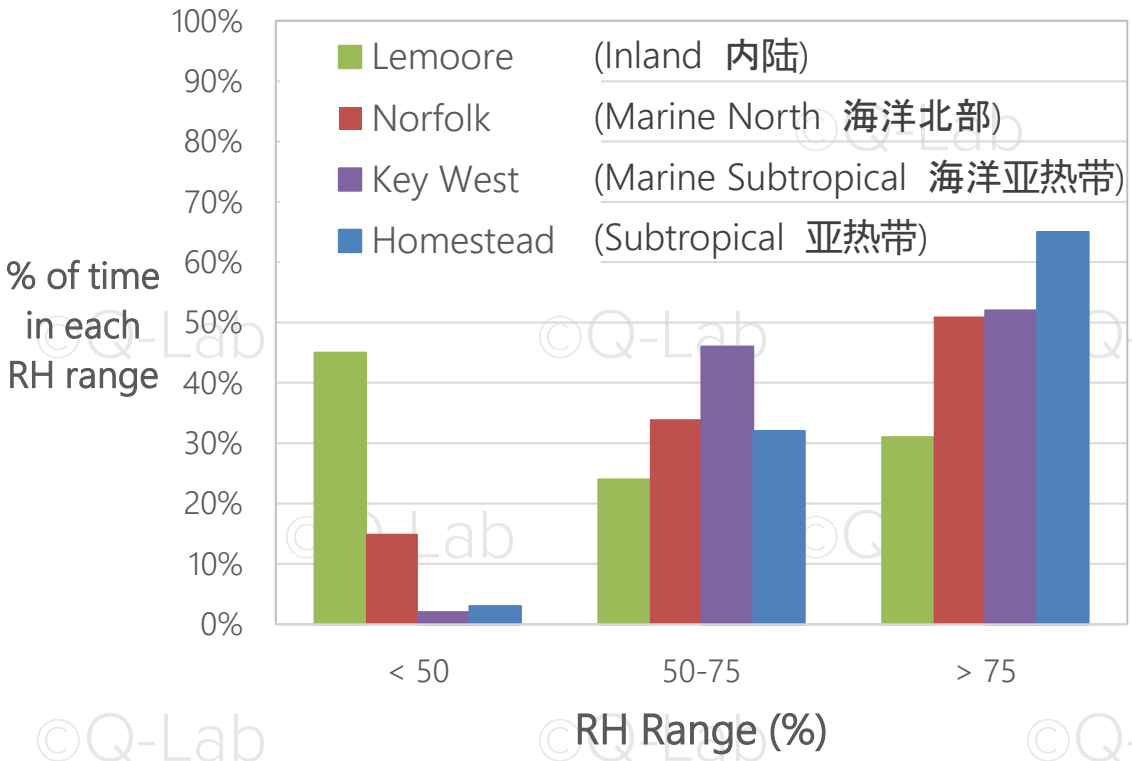
Technical Background 技术背景

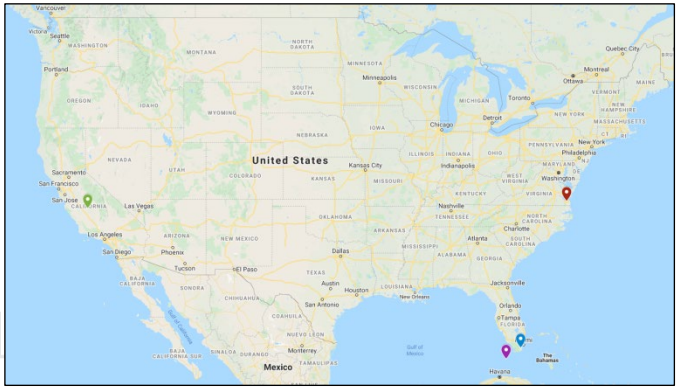
- Relative humidity control is critical to laboratory repeatability
- 相对湿度控制是实验室测试重复性的关键
  - It's also a key determinant of corrosion behavior
  - 也是腐蚀行为的关键决定因素
  - Different RH levels can produce different corrosion mechanisms
  - 不同的相对湿度会产生不同的腐蚀机制
- During last 10-15 years, automotive methods with precise RH control have become popular
- 在过去的10-15年中，带精确相对湿度控制的汽车试验方法已常见

Relative Humidity and Galvanic Corrosion 相对湿度与电偶腐蚀

Condition 条件	RH Range 相对湿度范围	Result 结果
Dry 干燥	≤ 50%	Very little corrosion from NaCl 几乎不发生腐蚀
Electrolytic cells near salt crystals; film formation as RH increases 随着相对湿度增加，薄膜形成	50-76%	• Corrosion of steel and aluminum • 钢和铝都可能发生腐蚀 • Al-Steel galvanic couple broken • 未形成铝-钢电偶腐蚀
Uniform Electrolytic Film formation 均匀的电解液形成	≥76%	• Maximum cathode area for steel • Deeper non-uniform corrosion • Al corrosion in galvanic couple with steel • 铝-钢电偶腐蚀形成，铝发生腐蚀

RH Conditions in the Natural Environment 自然环境中的相对湿度





Summary of Environmental Conditions

First-Generation Cyclic Automotive Standards

第一代循环汽车标准中的环境条件概述

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

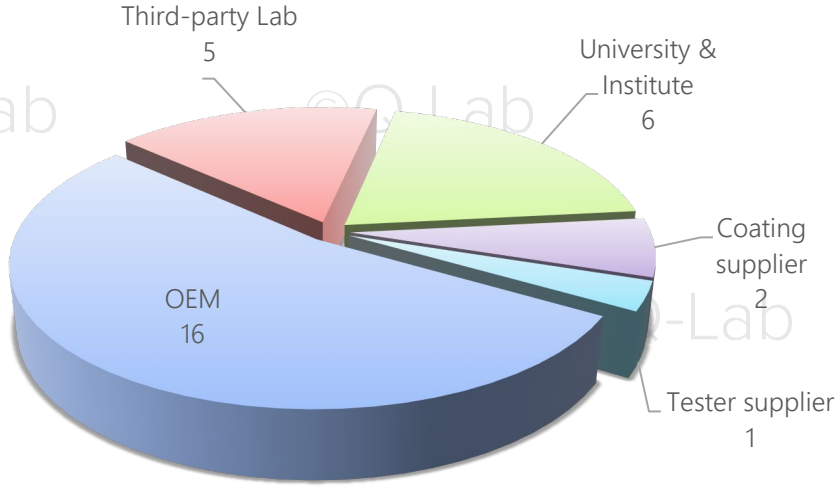
Modern Automotive Corrosion Standards 现代汽车腐蚀标准中的环境条件

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% of cycle <30%)	**15%** **(40% of cycle is 30-76%)**	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%

Initial Study: Steel Substrates
最初研究：钢基材

Initial Study Participants 最初研究参与单位

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
Km-Tech - Shanghai
Wuhan University of Science & Technology
University of Science & Technology Beijing



Test Methods & Materials 试验方法与材料

Steel Substrate Study 钢基材研究

Methods

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

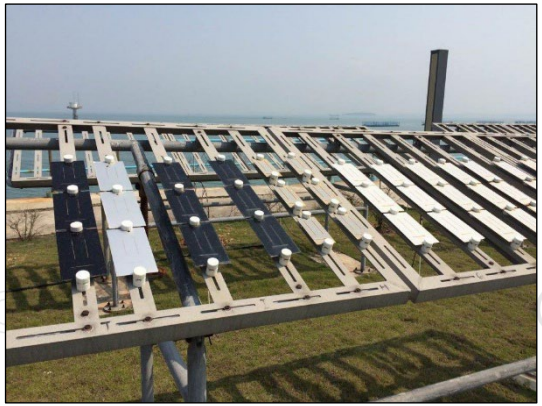
Materials

- 5000 specimens total 样板数量5000片
- Substrates 底材
  - Cold-Rolled Steel (various OEM specifications) 冷轧钢
  - Galvanized sheets 镀锌板
- Pretreatments 前处理
  - 6 Types 6种不同前处理
- Primers 底漆
  - 3 types, or omitted 3种底漆或不涂底漆
- Basecoat/clearcoat (several varieties) 色漆/清漆（几种）

Test Methods Evaluated 试验方法

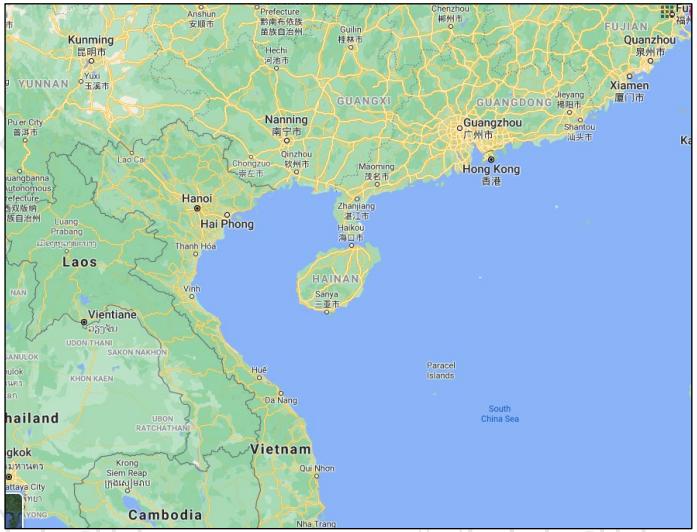
Test Method	ASTM B117	ISO 11997-1 Cycle A	GMW 14872	Ford L-467	PV 1210	CATCH
Total duration (time)	2016 h 84 days	2016 h 84 days	1728 h 72 days	1728 h 72 days	2016 h 84 days	1728 h 72 days

Outdoor Tests 户外试验



Xiamen, China

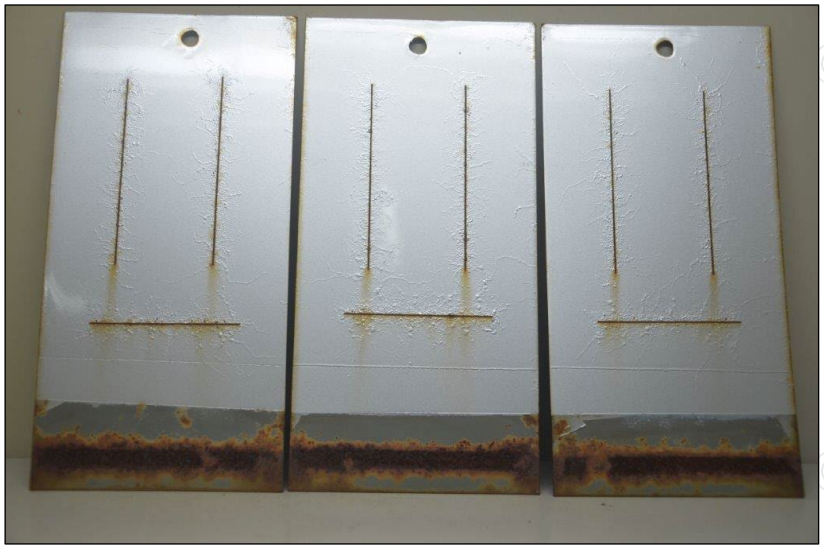
- Oceanfront Racks
- 12 months
  natural exposure



Hainan Island, China

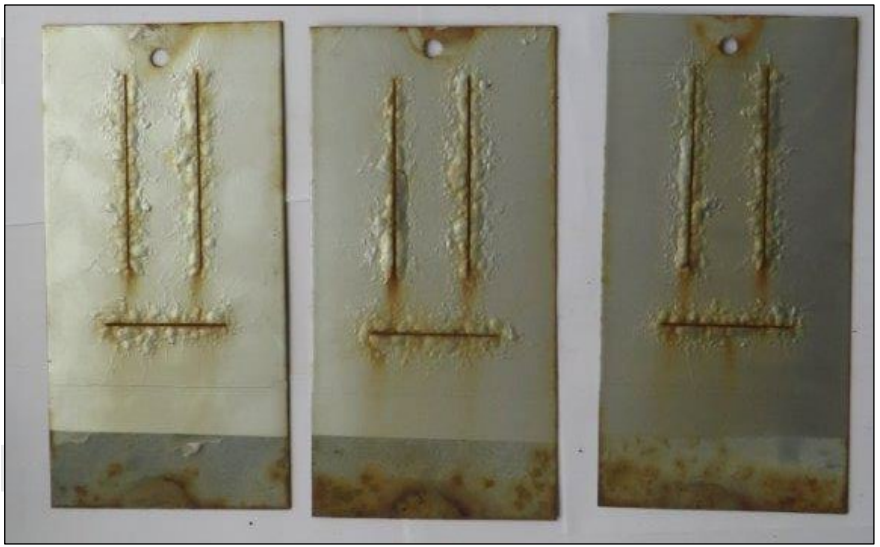
- 12 months, natural
- 21 months, natural
- 12 months, salt spray enhanced

Filiform Corrosion on Steel Panels 钢板上的丝状腐蚀



Subtropical Site (not near ocean) **不靠海**

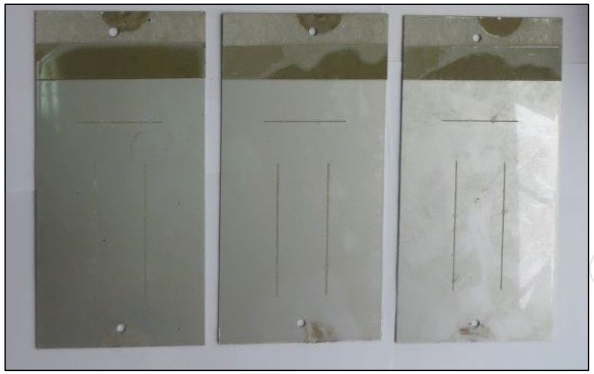
Filiform corrosion 丝状腐蚀



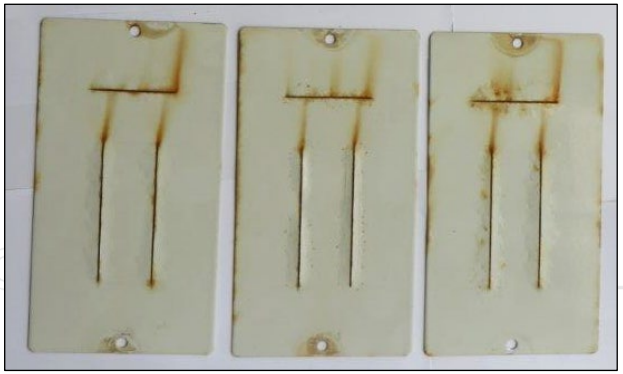
Oceanfront Site **海边**

Blistering, filiform corrosion 起泡, 丝状腐蚀

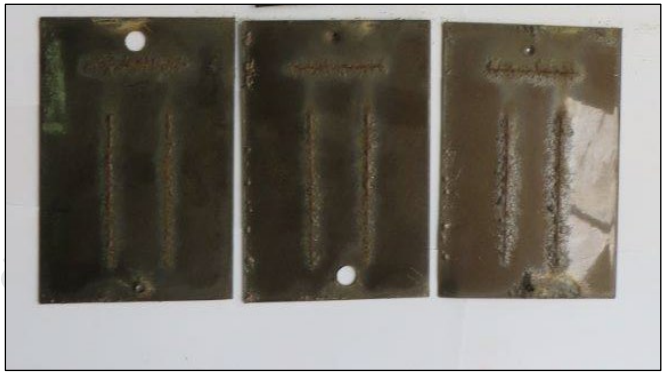
Wide Range of Durability 耐腐蚀性不同



Good



Intermediate



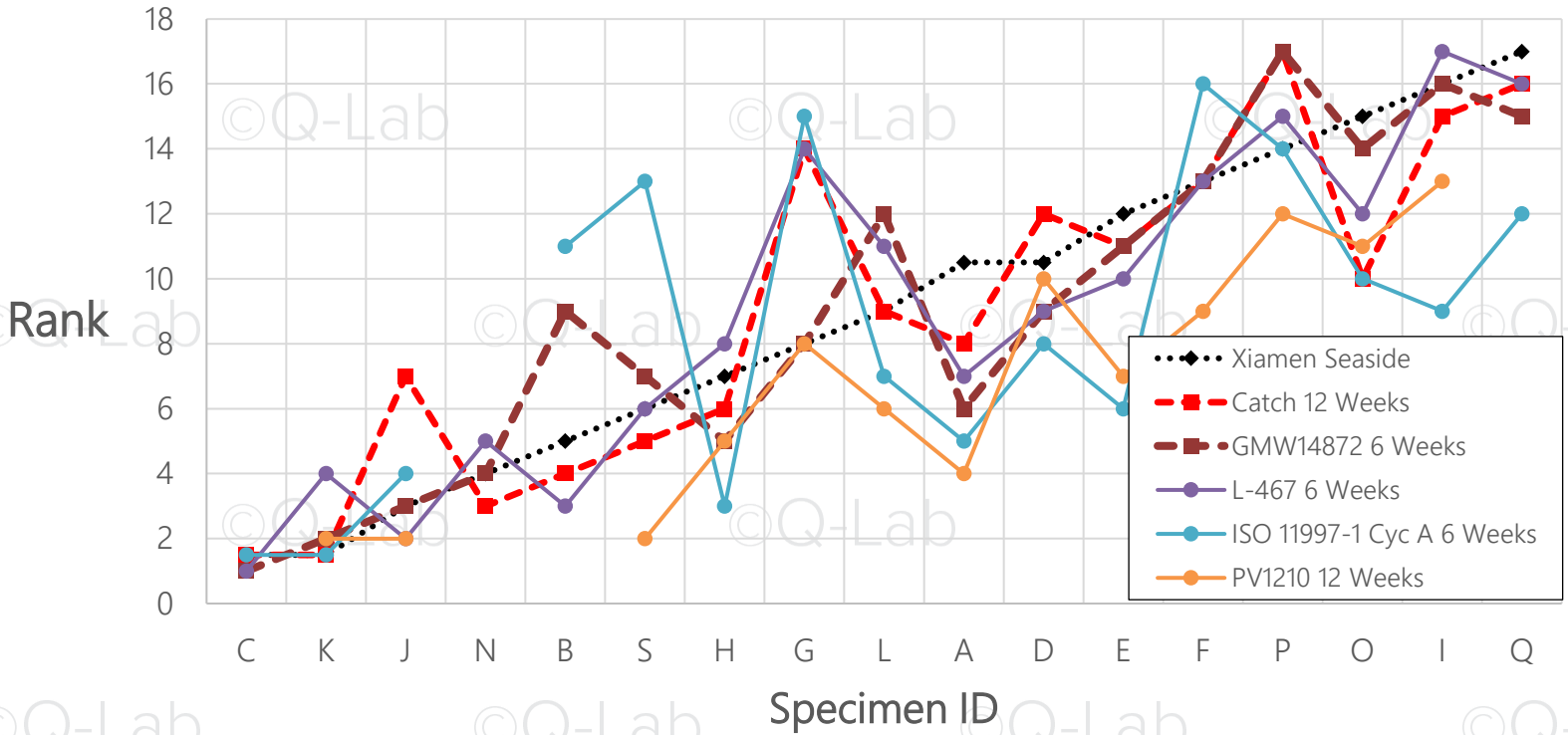
Poor

Spearman Rank 相关性

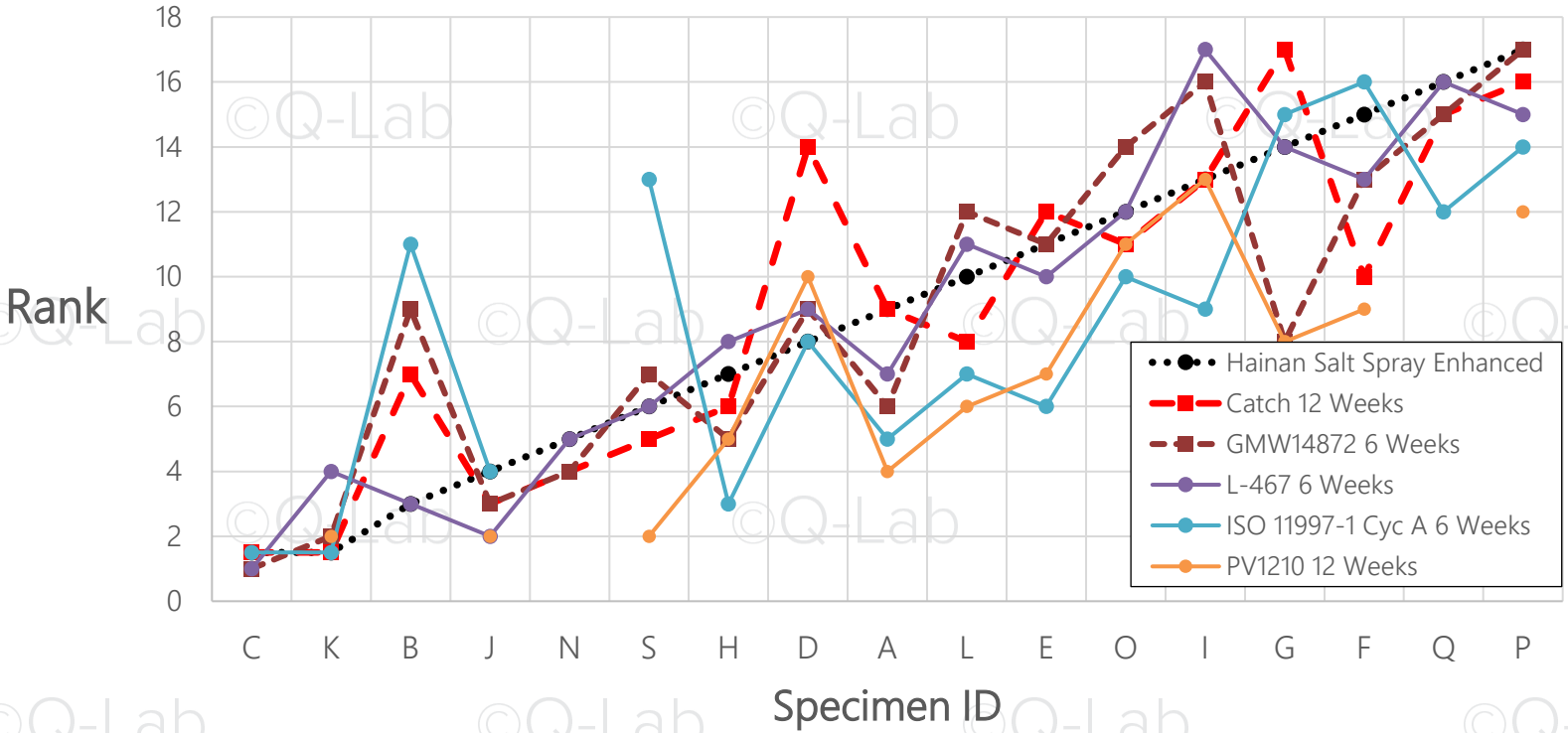
Laboratory versus Outdoor Tests 实验室与户外

Laboratory Test (weeks) →	CATCH		GMW14872		Ford L-467		ISO 11997-1 Cyc A		PV1210
Outdoor Test ↓	6	12	6	12	6	12	6	12	12
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: Xiamen Seaside Exposure



Rank Order: Hainan Salt Spray Outdoor



Aluminum Substrates 铝基材

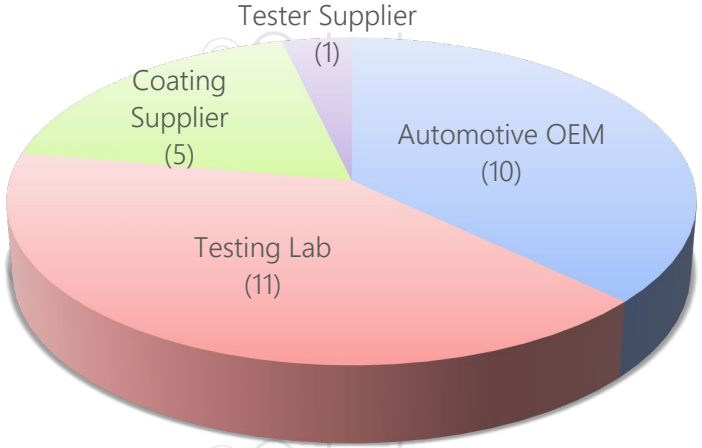
First-round test 第一轮试验

Aluminum Substrate Study 铝基材研究

- Automotive lightweighting efforts are aimed at better efficiency 汽车轻量化旨在提高效率
- There was no clear standard for aluminum body panels 铝车身板没有明确的标准
- Goal: conduct comparison tests between laboratory and outdoor methods in order to achieve:
- 进行实验室与户外比对试验，以实现：
  - Verification of corrosion resistance of aluminum alloy coatings 铝合金涂层耐腐蚀性的验证
  - Performance verification of coatings developed and applied to aluminum alloy substrates
  - 开发并应用于铝合金基材的涂层的性能验证
  - Quality control of anti-corrosion performance for aluminum alloy coating
  - 铝合金涂层防腐性能的质量控制

Participants in This Study 这项研究的参与单位

- Lead company: JAC Auto
- Participant companies (27):
  - **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



Comparison test 比对试验

Two rounds of tests: 一共两轮试验

- **First-round goal**: Achieve acceptable correlation to outdoor tests and pass/fail QC results with good agreement
- 第一轮试验：实现与户外试验的可接受的相关性，且“通过/失效”质量控制结果具有良好的一致性
- **Second-round goal**: Determine if the test can be run faster
- 第二轮试验：确定测试是否可以更快

Test specimens 试样

- 53 different specimens, 1033 panels
- 53种不同试样，一共1033片
- Variables: 试样的差异：
  - **Aluminum Substrate**: 5000 series, 6000 series, different profiles
  - 底材：5000系列，6000系列
  - **Pre-processing:** silane, phosphating, zirconium
  - 前处理：硅烷、磷化、锆化
  - **Electrophoretic coating**: 3 types 电泳：3种
  - **Finish**: 2 types 面漆：2种

Corrosion test methods 腐蚀试验方法

Test method Reference	CASS ISO 9227	AASS ISO 9227	Filiform SAE J2635	CATCH* T/CSAE 71	Outdoor - Spray salt water ASTM D6675	Road enhanced corrosion QC/T 732
Salt solution pH value Deposition rate	NaCl: 50 g/L $CuCl_2$ dehydrate: 0.26 g/L pH = 3.1~3.3 1 ~ 2mL/h	NaCl: 50 g/L pH = 3.1~3.3 1 ~ 2mL/h @80 cm^2	Same as CASS	NaCl: 10 g/L pH = 4.0 39-79 mL/h	NaCl: 50 g/L 2× per week	NaCl: 50g/L
Temperature and RH	50 °C	35 °C	6 hours CASS + 60 °C, 85 %RH	-	-	-
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 cycle

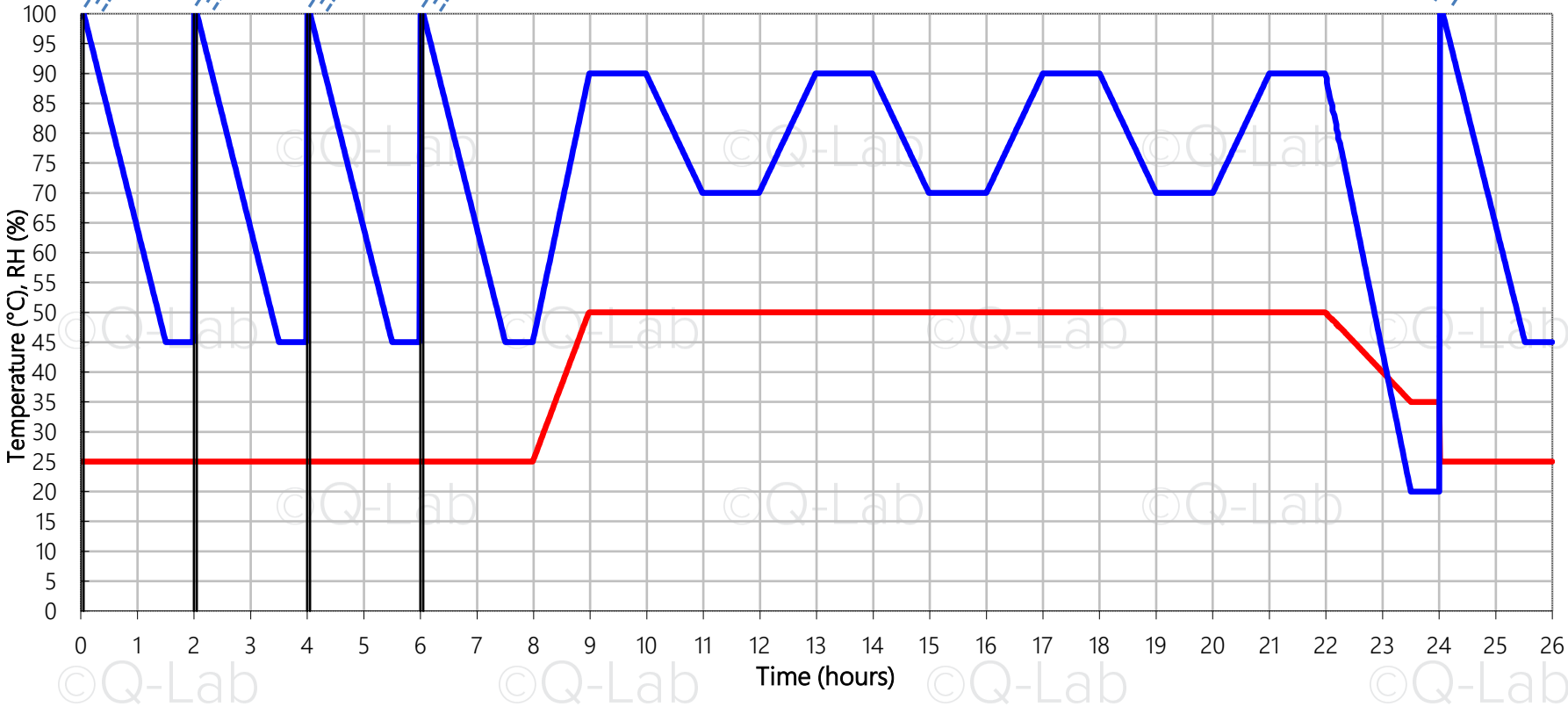
Step	Function	Chamber air temp (°C)	RH (%)	Step time (hh:mm)	Ramp	Ramp time (hh:mm)
1	Subcycle: repeat steps 2-3 4×					
2	Shower	25		0:04		
3	RH	25	45	1:56	Linear	1:26
4	Subcycle: repeat steps 5-6 3×					
5	RH	50	90	2:00	Linear	1:00
6	RH	50	70	2:00	Linear	1:00
7	RH	50	90	2:00	Linear	1:00
8	RH	35	20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

Solution: Sodium Chloride (NaCl): 1% **pH** = 4.0,
Shower deposition: 39-79 mL @ 80 cm^2

CATCH Cycle

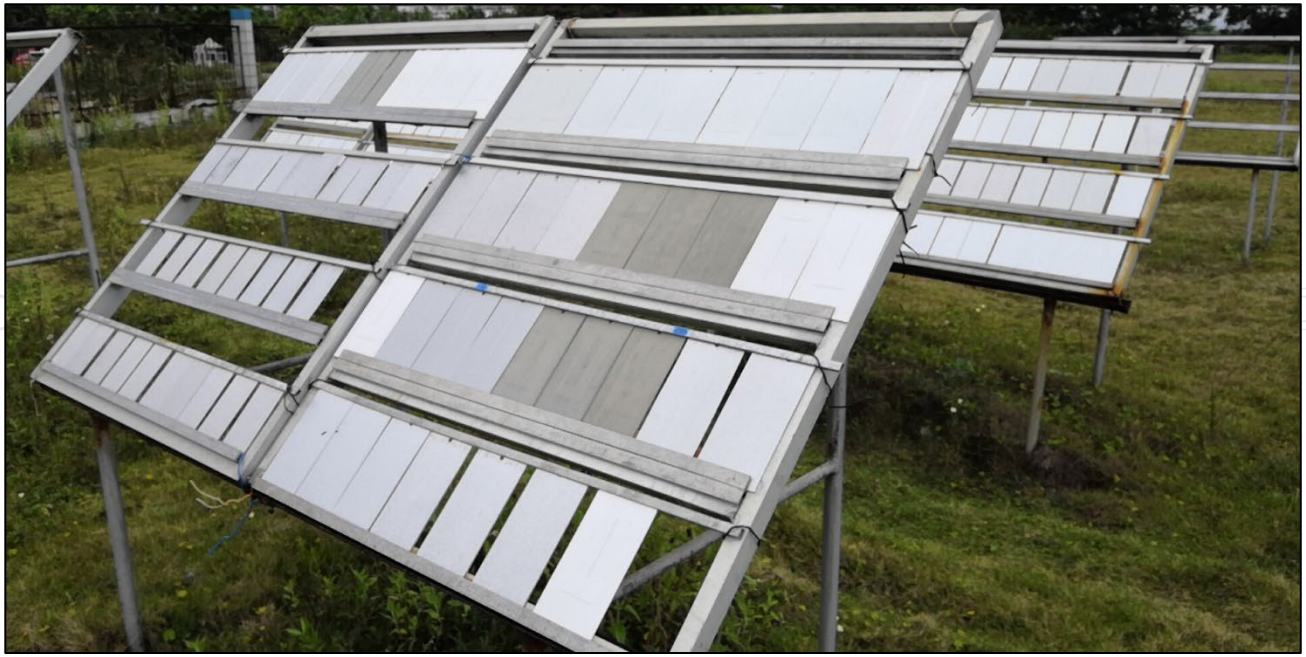
Chamber Temperature
Chamber Relative Humidity

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



Q-FOG CRH cyclic corrosion chamber

Outdoor accelerated corrosion 户外加速腐蚀



Outdoor accelerated corrosion 户外加速腐蚀

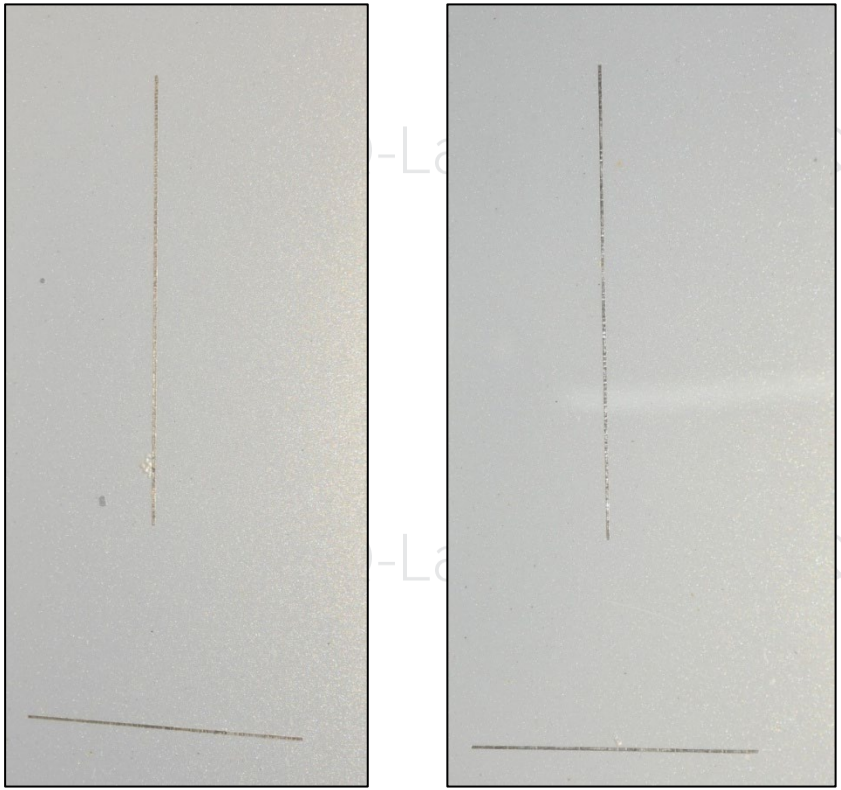
Road-Enhanced Test

道路强化腐蚀

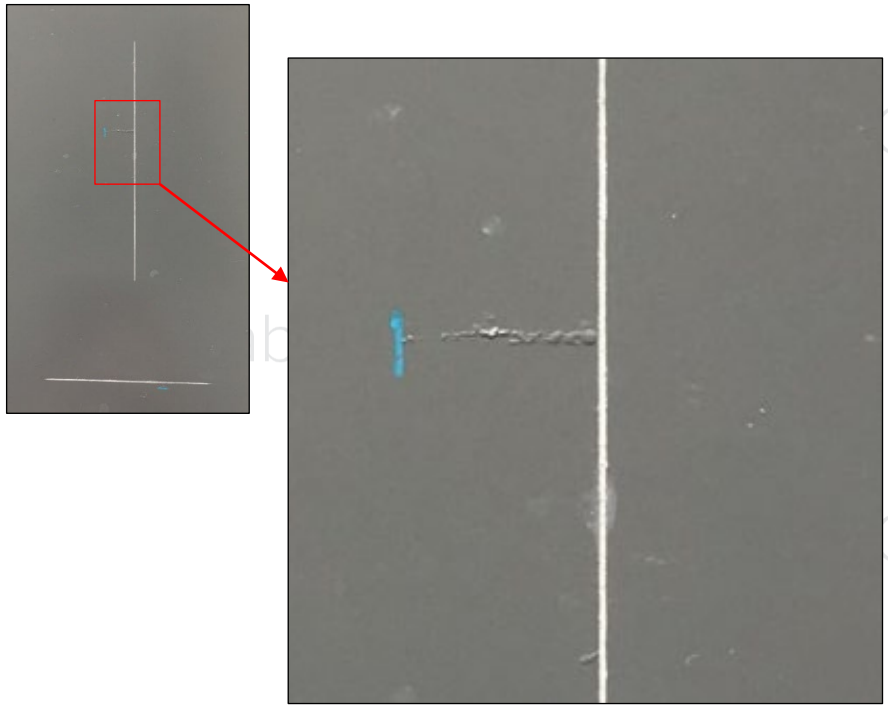
Typical corrosion morphologies of aluminum alloy composite coating
铝板几种常见的腐蚀形貌

Type	Description 描述
A	Filiform corrosion—individual filaments 丝状腐蚀 – 单根丝状腐蚀
B	Filiform corrosion -- Multiple filaments which form a network and spread out from the scribed line 丝状腐蚀 – 多根丝状腐蚀，形成网状，从划痕处向外扩散
C	Single or multiple corrosion blisters from the scribed line 从划痕处长出单个或多个泡状腐蚀
D	Other forms of corrosion, usually a combination of the above three types 其他形式的腐蚀，通常是上述三种的组合

High-Performing Coatings 高性能涂层



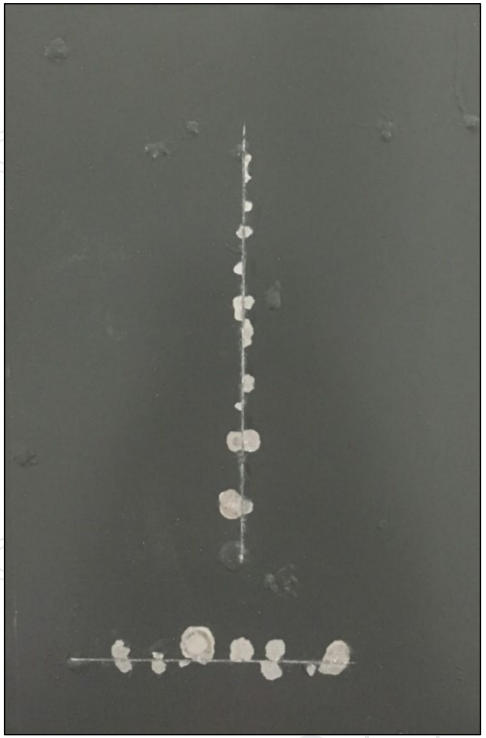
Corrosion Morphologies A&B 腐蚀形貌 – 类型A和B



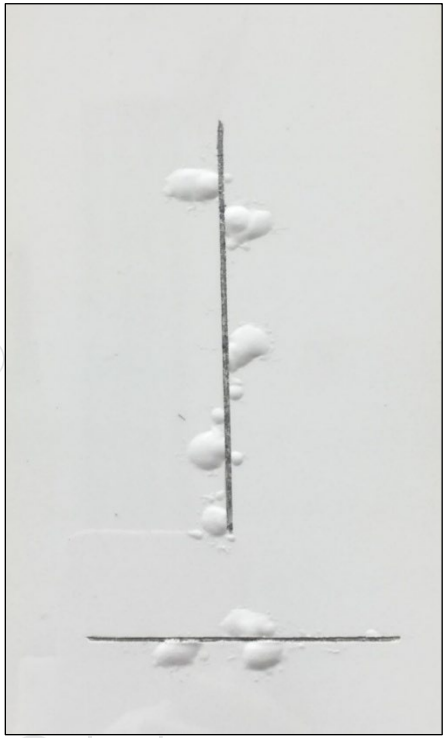
Corrosion morphology – Type A

Corrosion morphology – Type B

Corrosion Morphologies C&D 腐蚀形貌 – 类型C和D



Corrosion morphology – Type C



Corrosion morphology – Type D

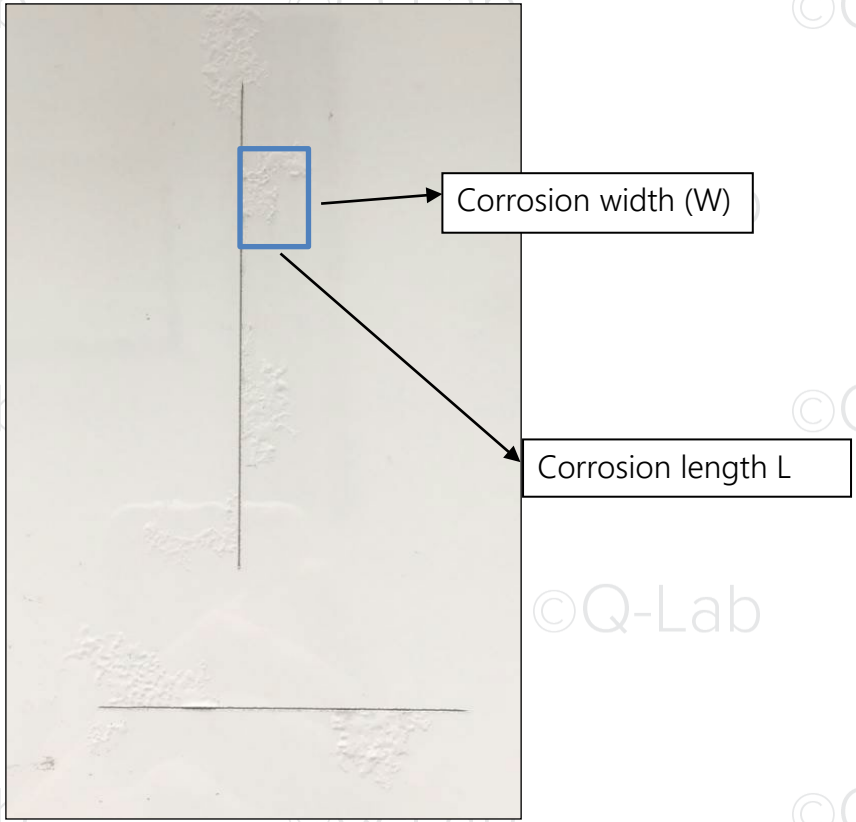
Test results 试验结果

- One set of specimens tested by road-enhanced corrosion – 120 days
- 一组试样进行道路强化腐蚀，120天
- A different set exposed to salt spray enhanced natural test – 12 months
- 另一组试样进行户外人工喷洒盐水试验，12个月
- Both tests compared with lab accelerated corrosion test methods
- 两组户外试验都与实验室加速腐蚀试验方法进行比较

Test results

Calculate the corrosion area:
Corrosion area = L × W
计算腐蚀面积:
腐蚀面积=腐蚀长度×腐蚀宽度

Measure manually or using photography and CAD software
手动测量或使用摄影和CAD软件



Lab tests compared to Road-enhanced test

Specimen no.	Road-enhanced corrosion	CASS	AASS	Filiform	CATCH
12	0	9.8	1.9	2.0	0.5
24	0	4.9	2.2	0.5	0.0
5	0.4	42.3	14.3	3.5	1.0
2	0.5	18.9	7.8	0.0	1.0
14	1.0	157.7	7.0	5.0	1.5
18	1.4	79.6	3.8	4.5	11.0
16	1.5	59.8	18.3	7.5	13.5
20	3.5	44.5	5.3	3.0	10.5
23	14.3	62.4	15.5	325.0	29.0
21	28.9	59.5	9.5	7.0	17.0

Note: the unit of corrosion area is mm^2

Lab tests compared to Salt Water Spray

Specimen no.	Spray salt water	CASS	AASS	Filiform	CATCH
35	0.0	3.3	0.0	2.5	0.0
45	10.7	31.6	12.0	9.4	2.3
44	20.0	28.0	10.6	5.1	4.6
50	31.0	33.2	8.3	17.7	9.3
47	73.7	65.9	171.1	10.3	108.6
46	53.7	356	392	35.9	102.0
42	133.0	363	2104	193.9	194.3
41	718.3	1508	3554	30.1	516.3
37	1750.7	615	2698	5.2	316.3

Note: the unit of corrosion area is mm^2

Correlation 相关性

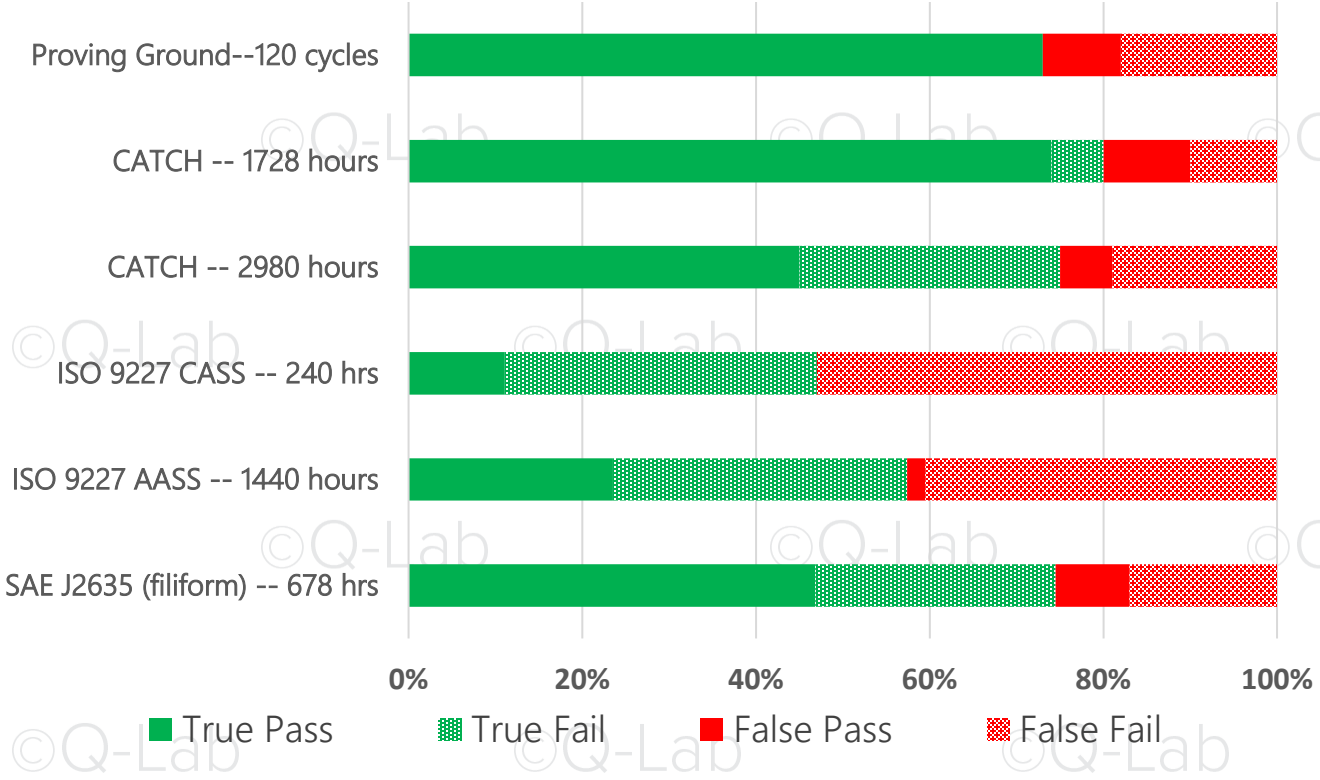
- Comparison of chamber versus outdoor test results
  - True pass/fail
  - False pass/fail
- Spearman Rank Correlation Coefficient 相关系数
  - Pearson correlation inappropriate due to non-linearity of dataset (2-3 orders of magnitude between best and worst performers)
  - Complete data and subsets examined

Spearman Rank

Test Method	Correlation vs Outdoor Salt Spray	Correlation vs Proving Ground
Outdoor Salt Spray	*1.00*	0.58
Proving Ground	0.58	*1.00*
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: Salt-Accelerated Outdoor



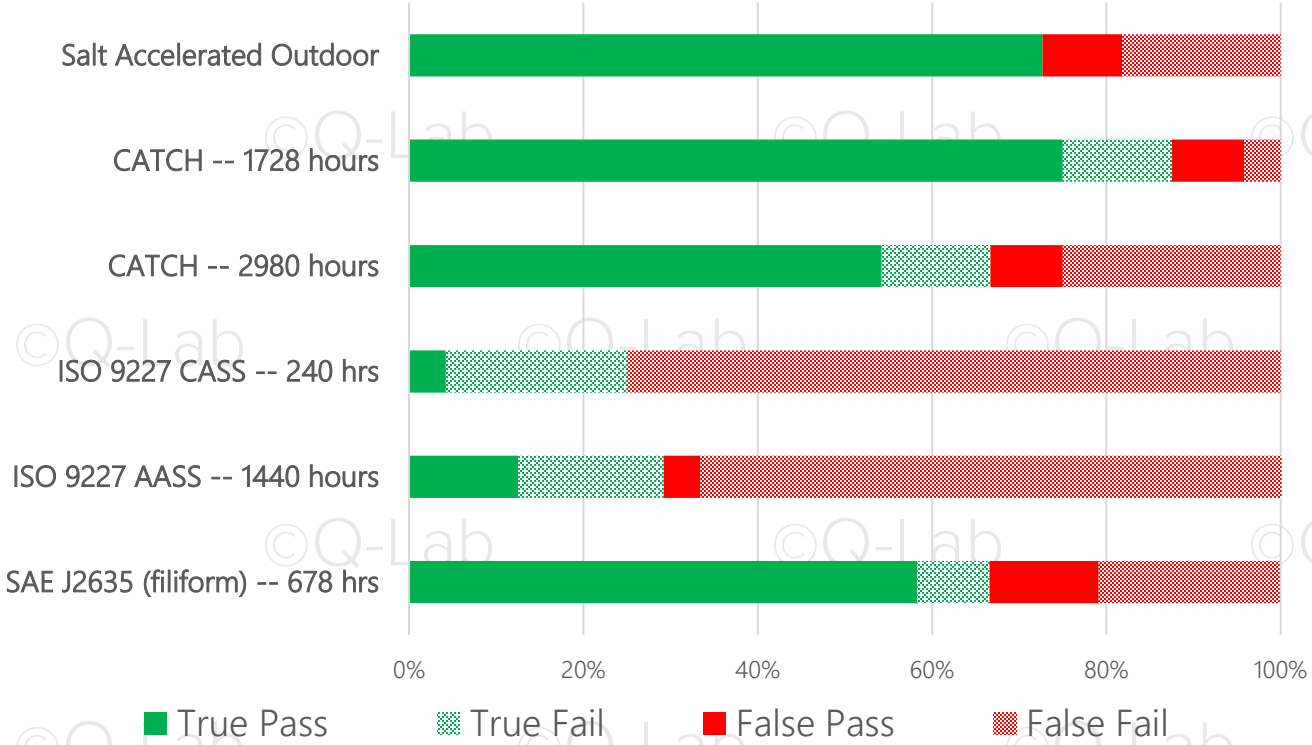
Green means agreement between outdoor test and chamber test

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: Proving Ground



Green means agreement between outdoor test and chamber test

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

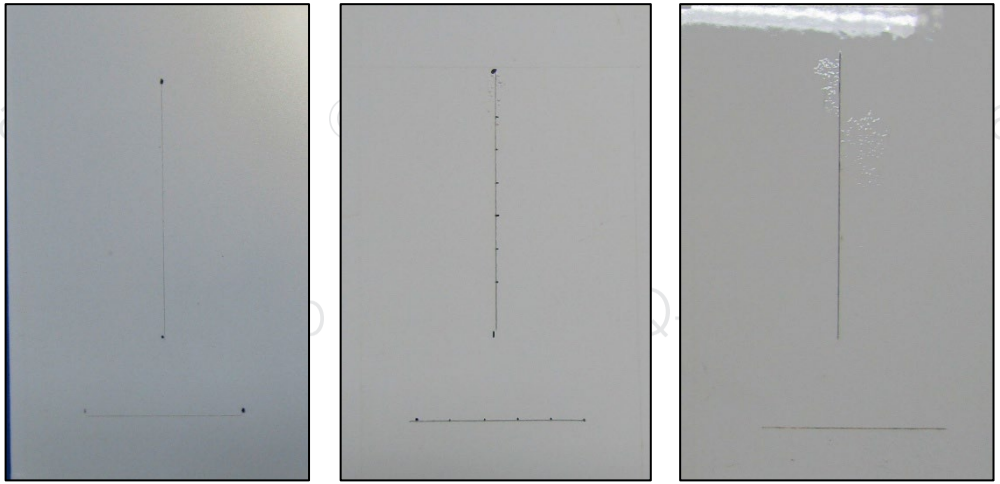
Solid colors refer to specimens that passed the chamber test

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

CASS
240 hours

Spray salt water
12 months

Corrosion morphology comparison

AASS
1980 hours

Spray salt water
12 months

Corrosion morphology comparison

Filiform
678 hours

Spray salt water
12 months

Corrosion morphology comparison

CATCH
2498 hours

Spray salt water
12 months

Summary of Aluminum test 铝基材测试总结

- CATCH results show that anti-corrosion performance of Al panels is better than that of steel panels. 铝板耐腐蚀性能比钢板好
- CATCH produces similar corrosion morphology to outdoor spray salt water, with good correlation CATCH方法与户外喷洒盐水试验，腐蚀形貌相似，相关性好
- Anti-corrosion performance of coated Al panels: 涂层铝板的防腐性能：
  - Closely related to electrophoresis, surface treatment, and substrate
  - 与电泳、表面处理和底材密切相关
  - Not correlated to finish type
  - 而与面漆关系不大
- Corrosion morphology of Al panels is quite different from that of steel panels
- 铝板的腐蚀形貌与钢板有很大不同

Analysis of Aluminum test results 铝试验结果分析

- There are differences of corrosion morphology between different test methods
- 不同试验方法的腐蚀形貌不同
- CATCH test method is consistent with the test design
- CATCH试验方法与试验设计一致
- CATCH test method delivers similar corrosion morphology with outdoor spray salt water, with good correlation CATCH试验方法与户外喷洒盐水试验的腐蚀形貌相似，相关性好
- CATCH test method also has good correlation with road enhanced corrosion
- CATCH试验方法与道路强化腐蚀的相关性也好

Aluminum Substrates 铝基材

Second-round test 第二轮试验

Second round test 第二轮试验

- The correlation between CATCH and both outdoor spray salt water and road-enhanced corrosion is good, but the CATCH test method is slow
- CATCH试验方法与户外试验相关性好，但测试较慢
  - CATCH 1728 h (2.4 months) or 2980 h (4.1 months)
  - Outdoor spray salt water 12 months
- CASS, AASS, and SAE J2635 tests suggest acidifying solution to accelerate corrosion (pH 3.0 instead of 4.0)
- CASS, AASS和SAE J2635试验建议降低溶液pH值以加速腐蚀

Correlation between different-pH CATCH Tests

pH	CATCH 3.0					CATCH 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	5.2	13.4	19.0	29.5	46.1	4.0	8.4	12.3

CATCH pH3.0 vs. CATCH pH4.0

- The corrosion area of CATCH pH3.0 after 600 h matches CATCH pH4.0 after 1728 h
- pH值为3.0的CATCH试验方法测试600h与pH值为4.0的CATCH试验方法测试1728h的腐蚀相当
- The correlation coefficient between CATCH pH 3.0 600 h and CATCH pH4.0 1728 h is **0.87**
- CATCH试验方法pH值3.0测试600h与pH值4.0测试1728h的相关系数为**0.87**

CATCH 3.0 Correlation

Test Method	CATCH 3.0 Test Time			
	600 h	864 h	1296 h	1728h
Proving Ground	0.73	0.72	0.82	0.80
CATCH 4.0 1728 hrs	0.87	0.77	0.84	0.84

Good correlation in all cases

CATCH Conclusions

- CATCH demonstrated good correlation in corrosion extent and morphology compared to outdoor tests
- CATCH试验方法与户外试验相比，腐蚀程度和腐蚀形貌都具有很好的相关性
- SAE China published CATCH 3.0 as a new standard: T/CSAE 130-2020
- SAE中国发布了新标准T/CSAE 130-2020， 把CATCH 3.0方法写在标准中
- 672 hours exposure recommended 推荐测试672h
- 1 hour “pressure cooker” test can be used for pre-screening to eliminate very bad performers
- 1h的压力锅测试作为预筛选

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