NIST / UL Workshop on PV Materials Durability

UL Standards Update: Corrosion Testing for PV Applications

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UL 2703 Scope / Impacts of Corrosion

- UL 2703 corrosion protection requirements apply • to certain metals used in:
 - Fixed tilt mounting systems
 - Trackers compliant with UL 3703 (references to — 2703)
 - Hardware used for ____
 - > Securement of PV modules
 - > Bonding and grounding of PV modules and mounting system components (per NEC)
- Corrosion of these components could create fire, shock, injury and performance risks:
 - Compromise securement of PV modules or Integrity of structure
 - Disrupt path to ground





Grounding electrode typically at inverter pad



Overview of UL 2703 Corrosion Protection Requirements

- Maximum galvanic potential between two dissimilar metals is 0.6 V
- Unless inherently corrosion resistant, metals (steel, iron) must have corrosion resistance equivalent to G90 hot dipped galvanized with an average 0.015 mm thick Zn (for underground 0.046 mm Zn / G210)
- Two options to demonstrate equivalence of coatings to G90:
 - List of prequalified coating types in UL 2703 (Zn, Cd) not typically used for fasteners
 - Conduct atmospheric corrosion testing on test samples side by side with G90 reference sample:
 - > Salt spray: continuous spray of 5% NaCl (by weight) in water until corrosion is observed on test or reference sample
 - > Moist CO₂/SO₂ test: exposure to SO₂ and CO₂ (1% of chamber volume) in presence of moisture, exposed until corrosion is observed on test or reference sample (spoiler - now optional)

*Note: G90 hot dipped galvanized steel is used as a test reference as it is appropriate for many typical environments. Additionally, designers of structures and electrical systems are familiar using G90 when suitable for outdoor applications. This does not mean it is suitable for all environments.







UL 2703 Corrosion Research – Fastener Failures

Concerns raised by NEXTracker:

- Initial top choice "C" for fastener coatings failed CO_2/SO_2 , despite track record in similar applications
- Second choice fastener "D" passed all corrosion tests but failed after 20 months in the field - root cause found to be corrosion due to high chloride levels in the soil
- Questions to Corrosion Task Group:
 - Is CO₂/SO₂ test still relevant?
 - Is CO₂/SO₂ test too harsh?
 - Can the salt spray test be improved?





Zn Coated



7 Days CO2/SO2 Exposure on Coating Samples



"D"

"C"

Photos courtesy of NEXTracker

UL 2703 Corrosion Task Group - Overview

- Corrosion Task Group formed in August 2020 to: •
 - Investigate reported corrosion failures of fasteners
 - Consider updates to corrosion test methods
 - Consider use of weathering or plain steel foundations
- 45 members from various sectors:
 - testing / certifications
 - utility / plant operator
 - nonprofit / industry organizations
 - independent consultants
 - manufacturers: racking / tracking, fasteners / coatings, PV modules, steel



| | Testing / Certific | | |
|------------------|-------------------------|-----------------------|--|
| | Liang Ji | UL (C | |
| | Alex Di Sciullo Jones | UL | |
| | Colleen O'Brien | UL | |
| | John Doty | UL | |
| | Michael Hoffnagle | CSA | |
| | Zen Villanueva | RETO | |
| | | Utility Secto | |
| | Stephen Barkaszi | Duke | |
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| | Neil Murray | EPRI | |
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| Jack West | Tesla | Nikhil K | |
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Kent Whitfield

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on Sector Group Chair)

Group or Energy rganization

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Fastenal Unirac **RBI Solar Steel Dynamics** Nucor **ITW Commercial** Construction Roof Tech Array Technologies Stanley Engineered Fastening Tecsi Solar GameChange Solar **NEXTracker** FTC Solar CAB Products Iron Ridge

UL 2703 Corrosion Research – CO₂/SO₂ Corrosion Test

- SO₂ is released during the combustion of coal and oil, also certain manufacturing processes
- SO_2 + water in atmosphere = sulfuric acid = corrosive acid rain
- SO₂ emissions in U.S. peaked in 1970 with 31.2 ppb but have steadily declined; 1.8 ppb in 2020

SEPA United States Environmental Protection **Report on the Environment** https://www.epa.gov/roe/

Sulfur Dioxide Concentrations

Exhibit 2. Ambient annual SO₂ concentrations in the contiguous U.S. by EPA Region, 1980-2016





Data source: U.S. EPA, 2017a

UL 2703 Corrosion Research – CO₂/SO₂ Corrosion Test



https://www3.epa.gov/airmarkets/progress/reports/acid_deposition_figures.html



USEPA, 2020

UL 2703 Corrosion Research – CO₂/SO₂ Corrosion Test

- Task Group corrosion experts have confirmed that SO₂ testing is no longer done for products used in outdoor applications such as automotive and fastener coatings
- Proposal to UL 2703 STP in February 2021 to make CO_2/SO_2 test optional
- Positive STP vote and UL 2703 published with optional CO_2/SO_2 test in March 2021

Chrysler Group LLC Process Standard Category Code: G-3 EASL Requirement: Yes Restricted: No

| TABLE 2: PERFORMA | ANCE REQUIREMEN |
|---|-----------------|
| Attribute | Performa |
| Neutral Salt Spray: Hrs to White (< 1%) | 240 |
| Neutral Salt Spray: Hrs to Red (first red) | 1000 |
| Handling Resistance | Requir |
| Dry to Touch | Requir |
| Condensing Humidity: Hrs Exposure | 240 |
| Galvanic Compatibility: Number of Cycles | 30 |
| Tapping Screw Test | Requir |
| Washer Assembly Breakaway Force | Requir |
| Head Fill | Requir |
| Decorative Appearance | Requir |
| Windshield Washer Soln: Hrs Exposure | 72 |
| UV Resistance Exposure Level | 2400 |
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UL 2703 Corrosion Research – Salt Spray Test

Static versus cyclic salt spray test comparison:

- Natural drying periods increase NaCl concentration in water more harsh, more realistic
- Continuous spray with no air exposure prevents formation of a natural patina; the bare Zn metal is attacked during the test
- With wet-dry cycles, zinc oxide, zinc hydroxide, zinc carbonate patina is formed – this patina should be attacked in the test
- If the wrong mechanism is accelerated by the testing method, then the • test results cannot be compared to existing parts in the field - cyclic salt spray (wet-dry cycles) accelerates similar corrosion mechanisms as real world
- IEC 60068-2-52 Environmental testing cyclic salt mist, (also • required in IEC 61701 PV Salt mist corrosion testing)
- Annex A of 61701 gives guidance on test method choices •
- Test method 5 (28 days) corresponds to 1 year in a C4 environment (per ISO 9223 - highly corrosive, near saltwater)

| Corrosivity classification of module location | Location characteristics | | One-year | 60068-2-52 test |
|---|------------------------------------|-------------------------------------|--|--|
| | Distance from saltwater (km) | Percentage Time of Wetness (ToW) | mass loss range (g/m²) of bare steel coupons | achieving similar one-year corrosivity |
| C1 (testing per this document not necessary) | - | | <10 | none |
| C2 (testing per this document not necessary) | ≥ 10 | <25 % | 10-200 | 2, 3 |
| C3 | ≥ 10 2 to 10 | ≥ 25 % <25 % | 200-400 | 4 (14 days) |
| C4 | 2 to 10 < 2 | ≥ 25 % <25 % | 400-650 | 1 (28 days) 5 (28 days) |
| C5 | < 2 | ≥ 25 % | 650-1 500 | 6 (56 days) |
| сх | offshore | | 1500-5 500 | 7 (90 days) 8 (70 days) |

NOTE 1 Percentage time of wetness (ToW) is defined as the number of hours during the year at which the RH is at 80 % or higher and the temperature is greater than 0 °C, divided by the total hours in a year. The distance and ToW parameters are simplified approximations from a corrosivity mapping tool that can be found at https://www.wbdg.org/tools/corrdefense/iso.html.

NOTE 2 The cycle times for test methods 1 through 6 are fixed in the IEC 60068-2-52 method. Each of these methods achieves steel mass loss values near the midpoints of their respective corresponding ISO 9223 classification ranges. Test methods 7 and 8, at the durations specified achieve steel mass loss near the middle of the range for the CX classification.



Table A.1 – Simplified guidance for determining corrosivity classifications according to ISO 9223 and test methods correlating to one-year corrosivity based on mass loss of steel coupons



Unloaded Bolt Test After 12 Weeks...cyclic testing appears much more aggressive.

Static

Cyclic







Photos courtesy of NEXTracker and RETC

Conclusion: Cyclic is more severe for the coatings tested on flat plate samples and unloaded bolt samples

Cyclic vs. Static Testing on Preloaded Bolts 2^{nd} Choice – chosen as it passed CO₂/SO₂



Additional conclusions:

- Prior result cyclic was worse on all unloaded bolts but when preloaded, some coatings did worse in the static test
- No drastic failure of Fastener D in static nor cyclic test on par with G90
- Why did Fastener D fail in the field? High soil chloride levels possibly exceeds G90 capability
- Cyclic test still considered a better test because it simulates real world conditions and has a better correlation to field performance (28d=1 yr in C4)



Fastener D - Cyclic



Fastener D - Static



Photos courtesy of NEXTracker and RETC

Summary and Future Work

- Corrosion Task Group has decided to propose change to cyclic salt spray test IEC 60068-2-52 (Test Method 5) – working on proposal (sample prep, duration and acceptance criteria)
- CO₂ / SO₂ research complete: due to reduction on SO₂ emissions, no longer needed for most locations; March 2021 publication of UL 2703 makes the test optional
- Subgroup working on proposal for an exception for G210 requirement for underground steel piles for utility-scale, ground-mounted, restricted access systems where piles are protected from becoming directly energized







Galvanized steel rack

Weathering steel rack



Questions?

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