Standardizing Accelerated Aging Testing Conditions for Silvered-Glass Reflectors

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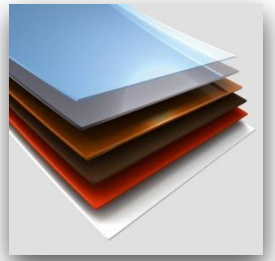
Standardizing Accelerated Aging Testing Conditions for Silvered-Glass Reflectors

Industry demand: reflectors that maintain a high specular reflectance over the lifetime of a power plant (20-30 years minimum)



Accelerated laboratory tests:

- Quality control of manufacturing process for mirror companies
- Lifetime prediction of components for plant developers
- Results can be achieved in a reasonable time

Standardization:

- Agreement on testing procedures and parameters
- Meaningful, reproducible and comparable results

"Our new mirror successfully passed the NSS test" ☑

AENOR standard

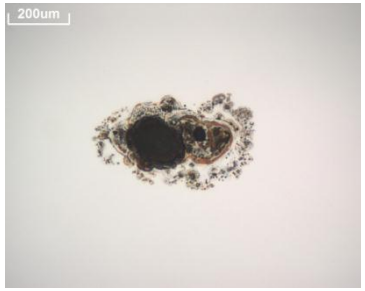
"Reflector Panels for Concentrating Solar Technologies"

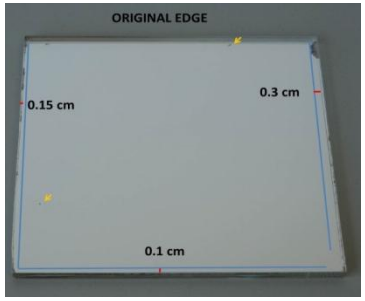
- Draft is close to being published
- Standard includes measurement and testing protocols

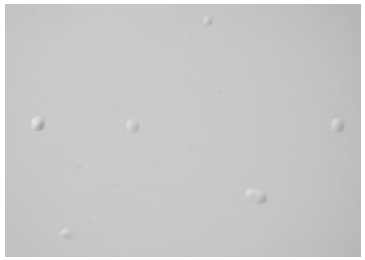
- Set of accelerated standard tests adapted from other industries and applications
- Test standards and parameters
- Set of minimum requirements
- No pass/fail criteria

Test	Standard	Testing conditions	Duration
Neutral Salt Spray (NSS)	ISO 9227	T: (35±2)°C; pH: 6.5 to 7.2 Sprayed NaCl solution of 50 ± 5 g/l, condensation: 1.5 ± 0.5 ml/h per 80cm²	480h
Copper-accelerated acetic acid salt spray (CASS)	ISO 9227	T: (50±2)°C; pH: 3.1 to 3.3 Sprayed NaCl solution of 50 ± 5 g/l and 0.26 ± 0.02 g/l CuCl2 Condensation: 1.5 ± 0.5 ml/h per 80cm²	120h
Condensation	ISO 6270-2	T°: 40°C RH: 100%	480h
UV radiation/ condensation	ISO 16474-3	4h UV exposure at 60°C; 4h 100% r.h. at 50°C	1000h 2 sides (tot. 2000h)
Damp Heat	IEC 62108 (section 10.7b)	T°: (65±2)ºC; RH=(85±5)%	2000h
Cyclical temperature and humidity tests	AENOR draft	4h 85°C, 4h -40°C, Method A: 16 h T°: 40°C and 98±2% r.h.	10 cycles (240 h)

AENOR standard







Main parameters evaluated after testing defined

- Reflectance loss (hemispherical solar-weighted and at 660nm, specular)
- Spots over 200µm
- Edge corrosion penetration (length)
- Bubbles in the back coating

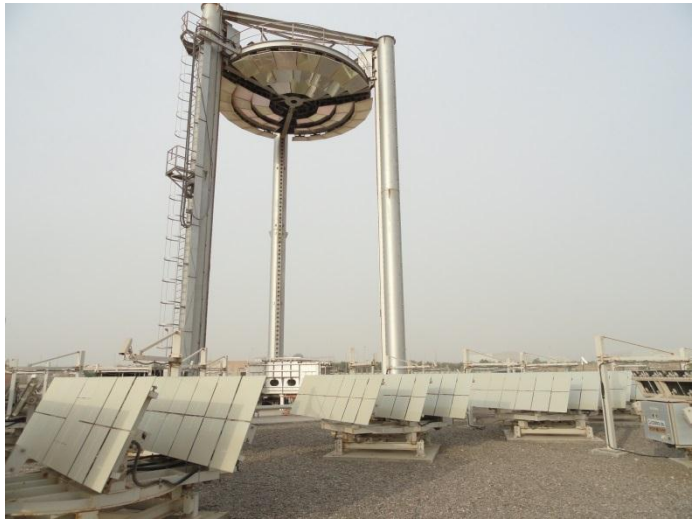
Minimum requirement for the standard:

- Can tests separate “good” reflectors from “bad” ones?
- Can weak materials be identified?

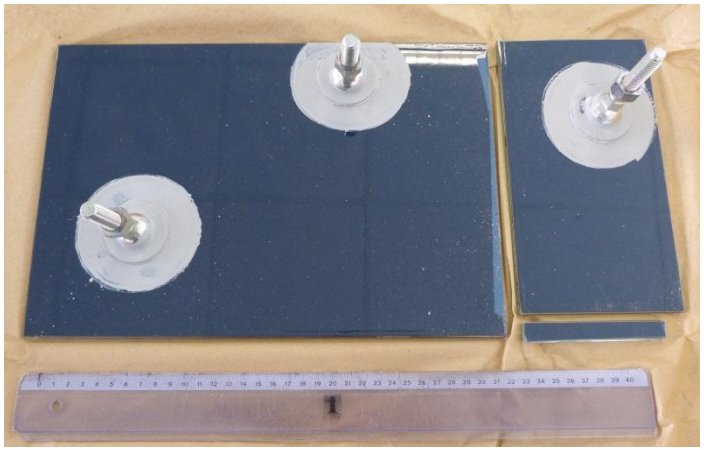
Testing of material that is known to be weak

Outdoor exposure site & tested material

- Masdar Institute Solar Platform (MISP) in Abu Dhabi, Beam-Down Tower demonstration plant
- Facets installed in 2009, ca. 7 years
- 5 mm glass mirrors from Nishio Glass Mirror Co.
- Coating structure different from most commercial reflectors
- Outdoor and warehouse facets are available

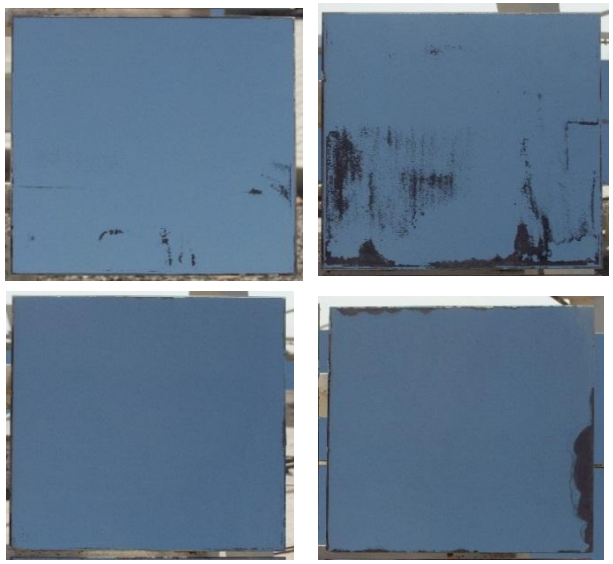


Outdoor facet



Warehouse facet, backside

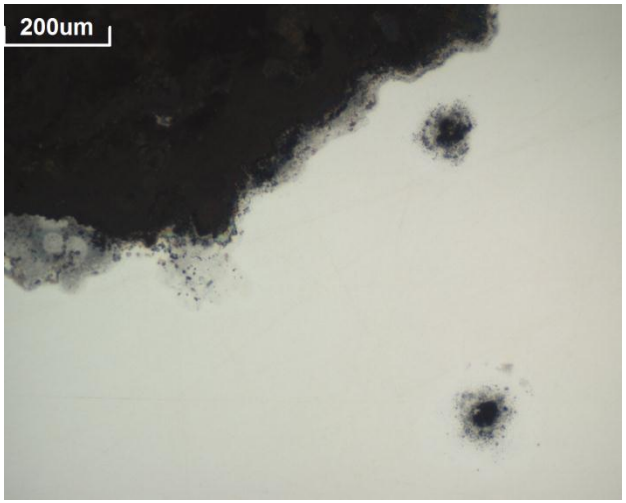
Analysis of outdoor facets

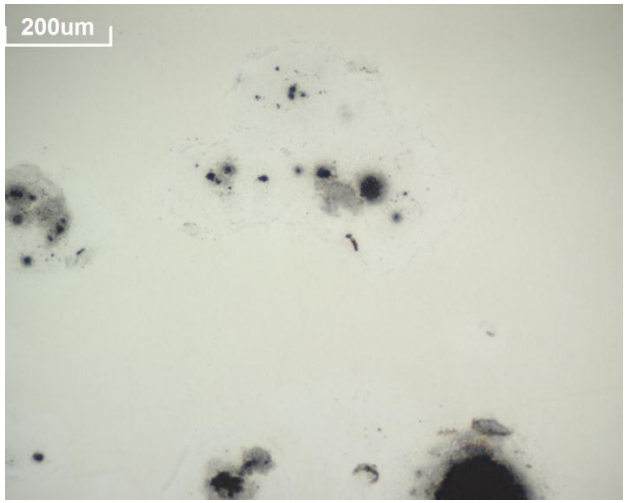


- Degradation on all of the 1419 installed facets
- Ranging from little to very severe degradation

- Microscopic analysis shows similar patterns known from other mirrors where silver layers gets attacked

- For details on the material composition and degradation: *“Study and Comparison of Naturally-Aged and As-Received Silvered-Glass Reflectors”*

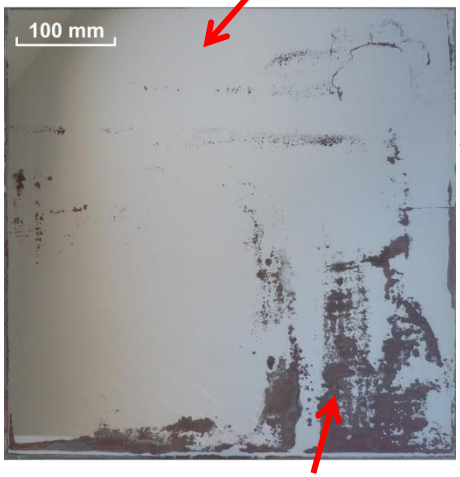




Reflectance/degradation outdoor facet

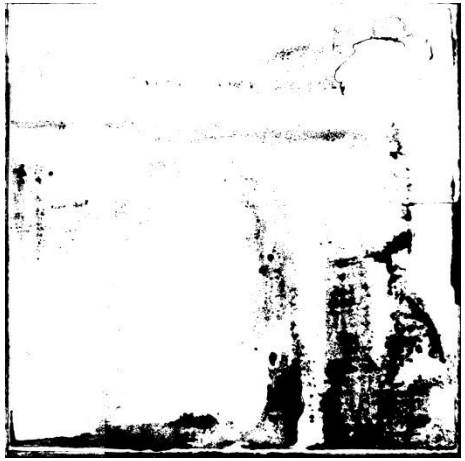
- Estimation of the specular reflectance drop and the affected area was done
- Specular reflectance measurements on corroded and uncorroded areas

uncorroded



corroded

Image processing software



- 14.1% of facet corroded

- ρ_{non}=0.838±0.003
- ρ_{deg}=0.103±0.049

Weighting of reflectance values with the corresponding area fractions

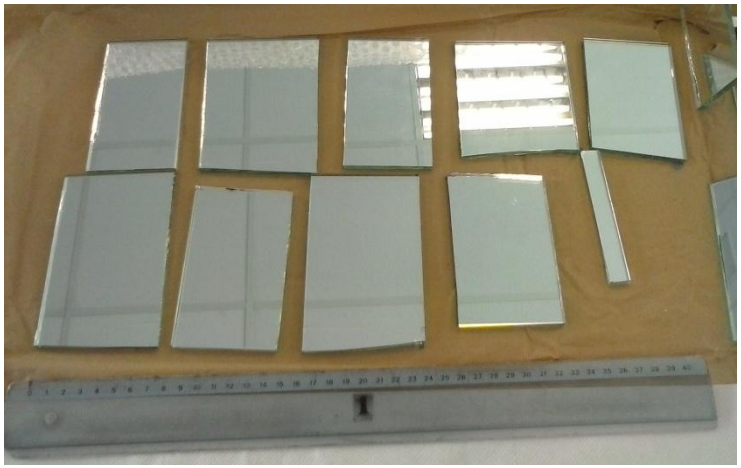
$$\rho_{tot} = a_{non} * \rho_{non} + a_{\deg} * \rho_{\deg} = 0.859 * 0.838 + 0.141 * 0.103 = 0.734$$

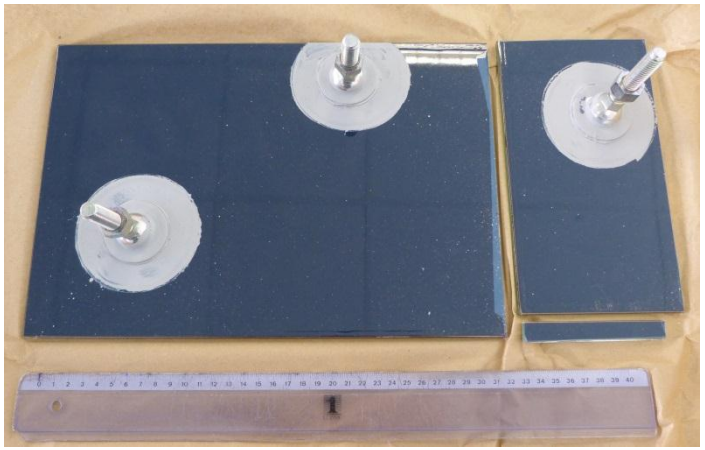
Initial reflectance 0.846 (warehouse facet)

Total specular reflectance loss of 0.112

Sample preparation for accelerated tests

- Samples were cut out of the warehouse facet
- Size around 10x10 cm²





- Sample cut edges were protected
- Initial reflectance measurements
- 2 samples per test

Results accelerated tests

- Tests were conducted, first measurements after AENOR minimum duration
- Tests went on for longer durations (up to 4x AENOR minimum)
- Solar-weighted and specular reflectance were measured after testing
- Degradation parameters were evaluated

Reflectance losses after testing

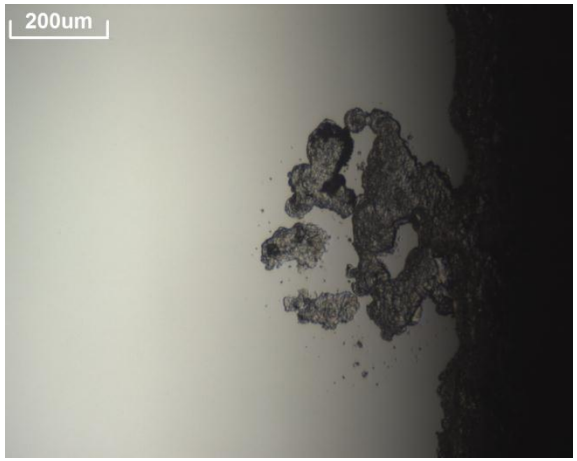
Test	Duration (h)	$\rho_{s,h}$ ([280,2500]nm ,8°,h)	$\rho_{\lambda,\phi}$ (660nm,15°, 12.5mrad)
NSS	480*	-0.004	-0.010
	1000	-0.004	-0.014
	1550	-0.007	-0.034
	2000	-0.010	-0.045
CASS	120*	-0.001	-0.002
	480	-0.001	0.000
Condensation	480*	-0.001	-0.003
	1000	-0.001	-0.001
	2000	-0.001	-0.002
Thermocycles	10 cycles*	-0.001	-0.001
UV/Humidity	2000*	0.003	0.000
	3000	0.002	0.002

NSS Test

- Strongest reflectance drop of all tests (hemispherical and specular)
- Glass corrosion
  - Known degradation of glass surfaces in high humidity environments
  - Usually not detected outdoors
- Minimal edge corrosion
- Total testing time more than 4x AENOR

Glass surface corrosion

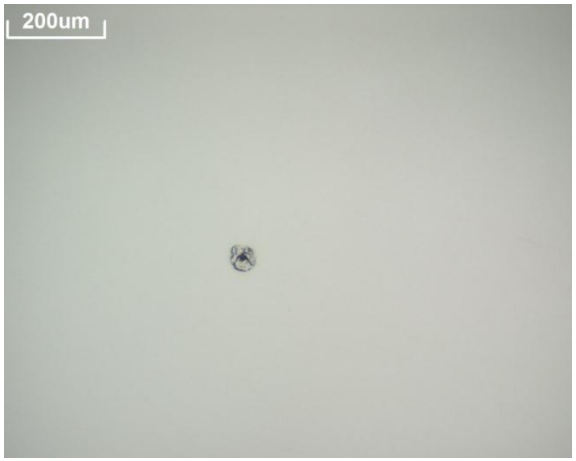
Test	Duration (h)	$\rho_{s,h}$ ([280,2500]nm, 8°,h)	$\rho_{\lambda,\phi}$ (660nm,15°, 12.5mrad)
NSS	480*	-0.004	-0.010
	1000	-0.004	-0.014
	1550	-0.007	-0.034
	2000	-0.010	-0.045



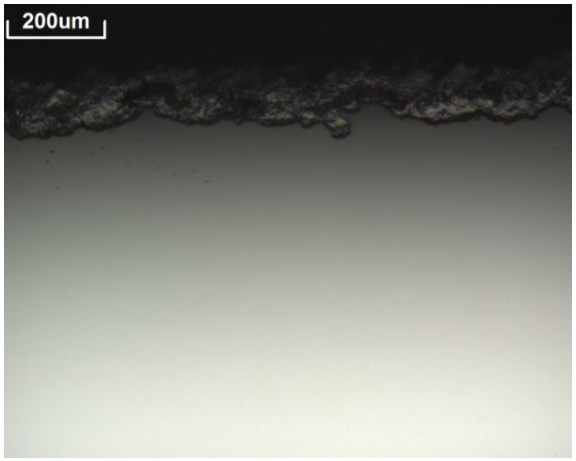
CASS Test

- Very aggressive corrosion test
- Only very minor degradation after testing
- Total test duration 4x AENOR

Test	Duration (h)	$\rho_{s,h}$ ([280,2500]nm ,8°,h)	$\rho_{\lambda,\phi}$ (660nm,15°, 12.5mrad)
CASS	120*	-0.001	-0.002
	480	-0.001	0.000



Appearance of microscopic, stable spots



Beginning edge corrosion on micrometer scale

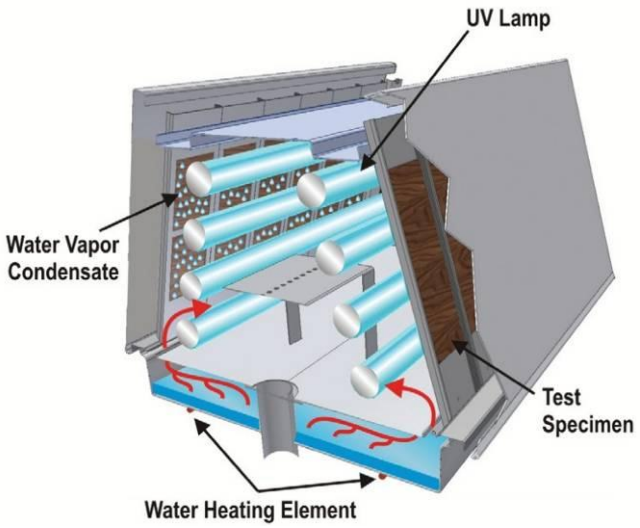
Condensation & Thermocycles testing

- Both tests: No changes
- Some bubbles in paint after Condensation test
- Condensation: total testing time more than 4x AENOR

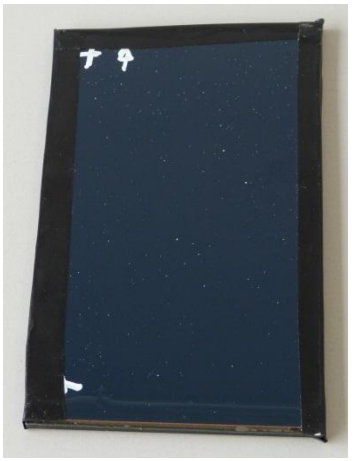
Test	Duration (h)	$\rho_{s,h}$ ([280,2500]nm, 8°,h)	$\rho_{\lambda,\phi}$ (660nm,15°, 12.5mrad)
Condensation	480*	-0.001	-0.003
	1000	-0.001	-0.001
	2000	-0.001	-0.002
Thermocycles	10 cycles*	-0.001	-0.001

UV/Humidity test

- Cyclic test, one cycle: 4h UV light + 4h condensation



Test chamber scheme

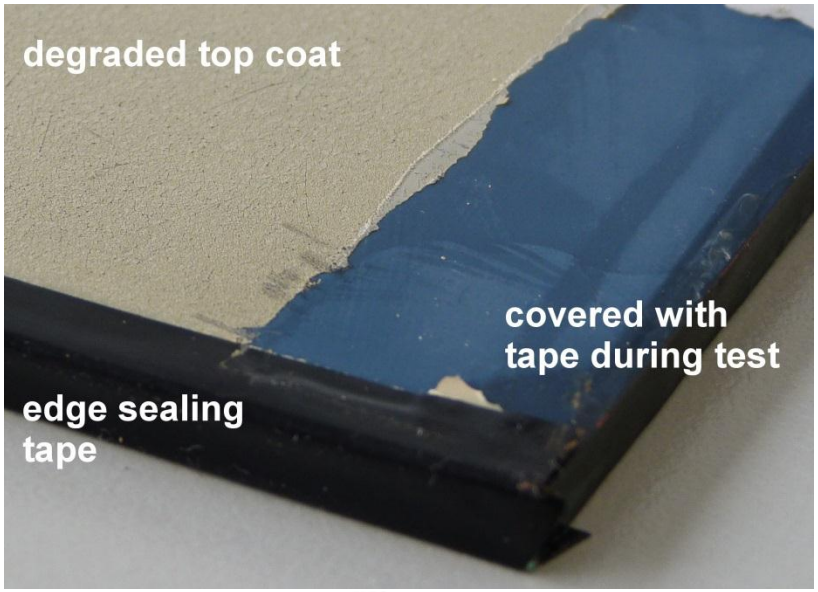


- 2 samples being testes
  - 1 front side (glass) facing into the chamber
  - 1 backside (protective paint) facing into the chamber

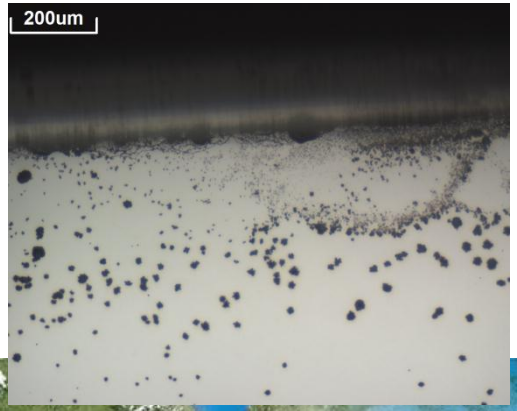
UV/Humidity test

- Severe attack of the backside coating exposed to chamber
- No considerable degradation of the silver layer on both samples
- Minimal edge corrosion

initial 350h 3000h



Test	Duration (h)	$\rho_{s,h}$ ([280,2500]nm, 8°,h)	$\rho_{\lambda,\phi}$ (660nm,15°, 12.5mrad)
UV/Humidity	2000*	0.003	0.000
	3000	0.002	0.002



Conclusion

- Standardization of testing is a good progress
- Degradation found during exposure is not reproduced by accelerated tests
- Test procedure is unable to identify weak material

- Samples from all 5 accelerated tests
- No macroscopic degradation for AENOR

Outdoor facet

Testing and parameters have to be optimized

Next steps

- Development of a more realistic test procedure
- Further testing:
  - Not only longer test durations
  - Combination of tests: UV/humidity followed by NSS/CASS
  - Complex cycles at LNEG (Portugal): ISO 21207

1) Cycle Corrosion Tests

Each cycle:
2 h neutral salt spray (ISO 9227) + 22 h standard laboratory climate (23ºC and 50% RH) + 120 h with corrosive atmosphere (NO_2=1.5x10^{-6} + SO_2=0.5x10^{-6}) (25ºC and 95%RH) + 24h standard laboratory climate (23ºC and 50% RH)

2) Alternative Cycle Corrosion Tests

500 h of UV radiation (ISO 16474-3) followed by cycles of:
2 h neutral salt spray (ISO 9227) + 22 h standard laboratory climate (23ºC and 50% RH) + 120 h with corrosive atmosphere (NO_2=1.5x10^{-6} + SO_2=0.5x10^{-6}) (25ºC and 95%RH) + 24h standard laboratory climate (23ºC and 50% RH)

- Characterization of exposure site, determination of corrosivity class according to ISO9223

Thank you for your attention!

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