Advanced Cyclic Accelerated Aging Testing of Solar Reflector Materials

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The Raiselife Project

- EU funded project (H2020)
- Goal: Raising the lifetime of functional CSP materials
- One work package on **primary reflectors**, includes:
  - Outdoor exposure campaign
  - Accelerated testing

- Develop **realistic accelerated aging & lifetime prediction methods**
- Work carried out by DLR&CIEMAT at the PSA, Almería

Motivation

- CSP plants require **durable mirrors**
  - Little degradation causing no or low reflectance loss during service life of 20 – 30 years
  - High number of environmental stresses can cause degradation

- **Accelerated aging** tests are used for
  - Lifetime prediction
  - Quality control during manufacturing
  - Comparison of materials

- Goal:
  - Find **realistic and fast procedures**
  - **Standardization** of tests
    - UNE (first standard for CSP published)

UNE standard

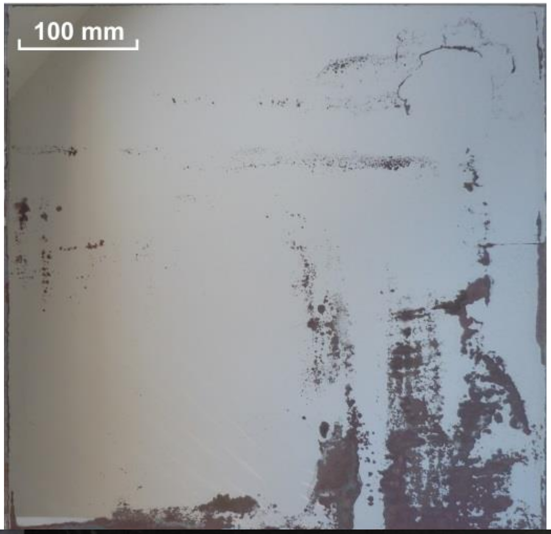
"Reflector Panels for Concentrating Solar Technologies"
UNE 206016 from 2018

- Document includes measurement and **testing** protocols

- Set of accelerated standard tests adapted from other industries and applications
- Definition of test conditions and parameters
- Set of minimum requirements, durations
- 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/ humidity	ISO 16474-3	4h UV exposure at 60°C; 4h 100% r.h. at 50°C	1000h 2 sides (tot. 2000h)
Cyclical temperature and humidity tests	UNE 206016	4h 85°C, 4h -40°C, Method A: 16 h T°: 40°C and 98±2% r.h.	10 cycles (240 h)

Results outdoor in-service facets

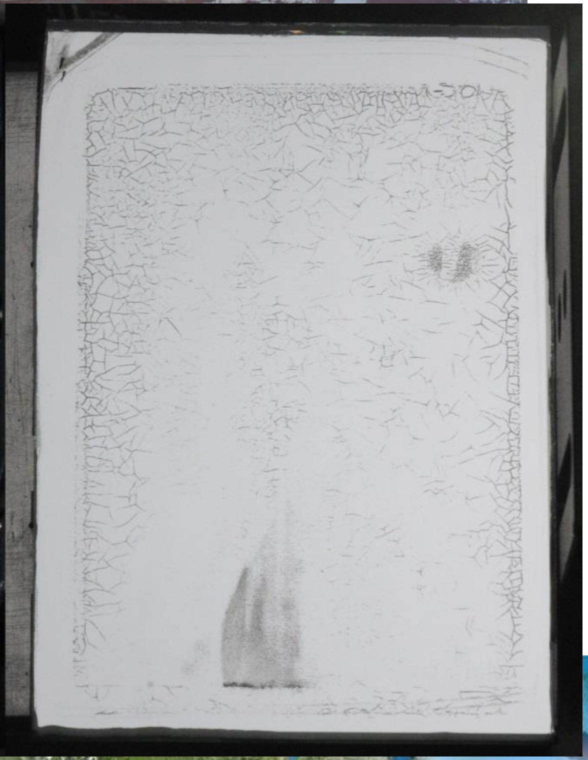


- Weak material analyzed in previous work
- Strong degradation outdoor
- After only 7 years of exposure

- **UNE tests** done, long testing times up 2000-3000 h
- **Degradation is not provoked**

- But backside degradation in UVH

- **Combined UVH & CASS** provokes corrosion silver layer



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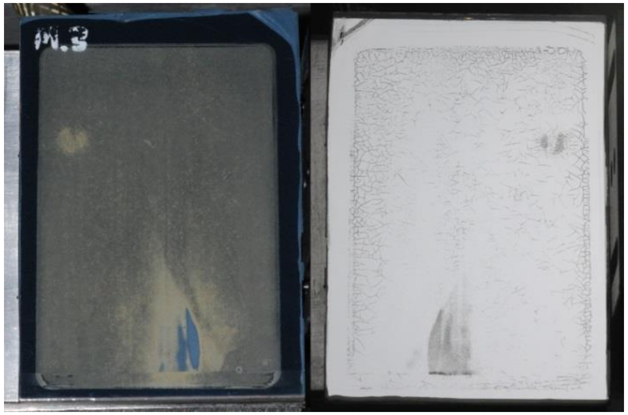
Test of commercial samples



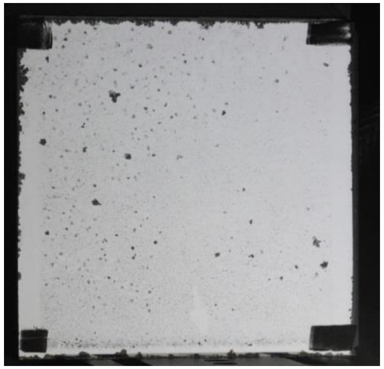
- 1000 h UVH followed by 480 h CASS produces corrosion in silver layer

- This result was reproduced for two further materials from old test campaigns
    - CASS only shows no/little corrosion
    - UVH + CASS provokes considerable corrosion

CASS

Conclusion

- Combination of tests with higher number of stresses is necessary
- Design of new test campaign



UVH+CASS

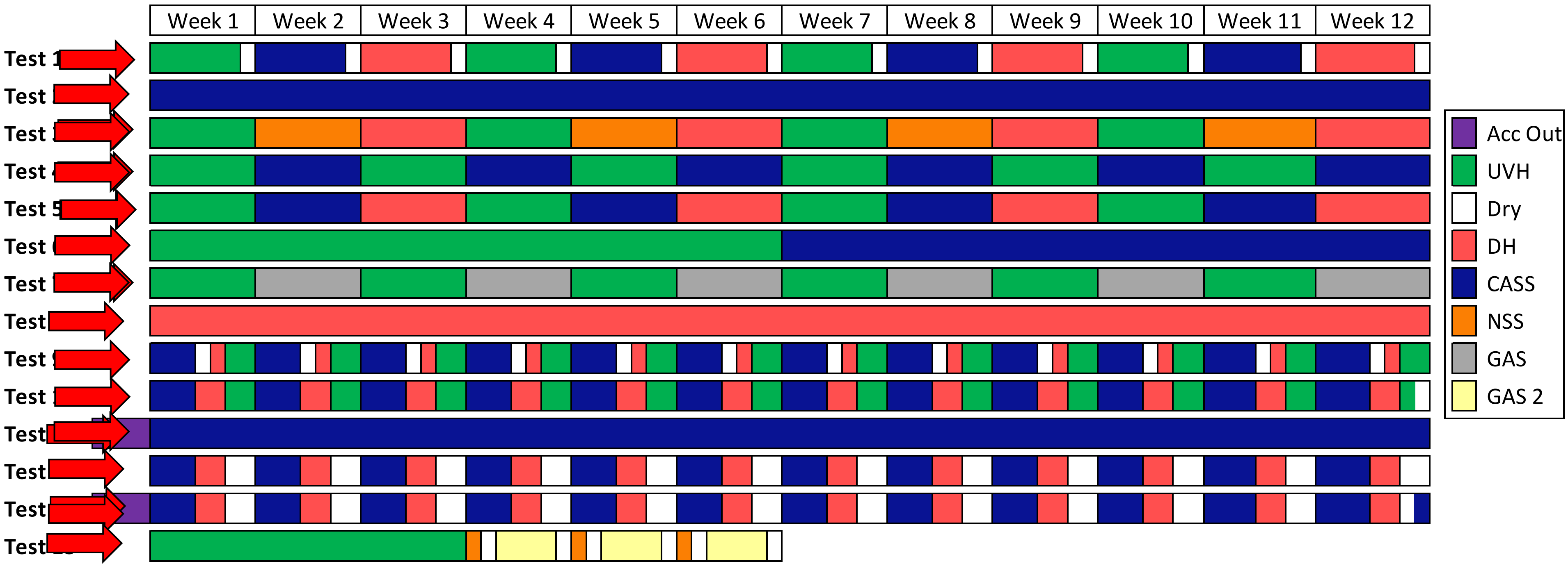
Set up combination/cycle test campaign

- **High number of parameters** to be investigated (single tests, combinations, duration, cycling)
- 3 materials: A, B, C (weaker, reduced coating thickness)
- Only **one sample** per material & test
- Investigate influences of parameters on degradation/ corrosion mechanisms
- “Screening test campaign”

Test	Name	Standard	Conditions
NSS	Neutral Salt Spray	ISO9227 [4]	[NaCl]=50±5 g/l; T=35±2°C; r.H.=100%; pH=6.5-7.2
CASS	Copper accelerated salt spray	ISO9227 [4]	[NaCl]=50±5 g/l; [CuCl2]=0.26±0.02 g/l; T=50±2°C; r.H.=100%; pH=3.1-3.3
UVH	UV light/ Humidity	ISO16474-3 [5]	4h: UV (with 1.55W/m^2/nm at340 nm); T=60±3°C 4h: T=50±3°C; r.H.=100%
DH	Damp Heat	IEC 62108 [6]	T=65±2°C; r.H.=85±5%
GAS	H_2S/H_2S corrosive gases	Based on EN 60068-2-60 [7]	[H_2S]=0.025 g/l;[H_2S]=0.025 g/l;T=40 ºC; r.H.=80%
GAS 2	NO_2/SO_2 corrosive gases	ISO21207 [8]	[NO_2]=1.5x10-6; [SO_2]=0.5x10-6; T=25ºC; r.H.=95%
Dry	Laboratory ambient conditions	-	T=25°C±3°C
Acc. Out	Accelerated Outdoor	Based on ASTM G90 [9]	8x concentrated natural radiation at PSA

Test scheme

- 14 different test
- 2000 h hours



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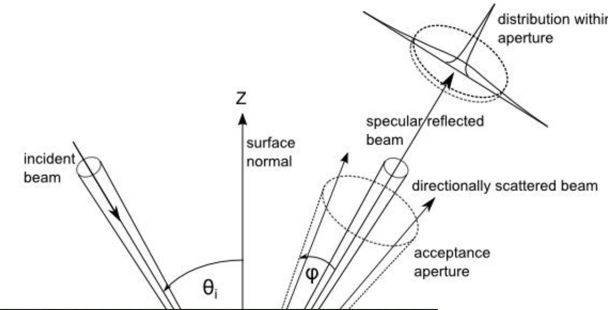
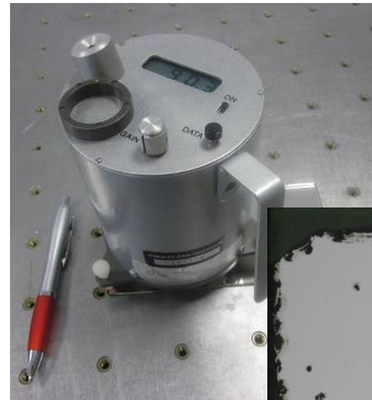
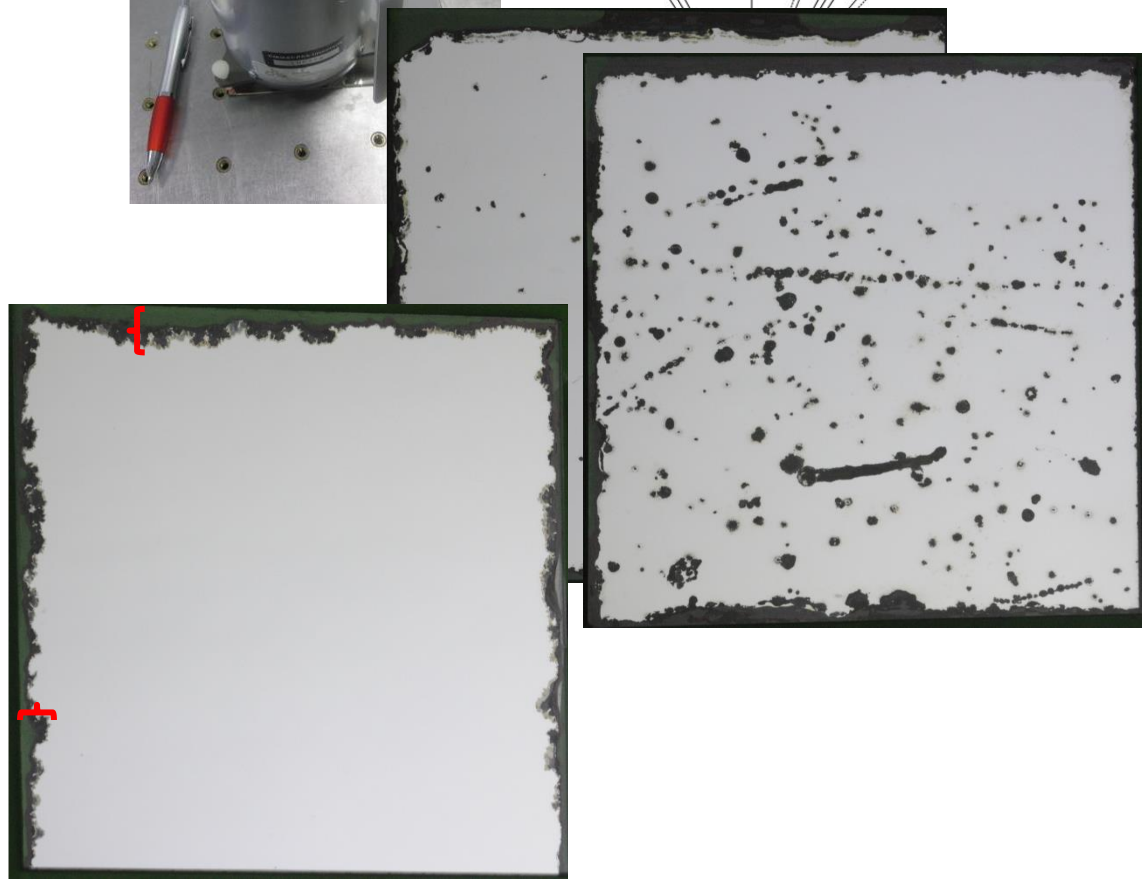
Analyzed degradation parameters



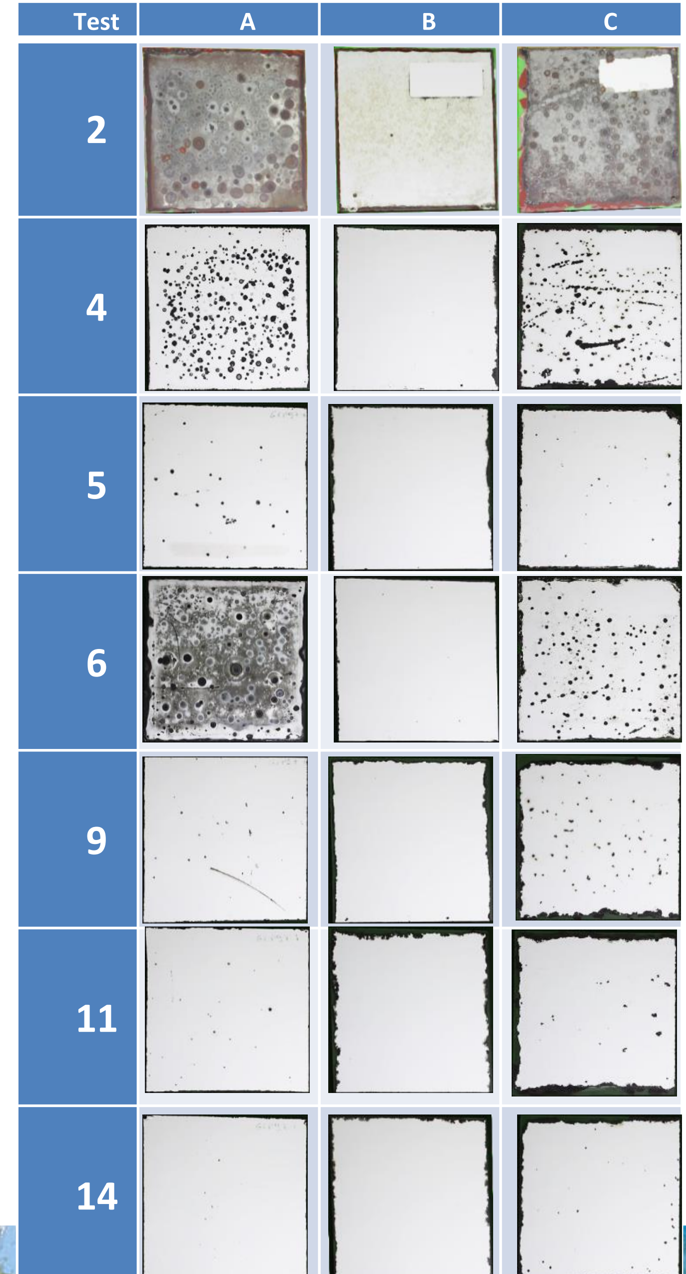


- Specular reflectance drop
- Corrosion spot density
- Degraded area fraction
- Edge corrosion area



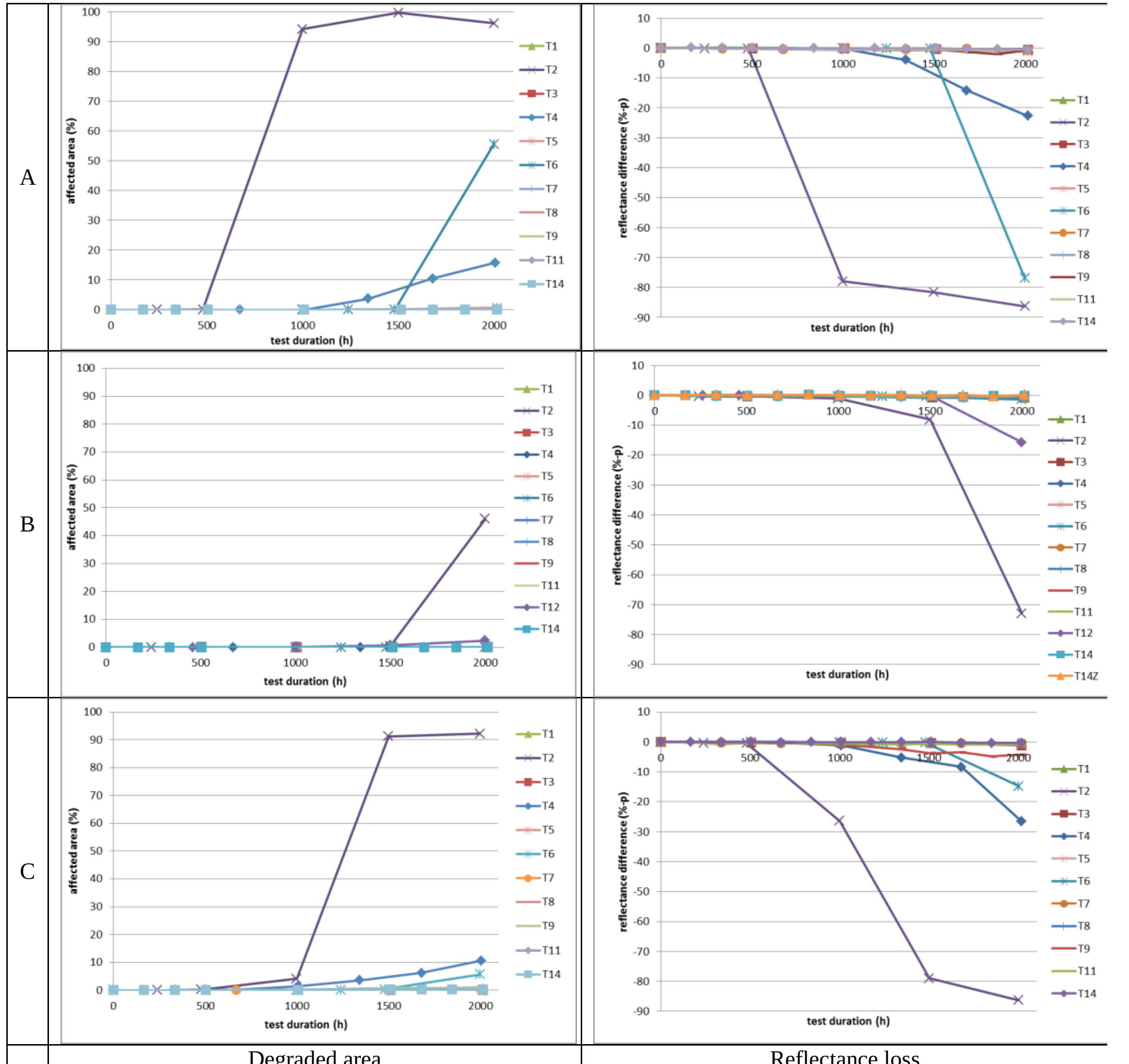
Results – detected degradation

- Detected degradation after 2000h
- Only tests with considerable degradation displayed
    - All include **CASS, determining factor**
    - Most durable material B
    - Important differences between materials
    - Care has to be taken choosing CASS duration, total break down of samples after long exposure
    - CASS degradation is similar to outdoor degradation
    - High frequency cycles are less aggressive



Degraded area & reflectance loss

- Most aggressive tests:
  - T2 (pure CASS)
  - T4 (UVH-CASS weekly)
  - T6 (UVH-CASS seq.)
- Reflectance loss and degraded area correlate well
- Break down point of samples in CASS (measurement intervals)



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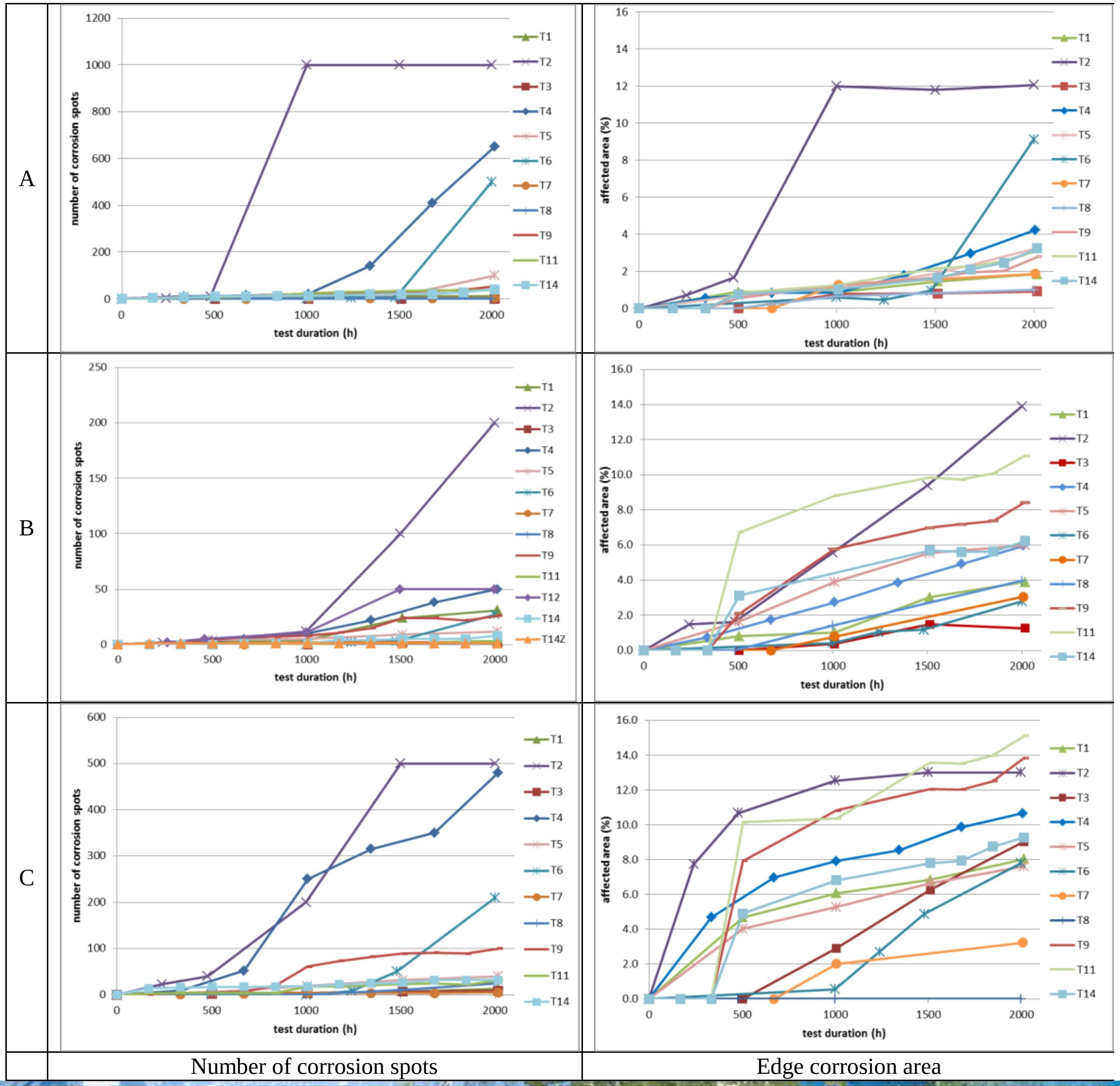
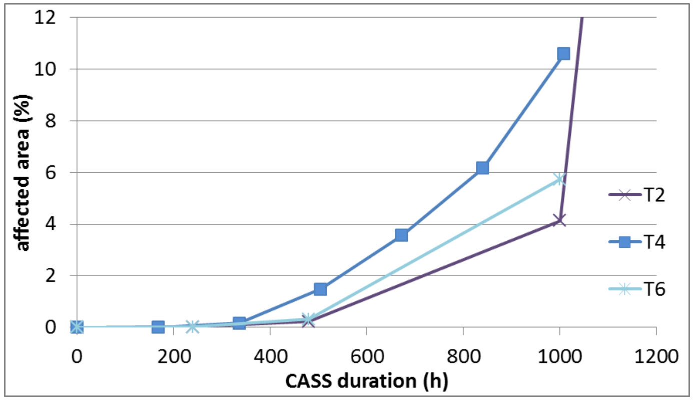
Number of corrosion spots & edge corrosion area

- Correlation of spot number depends on spot size
- Edge corrosion area usually independent from other parameters
- Edge corrosion more similar for different tests and materials



Combination UVH - CASS

- **UVH influence** on degradation seems to be **weak**
- **But** comparing
  - T2: CASS only
  - T4: UVH-CASS weekly cycles
  - T6: sequence UVH followed by CASS



- When only duration in CASS is considered T4 is the most aggressive one

T2

ca. 500h CASS

- This influence was only detected in certain cases

T4

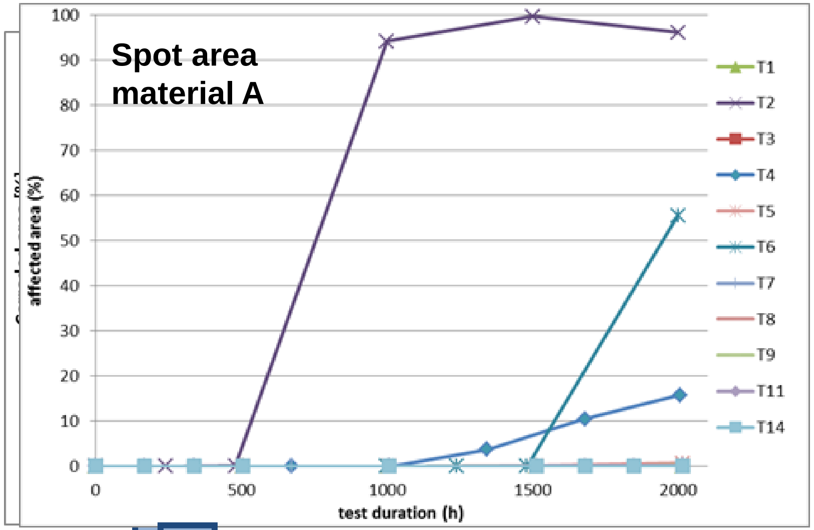
T6

Ranking of tests and materials

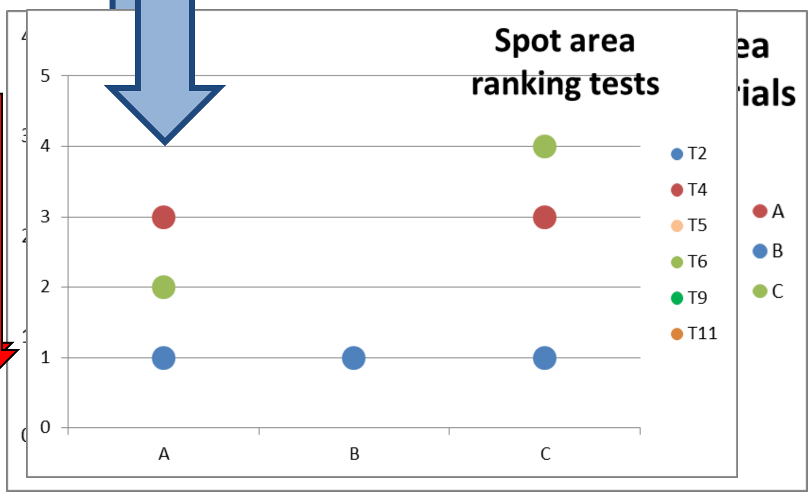
- Comparing parameter evolution of tests and materials

- Ranking of **test aggressiveness** and **material durability**

- Depends on analyzed parameter, only possible when sufficient degradation takes place
- Can be different for tests and materials



More affected



Correlations to outdoor results

- Further analysis with outdoor data
- 11 sites available

but

- Exposure duration of 1 year or less for the analyzed materials
- Considerable corrosion only at 1 site
- **Longer outdoor durations necessary**

Conclusions

- CASS test is aggressive
  - It is the determining factor also in combination with other tests
  - Useful to provoke degradation in solar mirrors in a reasonable time
  - To compare different mirror materials
  - Appropriate testing duration to avoid unrealistic strong degradation
- The higher frequency cycles are less aggressive
  - Also higher effort, more handling
  - Possibly interesting when further outdoor data is available
- UVH pre-damaging effect is material dependent
  - Further investigation of UVH-CASS combination
  - More samples and measurements used in next campaigns
- For useful correlations longer outdoor exposure durations necessary
  - Also final test selection will depend on these results

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Thank you for you attention!