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

<table>
<thead>
<tr>
<th>Test</th>
<th>Standard</th>
<th>Testing conditions</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Salt Spray (NSS)</td>
<td>ISO 9227</td>
<td>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</td>
<td>480h</td>
</tr>
<tr>
<td>Copper-accelerated acetic acid salt spray (CASS)</td>
<td>ISO 9227</td>
<td>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</td>
<td>120h</td>
</tr>
<tr>
<td>Condensation</td>
<td>ISO 6270-2</td>
<td>T*: 40°C RH: 100%</td>
<td>480h</td>
</tr>
<tr>
<td>UV radiation/humidity</td>
<td>ISO 16474-3</td>
<td>4h UV exposure at 60°C; 4h 100% r.h. at 50°C</td>
<td>1000h 2 sides (tot. 2000h)</td>
</tr>
<tr>
<td>Cyclical temperature and humidity tests</td>
<td>UNE 206016</td>
<td>4h 85°C, 4h -40°C, Method A: 16 h T*: 40°C and 98±2% r.h.</td>
<td>10 cycles (240 h)</td>
</tr>
</tbody>
</table>
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
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

Conclusion

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

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<tr>
<td>NSS</td>
<td>Neutral Salt Spray</td>
<td>ISO9227 [4]</td>
<td>[NaCl]=50±5 g/l; T=35±2°C; r.H.=100%; pH=6.5-7.2</td>
</tr>
<tr>
<td>CASS</td>
<td>Copper accelerated salt spray</td>
<td>ISO9227 [4]</td>
<td>[NaCl]=50±5 g/l; [CuCl2]=0.26±0.02 g/l; T=50±2°C; r.H.=100%; pH=3.1-3.3</td>
</tr>
<tr>
<td>UVH</td>
<td>UV light/ Humidity</td>
<td>ISO16474-3 [5]</td>
<td>4h: UV (with 1.55W/m²/nm at340 nm); T=60±3°C 4h: T=50±3°C; r.H.=100%</td>
</tr>
<tr>
<td>DH</td>
<td>Damp Heat</td>
<td>IEC 62108 [6]</td>
<td>T=65±2°C; r.H.=85±5%</td>
</tr>
<tr>
<td>GAS</td>
<td>H₂S/H₂S corrosive gases</td>
<td>Based on EN 60068-2-60 [7]</td>
<td>[H₂S]=0.025 g/l; [H₂S]=0.025 g/l; T=40 °C; r.H.=80%</td>
</tr>
<tr>
<td>GAS 2</td>
<td>NO₂/SO₂ corrosive gases</td>
<td>ISO21207 [8]</td>
<td>[NO₂]=1.5x10^-6; [SO₂]=0.5x10^-6; T=25°C; r.H.=95%</td>
</tr>
<tr>
<td>Dry</td>
<td>Laboratory ambient conditions</td>
<td>-</td>
<td>T=25°C±3°C</td>
</tr>
<tr>
<td>Acc. Out</td>
<td>Accelerated Outdoor</td>
<td>Based on ASTM G90 [9]</td>
<td>8x concentrated natural radiation at PSA</td>
</tr>
</tbody>
</table>
Test scheme

• 14 different tests
• 2000 h hours
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)
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

- This influence was only detected in certain cases
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
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
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 686008

Thank you for your attention!