A Guideline for Realistic Accelerated Aging Testing of Silvered-glass Reflectors

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Solar Mirror Aging

- Primary mirrors first component in energy conversion process
  - Direct influence on output
  - No large scale replacement foreseen
- Exposure to harsh environmental conditions: desert (UV, erosion), coastal (corrosion)
- Crucial to maintain good optical properties
  - High specular reflectance
  - Expected lifetime: 25 years +

Evaluate durability by accelerated aging
Accelerated Aging Testing/Standardization

- Useful tool for durability evaluation
  - Fast results
  - Different purposes
    - Quality control
    - Material comparison
    - Lifetime prediction
  - Selection of realistic test procedures/parameters
- Standardization
  - Comparability of results
  - Assure meaningful, consistent results
- Up to today lack of agreement on which test are meaningful, parameters
- Few standards exist
  - Spanish UNE206016 (2018)
  - Guideline from Raiselife project (2020)

Input for international IEC proposal
Guideline Development

- EU Horizon 2020 project **Raiselife**
  - Goal to raise lifetime of CSP components (Receivers, Mirrors, etc.)
  - Work package on primary mirrors
- Guideline development
  - Public deliverable:
    
    **Guideline for accelerated aging testing of silvered-glass mirrors**

  [http://raiselife.eu]

- Based on results from large outdoor exposure and accelerated aging test campaign (20 materials, 11 outdoor sites, large number of laboratory tests and combinations)
## Comparative procedure

- **Direct comparison between different reflector materials**

<table>
<thead>
<tr>
<th>Test</th>
<th>Duration</th>
<th>Summary of testing conditions</th>
<th>Acceptance criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Salt Spray (NSS) ISO 9227</td>
<td>480/1000 h</td>
<td>T=35 ± 2° C, pH=[6.5, 7.2] at T=25 ± 2° C Sprayed NaCl solution of 50 ± 5 g/l Condensation rate of 1.5 ± 0.5 ml/h on a surface of 80 cm²</td>
<td>Δρ_s,h ≤0.004, Δρ_λ,φ ≤0.004, d_corr ≤0.01 cm², l_corr ≤0.1 cm</td>
</tr>
<tr>
<td>Copper accelerated acetic acid salt spray (CASS) ISO 9227</td>
<td>120/360 h</td>
<td>T=50 ± 2° C, pH=[3.1, 3.3] at T=25 ± 2° C Sprayed NaCl solution of 50 ± 5 g/l and 0.26 ± 0.02 g/l of CuCl₂ Condensation rate of 1.5 ± 0.5 ml/h on a surface of 80 cm²</td>
<td>Δρ_s,h ≤0.002, Δρ_λ,φ ≤0.002, d_corr ≤0.01 cm², l_corr ≤0.1 cm</td>
</tr>
<tr>
<td>Condensation ISO 6270-2 CH</td>
<td>480/2000 h</td>
<td>T=40 ± 3° C RH=100%, with condensation on the samples</td>
<td>Δρ_s,h ≤0.002, Δρ_λ,φ ≤0.002, d_corr ≤0.01 cm², l_corr ≤0.1 cm</td>
</tr>
<tr>
<td>Combined thermal cycling and humidity UNE206016</td>
<td>10/40 cycles</td>
<td>4 h at T=85 ± 2° C, 4 h at T=40 ± 2° C Method A: 16 h at T=40 ± 2° C and RH=97 ± 3% Method B1: 16 h at T=85 ± 2° C and RH=85 ± 3% Method B2: 40 h at T=65 ± 2° C and RH=85 ± 3%</td>
<td>Δρ_s,h ≤0.002, Δρ_λ,φ ≤0.002, d_corr ≤0.01 cm², l_corr ≤0.1 cm</td>
</tr>
<tr>
<td>UV and humidity ISO 16474-3</td>
<td>1000 h (front side) + 1000 h (back side)</td>
<td>1 cycle: 4h at UV exposure at T=60 ± 3° C followed by 4h at RH=100% at T=50 ± 3° C</td>
<td>Δρ_s,h ≤0.004, Δρ_λ,φ ≤0.004, d_corr ≤0.01 cm², l_corr ≤0.1 cm</td>
</tr>
<tr>
<td>Taber Abrasion UNE206016</td>
<td>1000 cycles</td>
<td>Abradant of diameter ¾”, mild abrading action, pushed force of 3.4 N on the mirror (0.012 N/mm²), 25 cycles per minute, stroke length of 8 ± 2 cm. Intermediate inspections after 200, 400, 600, 800 cycles.</td>
<td>Δρ_λ,φ ≤0.017</td>
</tr>
<tr>
<td>Damp Heat IEC 62108</td>
<td>2000 h</td>
<td>65° C and 85% RH</td>
<td>Δρ_s,h ≤0.01, Δρ_λ,φ ≤0.01, d_corr ≤0.2 cm², l_corr ≤0.1 cm</td>
</tr>
</tbody>
</table>

- **Recommendation to complete whole UNE program + Damp Heat**
- **Especially if degradation modes are unknown**
- **Longer test durations than UNE minimum recommended to screen for additional degradation**
Comparative Procedure – Resistance to Corrosion

- Based on CASS test
  - Testing time usually between 360-720h depending on appearing degradation
  - Ranking of the materials according to affected area by corrosion
- Comparison of CASS results with outdoor data showed very good correlation (2-3 years outdoor exposure on C3/C4 sites)
- Degradation after 3 years outdoor is still low even for aggressive sites

- Verification of results with longer outdoor duration
  - Stronger degradation
  - Also for less aggressive sites
Lifetime Prediction Procedure/Environment acceptance test

- End user of this standard needs to define admissible reflectance loss $\Delta \rho_{ad}$

- Erosion and corrosion are the main degradation modes. Other modes (e.g. silver-tarnishing or surface incrustations) are not considered in this standard

Reflectance loss due to degradation:

$$\Delta \rho_{ad} = \Delta \rho_e + \Delta \rho_c + \Delta \rho_o$$

Test C.1: Erosion

Test C.2: Corrosion
Corrosion Prediction Procedure

- **Scope:** Reproducing the corroded area $A_c$ (reflectance), excluding edge corrosion, of mirror samples exposed outdoors

- **Method:**
  - Up to 2000h of CASS test
  - **Quick method:** depending on site corrosivity class (C2-C4, ISO9223), admissible degradation in CASS is given (see parameters table)
  - **Improved method:**
    - Exposure of material samples on site (3 years)
    - Determination of acceleration factors to CASS
    - Calculation of expected degradation over time

**Predicted reflectance drop for site classes**

<table>
<thead>
<tr>
<th>Guidance</th>
<th>$\Delta \rho_c = 1%$</th>
<th>$t = 20$ yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE</td>
<td>480 (4 cycles)</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>720 (6 cycles)</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>1080 (9 cycles)</td>
<td>0.310</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Guidance</th>
<th>$\Delta \rho_c$ and $t$</th>
<th>Corrosivity class (according to ISO 9223) in which reflector shall be employed</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE</td>
<td></td>
<td>C2</td>
</tr>
<tr>
<td></td>
<td>$t$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$&lt; 1 - \exp \left[ \ln(1 - \Delta \rho_c) \cdot \left( \frac{t}{t_1} \right)^4 \right]$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$&lt; 1 - \exp \left[ \ln(1 - \Delta \rho_c) \cdot \left( \frac{t}{t_2} \right)^4 \right]$</td>
<td></td>
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<tr>
<td></td>
<td>$&lt; 1 - \exp \left[ \ln(1 - \Delta \rho_c) \cdot \left( \frac{t}{t_3} \right)^4 \right]$</td>
<td></td>
</tr>
</tbody>
</table>
Erosion Prediction Procedure

- **Scope:** reproducing the erosion defects in size and density of reflector samples exposed at a height of 1.5 m above ground not surrounded by a wind fence, collectors or any other barriers, in two types of desert environments, named as E1 and E2.

- **Method:** Erosion is tested with sand blasting devices or wind tunnels with particle flow. $v=20\text{ m/s, }\alpha=45^\circ$

<table>
<thead>
<tr>
<th>Environment in which reflector shall be employed</th>
<th>CASE</th>
<th>Guidance $t_i=20$ yrs</th>
<th>Custom</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>m_d = 0.12 g/cm²</td>
<td>m_d = 0.12 g/cm², m_s = 0 g/cm²</td>
<td>m_d = 0.006 $\frac{g}{cm^2\cdot yr}\cdot t_i$, m_s = 0 g/cm²</td>
</tr>
<tr>
<td>E2</td>
<td>m_d = 0.32 g/cm², m_s = 1.46 g/cm²</td>
<td>m_d = 0.016 $\frac{g}{cm^2\cdot yr}\cdot t_i$, m_s = 0.073 $\frac{g}{cm^2\cdot yr}\cdot t_i$</td>
<td></td>
</tr>
</tbody>
</table>

$m_d$ Impacting mass density of MIL-STD-810 blowing dust particles (97-99% quartz, diameter 1-150µm)

$m_s$ Impacting mass density of MIL-STD-810 blowing sand particles (>95% quartz, diameter 149-850µm)

E2 sites fulfill at least 2 of the following criteria: (a) the soil exhibits a significant proportion of fine sand (0.063-0.2 mm), (b) the average relative humidity over a meteorological year lies below 30%, (c) events with wind velocities stronger than 10m/s are taking place at least 300 hours per year.

E1 sites are less erosive and only one of the above listed criteria applies.
Thank you for your attention!
Questions?

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