Real prediction of ground aging of materials using thermokinetic analysis – correlation with real time aging
Aknowledgments

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MAP coatings and CNES for their collaboration

Special thanks to Bertrand RODUIT (AKTS)
1. What is Long Term Storage?
2. What is currently used?
   a. Hygrothermal aging tests
   b. Risk mitigation plans
3. New predictive approach
   a. Thinking differently
   b. In practice
4. Preliminary results
5. Conclusion and way forward
1- What is Long Term Storage (for spacecrafts) ?

• No definition …

1. 5 years and 10 years storage are commonly used as milestones to define Long Term Storage
   o < 5 years, usually no occurrence of significant degradation observed on materials
   o > 10 years, usually contractual requirements to have Long Term Storage plans and reports delivered to customer

2. Storage in cleanroom conditions (22°C, 55% HR) does not prevent from material degradation.
   o Need to identify materials that might be degraded by long term storage and have an impact on EOL value
   o For these materials, need to identify parameters “Critical To Aging”, and monitor them all along the life cycle

• Planned and unplanned Long Term Storage

1. Planned / Controlled Long Term Storage
   o MetOp SG ➔ 20 years LTS (contractual requirements)

2. Unplanned / Uncontrolled Long Term Storage
   o Satellite delays ➔ e.g. Bepi Colombo
   o Reuse spare parts from previous models
1- What is Long Term Storage (for spacecrafts) ?

What means « critical to aging » ?

Example : very high accuracy images need :

1. **Oustanding optical performance**
   
   ![Image of optical system](image1.png)

2. **Reduce straylight and vibrations**
   
   o Highly performant baffles for optics and detectors
     
     o Solar absorptivity $\alpha$
     
     o Accurate dampers and isolators
       
       o Static stiffness $k$
       
       o Loss factor (dynamics)

Solar absorptivity $\alpha$ and static stiffness $k$ are key parameters to monitor for this specific application.
1- What is Long Term Storage (for spacecrafts) ?

• EOL in orbit values are contractually required to achieve performance

*BOL : Beginning Of Life
*EOL : End Of Life
1- What is Long Term Storage (for spacecrafts) ?

• « Critical to aging » is a parameter which impacts final performance

Examples of key parameters to be monitored during Long Term Storage in cleanroom

<table>
<thead>
<tr>
<th><strong>Adhesive bonding</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Mechanics (assy) : traction, shear or peel test (minimum value).</td>
<td></td>
</tr>
<tr>
<td>b. Mechanics (glue) : hardness (HV), viscosity (Pa.s), Tg (°C), DMA</td>
<td></td>
</tr>
<tr>
<td>c. Electrical and thermal : conductivity (S/m, W/m)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Surface treatment</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Mechanics and Geometry : thickness value, roughness (Ra), adhesion (peel test, scribes)</td>
<td></td>
</tr>
<tr>
<td>b. Electrical and thermal : conductivity (S/m, W/m)</td>
<td></td>
</tr>
<tr>
<td>c. Electrochemical: Electrochemical Impedance (Corrosion sensitivity)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Optical coating, paintings</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Mechanics and Geometry : thickness value, adhesion (peel test, scribes)</td>
<td></td>
</tr>
<tr>
<td>b. Electrical and thermal : conductivity (S/m, W/m)</td>
<td></td>
</tr>
<tr>
<td>c. Optics : absorptivity, IR emittance (normal or hemispheric), BRDF</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th><strong>Dielectric material</strong></th>
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<tbody>
<tr>
<td>a. Electrical : conductivity (S/m), dielectric permittivity, dielectric strength (V/m)</td>
<td></td>
</tr>
<tr>
<td>b. Geometry : thickness value</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Pyro device</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Hermeticity : leakage rate (of squib sealant)</td>
<td></td>
</tr>
<tr>
<td>b. Thermodynamics : burning time (for the ignition)</td>
<td></td>
</tr>
</tbody>
</table>
2 – What is currently used: hygrothermal aging tests

Example of accelerated tests on adhesive bondings

• Shear test value $\tau_R$ (often considered as a dimensioning parameter in adhesive bondings) after ground ageing is modelled as a fonction of Temperature and HR parameters, through an Hallberg Peck law.

• Accelerated tests are performed accordingly depending on ground storage duration requested at project level.
2 – What is currently used: risk mitigation plans

1 – At materials level (examples)

- Thermal control and protections
  - Paints, coatings and finishes, tapes, MLIs → values of α et ε (IR).

- Electrical grounding
  - Electrically conductive adhesives → values of electrical conductivity, dielectric constant

- Mechanical functions
  - Adhesive bondings → values of traction, shear or peel test
  - Dampers / elastomer → values of stiffness (statics) or loss factor (dynamics)

2 – At subsystem level (examples)

- Actuate or rotate regularly
- Change the part
  - E.g. Bepi Colombo radiator fins

3 – At spacecraft level (examples)

- Storage in inert gaz

9/20
3 – New predictive approach

Thinking differently …

• Why ?
  • Arrhénius-like laws to simulate accelerated aging are empiric.
  • Value of activation energies is usually unknown (or not measured).
  • Humidity values over 70% may over-stress materials or are not relevant (elastomers).
  • Taking benefit of other industries in long term storage predictions:
    ➔ Sanofi-Pasteur vaccine stability, French DGA and Swiss Armasuisse ammunition long term storage.

• What’s new ?
  • Collect data with *isothermal* tests
  • Enter data in the tool to find most appropriate aging laws using RSS criteria (Residual Sum of Squares) and relying on model quality criteria (AIC and BIC).
  • Use model to predict real aging (e.g. 15 years, 22°C).
  • Correlate with real time aging and update model.

*Note*: real data from cleanrooms can be used.

\[
\frac{d\alpha}{dt} = A_1 \cdot \exp \left( -\frac{E_1}{R \cdot T}(1-\alpha)^{m_1} \alpha^{m_1} + A_2 \cdot \exp \left( -\frac{E_2}{R \cdot T}(1-\alpha)^{m_2} \alpha^{m_2} \right) \right)
\]

15 years at 22°C (15 x year 2017)
1 month shipment, 2 months Kourou
3 – New predictive approach

In practice …

Accelerate, Collect data, Predict, Correlate with real time aging
4 – Work achieved

1200 samples (2018)

Key drivers for materials selection

• Most used materials in space industry:
  • Epoxy and silicone adhesives, electrically conductive glue
  • Adhesive tapes (one electrically conductive)
  • Black and white paintings, surface treatments and finishes
  • Elastomers, …
  • REACh compliant materials (now and “in the future”)
  • Most representative substrates

Major challenges

• Resources and know how keeping
• Costs (limitation of number of substrates)
• Learning curve in AKTS tool
• Management of huge amount of samples
• Protection of samples (in storage racks, in ovens)
  • Removals or works in cleanroom
• Configuration of data collected
4 – Work achieved

1200 samples (2018)

- **Epoxy glues**
  - (Assembly)
  - (e.g. EC 2216, EC 9323-2)
  - **Lap shear tests**
  - 288 samples

- **Epoxy glues**
  - (bare material)
  - **Hardness**
  - **Tg**

- **Silicone glue**
  - (Assembly)
  - (e.g. CV 1142 / DC1200)
  - **Lap shear tests**
  - 144 samples

- **Elastomer**
  - **Stiffness**
  - **Loss factor**
4 – Work achieved

1200 samples (2018)

<table>
<thead>
<tr>
<th>Adhesive tape</th>
<th>Tyraps</th>
<th>White paint</th>
<th>Black paint</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e.g. Y-966, P 224)</td>
<td>(ETFE, PEEK)</td>
<td>(e.g. MAP SG 121/122)</td>
<td>(e.g. MAP AQ PUK)</td>
</tr>
<tr>
<td>Peel Test</td>
<td>Traction test</td>
<td>Absorptivity α</td>
<td>Absorptivit α</td>
</tr>
<tr>
<td>288 samples</td>
<td>72 samples</td>
<td>Emissivity ε</td>
<td>Emissivity ε</td>
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<td></td>
<td></td>
<td>Peel test</td>
<td>Peel test</td>
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<tr>
<td></td>
<td></td>
<td>108 samples</td>
<td>81 samples</td>
</tr>
</tbody>
</table>
4 – Work achieved

Elastomers 1st results

Anomalie sur mesures 23 & 24
4 – Work achieved

Elastomers 1st results

Good accuracy
4 – Work achieved

Elastomers 1st results
4 – Work achieved
Elastomers 1st results

EOL value after 20 years: EOL stiffness loss after ground storage predicted = \(-11\%\) (\(+/- 4.5\%\))
i.e. max loss of \(15.5\%\)
## 4 – Work achieved

### Black and white paints

<table>
<thead>
<tr>
<th>Matériau</th>
<th>Propriété</th>
<th>Temps (jours)</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peinture noire</td>
<td>Absorptivité solaire $\alpha$</td>
<td>1</td>
<td>0,949</td>
<td>0,949</td>
<td>0,948</td>
<td>0,947</td>
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<tr>
<td></td>
<td></td>
<td>3</td>
<td>0,948</td>
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<td>0,949</td>
<td>0,948</td>
<td>0,950</td>
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<td>15</td>
<td>0,948</td>
<td>0,947</td>
<td>0,947</td>
<td>0,947</td>
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<td></td>
<td>25</td>
<td>0,949</td>
<td>0,947</td>
<td>0,948</td>
<td>0,946</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>0,949</td>
<td>0,947</td>
<td>0,946</td>
<td>0,945</td>
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</table>

<table>
<thead>
<tr>
<th>Matériau</th>
<th>Propriété</th>
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<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peinture blanche</td>
<td>Absorptivité solaire $\alpha$</td>
<td>1</td>
<td>0,184</td>
<td>0,186</td>
<td>0,186</td>
<td>0,182</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0,188</td>
<td>0,18</td>
<td>0,182</td>
<td>0,187</td>
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<tr>
<td></td>
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<td>7</td>
<td>0,191</td>
<td>0,193</td>
<td>0,186</td>
<td>0,191</td>
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<td>15</td>
<td>0,195</td>
<td>0,186</td>
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<td>25</td>
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<td>0,187</td>
<td>0,189</td>
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<tr>
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<td>40</td>
<td>0,192</td>
<td>0,188</td>
<td>0,187</td>
<td>0,192</td>
</tr>
</tbody>
</table>

Too early to run the tool as no significant change has been observed in values
5 – Preliminary conclusion and way forward

• Preliminary conclusion
  - Predictive approach for Long Term Storage aging of materials for space is pertinent.
  - Results obtained in elastomers are achieved for static stiffness, to be analysed for dynamics.
  - First results in epoxy adhesive bondings are promising
  - First results obtained in paints and surface finishes need more time as no variations occurred yet.
  - To be started for silicone glues and adhesives tapes.

• Way forward
  - 1st intended to be an internship work, decision was taken to extend the study as a full time permanent job with investment in ovens, storage facilities, and a first set of 1200 samples.
  - 3000 samples are targeted in 2019 to extend to other materials and substrates (ceramics, CFRP, etc.)
  - Any ITT or reliable data already existing is welcome 😊
Merci !
4 – Work achieved

Elastomers 1st results
4 – Work achieved

Preliminary results (1st trial on epoxy glue)
4 – Work achieved

Preliminary results (1st trial on epoxy glue)

EOL value after 20 years: EOL after ground storage predicted = 9 Mpa (T0 = 12 Mpa)