AMAP INTERaCT

Intergranular Corrosion Testing of 6000 Aluminum Alloys
Objectives

- **Main Goal 1:** Understanding the influence of the allowed parameter variation on the test results of ISO11846 Method B
  
  WP 1.1 “Reference“ Conditions → defined by the consortium
  WP 1.2 Volume-to-Surface Ratio R
  WP 1.3 Surface Treatments
  WP 1.4 Solution Temperature
  WP 1.5 Post-etching with HNO₃ / Storage Time

- **Main Goal 2:** Methodical investigation and comparison of established testing methods

Accelerated IGC testing

- ISO11846 B
- PV1113

Climate chamber testing

- VDA233-102
- VDA621-415
- ASTG G85-2

Realistic outdoor testing

- Urban Exposure
- Marine Exposure
## Overview Corrosion Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Type</th>
<th>Environment</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 11846 Method B</td>
<td>Permanent immerison</td>
<td>30g/l NaCl + 10ml/l HCl pH~1</td>
<td>24 hours</td>
</tr>
<tr>
<td>PV1113</td>
<td>Permanent immerison</td>
<td>100g/l NaCl + 25ml/l HCl pH&lt;1</td>
<td>2 hours</td>
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<tr>
<td>VDA233-102</td>
<td>Cyclic testing</td>
<td>1% NaCl, pH: 6,5-7,2</td>
<td>12 weeks</td>
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<tr>
<td>VDA621-415</td>
<td>Cyclic testing</td>
<td>5% NaCl, pH: 6,0-7,0</td>
<td>10 weeks</td>
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<tr>
<td>ASTM G85-A2</td>
<td>Cyclic testing</td>
<td>5% NaCl, pH: 2,8-3,0</td>
<td>10 weeks</td>
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<tr>
<td>Urban Exposure</td>
<td>Natural weathering</td>
<td>3% NaCl (weekly)</td>
<td>1 year</td>
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<tr>
<td>Marine Exposure</td>
<td>Natural weathering</td>
<td>Splash zone / permanent immersion</td>
<td>1 year</td>
</tr>
</tbody>
</table>
### Materials & Test Specifications

### Materials

- AA6014 and AA6016 each in high Cu and low Cu
  - T4
  - BH (20min / 185°C, cooling in air)
  - T6 (2h / 205°C, cooling in air)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>V</th>
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<td>High Cu</td>
<td>1.38</td>
<td>0.20</td>
<td>0.1620</td>
<td>0.061</td>
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<td>Low Cu</td>
<td>1.49</td>
<td>0.19</td>
<td>0.0023</td>
<td>0.078</td>
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<td>High Cu</td>
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<td>0.17</td>
<td>0.3</td>
<td>0.15</td>
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<tr>
<td>Low Cu</td>
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<td>0.17</td>
<td>0.1</td>
<td>0.10</td>
<td>0.65</td>
<td>0.1</td>
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</table>
Main Goal 1: Parameter Study ISO11846 Method B

- WP 1.1 "Reference“ Conditions → defined by the consortium
- WP 1.2 Volume-to-Surface Ratio $R$
- WP 1.3 Surface Treatments
- WP 1.4 Solution Temperature
- WP 1.5 Post-etching with $\text{HNO}_3$ / Storage Time

Reference Conditions:
- $30\text{g/l NaCl} + 10\text{ml/l HCl}$ (pH~1)
- $T = 30^\circ\text{C}$, $t = 24$ h
- Vol./Surface ratio $R = 5$
- Etching: 2 min @ $50^\circ\text{C}$ in 5 wt.% NaOH
Results: WP 1.2 Volume-to-Surface Ratio

The volume-to-surface ratio can significantly influence the results!

Higher amount of HCl (delayed pH shift)

\[ 2\text{Al} + 6\text{HCl} + 12\text{H}_2\text{O} \rightarrow 2\text{Al(H}_2\text{O)}_6\text{Cl}_3 + 3\text{H}_2 \]
The surface treatment can significantly influence the test results!

Cathodic Si-rich particles on the surface resist alkaline pickling!
Results: WP 1.4 Solution Temperature

The solution temperature can significantly influence the test results!

Currently not clear/possible further research topic
Results: WP 1.5 Post-etching / Storage Time

The test results are independent of post-etching and storage time!
Summary Main Goal 1: ISO11846 Method B

Main Findings

• **Cu** has dominant **detrimental effect** on IGC

• The **test results** according to ISO 11846 Method B are **highly dependent on** the used parameters

• A **narrower specification** of the test parameters is required in order to obtain more reliable and comparable test results
Main Goal 2: Comparison of established Testing Methods

- ISO11846 Method B → Reference
- PV1113
- VDA233-102
- VDA621-415
- ASTM G85
- Urban Outdoor Exposure
ISO11846 Method B vs PV1113

Systematical difference of 20 to 40 µm

High comparability
IGC susceptibility increases with increasing heat treatment

BUT: detrimental effect of Cu is less distinct!
→ Cu less critical for in-service conditions than usually assessed using immersion tests?
Influence of heat treatment and Cu-content seems to be rather low (at least when compared with immersion tests)
Summary Main Goal 2: Testing Methods

- For all tests localized corrosion occurred **predominantly as intergranular corrosion**. ASTM G85 Annex 2 predominantly caused pitting corrosion on all materials.

- The highly accelerated lab tests, ISO11846 Method B and PV1113, showed a very **good correlation** with a systematic deviation ranging from 5 to 45 µm.

- ISO11846 Method B and PV1113 showed a distinct dependence between the penetration depth and the Cu content; the average penetration depth is significantly increased with **increasing Cu content**.

- ASTM G85 Annex 2, as well as the urban outdoor exposure, showed a less strong correlation between penetration depth and Cu content → the **detrimental effect of Cu** is likely to be less critical for in-service conditions than usually assessed using ISO11846 and PV1113.

- VDA233-102 and VDA621-415 are **not recommended** for the testing of blank aluminum sheets since the corrosion attack is very little even after a duration of 12 or 10 weeks, respectively.

- The **highest correlation** to accelerated outdoor exposure in terms of penetration depths was found for ASTM G85 A2.
Project Goals

- Project aims fulfilled, various influence factors on IGC testing identified and differences between corrosion tests displayed ✓

- Project finished within proposed project timeframe ✓

- First AMAP research project with advisory board consisting of OEMs ✓

- Highly beneficial collaboration between industry partners, OEMs and the Chair of Corrosion and Corrosion Protection ✓

- Initiation of new VDA standard and round robin tests → Further analysis of influence factors ✓

- New successor project: AMAP P22 UniCorn – Understanding the Intergranular Corrosion of 6000-Aluminum Alloys
Future Activities

• 1st publication of the ISO 11846 parameter study in *Materials & Corrosion*

• 2nd publication about cyclic corrosion testing is in *Materials & Corrosion*

• Presentation at EUROCORR´17

• Presentation at EUROCORR´18

• Development of a VDA standard in cooperation with AK Korrosionstechnik
Thank you very much for your attention!