Environmental Durability of Aluminum Adhesive Joints and Corrosion-Sensitive Aluminum Alloys: One More Step Toward a More Reliable Laboratory Evaluation of In-Service Performance

Danick Gallant  Ph.D., NACE Coating Inspector
Research Officer
Technical Leader – Corrosion Control and Performance Evaluation of Lightweight Materials and Assemblies
NRC Aluminum Technology Center

Global Lightweight Materials Manufacturing
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NRC Aluminum Technology Center contributes to find solutions to « showstoppers » in the use of aluminum.

Today’s GLMM presentation adresses 2 of them:

- **Environmental durability of adhesive joints**: How can automotive OEMs (buses, heavy trucks, trains, subways, specialty vehicles, cars) become more confident in the use of 2K epoxy and MMA adhesives?
- **Corrosion protection of high-strength aluminum alloys**: How can corrosion protection of aluminum underbody be simulated in the lab?

This presentation will emphasize on methodologies developed at NRC Aluminum Technology Center.
Corrosion and durability activities
An integrated 3-level approach

**Level 1 - Electrochemical characterization**
- Determination of sensitivity to pitting corrosion, electrodissolution rate, filiform corrosion, SCC, etc.
- Alloys selection and development
- Rapid electrochemical assessment of coatings
- Non destructive inspection

**Level 2 - Exposure to artificial environments**
- Cyclic corrosion testing (ISO, ASTM, SAE)
- OEMs procedures (GMW, FLTM, Volvo)
- Samples health monitoring during laboratory environmental exposure
- Exposure to outdoor environments with intermittent salt spray

**Level 3 - Exposure to in-service conditions**
- Exposure of specimens to road conditions
- Periodic samples removal for condition evaluation

Current state-of-the-art
- Data acquisition rate
- Prediction accuracy of in-service behavior

Where we are going
- Data acquisition rate
- Prediction accuracy of in-service behavior

Current state-of-the-art +

Where we are going +

Data acquisition rate +

Prediction accuracy of in-service behavior +
Environmental durability of adhesive joints

NDI of adhesive joints using electrochemical techniques

Correlation between in-service & laboratory exposure

Evidencing degradation mechanisms of adhesive joints

Reproducing in-service conditions from the knowledge of degradation mechanisms
Monitoring of adhesive joint health during environmental exposure

- Sensors are embedded inside the adhesive joint
- DC current component is analyzed using a simplified electrical circuit, assuming that moisture will penetrate the adhesive
Monitoring of adhesive joint health during environmental exposure

Method efficient for adhesive & surface treatment selection

Phase-I: slow moisture ingress in the adhesive joint – normal for any polymer.

Phase-II: moisture penetration accelerates – the adhesive joint will fail.

Phase-III: saline moisture diffuses in the joint – Al and adhesive are now separated.

Phase-IV: saline moisture is located at the Al/adhesive interface – the joint fails.
Monitoring of adhesive joint health during environmental exposure

Simplified electrical circuit – Analysis of the DC component

Phase-I
Adhesive joints exposed to in-service environments
Winter exposure – Nov. 2013 to May 2014
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Overall, for the 2K epoxy adhesive evaluated in combination with 4 surface treatments, the main moisture intrusion route is the Al-adhesive interface.
Durability of Al-epoxy adhesive joint
Winter exposure - Nov. 2013 to May 2014 - Influence of surface treatment

Road exposure vs Lab exposure

- Road exposure vs Lab exposure
- Epoxy adhesive, basic surface treatment
- Epoxy adhesive, chemical-based surface treatment

Road distance (km) vs Mechanical resistance loss (%)

Hours of exposure in lab

After 15,000 km

100% cohesive failure: what is the degradation mechanism?

After lab exposure

Mechanical resistance loss (%) vs Road distance (km)

After 15,000 km

After lab exposure

100% cohesive failure: what is the degradation mechanism?
Durability of Al-epoxy adhesive joint
Summer exposure - Chemical-based surface treatment, after 25,000 km between May & Nov. 2014

Samples in front of the pad

Samples behind the pad

Pristine assemblies
Samples in front of the pad
Samples behind the pad

Pristine samples

After 25,000 km
Durability of Al-epoxy adhesive joint
Influence of load – ongoing work

In the lab

On the road
Durability of AI-MMA adhesive joint
Winter exposure - Nov. 2013 to May 2014

**System 1** – Adhesive 1 + Surface Treatment 1

**System 2** – Adhesive 2 + Surface Treatment 2
Durability of Al-MMA adhesive joint

Winter exposure - Nov. 2013 to May 2014

**Position of the assembly**

**Road exposure**

- Mechanical resistance loss (%)
- Road distance (km)

**Lab exposure**

- Hours of exposure in lab

**Mechanical resistance loss (%)**

- Position of the assembly
- Road distance (km)

**Mechanical resistance loss (%)**

- Position of the assembly
- Road distance (km)
Durability of Al-MMA adhesive joint
Summer exposure - After 50,000 & 100,000 km between May & Nov. 2014

• With an appropriate surface treatment (non tank immersion required), the adhesive/substrate interface becomes protected from degradation;
• Adhesive selection can be supported by NDI techniques, and an appropriate coating applied on the assembly can slow down moisture ingress in the adhesive itself.
Painted AA7075 samples exposed on vehicles
Painted AA7075 samples exposed on vehicles

Accumulation of saline mud, with minimum exposure to impact and erosion conditions
Impact (chipping) resistance of protective coatings
Development of a fast quantitative evaluation methods of SAE J400 results

- AA7075 coated samples exposed to gravelometer test, according to SAE J400;
- Damage evaluation, using electrochemistry, of AA7075 coated samples exposed to SAE J400: more accurate than the classical method.
Impact (chipping) resistance of protective coatings
Development of a fast quantitative evaluation methods of SAE J400 results

The classical evaluation method ...

The electrochemical method ...

\[ R_p = \left( \frac{dE(i)}{di} \right)_{i=0} \]

\[ R_p = 25.5 \text{ kOhms cm}^2 \]

\[ i_{corr} = \frac{1}{2.303 R_p} \left( \frac{\beta_a \beta_c}{\beta_a + \beta_c} \right) \]

\[ i_{corr} = \frac{B}{R_p} \]

\[ i_{corr} \propto \frac{1}{R_p} \]

\[ E(i) = 9(10)^{34}x^6 + 2(10)^{29}x^5 + 9(10)^{22}x^4 + 2(10)^{16}x^3 + 2(10)^{10}x^2 + 25554x - 0.7626 + 0.9998 \]
Impact (chipping) resistance of protective coatings
Rp values for coatings after SAE J400

Higher is Rp, higher is the chipping resistance

1/Rp is proportional to the metallic surface exposed
Coating adhesion

Coating adhesion strength (psi)

- Initial adhesion
- After REAP
- After ISO14993 / ASTM870 / -30C

Coating

#1  #2  #7  #10  #14
Painted AA7075 samples exposed on vehicles
Influence of position under the vehicle / Coating #7 / After 7 months

Closer to the pad
Rapid electrochemical assessment of paints (REAP)
In-service vs laboratory
Coating #1

In-service vs laboratory
Coating #1

In-house combined technique

In-service vs laboratory
Coating #1

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Coating #14
When a small detail contributes to make a big difference

After 1,500h ISO14993
+ 96h ASTM D870
+ 72h @ –30°C

Scribed sample

Impacted sample

Bare AA6061

Painted AA7075

Thin layer of salt water
Coating
AA7075

AA6061
Galvanic corrosion AA6061-AA7075

AA7075 = anode

AA7075 = cathode
Development of a corrosion assisted fatigue (CAF) & stress corrosion cracking (SCC) testing cell

- Corrosion cell designed for corrosion assisted fatigue (CAF) and stress corrosion cracking (SCC) installed on a servohydraulic machine with a 25 kN capacity, and equipped with 2 actuators for torsion and tension modes;
- Cell made of Ti64 et SS316 alloys;
- Solution continuously flows through the cell, at a controlled temperature;
- The sample is electrically insulated from the cell, thus allowing *in situ* electrochemical measurements and control;
  - The cell can be used to evaluate bare alloys, protected alloys, adhesive joints, welded joints, etc;
  - This cell will first be used for the development and evaluation of protective solution for AA7075 high strength aluminum alloy, which is sensitive to SCC.
Thank you

Danick Gallant Ph.D., NACE Coating Inspector Level 2 No. 37804
Research Officer
Technical Leader – Corrosion Control and Performance Evaluation of Lightweight Materials and Assemblies
NRC Aluminum Technology Center
Office: +1-418-545-5096
Email: Danick.Gallant@cnrc-nrc.gc.ca