Improvements in Surface Preparation Methods for Adhesive Bonding

Kay Blohowiak
Material and Process Technology, The Boeing Company
Seattle, Washington, USA

SERDP/ESTCP Workshop
27 February, 2008
<table>
<thead>
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<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
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<td>27 FEB 2008</td>
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<td>Improvements in Surface Preparation Methods for Adhesive Bonding</td>
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<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
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<td>Boeing, Material and Process Technology, P. O. Box 3707, Seattle, WA, 98124</td>
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<th>12. DISTRIBUTION/AVAILABILITY STATEMENT</th>
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<td>Approved for public release; distribution unlimited</td>
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<th>13. SUPPLEMENTARY NOTES</th>
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<td>Surface Finishing and Repair Issues for Sustaining New Military Aircraft Workshop, February 26-28, 2008, Tempe, AZ. Sponsored by SERDP/ESTCP.</td>
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<th>14. ABSTRACT</th>
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<th>19a. NAME OF RESPONSIBLE PERSON</th>
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The purpose of this project is to:

- Demonstrate and validate the laboratory-verified, sol-gel processes developed under SERDP PP-1113 by addressing implementation issues for aluminum, titanium, and steel substrates utilized by tri-service aircraft platforms at the repair (depot and field) and OEM levels.
DEMONSTRATION/VALIDATION OF SOL-GEL SURFACE PREPARATION FOR METAL ADHESIVE BONDING

Team Participants

- **USAF AFRL/MLSA**  
  Mr. Jim Mazza

- **Naval Air Systems Command, Pax River**  
  Mr. Matt Tillman

- **US Army TACOM-ARDEC**  
  Mr. Bill De Piero

- **USAF WR-ALC/LBRE**  
  Mr. Jay Fiebig

- **USAF WR-ALC/EN**  
  Mr. Bill Schweinberg

- **NAVAIR-NADEP Jacksonville**  
  Dr. Don Knapp

- **NAVAIR-NADEP Cherry Point**  
  Mr. Bill Alexander

- **NAVAIR-NADEP North Island**  
  Mr. Doug Perl

- **US Coast Guard**  
  LCDR Werner Winz

- **The Boeing Company**  
  Dr. Kay Blohowiak

- **Advanced Chemistry & Technology**  
  Mr. Stephane Pyrek
Environmental Reduction Targets

Boeing Technology

- **Aluminum**
  - Pasa-Jell 105
    - Hexavalent Chromium, Sulfuric Acid, Contaminated Waste Water
  - FPL Etch
    - Hexavalent Chromium, Sulfuric Acid, Contaminated Waste Water

- **Titanium**
  - Chromic Acid Anodizing
    - Hexavalent Chromium, Hydrofluoric Acid, Contaminated Waste Water
  - Phosphate Fluoride Etch
    - Hydrofluoric Acid, Phosphoric Acid, Contaminated Waste Water
  - Pasa-Jell 107
    - Hexavalent Chromium, Chromic Acid, Nitric Acid, Hydrofluorosilicic Acid, Contaminated Waste Water

- **Steel**
  - Ferric Chloride/Hydrochloric Acid Etch
    - Hydrochloric Acid, Sulfuric Acid, Contaminated Waste Water
Designed Sol-Gel Interface

- Tailorable to different resin/paint chemistries
- Robust process conditions
- Greater range of properties using inorganic and hybrid polymers than current state-of-the-art systems
Repair vs. OEM

• Typically better controls at manufacturing level
  • Environmental controls
  • QC/inspection methods

• Fewer tools/materials available in field

• Training/certification

• New clean parts vs. dirty old parts

• Access to repair area

• Potential damage to areas adjacent to repair

Why we repair…
Sol-Gel Process Conditions

Mix AC-130 sol-gel kit

Induction time: 30 min

Sol-Gel Process Steps

Clean and deox Al alloy surface

Use specified sanding tools

Brush or spray apply sol-gel

Dry 30 min

Spray apply BR6747-1

Cure with heat
Surface Treatment Comparison

Grit blast treatment prior to sol-gel gives a comparable result to PAA pretreatment, but is more difficult than manual abrasion in field repair applications.
WR-ALC TESTING

THERMAL SHOCK

FATIGUE

STATIC STRESS DURABILITY
Examples of Repair Implementations

• C-5 Applications:
  • Flaps, Ailerons, Engine Pylon Panels, Floorboards, Torque Deck, Fuselage, Bulkheads, Ramps
  • Depot Level, Off-Aircraft Repair

• CH-46 and CH-47 Ti and Al:
  Rotor blade caps, erosion strips, underfloor corrosion repairs

• B-1 Stainless Repair

• F-18 Al and Ti Repairs

• F-16 Al Repairs

• F-16 Al Repairs

• F-22 Ti Repairs

• C-130 Al Repairs

• V-22 Al Repairs
OEM Sol-Gel Non-Cr Conversion Coatings

Boeing Technology

AC-131*

Aluminum

Ti, Stainless, Ni, etc

XBMS 10-128
BSMS-25-002

BAC 5663
D6-1816

BAC 5665
BSPS-07-002

AC-130*

Aluminum

Ti, Stainless, Ni, etc

XBMS 5-162
BSMS-25-001

SRM
51-70-10
51-70-09

BSPS-07-001
XBAC 5667

*AC-130 and AC-131 are products of AC Technology, Costa Mesa, CA, 2nd source supplier qualification currently in-work (Henkel, Socomor, PPG)
## Qualification Test Matrix

<table>
<thead>
<tr>
<th>TEST</th>
<th>TEST METHOD</th>
<th>TEST PROCEDURE</th>
<th>No. of Specimens*</th>
<th>MINIMUM REQUIREMENT</th>
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<tr>
<td>Lap Shear at 75 ± 5°F</td>
<td>BSS7202</td>
<td>BSS7202 Type V</td>
<td>10</td>
<td>4200 psi</td>
</tr>
<tr>
<td>Lap Shear at -67 ± 2°F</td>
<td>BSS7202</td>
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<td>Lap Shear at 180 ± 5°F</td>
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<tr>
<td>Lap Shear at 250 ± 5°F</td>
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<td>650 psi</td>
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<td>Lap Shear at 75 ± 5°F after 30 days at 120 ± 5°F and 100% Relative Humidity</td>
<td>BSS7211, BSS7202</td>
<td>BSS7202 Type V</td>
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<td>4200 psi</td>
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<td>Lap Shear at 75 ± 5°F after 30 days salt spray exposure at 95 ± 5°F</td>
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<td>Lap Shear at 75 ± 5°F after 7 days immersion in Jet A fuel at 75 ± 5°F</td>
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<td>Lap Shear at 75 ± 5°F after 7 days immersion in Reference Fuel B at 75 ± 5°F</td>
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<td>Lap Shear at 75 ± 5°F after 7 days immersion in BMS3-11 at 150 ± 5°F</td>
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<td>BSS7202 Type V</td>
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<td>4200 psi</td>
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<td>Lap Fatigue at 75 ± 5°F</td>
<td>BSS7201</td>
<td>BSS7202 Type IIIA</td>
<td>3</td>
<td>10⁷ cycles at 1500 psi</td>
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<tr>
<td>Sustained Stress Loading at 140 ± 5°F and 100% Relative Humidity</td>
<td>BSS7209</td>
<td>BSS7202 Type V</td>
<td>10</td>
<td>90 days at 900 psi</td>
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<td>Metal to Metal Climbing Drum Peel</td>
<td>BSS7206</td>
<td>BSS7206 Type II</td>
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<td>25 lbf/in width</td>
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<td>Wedge Crack after 7 days at 140 ± 5°F and 95% Relative Humidity</td>
<td>BSS7202</td>
<td>ASTM D3762</td>
<td>10</td>
<td>&lt;0.25 inch crack growth &gt;90% cohesive failure</td>
</tr>
</tbody>
</table>

*per batch for three batches for qualification
Sol-Gel Process Steps

1. Clean and prep surface to be treated
2. Prepare sol-gel coating solution (AC-130)
3. Apply sol-gel coating solution
   - Method 1: Spray
   - Method 2: Brush
4. Bond with Adhesive
5. Apply & cure bond primer (BR6747-1)
6. Dry/cure sol-gel coating solution

- 24 hours maximum elapsed time
- 60 month storage
- 30 minute induction time
- 10 hour pot life
- 60 minute air dry minimum or 30 minutes air dry + 30 minutes @ 140°F
- 24 hours maximum elapsed time
• Added as an option to SRM 51-70-09 and 51-70-10
  Implemented 2005-2006
    • Al 250F-cure repairs w/BMS 5-101
    • Al 350F-cure repairs w/BMS 5-137
    • Titanium repairs
• Only BMS 5-89 Ty II (Cytec BR 6747-1) allowed with Boegel-EPII
  • Compatibility of water-based product with sol-gel
• Goal: Replace HF/Alodine in fleet repairs
  • Health/Safety/Hazmat
  • Improved Durability
• Reduce process repair time/cost over anodize repair methods
• Uses specific abrasive materials and tools
• Robust process methods
Performance Comparisons

Lap Shear Testing

- Boegel PAA HF/Alodine
- psi
- 30 day salt spray
- 30 day 120°F/95% RH
- 7 day jet fuel

Lap Shear with Environmental Exposure

- Boegel PAA HF/Alodine
- psi
- 30 day salt spray
- 30 day 120°F/95% RH
- 7 day jet fuel

Wedge Crack Durability

- 24 hr exposure to 140°F/>98% RH
- Larger is bad

DCB Extended Durability Tests

- 10-month Exposure at Long Beach Test Site
- 2024 T3 Bare 7075 T6 Bare

Force (in.-lb./in.²)

- PAA
- Merit 180 + sol gel
- HF Alodine
BCA Repair Implementation

- Implemented in the Boeing Commercial Structural Repair Manuals in 2005
  - Metalbond Working Group
    - Airlines, Boeing R&D, Service Engineering, DERs
- Aluminum 250F repairs first
  - Added 350F Al repairs
  - Added Ti repairs
- Feedback from airline users good
  - Cost savings
  - Process robustness
  - Wanted some improvements
Boeing-EPIII for Al Bonding Updates

- Added new sandpaper alternatives for use in Al bonded repairs
  - 3M 361F, 300D, 777F, 900DZ
  - Merit ALO Resin Bond
- Incorporated 2-part Boegel kits (AC-130-2) into BCA SRMs
  - More stable shelf-life
  - Easier shipping to overseas locations
  - More robust, easier to use
  - Equivalent performance and durability
- Working on draft BMS/BAC for internal OEM Al bonding applications
- Testing new nonchromated adhesive bond primers
  - Cytec BR6747-1NC
  - Cytec BR6700-1 (sol-gel compatible)
  - Initial data promising
Future Work – Deoxidation Methods

• Alternatives to Abrasive Deoxidation Methods
  • Improve robustness of process
  • Reproducibility over larger areas
  • Evaluate energetic techniques
    – Plasma
    – Laser
Future Work – Bond Primer

- Non-Chromated Adhesive Bond Primers
  - Preliminary data on 3M and Cytec candidates
  - Compatibility with Multiple Surface Prep Methods
    - PAA
    - Sol-Gel
  - Corrosion Protection within Bondline and Outside of Bondline
- Non-Aluminum Applications
  - Want one primer for all
- Industry Team
  - March Telecon; Spring 2008 SAMPE meeting
  - Contact kay.y.blohowiak@boeing.com to get on the distribution list for participation
Future Work – Other Bonded System Improvements

• Composites bonding
  • Reduce haz/mats used

• Improved Adhesive Systems
  • Improved durability – longer life