Critical Materials & Processes
Bonded Joint Issues

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Topics

• Overall philosophy
• Metal Bonding
  Composite Bonding
    – Surface preparation
    – Primers
    – Adhesives
    – Repair
    – Inspection
Philosophy

• The substrate (e.g. specific alloy or composite), surface preparation, and adhesive are a unique system

• Boeing takes a system approach to the qualification and verifies all new products/processes by extensive compatibility tests
Metal Bonding

Aluminum
Titanium
Stainless
Other
# Boeing’s Historical Bonding Methods

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<tbody>
<tr>
<td><strong>surface</strong></td>
<td>FPL</td>
<td>PAA; PANTA; Wedge/DCB</td>
<td>PAD</td>
<td>CWR; Non-Cr, 0V deox; sol gel repair</td>
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<tr>
<td>dissolved</td>
<td>CIAP BMS 5-89 (‘69)</td>
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<td>adhesive resin</td>
<td></td>
<td>Low VOC 0 VOC CIAP</td>
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<td><strong>adhesive</strong></td>
<td>BMS5-10 cold bond; 350 F cure epoxies BMS 5-70 to BMS5-51 and 5-80</td>
<td>toughened epoxy nitrile BMS5-101 BMS 5-104</td>
<td>BMS 5-137 better toughness</td>
<td>next gen. adhesives EA9696, FM94 AF555</td>
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<td><strong>core</strong></td>
<td>Acid etched foil</td>
<td>pour coat CR core</td>
<td>PAA core</td>
<td>PAA core to carbon skins</td>
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Structurally Bonded Metal Applications

Heritage Boeing

Empennage Leading Edge Skins

Trailing Edge Wedges
Leading Edge, Skins

Side Fairing Panel

Tail Cone Skins

Empennage Fwd Torque Boxes

MLG Strut Door

Spoiler Assys

Wing Tip Assy

Tear Straps and Bear Straps to Body Skins (all sections)

Sect. 41 Doublers

Window Doublers

Door Skin Doublers and Lap Splices

Cowls and Strut Skins

Leading Edge Slat Trailing Edge Wedges
Adhesive Bond Failures

Corroded core

737 body skin waffle doubler
with unanodized area

Really corroded core

Corrosion products on repair doubler
Types of Prebond Surface Preparations

• Mechanical Deoxidation
  – Grit Blasting, Sanding
• Anodizing
  – PAA, CAA
• Chemical Etching
  – FPL, CAE, HF/Alodine, Pasa Jell 105/107
    FCHAE, Phosphate fluoride
• Functional Coatings
  – GBS, Sol-Gel
Manual Abrade / Solvent Wipe

- Grit Blasting
- Sanding
- ScotchBrite Abrasion

• Initial adhesion often very good
• Abrasion or roughening can give some mechanical interlock
• Deoxidation exposes fresh metal for bonding
• Fails at interface under hot/wet conditioning
  – Hydration of aluminum oxides
  – Corrosion
  – Secondary bonding interactions
Anodizing

- Phosphoric Acid Anodize
- Chromic Acid Anodize
- Boric Sulfuric Anodize
- Thin Film Sulfuric Anodize

- Microstructure promotes wetting of adhesive resins
- Mechanical interlock by flow of primer/adhesive into pores resulting in composite interphase
- Good under hot/wet conditioning
  - Phosphoric acid anodizing stabilizes the hydration of aluminum oxides
  - Corrosion control at interface
Phosphoric Acid Anodize

• **BAC 5555 issued in 1974**
  – US Patents 4,085012 & 4,793,903

• **Early issues**
  – Disbonded PAA waffle doublers (tear straps) on 737
  – “sporadic escapements” of panels with insufficient PAA
  – 747 Section 41 internal doubler disbonding
Chemical Etching

- Forest Products Laboratory Etch
- Chromic Acid Etch
- Pasa-Jell 105
- HF/Alodine

- Deoxidizes the metal surface
- May leave chromates that retard corrosion at the interface
- May provide some surface roughening

Issues:
- Health/environment
- Corrosion due to entrapped acid
- Embrittlement of high strength steel
- Performance
- Temp

Chromic acid etching process on underwing repair

Pasa-Jell treated surface
Boeing Service History
Original Bonding Process– FPL Etch

- FPL etch - industry standard until mid 1970s
- Numerous service bulletins and Airworthiness Directives (ADs) due to bond durability problems
  - 747 Section 41 flat-sided skin panel (SB 747-53A2321), L/N 1-430
  - 747 tear straps in section 46 (SB 747-53A2279), L/N 1-230
  - 747 Section 41/42 disbond inspection of large radius areas (SB 747-54-2406), L/N 1-430
Functional Coatings

- **Silane**
  - Australian silane process
  - Grit-blast/silane (GBS)
- **Sol-Gel**
  - Boegel-EPIII / AC-130

- Chemically bond adhesive to surface
- Crosslinking of resin to functionalized silane
- May be enhanced by surface roughening
- Performance highly dependent on pretreatment

Sol-gel coated metal surface
Sol-Gel Process Robustness

- Application procedure simple
- Sol-Gel Process will “work” under a variety of pretreatment conditions
- Best results achieved when using recommended abrasion processes
- Works with and without primer
- Paste and film adhesives

Issues:

- Must have clean surface
- Only optimized for use with certain bond primers
- Better results with recommended abrasive procedures
Issues in Qualifying New Surface Preps

- Scope of qualification
  - Cost
  - Meet all design scenarios
- Consistent process among OEM and suppliers
- What kind of specification to write

Qualification Issues

- What criteria do new surface preps have to meet?
- How do you demonstrate 30 year durability in the lab?
Adhesive Bond Primer

- Compatibility with surface preparations
- Bake vs. No-bake
- Primer thickness window
- Low VOC bond primer development
- Non-Chrome bond primer development

Qualification Issues

- How good is good enough?
- What are the real criteria for implementation?
- Extent of implementation

Cr vs. Non-Cr Primers

- Nitrile rubber based primers (e.g. BMS 5-42) do not contain any chrome
- Epoxy based primers (e.g. BR127, BR6747-1) do contain chrome
- Long term exposure of DCB specimens in various environments resulted in equivalent behavior of chrome and non-chrome.
- Chrome bond primer has a benefit in paint applications without additional primer.
Adhesive Issues- Engineering

- Thermal Capability
- Toughness
- Shear
- Filleting
- Moisture effects (hot/wet)
- Bondline Thickness

Qualification Issues

- Cost of allowables
- Long-term durability
Metal Bond Process Inspection

- Surface Prep Verification
- First Part Qualification correlations
  - Prefit
  - Verifilm
  - TTU
  - Destructive Test
- TTU
- Tap Testing

Questions

- How do you measure success of the process steps
- Kissing bonds
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
Composite Bonding
Philosophy

• The substrate (e.g. specific alloy or composite), surface preparation, and adhesive are a unique system

• Boeing takes a system approach to the qualification and verifies all new products/processes by extensive compatibility tests
Composite vs. Metal bond durability
1500 psi Cyclic Fatigue in 140F/100% RH

1500 psi lap shear cycles 140F/100% RH

Test stopped
Composite Surface Preparation Methods

- Peel Ply (baseline)
- Grit Blast
- Peel Ply + additional surface preparation
Peel Ply Surface Preparation

• Widely used at Boeing Commercial
• No “universally” functional peel ply
• Sensitivity to using the wrong peel ply
• Cleanliness and max delay requirements
• Excellent durability
• Specification and PCD control for critical applications
Mechanical Properties of Composite Bonds
(Optimal vs. not optimal peel ply)

Optimal Peel Ply

Not Optimal Peel Ply

RT Lap Shear (ksi)
DCB (in-lb/in2)
Peel Ply Affects Failure Mode

Optimal Peel Ply Cohesive Failure Mode

Not Optimal Peel Ply Adhesive Failure Mode
Using the Wrong Peel Ply Results in Adhesive Failure Mode

Peel Ply Pattern Replicated in Adhesive
Grit Blast Surface Preparation

• Provides an excellent surface for bonding
• Process control issues (pressure, distance, grit control etc.)
• Economics (process time, grit management)
Effect of Additional Surface Treatment on Mode I Fracture Toughness

- G_{IC} (in-lb/in^2)
- Interlaminar failure
- Mixed failure modes
- Adhesive failures

- as is
- as is + additional treatment

Legend:
- Bad peel ply 1
- Bad peel ply 2
- No peel ply (smooth)
- Good peel ply
Adhesive Issues - Manufacturing

- Stability – Long Out-time and Storage
- Appropriate Tack
- Rheological compatibility and stability
- Compatibility with autoclave and vacuum curing
Process Control Document

• Controls formulation, manufacturing and testing of product
• Controls changes to product
• Statistical process control
Adhesive Issues- Engineering

- Prebond humidity
- Thermal Capability including hot/wet
- Toughness
- Shear
- Filleting
- Bondline Thickness
Effect of Prebond Humidity on Adhesive performance

• Different adhesives have different responses to prebond humidity
  – Morphology
  – $G_{IC}$
  – Lap shear
  – Tg
  – Kinetics
Moisture Content vs. Environment
10 ply carbon epoxy laminate

Days

Percent Moisture

72F/0%
72F/50%
92F/50%
160F/100%RH
Effect of Prebond Humidity on Adhesive Morphology

Adhesive A bonded immediately

Adhesive A bonded after 28 days at 92F/50% of composite prebond exposure
Effect of Pre-bond Humidity on $G_{IC}$
Effect of Pre-bond Humidity on 270°F Lap Shear

![Graph showing the effect of pre-bond humidity on 270°F lap shear.](image)

Prebond Moisture Content (%)

- 42%
- 44%
- 42%

Shear (psi)

- 0
- 500
- 1000
- 1500
- 2000
- 2500
- 3000
- 3500
- 4000
- 4500

Kay and Pete FAA Wksp Rev A.ppt
5/28/2004, 38
Summary => New Directions

• Surface Preparation
  – Boegel-EPII/AC-130 for metals
  – Grit Blast or enhancements to peel ply for composites

• Adhesives
  – Stability in out-time and prebond humidity

• Inspection
  – Methods of detecting weak bonds