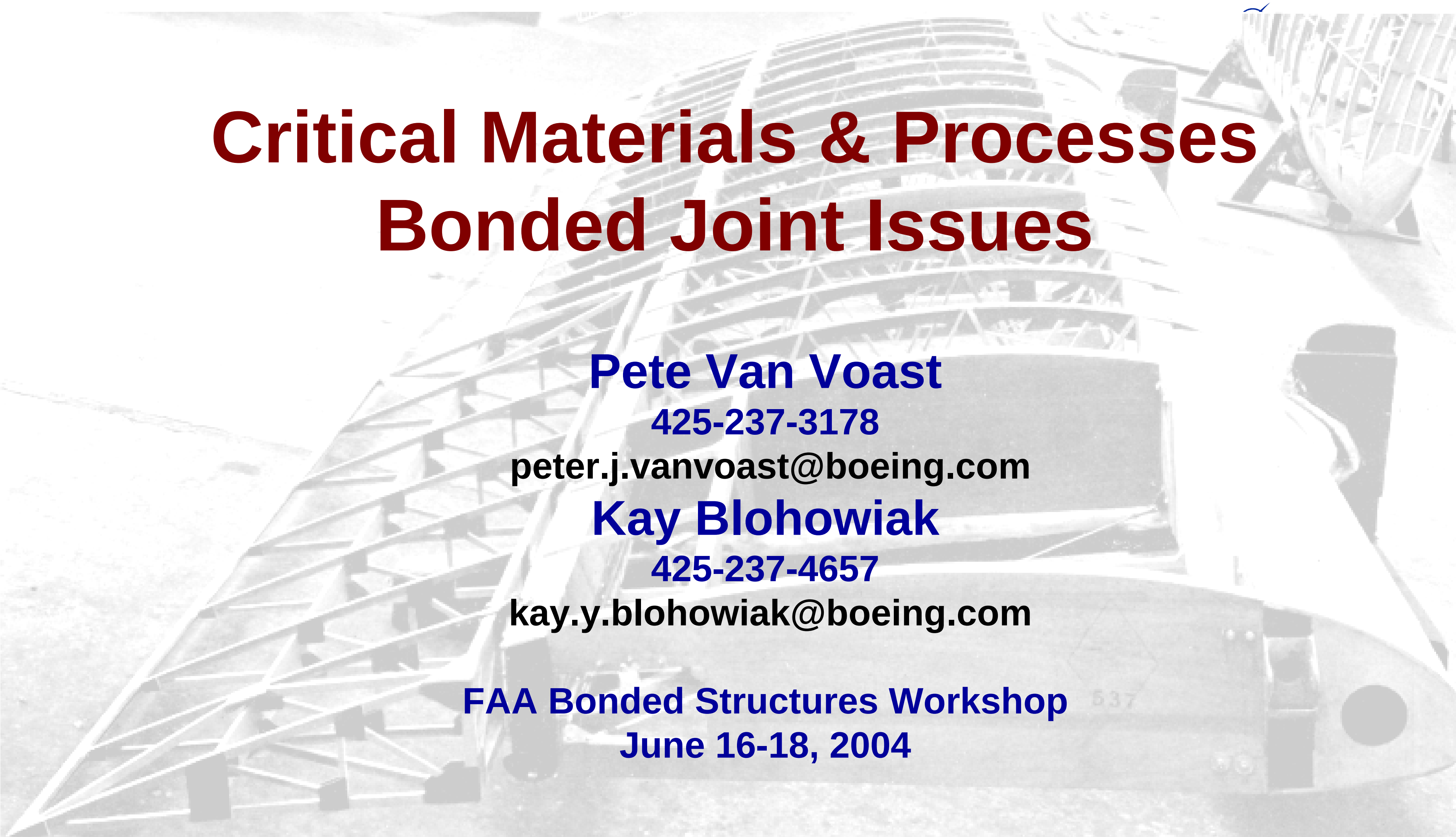


Critical Materials & Processes Bonded Joint Issues

Pete Van Voast
425-237-3178
peter.j.vanvoast@boeing.com
Kay Blohowiak
425-237-4657
kay.y.blohowiak@boeing.com

FAA Bonded Structures Workshop
June 16-18, 2004

BOEING®

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

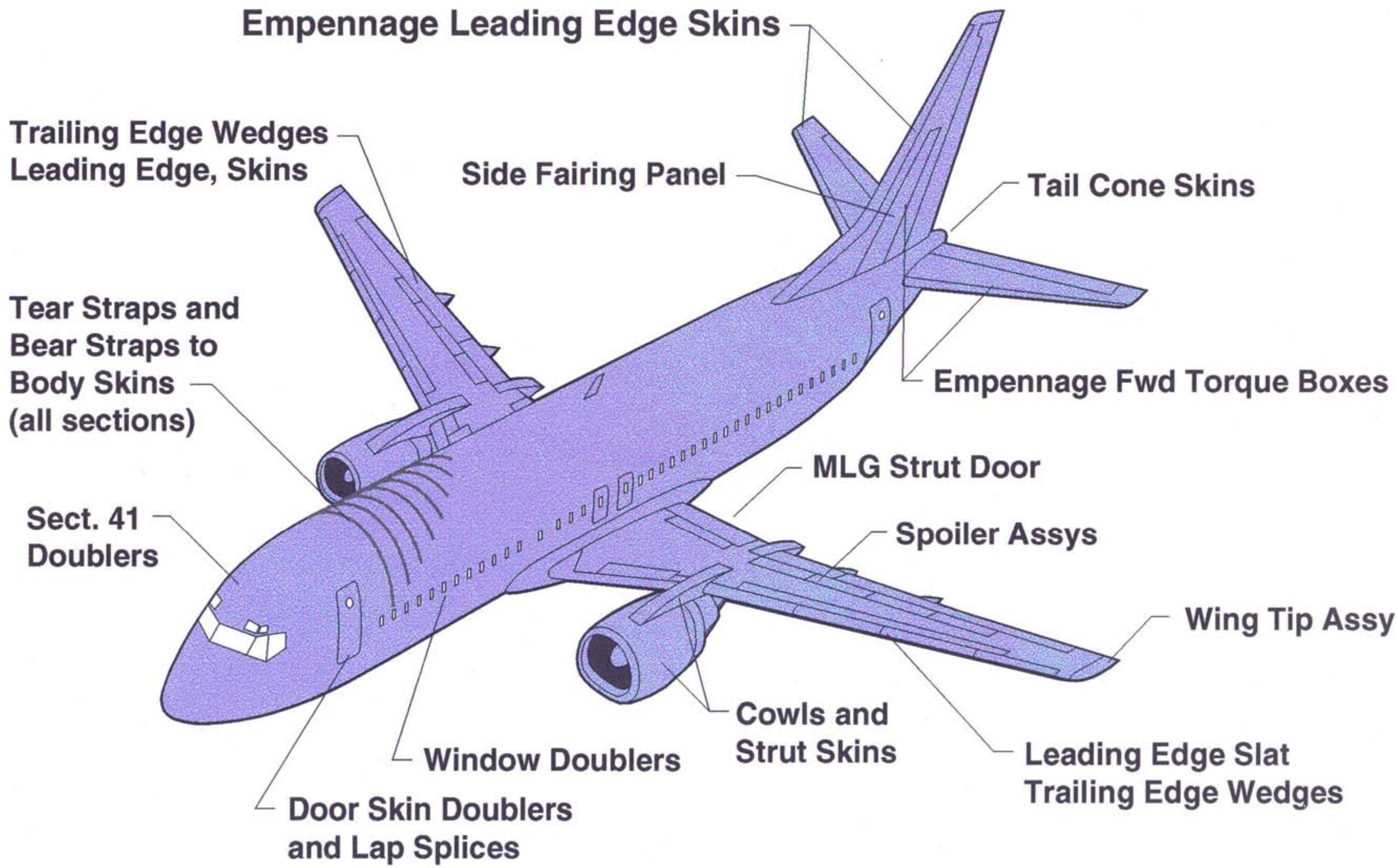
Aluminum
Titanium
Stainless
Other

Boeing's Historical Bonding Methods

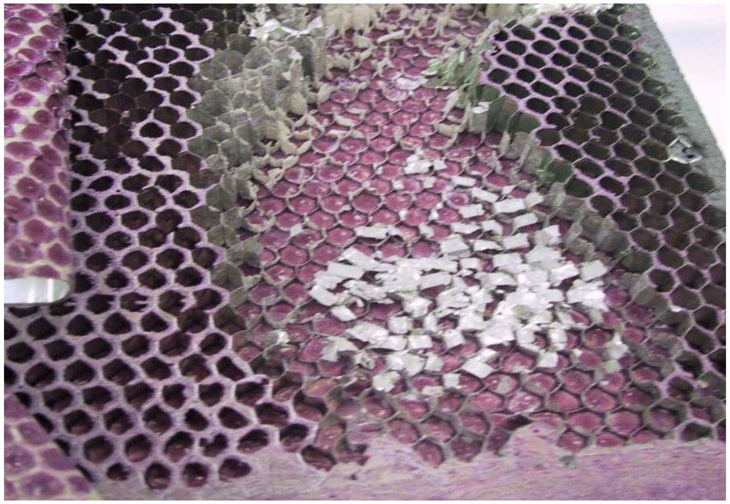
	1950's	1960's D16925	1970's	1980's	1990's D681704	2000+
surface	FPL		PAA; PANTA; Wedge/ DCB	PAD		CWR; Non-Cr, 0V deox; sol gel repair
primer	dissolved adhesive resin	CIAP BMS 5-89 ('69)			Low VOC 0 VOC CIAP	non-chrome
adhesive	BMS5-10 cold bond; 350 F cure nitrile phenolics BMS 5-42	250 F cure epoxies BMS 5-70 to BMS5-51 and 5-80	toughened epoxy nitrile BMS5-101 BMS 5-104	BMS 5-137 better toughness		next gen. adhesives EA9696, FM94 AF555
core		Acid etched foil	pour coat CR core		PAA core	PAA core to carbon skins

Structurally Bonded Metal Applications

Heritage Boeing



Adhesive Bond Failures



Corroded core

737 body skin waffle doubler with unanodized area

Really corroded core

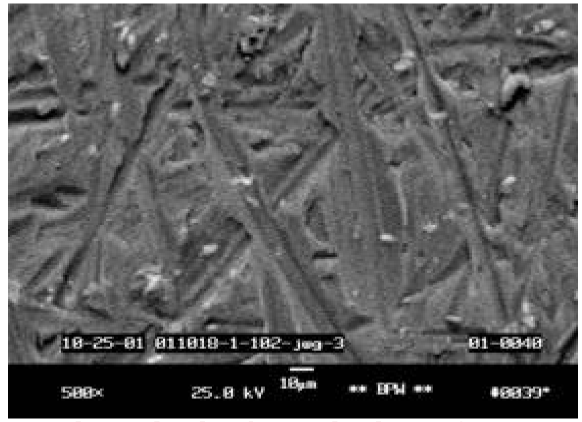
Corrosion products on repair doubler

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



Die grinder/sanded surface

Abraded repair area

- 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

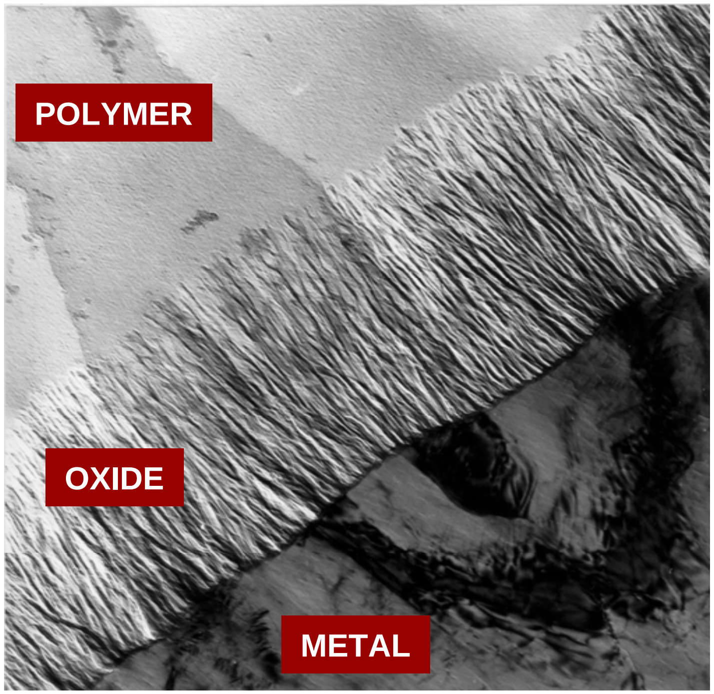
Anodizing

- 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

Chromic acid etching process on underwing repair

Issues:

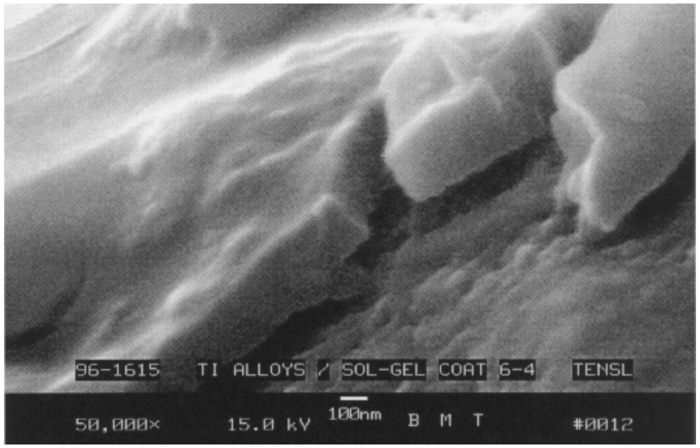
- Health/environment
- Corrosion due to entrapped acid
- Embrittlement of high strength steel
- Performance
- Temp

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-EPII / AC-130



Sol-gel coated metal surface

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

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

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.

Qualification Issues

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

Adhesive Issues- Engineering

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

Qualification Issues

- Cost of allowables
- Long-term durability

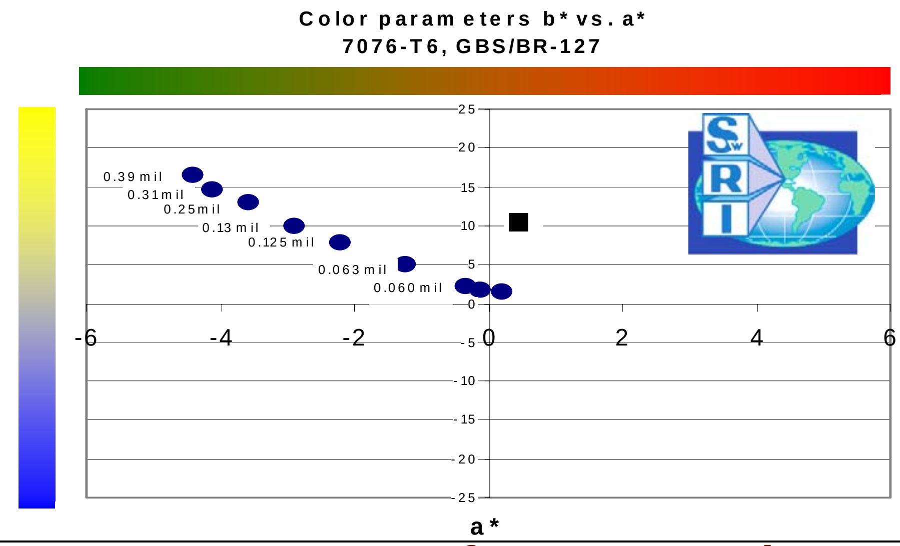
Metal Bond Process Inspection

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

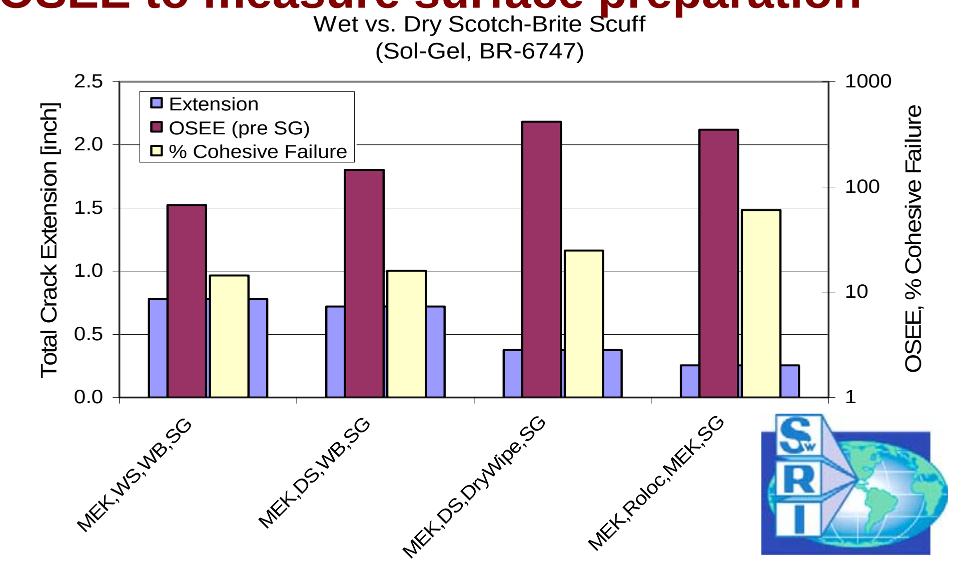
Questions

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

Colorimeter to measure primer thickness



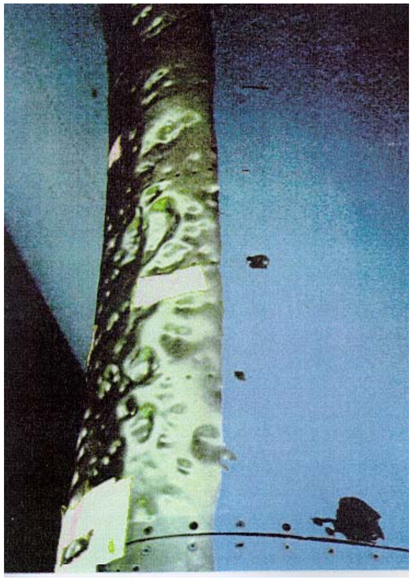
OSEE to measure surface preparation



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…

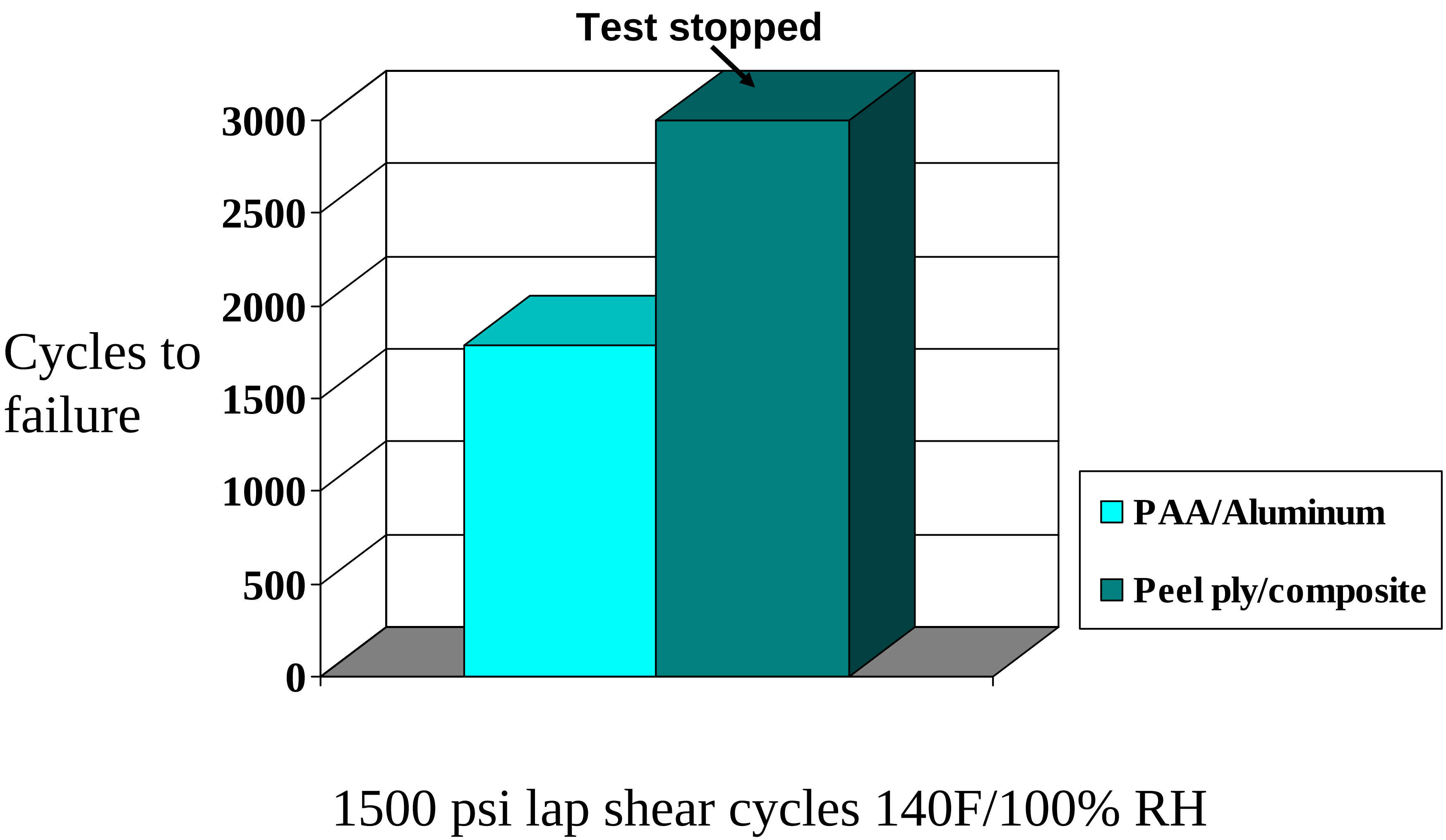


Composite Bonding

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



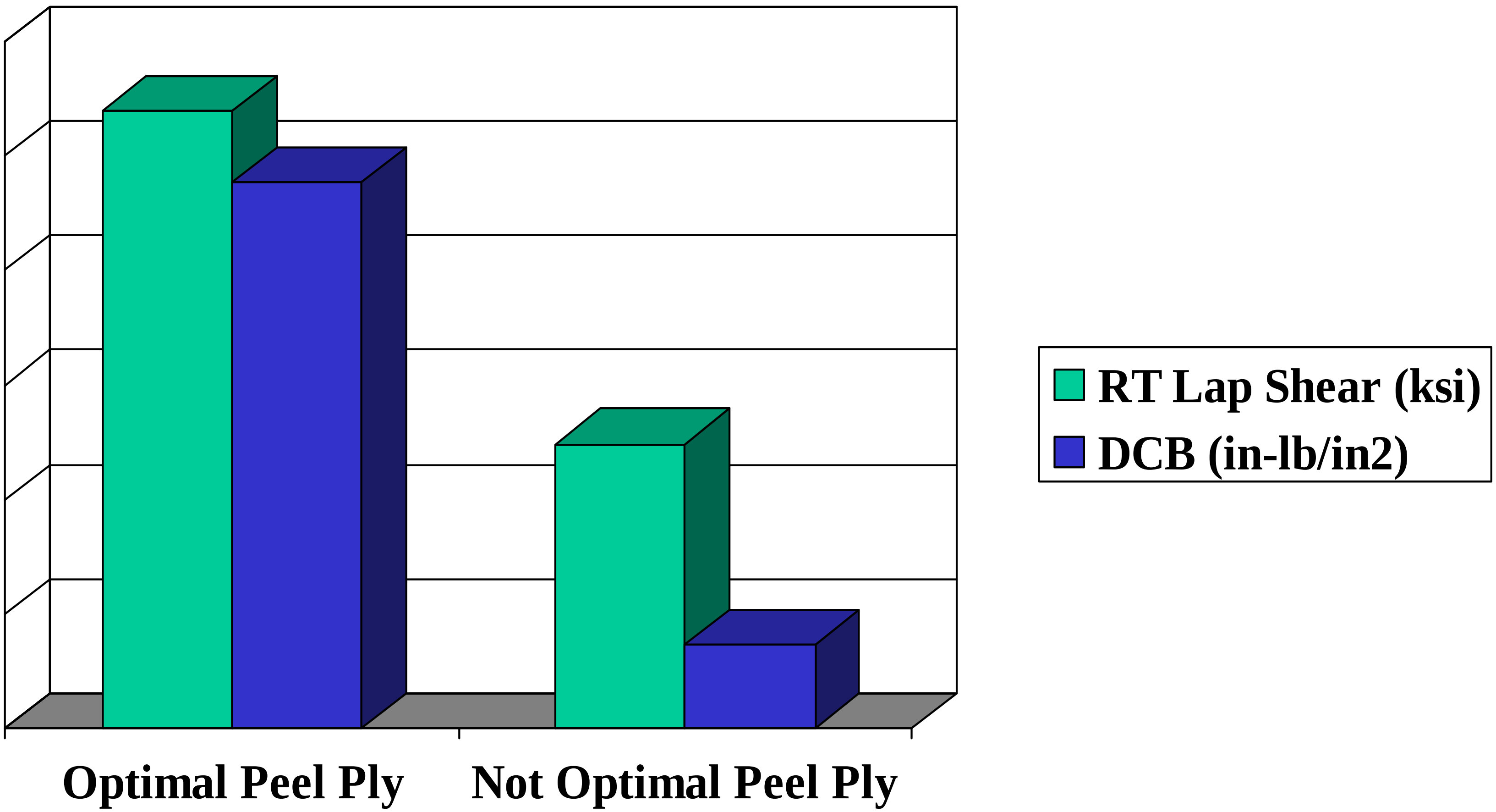
Composite Surface Preparation Methods

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

Peel Ply Surface Preparation

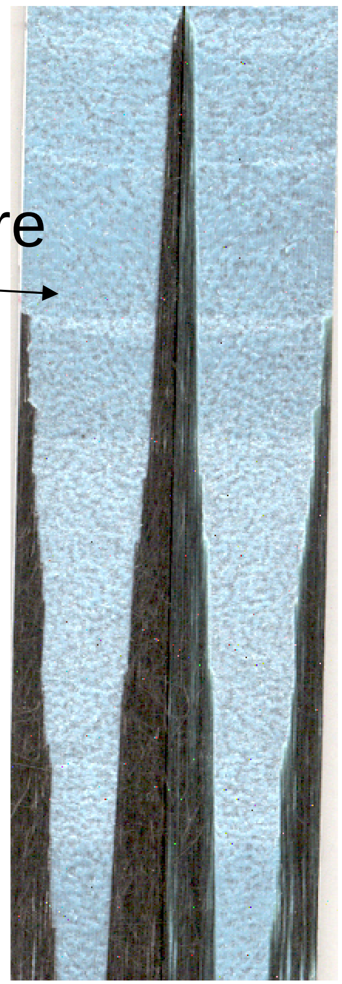
- Widely used at Boeing Commercial
- No “universally” functional peel ply
- Sensitivity to using the wrong peel ply
- Cleanliness and max delay requirements
- Excellent durability
- Specification and PCD control for critical applications

Mechanical Properties of Composite Bonds (Optimal vs. not optimal peel ply)

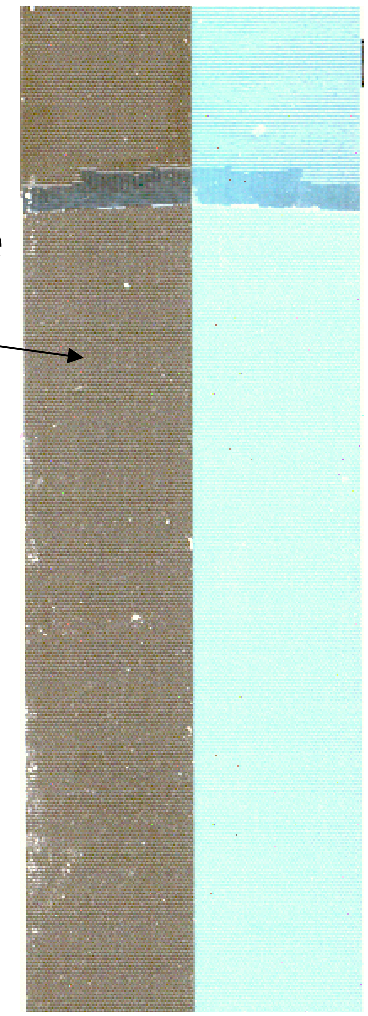


Peel Ply Affects Failure Mode

Optimal
Peel Ply
Cohesive Failure
Mode

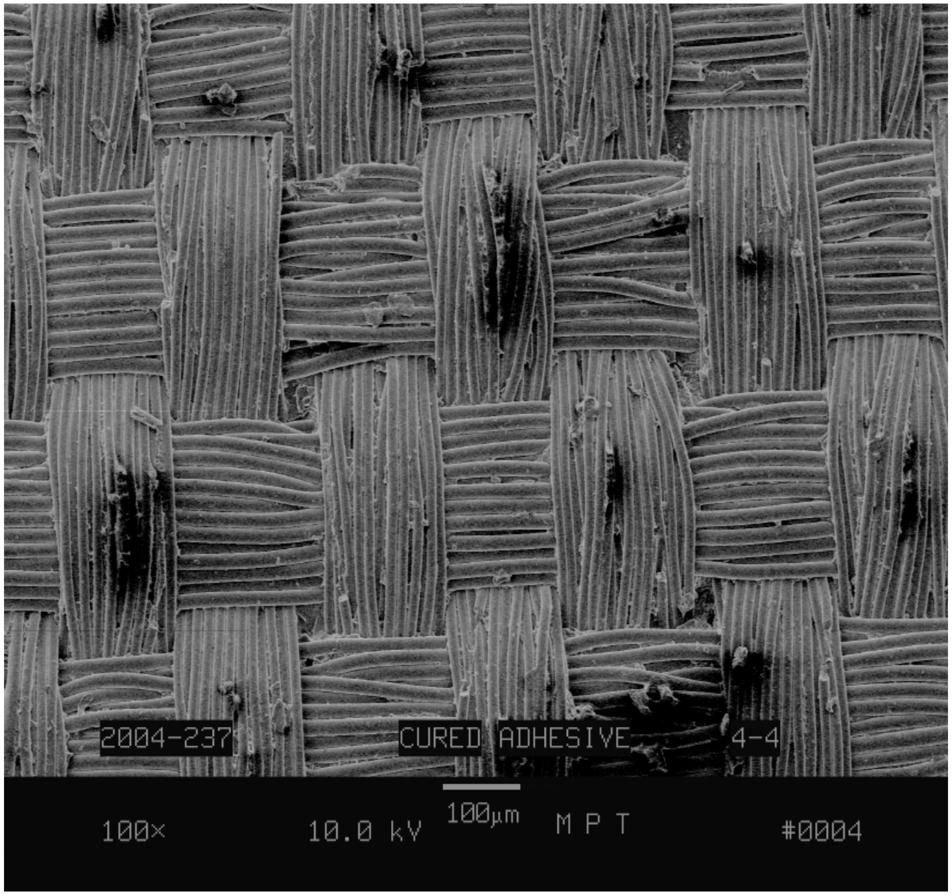


Not Optimal
Peel Ply
Adhesive Failure
Mode



Using the Wrong Peel Ply Results in Adhesive Failure Mode

BOEING

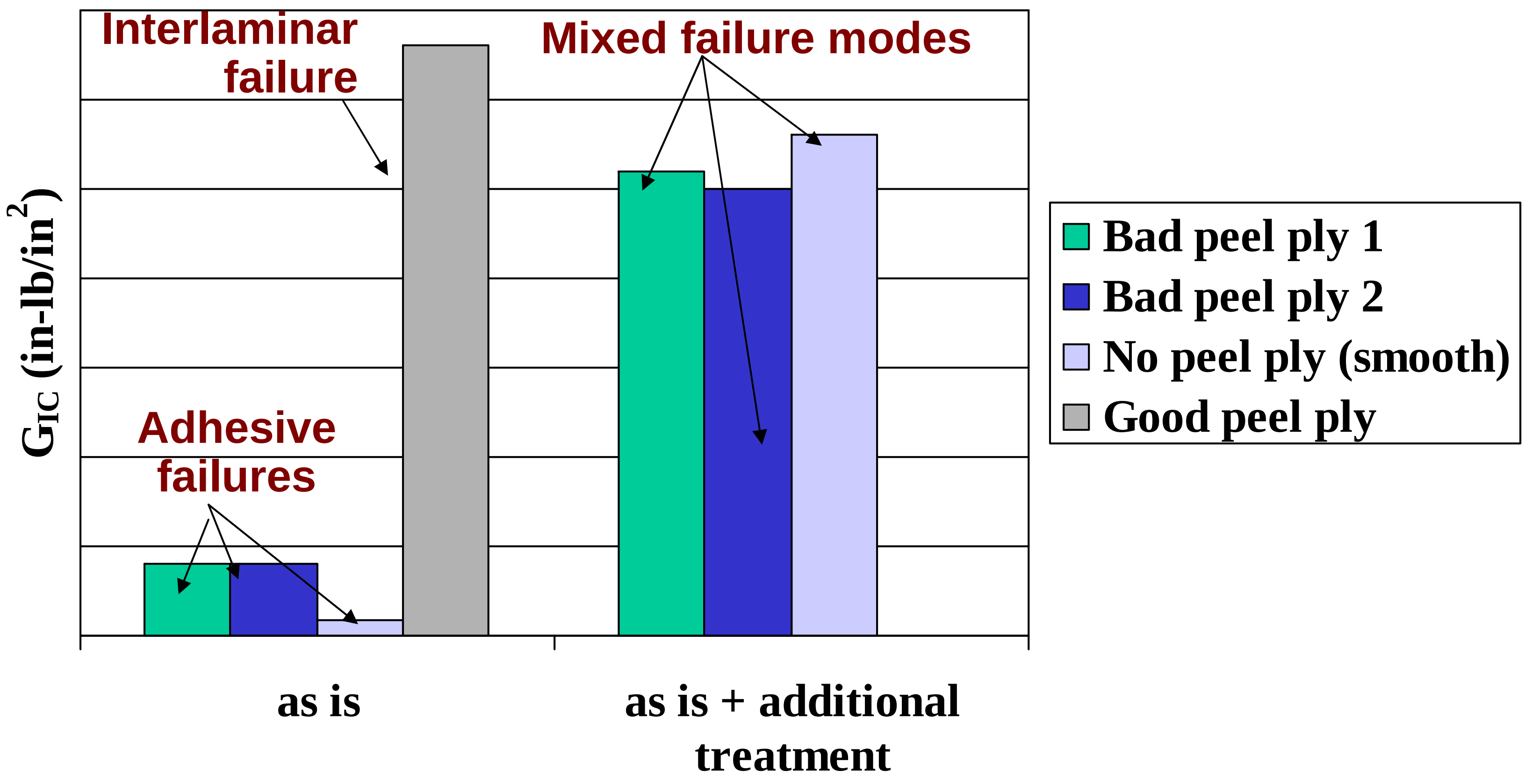


Peel Ply Pattern
Replicated in Adhesive

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



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

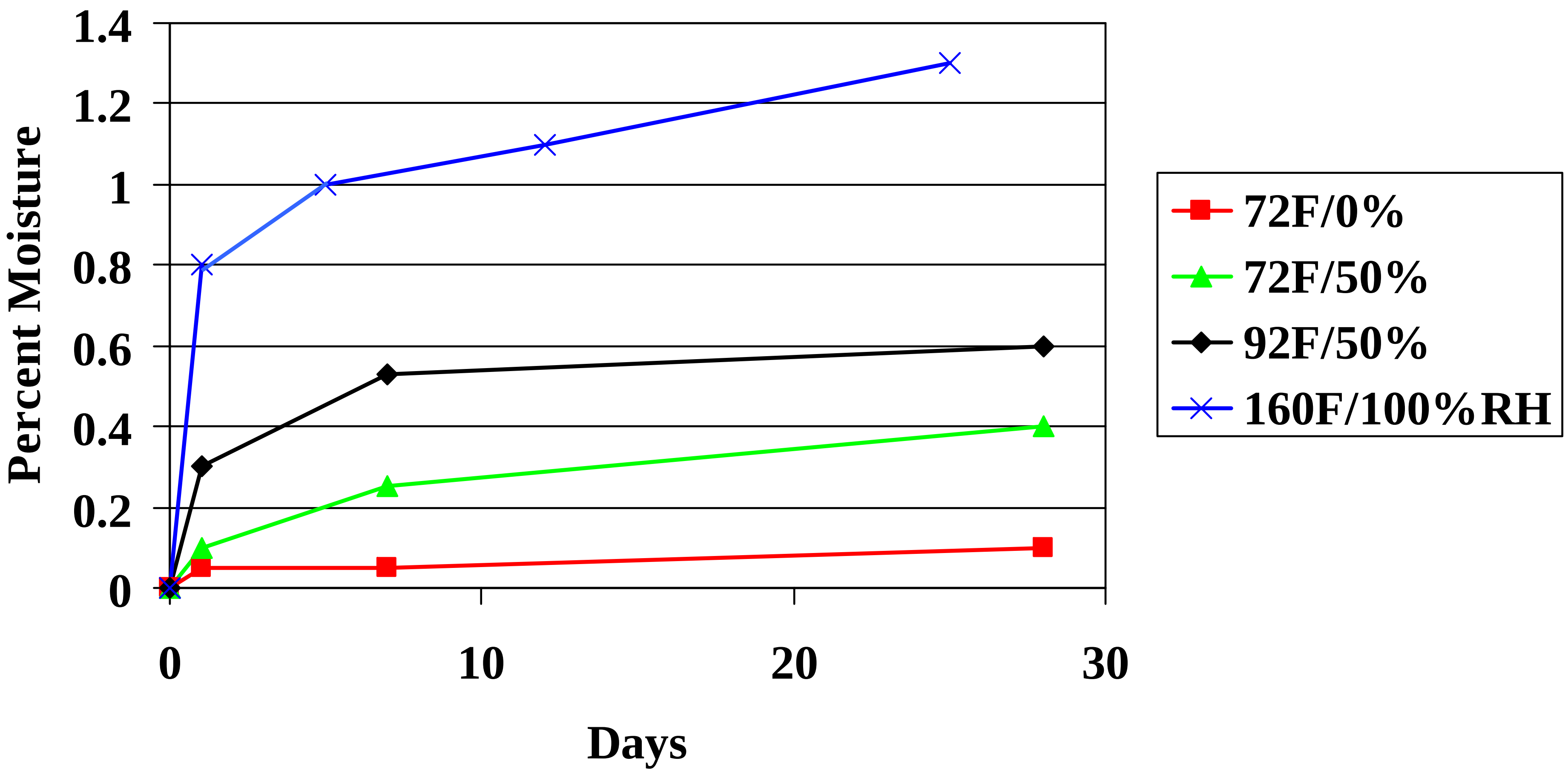
Adhesive Issues- Engineering

- Prebond humidity
- Thermal Capability including hot/wet
- Toughness
- Shear
- Filleting
- Bondline Thickness

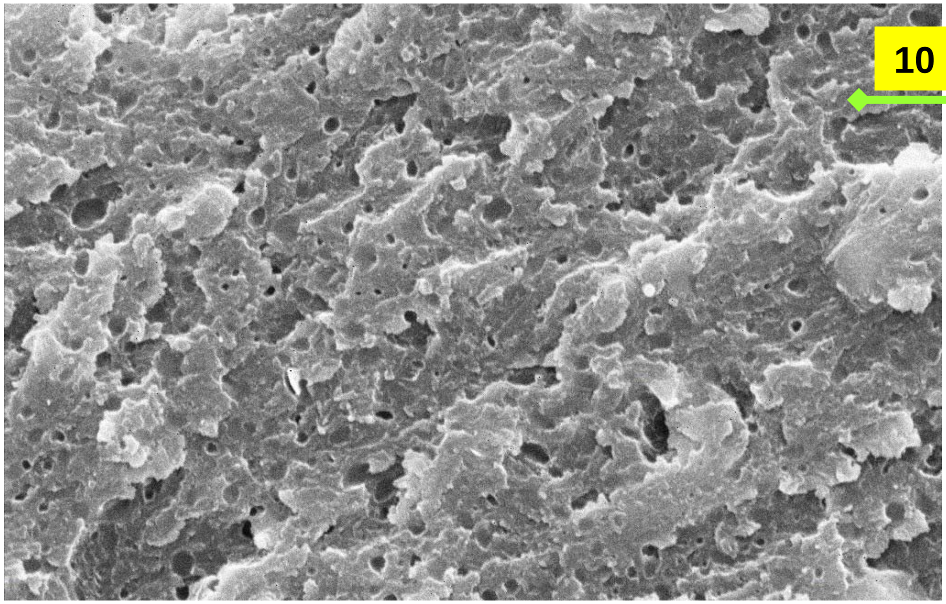
Effect of Prebond Humidity on Adhesive performance

- Different adhesives have different responses to prebond humidity
  - Morphology
  - G_{IC}
  - Lap shear
  - Tg
  - Kinetics

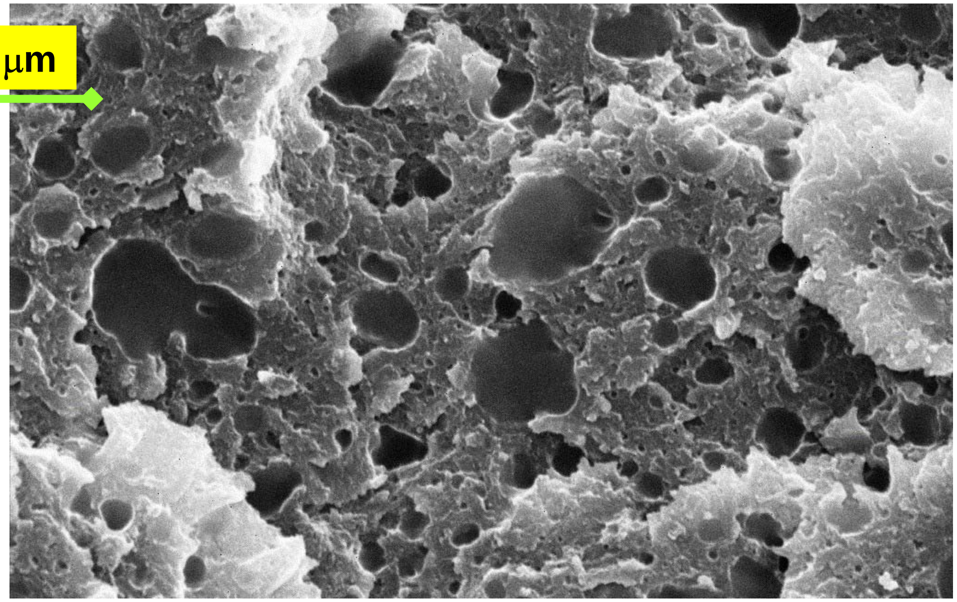
Moisture Content vs. Environment
10 ply carbon epoxy laminate



Effect of Prebond Humidity on Adhesive Morphology

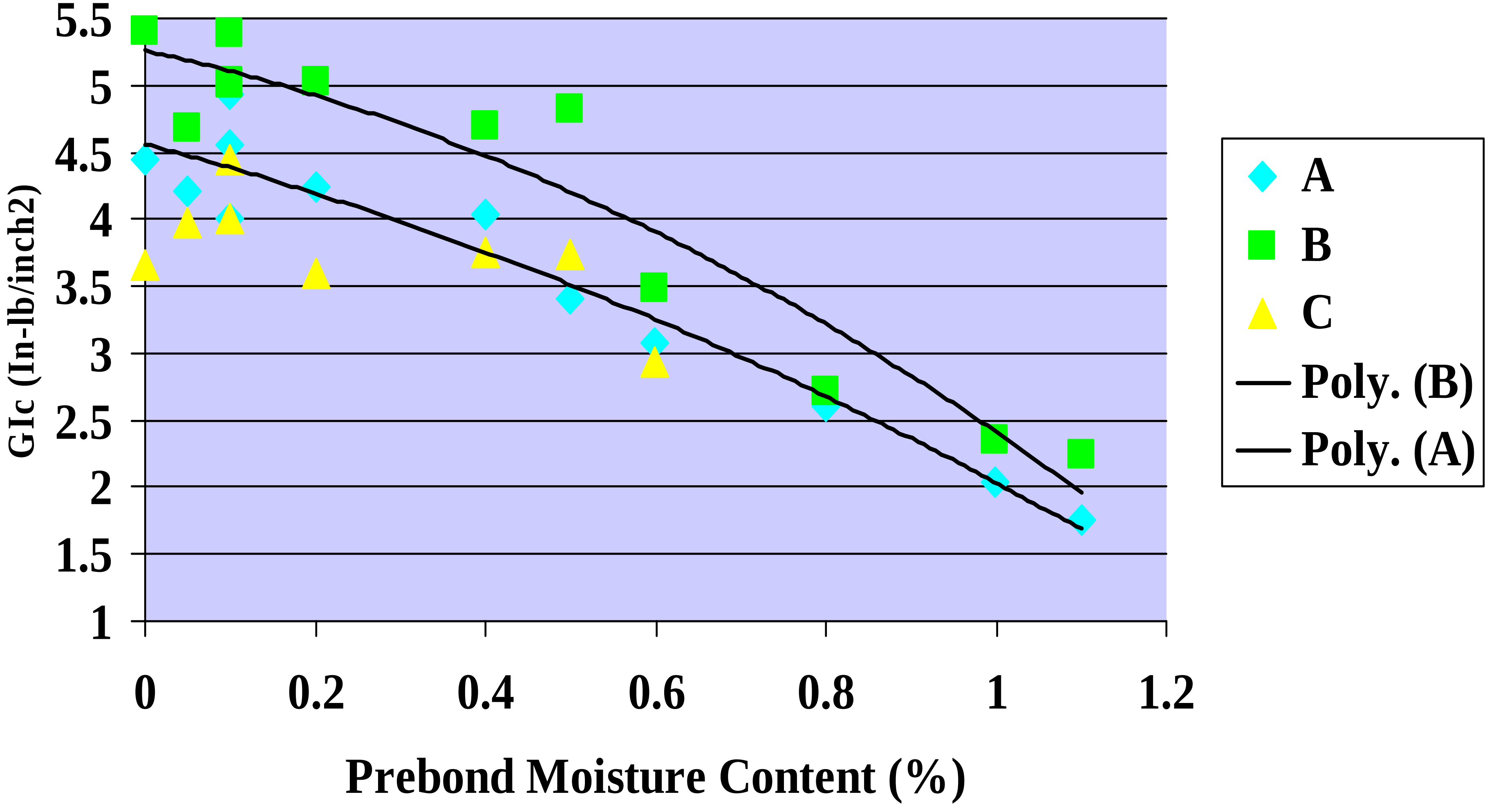


Adhesive A bonded immediately

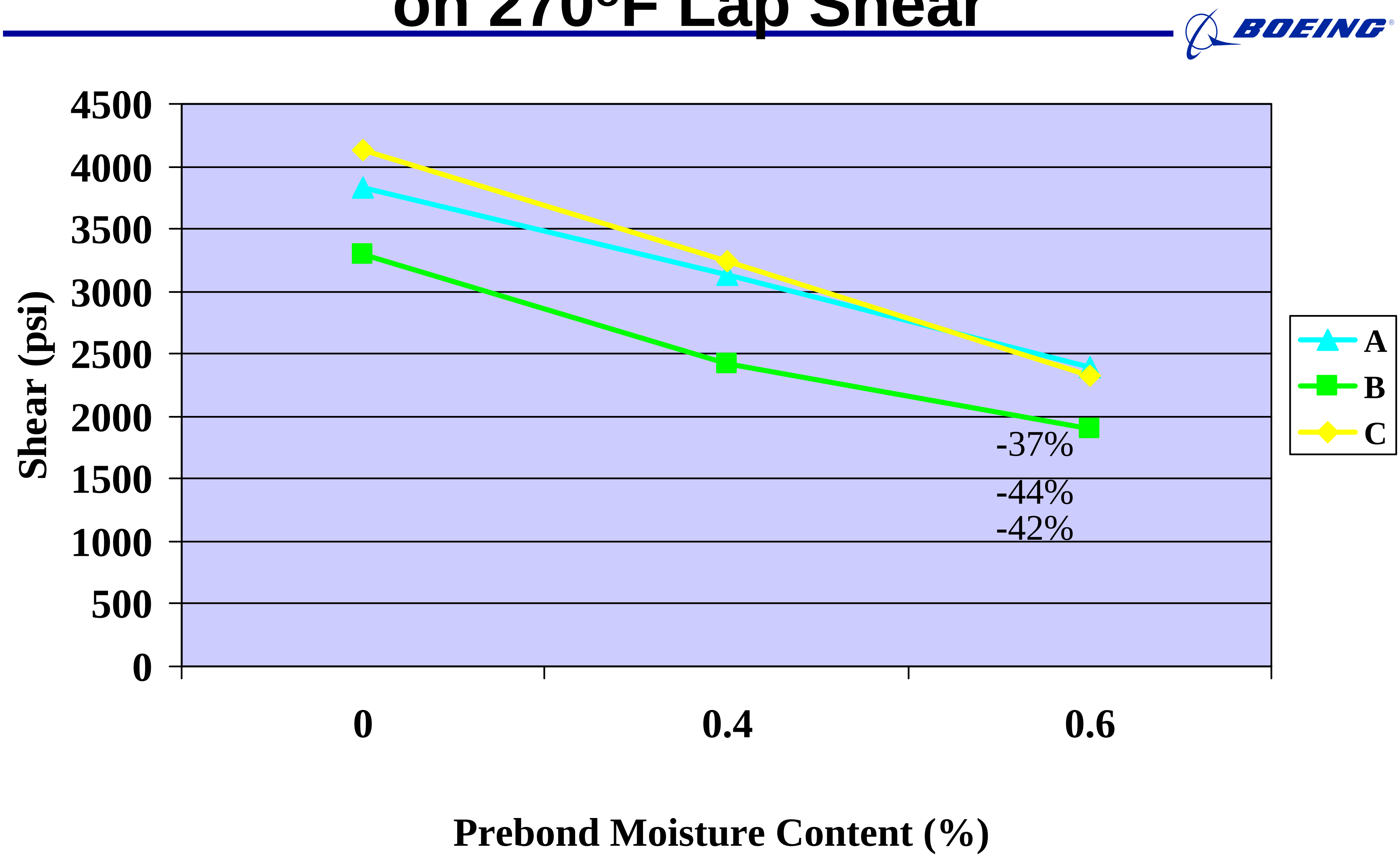


Adhesive A bonded after 28 days at 92F/50% of composite prebond exposure

Effect of Pre-bond Humidity on G_{IC}



Effect of Pre-bond Humidity on 270ºF Lap Shear



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