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AMTAS

Advanced Materials in Transport Aircraft Structures

Effect of Surface Contamination on Composite Bond Integrity and Durability

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Composite Bond Integrity/Long-Term Durability of Composite Bonds

Background:

- A significant amount of research has been conducted and documented regarding surface preparation on initial strength characterization of adhesively bonded composite joints.
- Surface analysis techniques that can improve the quality management system for bonding continue to be of interest to the industry and the FAA.
- Identifying key process parameters and their effects on short and long term bond quality has led to an in interest in demonstrating the applicability of quality control methods including surface analysis techniques that could be integrated into a quality management system.

Tasks:

1) Composite Bond Surface Characterization (UW)
2) Composite Bond Integrity/Long-Term Durability Testing of Composite Bonds (FIU)
3) Revision of ASTM D3762 Metal Wedge Crack Durability Testing (UU)

Adhesive Bonding Group:

University of Washington, University of Utah, Florida International University, Boeing, Cessna, NRC, NIAR, (among others collaborators).

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Motivation Task 2:

Past research has focused on verifying the required quality of an initial composite bonded system to be assured good initial bond strength. Additionally, the effects of contaminants has also been established on the initial bond strength.

What is less understood is the effects of contaminants on durability.

Specific Requirements:

- Develop a process to evaluate the durability of adhesively bonded composite joints
- Investigate **undesirable bonding conditions** by characterizing the initial performance at various contamination levels.
- Characterize the durability performance of the system using the same contamination levels.

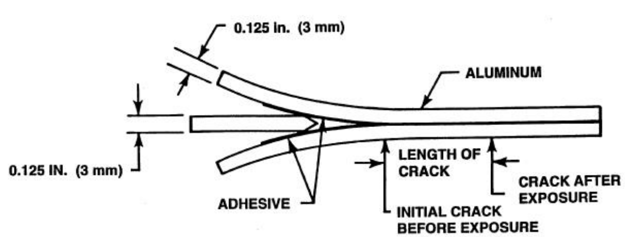
Composite Bond Integrity/Long-Term Durability of Composite Bonds

Literature Review:

- Previous research in evaluating bond strength durability: Lloyd Smith, Hart-Smith, Davis, Adams et al, etc.

- Available standards for initial strength characterization and durability testing (strengths and weaknesses: lap shear test, wedge test, three point bending, short beam strength, DCB for fracture toughness).

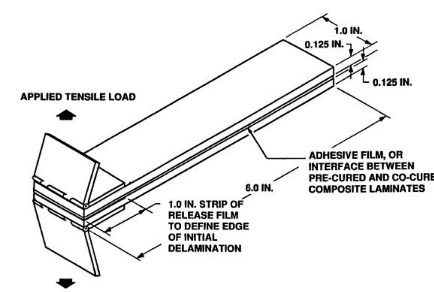
Wedge Test



Hart-Smith, International Journal of Adhesion & Adhesives (1999)

"The reason that the wedge test is suited to evaluation of bond durability is that the adhesive and the interface are placed under extremely high tensile stresses. The initial crack arrests when the tensile stresses are just below tensile ultimate for the adhesive. That leaves the interface under extreme stresses so any degradation of the interface, such as by hydration, will result in interfacial failure." - Davis and McGregor, 6/2010.

Double Cantilever Beam Test



The DCB can be use for initial bond strength characterization and with modifications can provide characterization of long-term durability. DCB provides quantitative and qualitative information including mode of failure and a measure of the strain energy release rate.

Composite Bond Integrity/Long-Term Durability of Composite Bonds

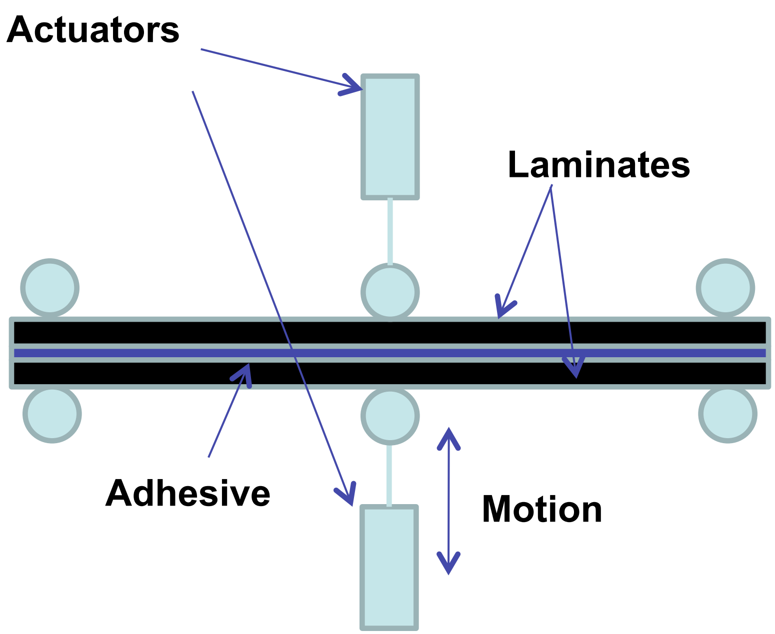
Selection of materials and testing procedures:

- Selection of materials and curing procedure for specimens: unidirectional carbon-epoxy system, film adhesive, secondary curing for bonding.
- Current materials:
    - DA 411U 150 Unidirectional Carbon Epoxy Prepreg System (350 F cure)
    - AF 163-2 Scotch Weld Structural Adhesive Film (250 F cure)
    - Polyester Release Peel Ply from Fibreglast
- Will include with future materials:
    - Precision Fabric peel ply 60001 (received)
    - 3M AF555 adhesive film (ordered)
    - Toray T800 unidirectional tape (TBD)

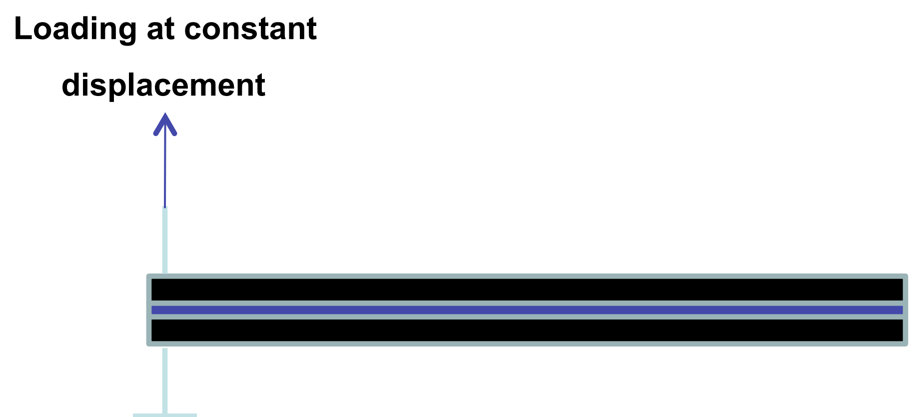
Composite Bond Integrity/Long-Term Durability of Composite Bonds

Selected testing procedure:

1- Mechanical loading (inside an environmental chamber) fully reversible reversed three point loading



2- Durability evaluation using double cantilever beam test for fracture toughness



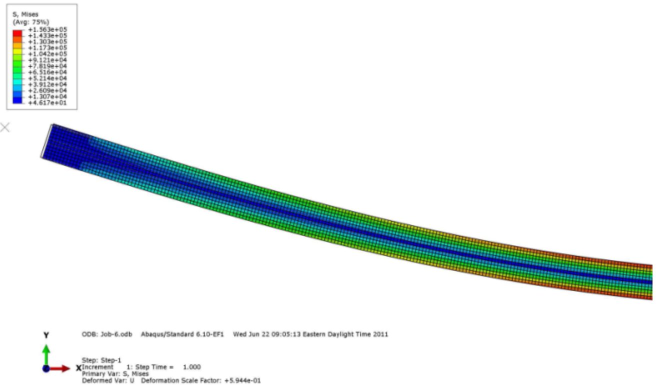
- Crack growth
- Fracture toughness
- Mode of failure

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Design and fabrication of specimens:

Known fatigue properties AF 163-2 (Metal to Metal for Double Lab Strap)

Max Stress (psi)	Avg. Life (Cycles)
4500	1.58×10^4
4000	5.28×10^4
3500	4.75×10^5
3000	2.67×10^6
2200	1.03×10^7 + (No failure)



Values of some of the evaluated laminate configurations

Ply Orientation	# of Plies	Ultimate Load (lb)	Shear @ 360 lb (psi)	Deflection (in)
Unidirectional	20	504	3500	0.93
Orthotropic	28	289	3340	3.03
Orthotropic	30	409	2910	2.18

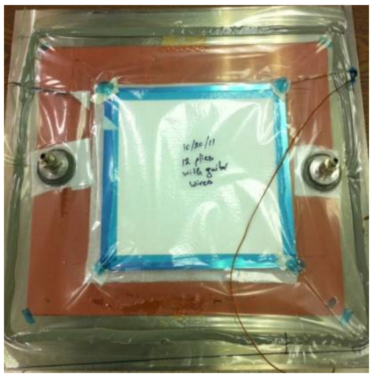
Selected laminate configuration:

- Specimen dimensions: 9 in long X 1 in wide
- 20 ply unidirectional laminate (0.12 in thick)
- 0.038 in bond line thickness

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Procedure for baseline data:

Fabrication of laminates



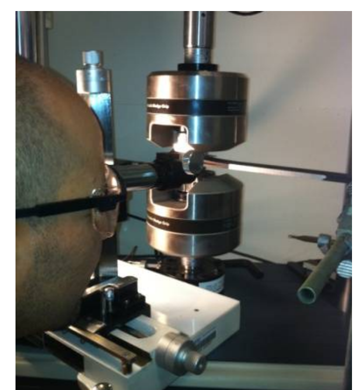
Cure cycle @350F

Bonding of laminates

Secondary cure @250F

DCB specimens

Surface characterization, testing, and data analysis



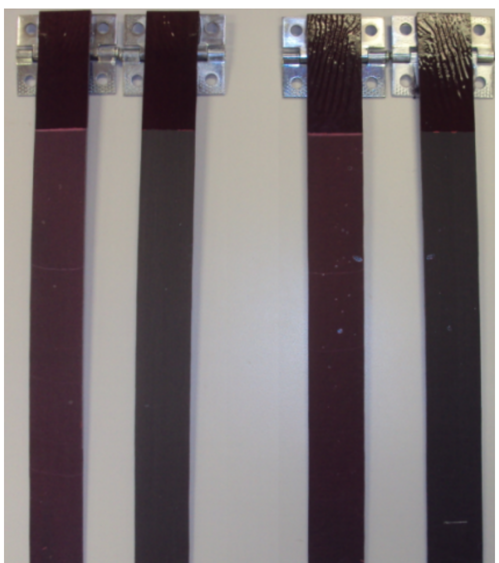
Composite Bond Integrity/Long-Term Durability of Composite Bonds

Results for the first set of baseline data:

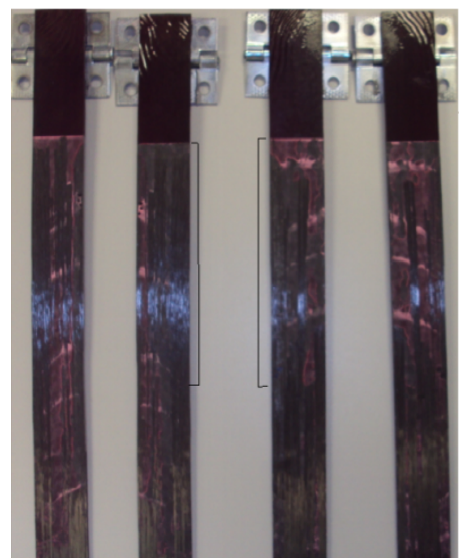
Double cantilever beam test fracture toughness results

	GI (in.lb/in^2)	GI (KJ/m^2)	Surface
Specimen 1	6.09	1.07	As tooled
Specimen 2	10.42	1.82	As tooled
Specimen 3	10.56	1.85	Sanded 200 grid
Specimen 4	17.89	3.13	Sanded 200 grid

As tool specimens



Sanded specimens (220 grid)



Composite Bond Integrity/Long-Term Durability of Composite Bonds

Testing for durability:

- Specimens with no environmental aging or fatigue loading
- Specimens subjected to environmental aging (progressive testing)*
- Specimens subjected to fatigue loading (progressive testing)*

Environmental aging:

Environmental chamber

DCB specimens during environmental aging

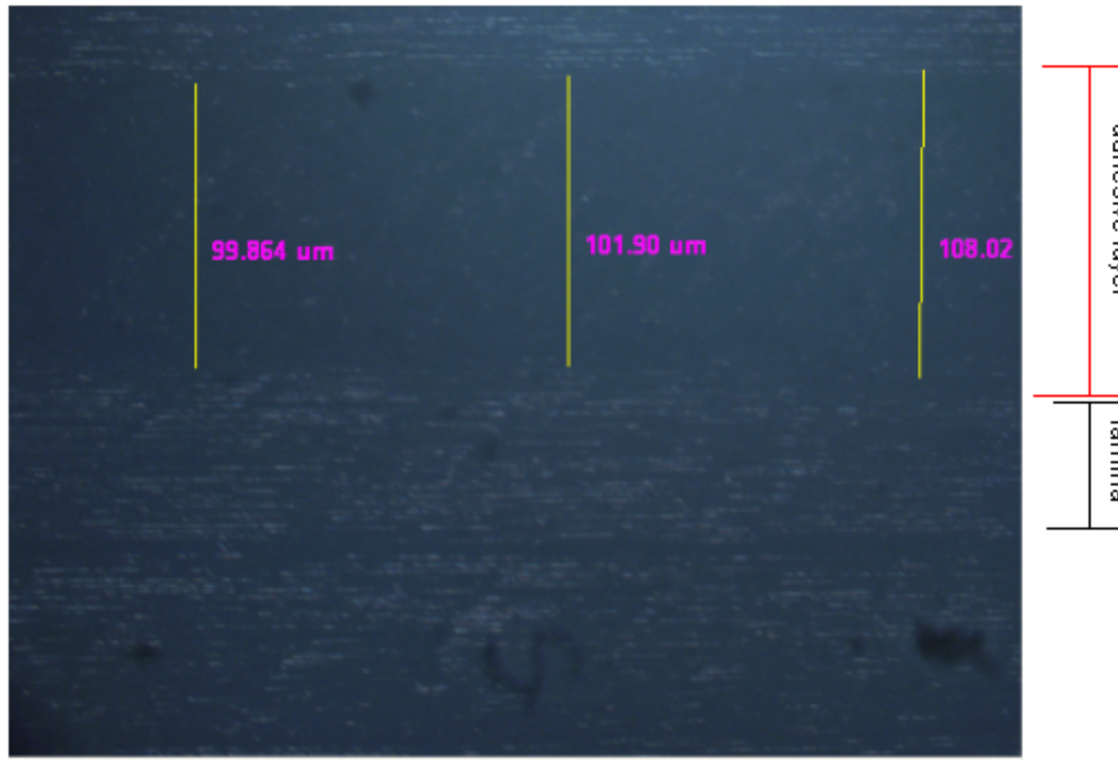
Specimens exposed to a controlled environment at temperature of 60°C (140F) and 95% humidity

*Set of specimens will be chronologically tested

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Bondline thickness control:

	Thickess (um)
Specimen_2_1A	79.71
Specimen_2_1B	92.20
Specimen_2_2A	47.11
Specimen_4_1A	149.85
Speicmen_4_1B	110.48
Specimen_4_2A	102.47
Speciment_4_2B	70.80
Specimen_5_2A	101.32
Specimen_5_2B	89.98
Specimen_6_1A	118.16
Speciment_6_1B	104.14
Speicmen_7_2A	72.29
Specimen_7_2B	50.48
Specimen_8_1A	70.86
Speicmen_8_1B	68.60
Specimen_9_2A	98.90
Specimen_9_2B	64.61



Bondline image captured with an optical microscope at 50X magnification

Composite Bond Integrity/Long-Term Durability of Composite Bonds

Results for the second set of baseline data:

Room environment conditions

	GI* (in.lb/in^2)	GI (KJ/m^2)
Specimen 2_2	84.74	14.84
Specimen 2_1	32.70	5.73
Specimen 4_2	35.97	6.30
Specimen 6_1	19.55	3.42
Specimen 7_2	36.49	6.39
Specimen 9_2	19.49	3.41

Environmental chamber conditions (2 days)

	GI* (in.lb/in^2)	GI (KJ/m^2)
Specimen 1_1	24.09	4.22
Specimen 3_1	32.86	5.75
Specimen 3_2	90.80	15.90
Specimen 5_1	38.87	6.81
Specimen 6_2	45.17	7.91
Specimen 7_1	93.83	16.43

Specimen 3_2

Specimen 2_2

Composite Bond Integrity/Long-Term Durability of Composite Bonds

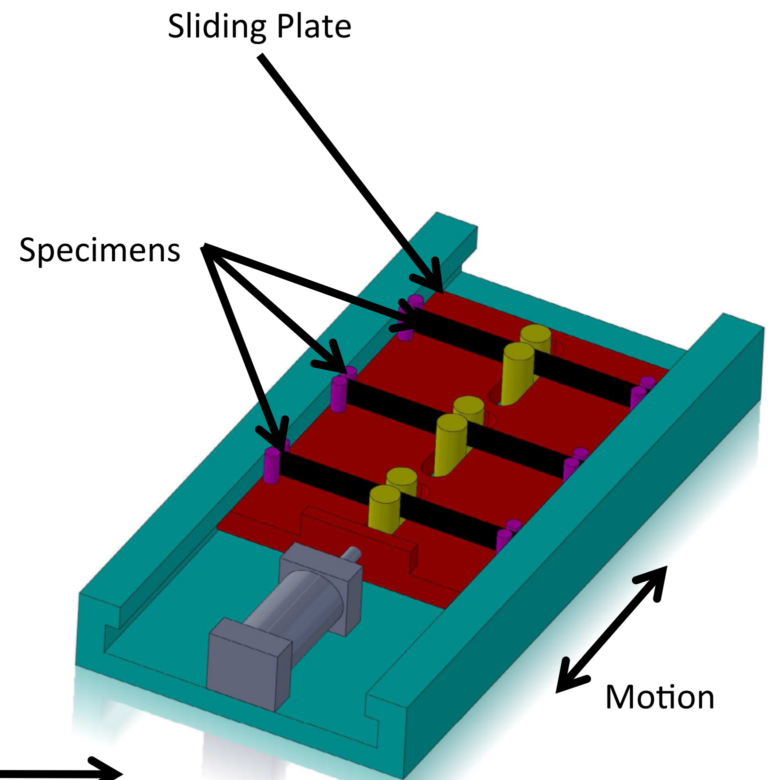
Fatigue loading:

Hydraulic Power unit

Rapid acting valve

Valve control software

Hydraulic piston



Testing assembly

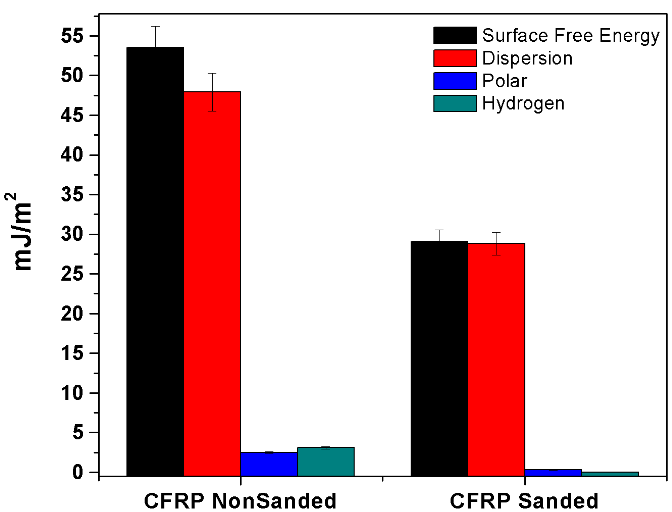
Composite Bond Integrity/Long-Term Durability of Composite Bonds

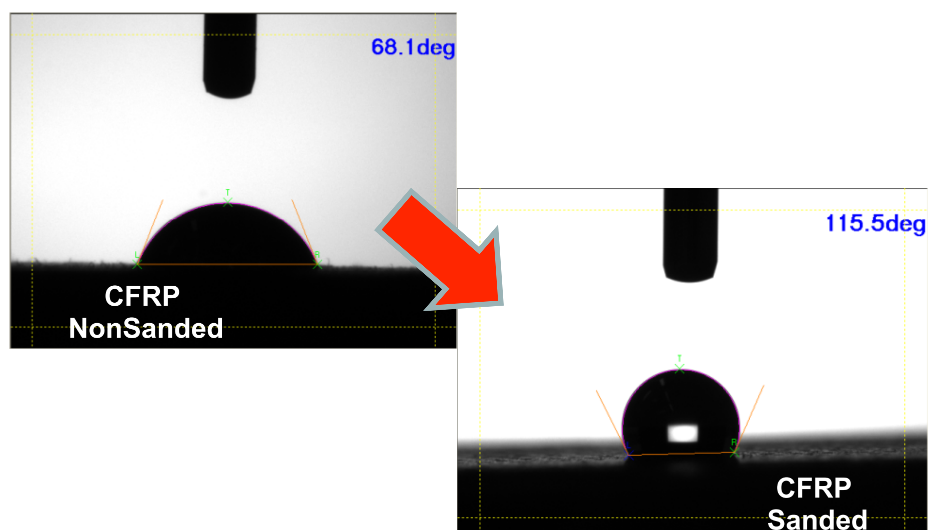
Surface Characterization:

Will work with Task 1 group – FTR/water contact angle. Can also use AFM and electrochemical sensor.

The results from the water contact angle are not consistent with the G

Contact Angle Test Results for Water (degree)							
Specimen	**1**	**2**	**3**	**4**	**5**	**Average**	**S.D.**
CFRP non-sanded	64.2	63.2	69.4	68.1	69.8	66.9	3.0
CFRP sanded	115.5	112.7	118.8	117.2	117.1	116.3	2.3





Composite Bond Integrity/Long-Term Durability of Composite Bonds

Future work:

- Continue improvements on specimen fabrication (materials & bondline thickness control)
- Fabrication of assembly for fatigue loading of specimens
- Subject specimens to environmental aging and fatigue loading (progressive testing)
- Analyze data to determine envelop for G_I values for specimens bonded with ideal conditions.
- Implement means for measuring surface contamination/energy (water contact angle, FTIR, electrochemical sensor, etc).
- Establish procedure to quantify surface contamination prior to bonding.
- Fabricate, test and analyze specimens bonded with less than ideal bonding conditions.