RESIN SELECTION AND DESIGN CONSIDERATIONS FOR HELICOPTER ROTOR BLADES

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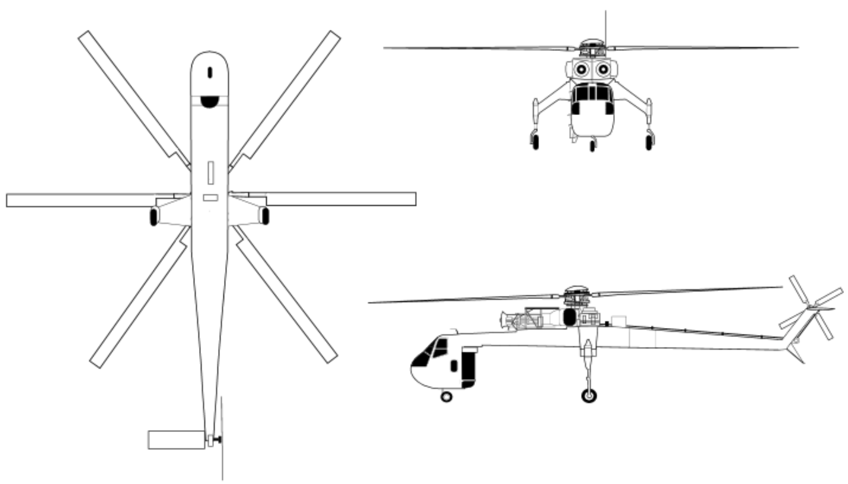
TENCATE materials that make a difference

Introduction

This presentation describes the cooperative testing and process development that Erickson Air-Crane and TenCate Advanced Composites engaged in to qualify BT250E-6 260°F Curing Epoxy Resin prepregs for rotorcraft blade applications



Erickson Air-Crane

- S-64 Heavy Lift Helicopter
- Six (6) blade rotor 72 ft diameter
- Twin 4050hp Pratt & Whitney JFTD12A turbofans
- Designed in late 1950s by Sikorsky, first flight in 1962 (Skycrane)
- Heavily used in Vietnam conflict for transport and recovery
- Erickson Air-Crane purchased type certification and exclusive manufacturing rights in 1992
- Erickson Air-Crane builds, maintain and refurbishes world wide fleet of S-64 helicopters
- Usages in firefighting, construction, and heavy lift
- Maximum payload - 20,000 lb (2,650 gal water)

Project Drivers

- Aluminum blade manufacturing not sustainable
  - Extrusion technology WWII machinery
  - Cost of extrusions >$1M minimum order
  - Man-hours >3000 hrs to hand carve & twist blade
  - Aluminum fatigue life & corrosion
- Rotorcraft composite blades have an older material as baseline
  - AGATE database available 3M-SP381
  - Other rotorcraft and composite blade builders use this basic epoxy
- Industry Need for 2nd Source with FAA Database
  - Erickson and others desire a second source supplier
  - TenCate and Erickson have completed a full design allowable database
  - TenCate addresses a market need for short lead times, and OOA processing.
- Goals
  - Improved production cycle and allow use of vacuum bag processing
  - Reduced initial and & operating costs
  - Address future growth in composite rotor blades

Partnering

- TenCate BT250E-6 Resin and Prepreg Development
  - Equivalence to industry standard system
  - Hot melt impregnation resin
  - 260°F Cure – Autoclave and OOA capable (*new feature*)
  - Develop prepreg process and product controls
  - 3 lots of 5 material types for qualification and blade testing
  - Qualification report summation and dissemination

- Erickson Air-Crane
  - Create FAA approved qualification plan
  - Qualification laminate production and FAA conformity
  - Qualification test and FAA conformity
  - Production trials of blades and process *(Erickson Air-Crane Proprietary)*
  - Fatigue and full scale testing *(Erickson Air-Crane Proprietary)*

Approach

- Utilize Simple 260°F Cure Epoxy Chemistry
  - Don't reinvent the wheel – build on industry experience
  - Replicate the AGATE testing - Category "3" change CHM-17 Vol 1 Chapter 2 Table 2.3.2.2
  - Use "out of autoclave" cure – cost reduction, and conservative results
  - Simple is better for rotorblades – literature & past experience

- Bridge results to existing data and utilize a building block approach
    - CHM-17 Volume 3 Chapter 4 Section 4.4.5.1.2
      - '*Testing for rotor systems is less extensive than for airframe, since the components are generally substantiated via full scale fatigue testing.*'
      - '*More detailed life prediction must be made using component-level fatigue testing….since delamination and local geometric effects not found in coupons dominate composite structural fatigue failures.*'
    - Basic lamina properties
    - Full scale fatigue testing required – customer specific (proprietary)
  - Equivalency laminates – for vacuum and autoclave cure cycles
  - Blade manufacturing

Building Block Diagram for Rotorblades

- Statistical methods
- Materials & Process Technologies
- Test & Analysis Methods
- NDI & Acceptance/Rejection criteria

→ **Analysis**

- **Full Scale Tests**
  - **Static**
  - Fatigue
- ~~Component Tests~~
- ~~Subcomponent Tests~~
- ~~Element Tests~~
- Coupon Tests
  - ~~Laminate~~
  - Lamina

↑

- Static Strength
- Durability
- ~~Damage Tolerance~~

- Match aluminum mass & inertial properties
- Primary load tensile strength and stiffness
- Stiffness critical for flexion and flutter
- Shear strength and stiffness at fastening locations – blade root

Qualification Prepreg Materials

- IM7 12k 148 gsm/BT250E-6 12”W 33% RC graphite uni-tape
- S2 284 gsm/BT250E-6 12”W 33% RC S2 fiberglass uni-tape
- AS4C 3k PW 195 gsm/BT250E-6 48-50”W 40% RC graphite fabric
- AS4C 3k ±45° 195 gsm/BT250E-6 50”W 40% RC graphite fabric*
- 7781 Fg 300gsm/BT250E-6 OST 50”W 37% RC fiberglass fabric

* Not required for lamina testing plan base properties on 3k PW.

Historical Prepreg Materials Data - Fg

	7781 Fg/SP381			S2 284gsm /SP381			S2 284gsm /SP381		
	AGATE Moisture 145°F 85%rH <0.05%			AGATE Moisture 145°F 85%rH <0.05%			CHM-17 Vol 2 Moisture 160°F immersion 14 days		
	Vacuum Cure 260°F 2 hrs			Vacuum Cure 260°F 2 hrs			50 psi Cure 260°F 2 hrs		
	CTD -65°F	RTD	ETW 180°F	CTD -65°F	RTD	ETW 180°F	CTD -65°F	RTD	ETW 160°F
F_1^{tu}	64.8	52.1	41.0	250.2	217.7	127.7	236	246	113
E_1^t	3.59	3.61	3.29	7.08	6.91	6.84	6.93	6.91	6.86
F_2^{tu}	-	-	-	-	8.2	7.2	9.1	9.0	4.2
E_2^t	-	-	-	-	1.97	1.24	2.10	1.93	1.07
F_1^{cu}	91.6	75.5	49.3	-	171.1	102.3	170.0	168	139
E_1^c	-	3.66	3.54	-	7.01	6.90	6.87	6.96	6.76
F_2^{cu}	-	-	-	-	39.8	24.0	-	-	-
E_2^c	-	-	-	-	2.61	2.10	-	-	-
$F_{12\ ult}$	22.9	19.0	12.0	24.7	19.2	11.9	13.6	14.3	9.5
G_{12}	0.67	0.59	0.47	0.62	0.59	0.38	0.88	0.69	0.47
F_{13}	-	8.36	-	-	9.85	-	14.6	12.4	7.2

Historical Prepreg Materials Data - Gr

	3k AS4 PW/SP381		IM7 145gsm /SP381	
	Datasheet Moisture??		Datasheet Moisture??	
	Autoclave Cure 260°F @ 50 psi - 2 hrs		Autoclave Cure 260°F @ 50 psi - 2 hrs	
	RTD	ETW 180°F	RTD	ETW 160°F
F_1^{tu}	110	-	358	331
E_1^t	10.7	-	24.0	24.5
F_2^{tu}	-	-	5.5	-
E_2^t	-	-	1.28	-
F_1^{cu}	98	-	215	188
E_1^c	-	-	21.5	21.7
F_2^{cu}	-	-	-	-
E_2^c	-	-	-	-
$F_{12\ ult}$	-	-	18.6[1]	11.9[2]
G_{12}	-	-	0.63	0.47
F_{13}	11.6	-	13.3	7.8

Notes:
1.) Ultimate
2.) 180°F Wet, Ultimate

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TENCATE materials that make a difference

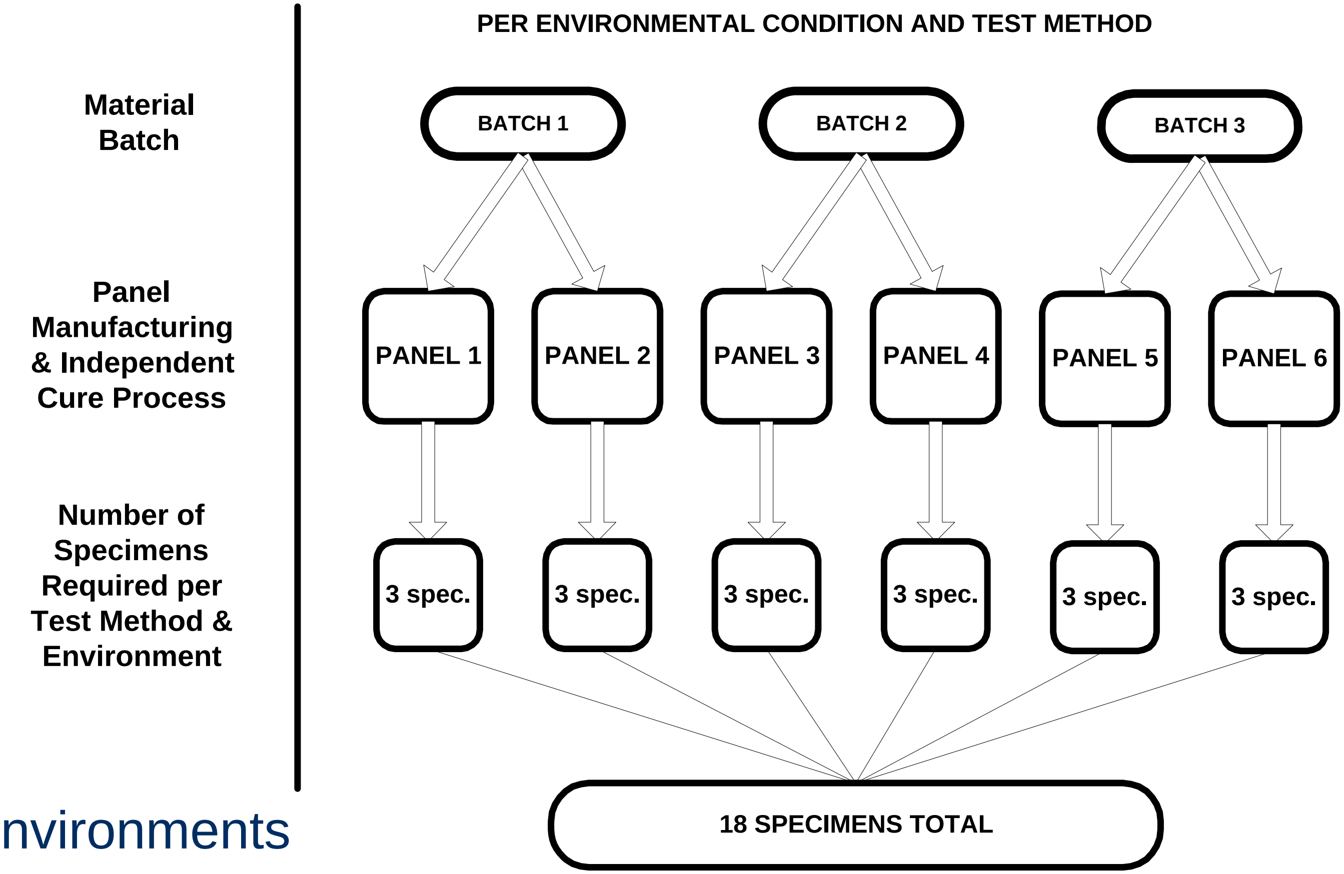
Typical Material Requirements – Autoclave cure

	7781 Fg/Epoxy			S2 284gsm /SP381			IM7 145gsm/SP381			3k PW/SP381		
	Customer A Moisture 160°F Immersion 14 days			Customer A Moisture 160°F Immersion 14 days			Customer A Moisture 160°F Immersion 14 days			Customer A Moisture 160°F Immersion 14 days		
	90 psi Cure 260°F 2 hrs			90 psi Cure 260°F 2 hrs			90 psi Cure 260°F 2 hrs			90 psi Cure 260°F 2 hrs		
	CTD -65°F	RTD	ETW 160°F	CTD -65°F	RTD	ETW 160°F	CTD -65°F	RTD	ETW 160°F	CTD -65°F	RTD	ETW 160°F
T_g °F	-	>250	-	-	>250	-	-	>250	-	-	>250	-
F_1^{tu}	-	55	-	210	225	105	340	335	300	-	91	-
E_1^{t}	-	3.2	-	-	6.4	6.4	22	22	22	-	9	-
F_1^{cu}	-	-	-	-	165	120	-	200	165	-	81	-
E_1^{c}	-	-	-	-	6.3	6.3	-	20	20	-	-	-
$F_{12\ ult}$	-	-	-	13	13	9	15	15	12	-	-	-
G_{12}	-	-	-	-	0.55	0.38	-	0.55	0.45	-	-	-
F_{13}	-	6.4	8	13	7.5	7	12	10.5	6.5	-	8	-

Typical Material Requirements – Autoclave cure

	7781 Fg/Epoxy			S2 284gsm /SP381			IM7 145gsm/SP381			3k PW/SP381		
	Customer B Moisture 160°F Immersion 14 days			Customer B Moisture 160°F Immersion 14 days			Customer B Moisture 160°F Immersion 14 days			Customer B Moisture 160°F Immersion 14 days		
	50 psi Cure 260°F 2 hrs			50 psi Cure 260°F 2 hrs			50 psi Cure 260°F 2 hrs			50 psi Cure 260°F 2 hrs		
	CTD -65°F	RTD	ETW 160°F	CTD -65°F	RTD	ETW 160°F	CTD -65°F	RTD	ETW 160°F	CTD -65°F	RTD	ETW 160°F
T_g °F		>250			>250			>246	>217		>246	>217
F_1^{tu}		67	46.7	210	219	127.7	330	320	290		91	
E_1^t		4.3	3.8		6.3	6.84	22	22	22		9	
F_1^{cu}					200	151		220	182		81	
E_1^c					6.4	6.4		20	20			
$F_{12\ ult}$		13.6	8.5	13	13	9	14	13.5	10.5		14.5	9
G_{12}		0.68	0.4		0.55	0.38		0.65	0.45		0.69	0.51
F_{13}		6.4		13	7.5	7	14	12	7		8	

Qualification Test Plan



- Environments
  - CTD = -67±5°F
  - RTD = 70±10°F dried after machining, no humidity limit
  - ETW = test @ 180±5°F, Humidity 160°F 85%rH saturation <0.02% change in 2 weeks

Qualification Plan

Uncured Prepreg and Resin Testing		
Cured neat resin density	ASTM D792-08	6
Fiber content/areal weight	ASTM D3776-09 Option C or SACMA SRM 23R-94	6
Resin content	ASTM D3529/D3529M-97(2008)	6
Volatile content	ASTM D3530/D3530M-97(2008)	6
Flow	ASTM D3531-99(2004)	6
Gel Time	ASTM D3532-99(2004)	6
HPLC (Note 4)	SACMA SRM 20R-94	3
FTIR (Note 4)	ASTM E168-06, ASTM E1252-98(2007)	3
Chemical reactivity and degree of advancement by DSC	SACMA SRM 25R-94	3

Qualification Plan

Cured Laminate Physical Testing		
Cured Ply Thickness	ASTM D3171-06	All specimens
Laminate Density	ASTM D792-08	3
Fiber Volume, % by Volume	ASTM D3171-06	3
Resin Content, % by Weight	ASTM D3171-06	3
Ultrasonic Through Transmission, C-Scan	MIL-HDBK-787A	1
Glass Transition Temperature, Tg by DMA flexural loading	Dry and Wet – ASTM D7028 *Each cure cycle*	1 Dry, 1 Wet
Glass Transition Temperature, Tg by DMA torsional loading	Dry and Wet – ASTM D5279 *Each cure cycle*	1 Dry, 1 Wet

Qualification Plan – 7781 Fg Example

Lamina Level Tests						
Lay-up	Test Type & Designation	Property	Number of Batches X # of Panels X # of Specimens			
			Test Temperature/Moisture Condition			
			CTD	RTD	ETD	ETW
$[0]_{6s}$	ASTM D 3039 0° Tension	Strength, modulus & poissons ratio	3X2X3	3X2X3		3X2X3
$[0]_{6s}$	ASTM D 6641 0° Compression	Strength & modulus	3X2X3	3X2X3		3X2X3
$[90]_{6s}$	ASTM D 3039 90° Tension	Strength & modulus	3X2X3	3X2X3		3X2X3
$[90]_{6s}$	ASTM D 6641 90° Compression	Strength & modulus	3X2X3	3X2X3	1X2X3	3X2X3
$[+45/-45]_{2s}$	ASTM D 3518 InPlane Shear	Strength & modulus	3X2X3	3X2X3		3X2X3
$[0]_{25}$	ASTM D 2344 Short Beam Shear	Strength	3X2X3	3X2X3	3X2X3	3X2X3

- + Fluid sensitivity SBS on IM7 unitape
- + Shelf life / Out life on IM7 unitape

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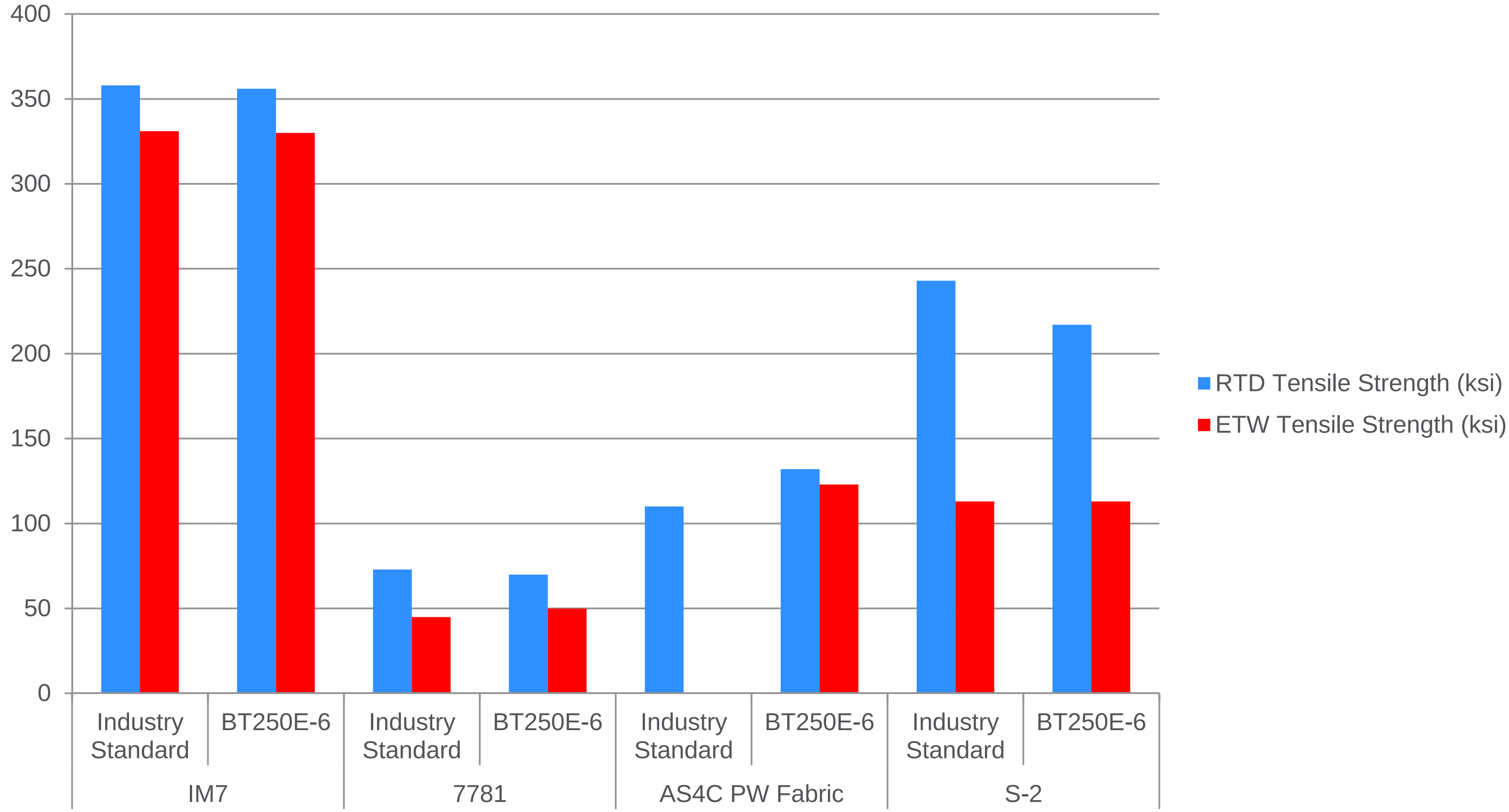
Tensile Strength Comparison



- Reasonably close for OOA & 260°F Cure
- Some graphed industry results are autoclave cured @50 psi.

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Tensile Modulus Comparison

- Reasonably close for OOA & 260°F Cure
- Some graphed industry results are autoclave cured @50 psi.

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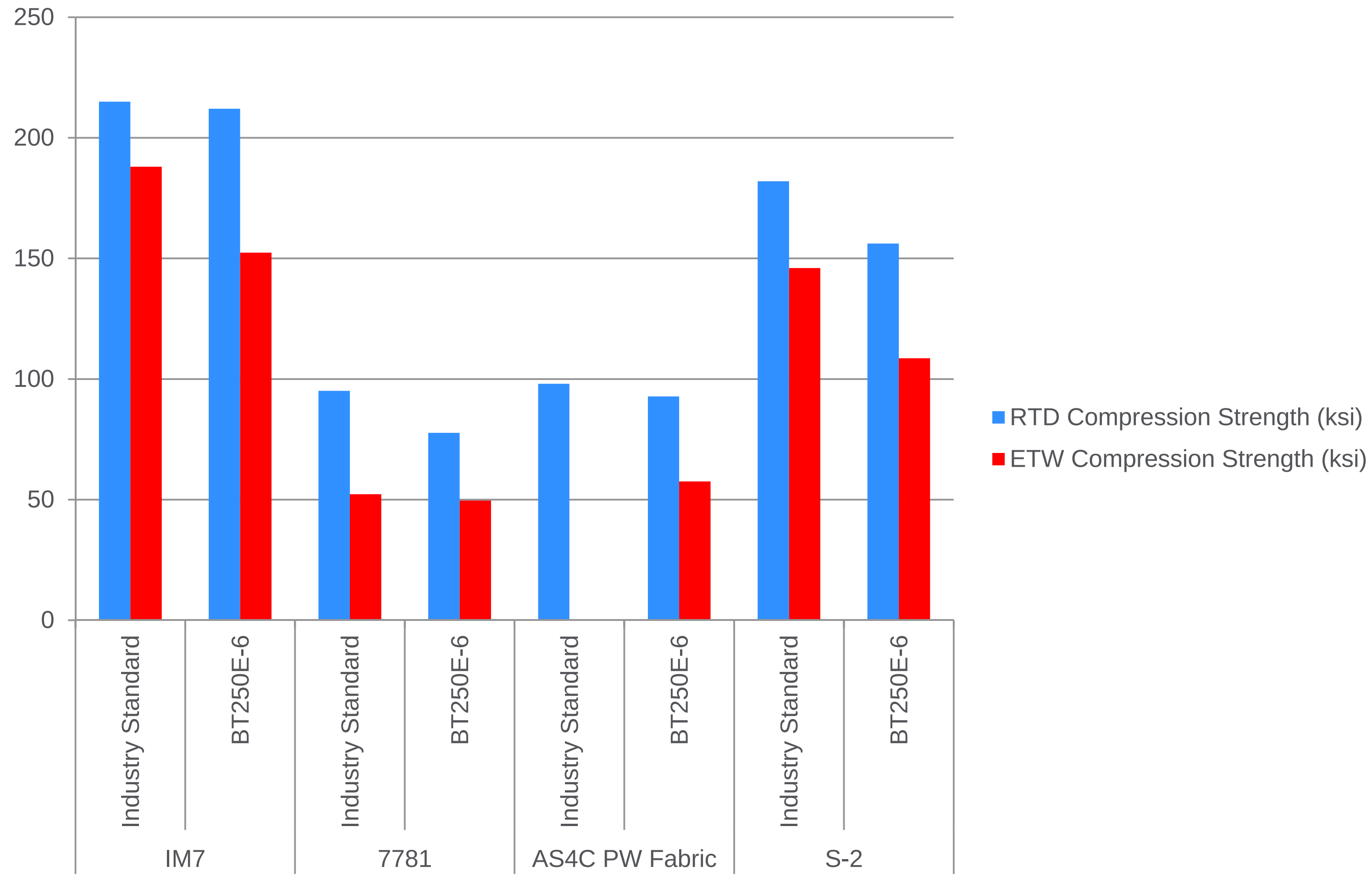
TENCATE materials that make a difference

Compression Strength Comparison



- Reasonably close for OOA & 260°F Cure
- Compression test and cure method differences

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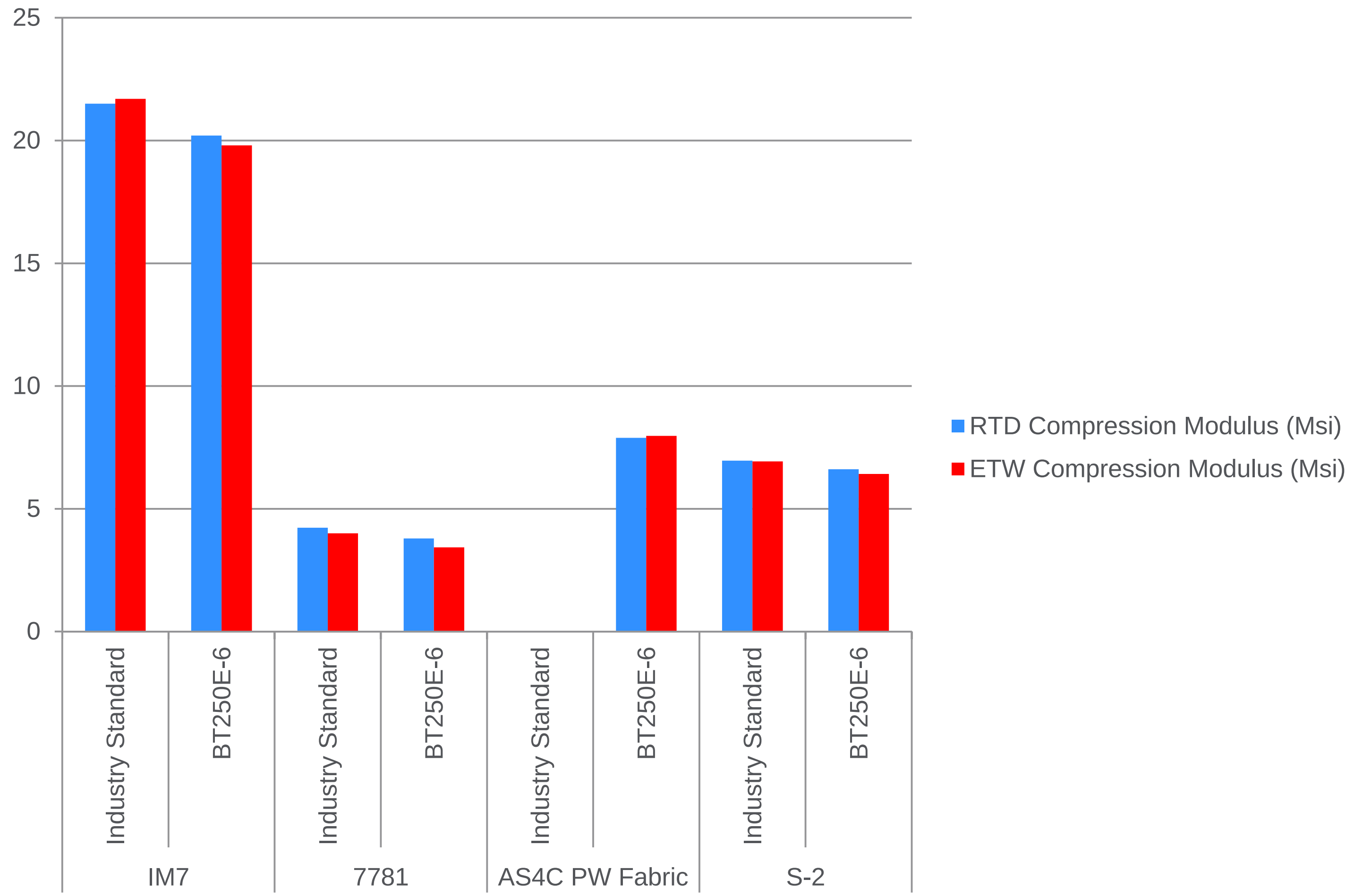
TENCATE materials that make a difference

Compression Modulus Comparison



- Reasonably close for OOA & 260°F Cure
- Some graphed industry results are autoclave cured @50 psi.

Shelf Life Evaluation

- TenCate investigated the effects of:
  - Storage Life: Time in the freezer
    - 0, 3, 6, 9, 12 months
  - Out-life: Time at Room Temperature
    - 1, 5, 7, 12, 15, 21 days
- Properties tested:
  - Flow
  - Gel
  - DSC Heat of Reaction (prepreg and resin)
  - Short Beam Shear Strength

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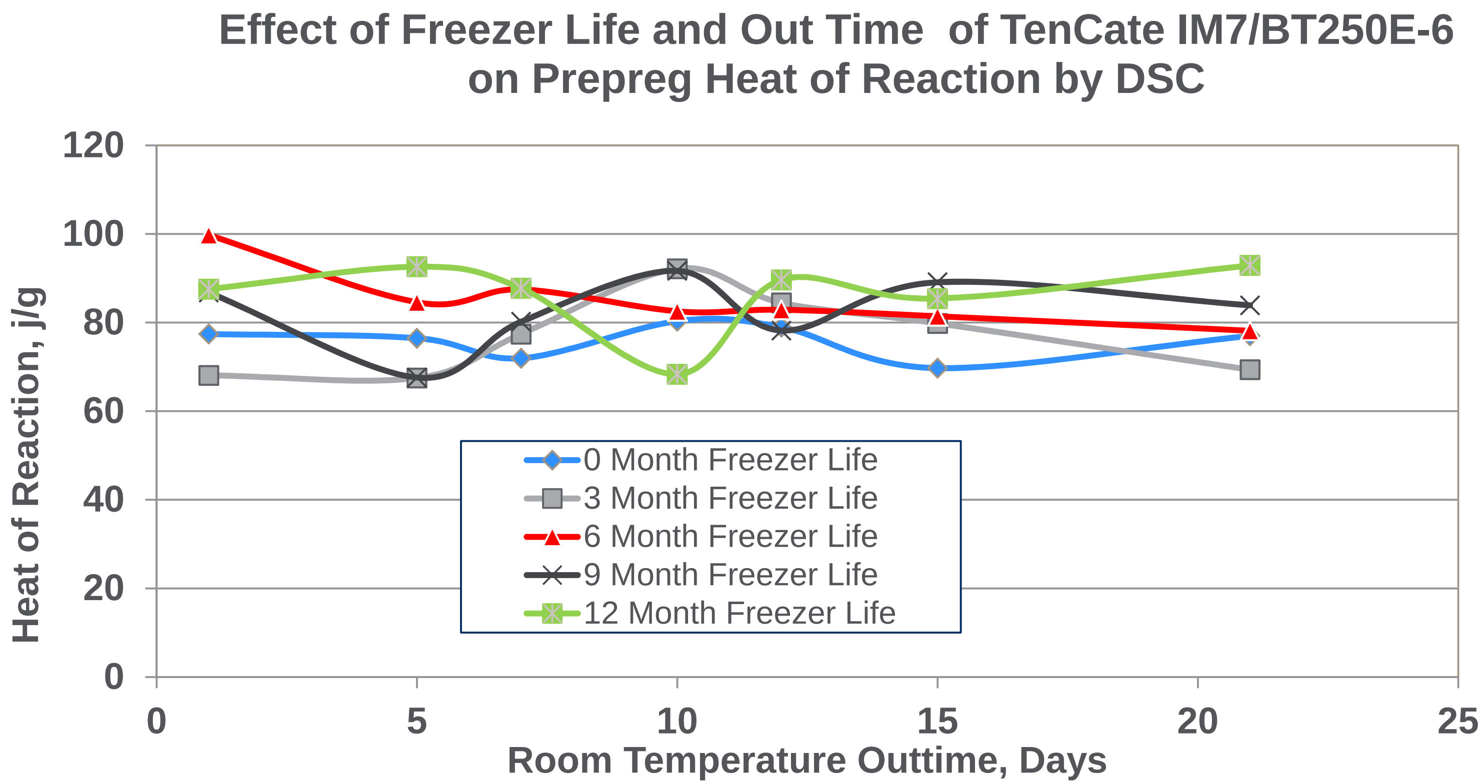
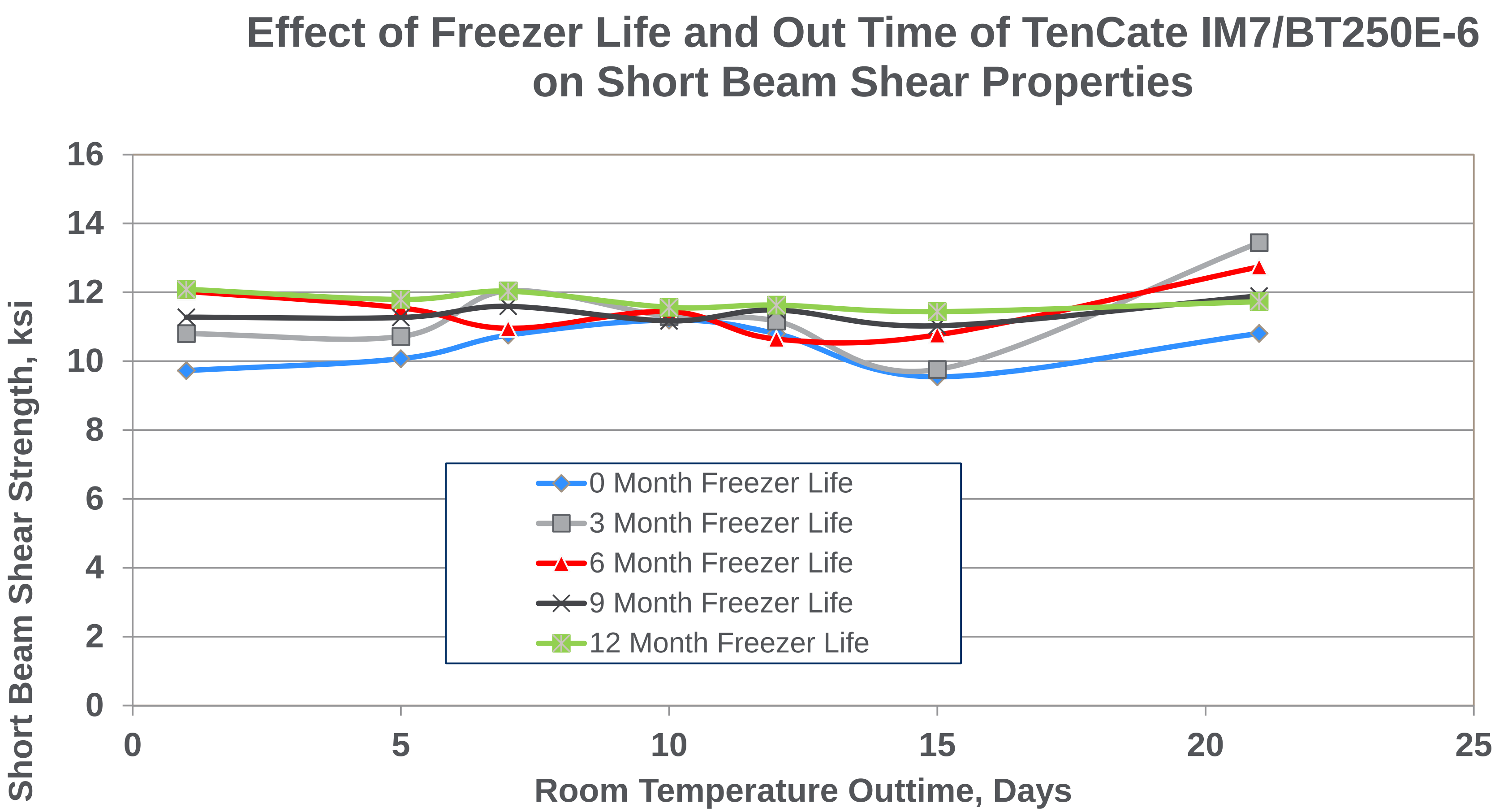
Shelf Life Evaluation (Continued)

- Result –BT 250E-6 showed no change in resin properties for the time periods tested



Shelf Life – Mechanical Properties

- Mechanical Properties also saw no effect



Qualification Test Results – IM7 145gsm/BT250E-6

Material IM7 12K 145 gsm/BT250E-6

Testing on 3 lots - 2 panels per lot -Typically 3 - 4 coupons per panel

		-65°Fdry			RTD			180°F Wet			180°F Dry			ETW%
		Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean *	B-Basis	A-Basis	Retention
Tg by DMA (°F)	**ASTM D 7028**				281.2			241.9						86.0%
0° Tension	***ASTM D3039***													
[0]8	Strength, ksi	359	310	275	356	307	272	330	267	222	--	--	--	92.7%
	Modulus, Msi	22.6	21.1	20.0	22.6	21.4	20.5	23.1	21.9	21.1	--	--	--	102.2%
	Poisson's Ratio	0.322	0.286	0.261	0.309	0.288	0.273	0.329	0.281	0.247	--	--	--	106.5%
90° Tension	***ASTM D3039***													
[90]16	Strength, ksi	6.03	4.67	3.71	5.70	4.64	3.89	2.25	1.74	1.38	--	--	--	39.5%
	Modulus, Msi	1.36	1.33	1.30	1.25	1.21	1.19	0.94	0.86	0.80	--	--	--	75.1%
0° Compression	***ASTM D6641***													
[0]20	Strength, ksi	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	--	--	--	
	Modulus, Msi	20.4	19.3	18.6	20.2	19.5	19.0	19.8	17.0	15.0	--	--	--	98.0%
90° Compression	***ASTM D6641***													
[90]20	Strength, ksi	33.2	26.1	21.0	27.5	23.6	20.9	14.8	13.1	11.9	--	--	--	53.8%
	Modulus, Msi	1.4	1.3	1.3	1.3	1.3	1.2	1.1	1.0	1.0	--	--	--	82.1%
90°/0°/90° Compression	***ASTM D 6641***													
0° Compression - Backout		230.5	200.0	178.3	215.5	190.9	173.3	156.5	125.7	103.8	177.9			72.6%
[90/0/90]7	Strength, ksi	86.0	74.6	66.5	79.7	70.6	64.1	56.4	45.3	37.4	65.8	--	--	70.8%
	Modulus, Msi	7.87	7.45	7.16	7.55	7.01	6.62	7.84	7.16	6.85	7.62*	--	--	103.8%
In-Plane Shear	***ASTM D3518***													
[±45°]4s	Strength (@ .2% offset), ksi	8.85	8.62	8.46	6.71	6.50	6.35	3.62	3.36	3.18	--	--	--	53.9%
	Strength (@ 5% Strain), ksi	12.7	12.1	11.6	10.1	9.6	9.3	5.1	4.8	4.5	--	--	--	50.9%
	Modulus, Msi	0.733	0.704	0.683	0.629	0.604	0.587	0.383	0.351	0.328	--	--	--	60.9%
Short Beam Shear	ASTM D2344													
[0]45	Strength, ksi	12.40	9.78	7.90	9.87	8.13	6.88	5.17	4.26	3.61	8.03	6.90	6.09	52.4%

Wet = To equilibrium at 160°F and 85% RH

* = Only 1 lot tested

Qualification Test Results AS4C 3k PW/BT250E-6

Material AS4C 3K PW 195 gsm/BT250E-6

Testing on 3 lots - 2 panels per lot -Typically 3 - 4 coupons per panel

		-65°Fdry			RTD			180°F Wet			180°F Dry			ETW%
		Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Retention
Tg by DMA (°F)	**ASTM D 7028**				275.46			249.55						90.6%
Warp Tension	***ASTM D3039***													
[0]15	Strength, ksi	125	111	101	132	120	111	123	114	108	--	--	--	93.2%
	Modulus, Msi	8.59	8.17	7.87	8.54	8.18	7.93	8.45	8.13	7.90	--	--	--	98.9%
	Poisson's Ratio	0.0576	0.0456	0.0372	0.0555	0.0491	0.0446	0.0506	0.0287	0.0133	--	--	--	91.2%
Fill Tension	***ASTM D3039***													
[90]15	Strength, ksi	120	107	98.4	125	115	107	110	97.4	88.3	--	--	--	88.0%
	Modulus, Msi	8.65	8.39	8.21	8.57	8.25	8.01	8.58	8.32	8.13	--	--	--	100.1%
Warp Compression	***ASTM D6641***													
[0]15	Strength, ksi	101	88.4	79.1	92.8	83.3	76.6	57.5	47.3	40.0	--	--	--	62.0%
	Modulus, Msi	7.94	7.70	7.53	7.89	7.64	7.47	7.97	7.62	7.38	--	--	--	101.0%
Fill Compression	***ASTM D6641***													
[90]15	Strength, ksi	93.2	80.4	71.3	85.2	77.4	71.8	51.3	46.0	42.2	72.1	--	--	60.2%
	Modulus, Msi	8.11	7.65	7.32	7.88	7.47	7.17	7.89	7.65	7.49	7.72	--	--	100.1%
In-Plane Shear	***ASTM D3518***													
[±45°]3s	Strength (@ .2% offset), ksi	8.40	8.02	7.75	6.40	6.13	5.94	3.69	6.48	3.33	--	--	--	57.7%
	Strength (@ 5% Strain), ksi	13.2	12.6	12.1	10.3	9.94	9.96	5.73	5.37	5.11	--	--	--	55.6%
	Modulus, Msi	0.662	0.631	0.609	0.578	0.552	0.533	0.379	0.36	0.345	--	--	--	65.6%
Short Beam Shear	ASTM D2344													
0[32]	Strength, ksi	8.47	7.94	7.56	8.16	7.63	7.25	5.04	4.62	4.32	7.11	6.48	6.04	61.8%

Wet = To equilibrium at 160°F and 85% RH

* = Only 1 lot tested

Qualification Test Results 7781 Fg/BT250E-6

Material 7781/BT250E-6

Testing on 3 lots - 2 panels per lot -Typically 3 - 4 coupons per panel

		-65°Fdry			RTD			180°F Wet			180°F Dry			ETW%
		Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Retention
Tg by DMA (°F)	**ASTM D 7028**				272.4			245.3						90.0%
Warp	***ASTM D3039***													
Tension	Strength, ksi	80.5	74.7	70.6	69.9	66.2	63.5	44.9	36.4	30.3	--	--	--	64.2%
[0]6s	Modulus, Msi	3.89	3.75	3.65	3.65	3.56	3.5	3.30	3.23	3.18	--	--	--	90.4%
	Poisson's Ratio	0.159	0.15	0.143	0.15	0.146	0.143	0.108	0.104	0.101	--	--	--	72.0%
Fill	***ASTM D3039***													
Tension	Strength, ksi	65.6	61.4	58.5	58.4	55.3	53.1	38.2	3.9	27.4	--	--	--	65.4%
[90]6s	Modulus, Msi	3.62	3.49	3.4	3.46	3.3	3.19	3.09	2.96	2.87	--	--	--	89.3%
Warp	***ASTM D6641***													
Compression	Strength, ksi	92.1	85	79.9	77.7	71.7	67.4	49.6	45.4	42.5	--	--	--	63.8%
[90]6s	Modulus, Msi	4.00	3.86	3.75	3.79	3.68	3.60	3.43	331	3.22	--	--	--	90.5%
Fill	***ASTM D6641***													
Compression	Strength, ksi	83.0	74.1	67.7	70.1	65.1	61.6	44.0	41.4	39.5	58.1	53.2	49.8	62.8%
[90]6s	Modulus, Msi	3.77	3.61	3.50	3.55	3.42	3.32	3.29	3.12	2.99	3.41	3.25	3.14	92.7%
In-Plane Shear	***ASTM D3518***													
[±45°]2s	Strength (@ .2% offset), ksi	7.38	7.07	6.85	5.58	5.34	5.17	3.16	2.99	2.86	--	--	--	56.6%
	Strength (@ 5% Strain), ksi	12.1	11.7	11.4	9.34	9.03	8.81	5.09	4.79	4.57	--	--	--	54.5%
	Modulus, Msi	0.702	0.666	0.641	0.57	0.544	0.525	0.325	0.313	0.303	--	--	--	57.0%
Short Beam Shear	ASTM D2344													
[0]25	Strength, ksi	11.4	10.7	10.2	10.3	9.98	9.73	5.32	4.74	4.33	8.23	8.01	7.86	51.7%

Wet = To equilibrium at 160°F and 85% RH

Qualification Test Results S2 Fg/BT250E-6

Material S2 Fg 284 gsm/ BT250E-6

Testing on 3 lots - 2 panels per lot -Typically 3 - 4 coupons per panel

		-65°Fdry			RTD			180°F Wet			180°F Dry			ETW%
		Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean	B-Basis	A-Basis	Mean *	B-Basis	A-Basis	Retention
Tg by DMA (°F)	**ASTM D 7028**				291.7			252.9						86.7%
0° Tension	***ASTM D3039***													
[0]5	Strength, ksi	230	197	173	217	190	171	113	99.7	90	--	--	--	52.1%
	Modulus, Msi	6.46	6.18	5.98	6.49	6.23	6.05	6.33	6.08	5.89	--	--	--	97.5%
	Poisson's Ratio	0.291	0.272	0.259	0.278	0.257	0.242	0.327	0.307	0.293	--	--	--	117.6%
90° Tension	***ASTM D3039***													
[90]12	Strength, ksi	6.72	5.71	4.99	6.18	5.65	5.27	3.30	2.87	2.57	--	--	--	53.4%
	Modulus, Msi	1.87	1.74	1.65	1.65	1.55	1.48	0.87	0.77	0.70	--	--	--	52.7%
0° Compression	***ASTM D6641***													
[0]12	Strength, ksi	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	--	--	--	
	Modulus, Msi	6.59	6.18	5.90	6.61	6.34	6.14	6.42	6.14	5.94	--	--	--	97.1%
90° Compression	***ASTM D6641***													
[0]12	Strength, ksi	30.4	26.8	24.3	24.0	21.5	19.7	12.2	10.8	9.8	--	--	--	50.8%
	Modulus, Msi	1.97	1.83	1.73	1.79	1.68	1.60	1.17	1.09	1.03	--	--	--	65.4%
90°/0°/90° Compression	***ASTM D 6641***													
0° Compression - Backout		173.4	152.6	137.7	156.3	139.7	128.0	108.7	97.4	89.2	121.3			69.5%
[90/0/90]5	Strength, ksi	91.0	80.1	72.3	79.2	70.8	64.9	49.1	44	40.3	61.5	--	--	62.0%
	Modulus, Msi	3.53	3.36	3.24	3.46	3.31	3.20	3.11	2.89	2.74	3.23	--	--	89.9%
In-Plane Shear	***ASTM D3518***													
[±45°]4s	Strength (@ .2% offset), ksi	7.13	6.80	6.57	5.60	5.38	5.22	3.14	2.84	2.62	--	--	--	56.1%
	Strength (@ 5% Strain), ksi	10.4	9.56	8.98	8.16	7.78	7.50	4.61	4.22	3.95	--	--	--	56.5%
	Modulus, Msi	0.65	0.614	0.587	0.547	0.532	0.52	0.326	0.292	0.268	--	--	--	59.6%
Short Beam Shear	ASTM D2344													
[0]27	Strength, ksi	10.6	8.62	7.23	8.58	7.14	6.12	4.93	4.14	3.59	7.10	6.20	5.55	57.5%

Wet = To equilibrium at 160°F and 85% RH

* = Only 1 lot tested

Qualification Lessons Learned

- Engage FAA representative early to scope project
  - DAR: Designated Airworthiness Representative
    - FAA Forms 8120-10, 8130-3 panels, 8100-1 specimens
  - DER: Designated Engineering Representative (Customer/consultants)
  - MIDO: Manufacturing Inspection District Office (Conformity)
- Use NCAMP Templates – FAA familiarity
  - Test plans
  - Process documents – high quality tool & caul plates, consumables, debulk, breathing and cure cycle *No detail too small*
  - Material specifications
  - Have certifications, labels and shelf life/out life records in good order
  - Write high quality work orders for each laminate w/QA stamps
  - Trial run laminate fabrication and technician training
    - Fill gaps – instruction, training, cure equipment and instrumentation
  - Material specifications
  - Test lab – FAA or NADCAP
  - Reports – Stat-17 , ASAP, HyTeQ

Erickson Air-Crane S-64 Helicopter

Blade Design & Manufacturing

- Male mandrel & clam shell spar tool
- Hand laid wrap over bladder
- Debulk
- Insert in clam shell
- Remove mandrel
- Pressurize mandrel
- Cure cycle
- Secondarily bond foil, weights, leading edges, mounts
- Finish

Composite Rotorblade

ERICKSON AIR-CRANE INCORPORATED

TENCATE materials that make a difference

Next Steps

- Analyze data normalized to cure ply thickness (CPT) where appropriate
- Tabulate and analyze laminate void content results
- Sub-component level fatigue testing
- Verify that blade mold tooling improvements work
- Full scale blade proof load and fatigue testing

Summary

- Project objectives met during composite materials qualification
- Partnership to develop processes and data in parallel
- Researched existing composite rotorblade materials and properties
- Building block approach used specific to rotorblades
- FAA involvement
- Data review
- Parts processing description developed
- More to follow..

Conclusion

- Partnering early in the program saves all parties time, resources and money
- Understanding and documenting all parties roles and responsibilities is vital to achieving common objectives
- Sharing methods, data and results benefits all parties and the composites community

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