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MECHANICAL PROPERTY COMPARISON OF PULTRUDED GFRP AND CFRP SANDWICH PANELS VS VARTM PANEL

Ruifeng (Ray) Liang, Ph.D. rliang@mail.wvu.edu
Hota GangaRao, P.E. Professor and Director
ghota@mail.wvu.edu, 304 293 7608 x 2634
CFC-WVU

In collaboration with
Bedford Reinforced Plastics, Inc. (BRP)

Sponsored by ONR, U.S. Navy (Dr. Ignacio Perez)

THE PULTRUSION PROGRAM

ONR Grant No. N00014-04/05-1-0050/96

Dr. Ignacio Perez, Program Officer

OBJECTIVE

To demonstrate feasibility of an automated pultrusion process for producing composite sandwich panels (4' x 3.5" x unlimited length) which results in a product with improved mechanical performance and reduced production cost in relation to conventional process

Target panel: 1/4" FRP face sheets with 3" balsa core

MATERIALS AND FABRIC CONFIGURATION

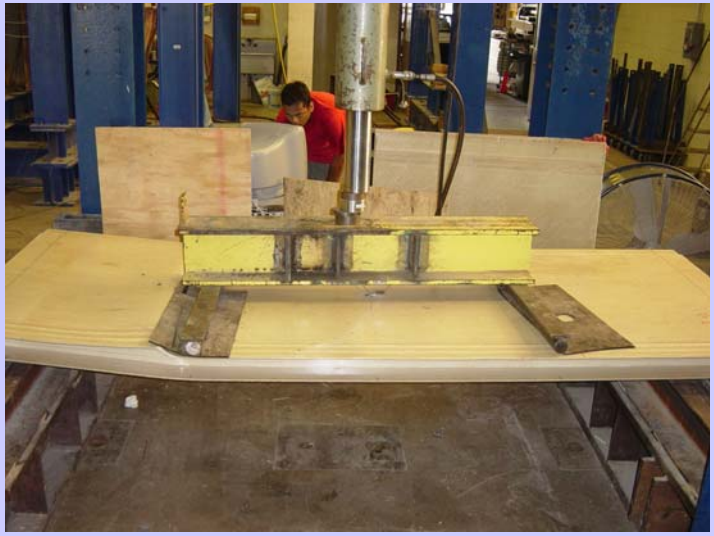
	Pultrusion 2005 GFRP	Pultrusion 2006 CFRP*	VARTM NGSS-GFRP
Fabric Layers	6	6	10
Weight (oz/sq yd)	40	28	24
Type	quadaxial stitched	quadaxial stitched	woven roving
Percent 0	33	21.4	30
Percent 90	27	21.4	30
Percent + 45	20	28.6	20
Percent - 45	20	28.6	20
Resin	Derekane 510A-40	Derekane 510A-40	Derekane 510A-40
Core	Baltek D-100 ~9.5 pcf	Baltek D-100 ~9.5 pcf	Baltek D-100 ~9.5 pcf

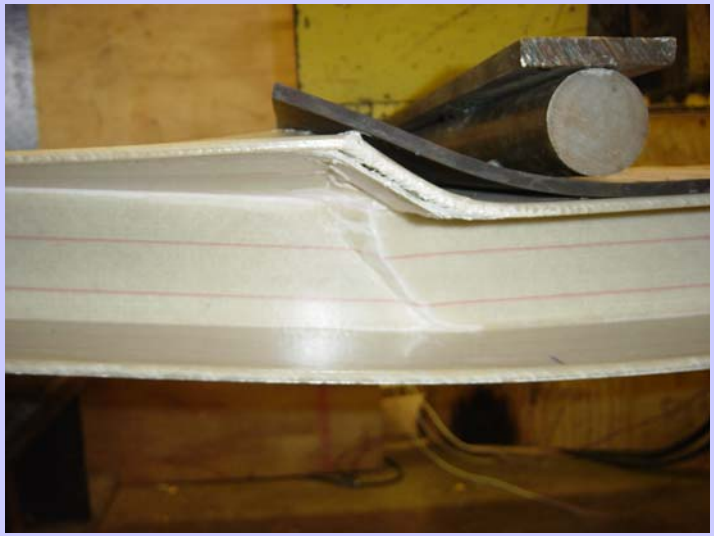
* Toray T700SC /12K / FOE carbon fabric

FABRICATION OF PULTRUDED GFRP PANEL

PULTRUSION OF CFRP PANEL -2006

PULTRUDED GFRP VS. NGSS VARTM (4’ x 10’): After test





SANDWICH PANEL BENDING PROPERTIES:

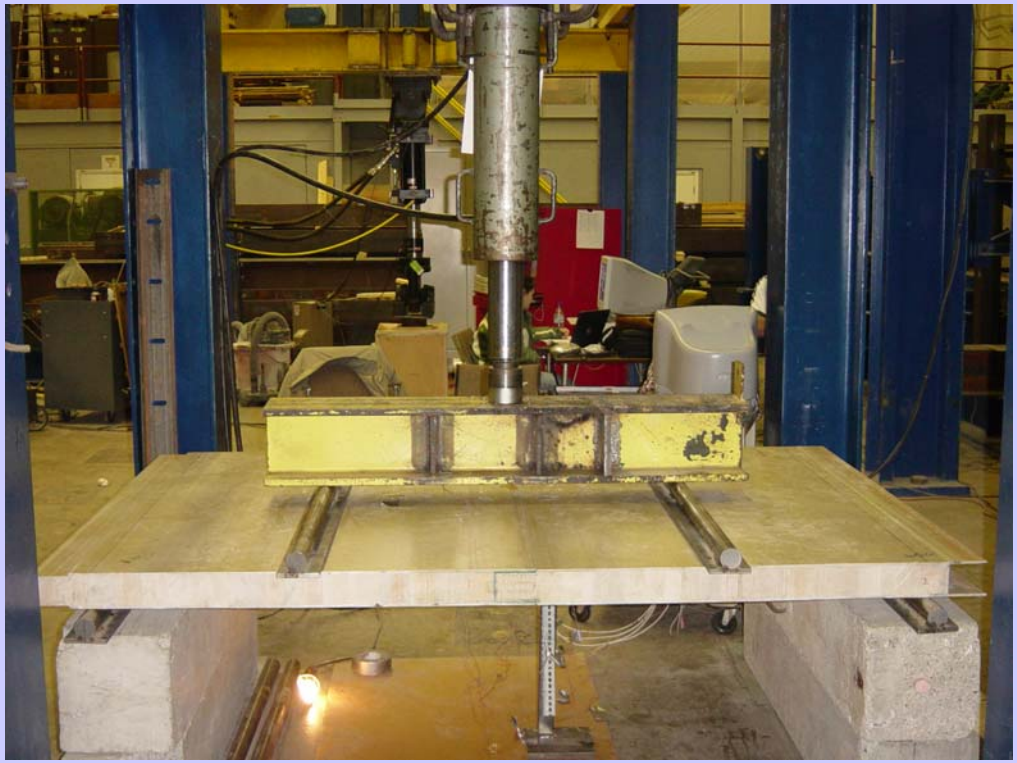
4’ x 10’ panels / 100” span, 4pt bending

	Unit	2005 Pultruded GFRP	2006 Pultruded CFRP	2005 VARTM GFRP
Failure strain	micro	5944	3982	6020
Balsa stress at failure	psi	204.7	232.5	172.2
FRP stress at failure	ksi	22.05	25.04	17.63
Modulus from strain	msi	4.06	6.48	2.96
Modulus from deflect.	msi	4.27	6.27	3.06

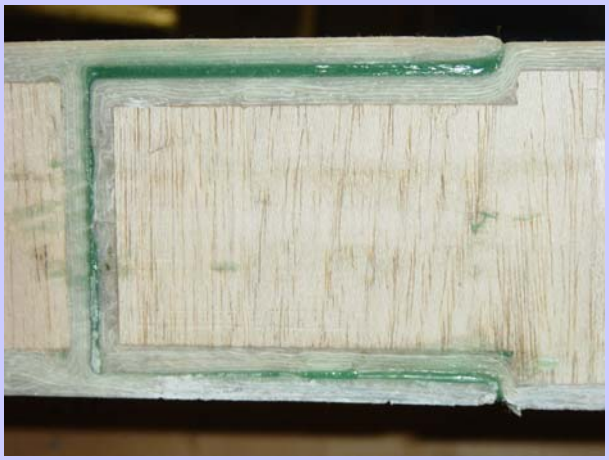
Failure is initiated by shear failure at balsa core.

Conclusion: Pultruded panel is about 15-20% stronger and stiffer than VARTM panel. Pultruded CFRP panel is about 50-80% stiffer than GFRP panel.

TESTING JOINED PANEL FOR JOINT EFFICIENCY



Panel: 5’ x 8’
Span: 80”
Test: 4 point loading with a load span of one-half of the support span



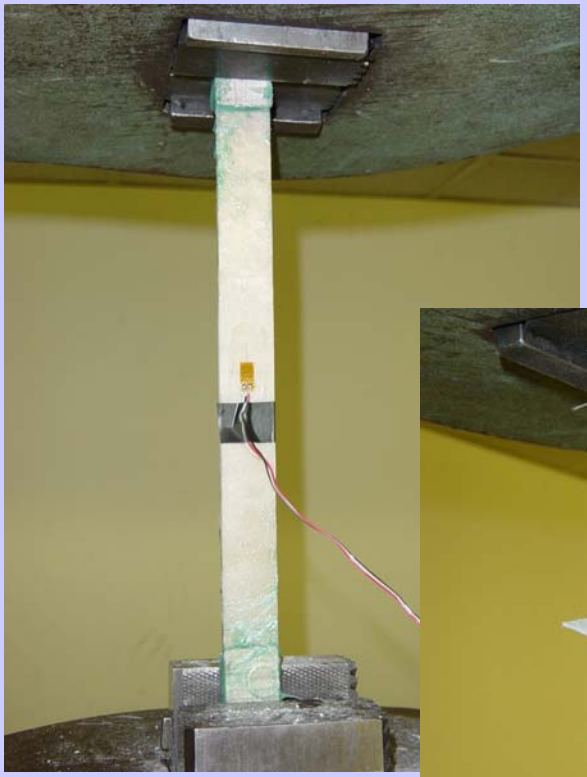
A Pultruded Joint

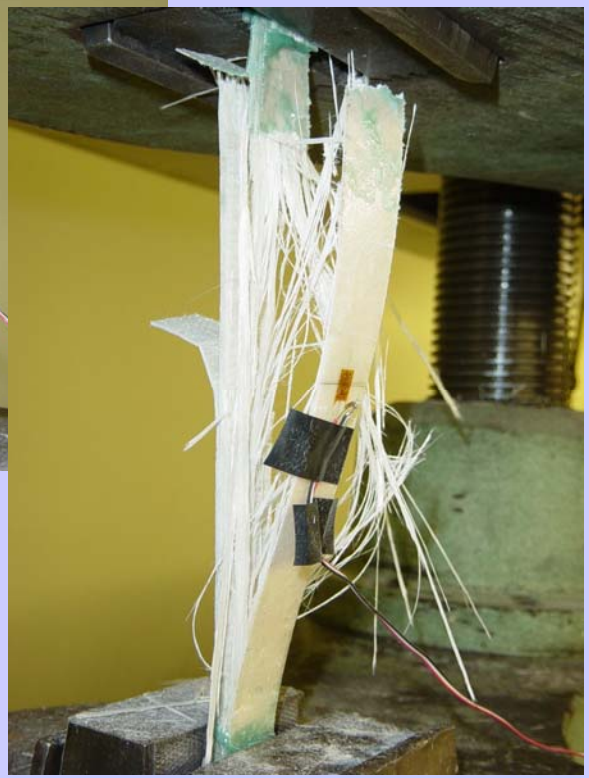
A VARTM Joint

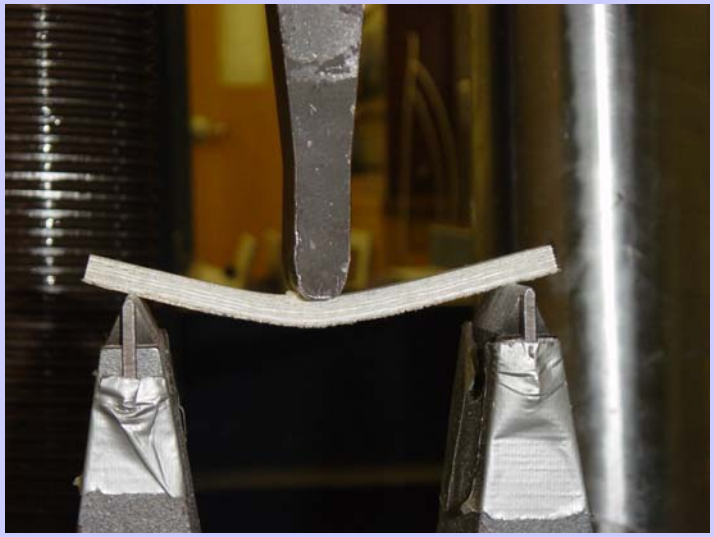
JOINED SANDWICH PANEL PROPERTIES

	Unit	2005 Pultruded GFRP	2005 VARTM GFRP
Bending at a span of 80” for 12” wide panel sections (“True Bending”)			
Failure load/unit width	lbs/in	1378 (no joint, pull direction test) 1433 (joint, no joint failure, perpendicular to pull direction)	1261 (no joint) 1444 (joint)
Failure strain	micro	5726 (no joint) 6774 (joint)	5695 (no joint) 5916 (joint)
Modulus from load/strain slope	msi	3.03 (no joint) 3.20 (joint)	2.76 (no joint) 3.08 (joint)
Joint efficiency	%	100 (No joint failure)	100 (No joint failure)
Bending at a span of 27” for 12” wide panel sections (“Shear Dominance”)			
Failure load/unit width	lbs/in	1613 (no joint) 1674 (joint)	1675 (no joint) 1523 (joint)
Failure strain	micro	1977 (no joint) 2096 (joint)	1912 (no joint) 1424 (joint)
Modulus from load/strain slope	msi	3.47 (no joint) 4.53 (joint)	3.28 (no joint) 3.96 (joint)
Joint efficiency	%	100 (No joint failure)	100 (No joint failure)

TESTING OF FRP LAMINATES







FRP LAMINATES: TENSILE PROPERTIES

Note: modulus data are from strain data.	Unit	2005 Pultruded GFRP	2006 Pultruded CFRP	2005 VARTM GFRP
Tensile strength (LW)	ksi	52.17	65.92	43.52
Tensile strength (CW)	ksi	39.32	47.20	42.98
Tensile modulus (LW)	msi	3.24	5.25	2.83
Tensile modulus (CW)	msi	2.91	5.24	2.76

Conclusion: Pultruded GFRP is about 15-20% stiffer and stronger, in pull direction, than VARTM GFRP under tension; pultruded CFRP is 30-40% stronger and 60-70% stiffer than pultruded GFRP.

FRP LAMINATES: FLEXURAL PROPERTIES

*** Different fabric architecture in CFRP and GFRP**

Note: modulus data are from deflection data.	Unit	2005 Pultruded GFRP	2006 Pultruded CFRP*	2005 VARTM GFRP
Flexural strength (LW)	ksi	79.6	67.08	57.7
Flexural strength (CW)	ksi	56.0	49.04	46.7
Flexural modulus (LW)	msi	3.03	5.21	2.55
Flexural modulus (CW)	msi	2.20	4.66	2.14

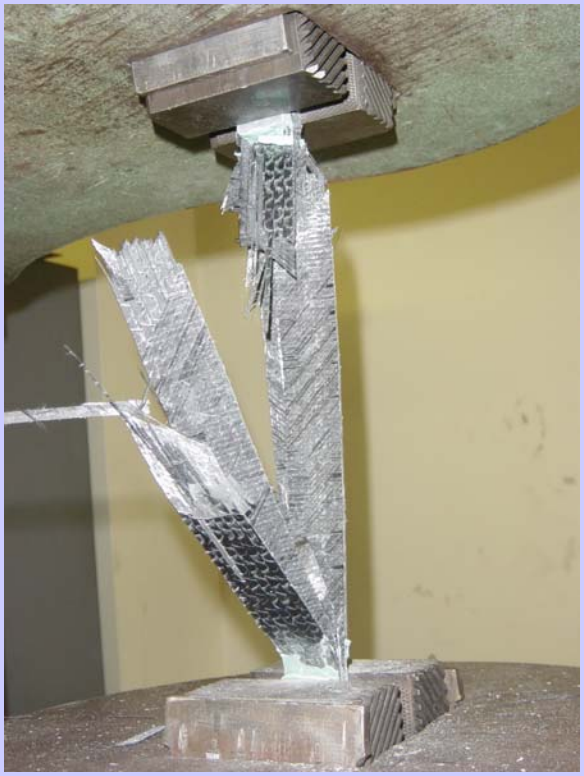
Conclusion: Pultruded GFRP is about 20-40% stiffer and stronger, in pull direction, than VARTM GFRP under bending; pultruded CFRP is 75-100% stiffer than pultruded GFRP.

SUMMARY AND ONGOING WORK

Pultrusion process - a viable mass- manufacturing process of composite sandwich panels

- **E-glass/Vinyl ester Pultrusion (2004, 2005)**
  - **Properties better than VARTM**
  - **100% joint efficiency**
  - **Significantly lower cost**
- **Carbon/Vinyl ester Pultrusion (2006)**
  - **Stiffness enhancement 50-100% over GFRP**
  - **Compatibility and durability issues?**
  - **15% lighter per sq ft panel**
  - **Expensive: ~$15 /lb of carbon fiber**
    ~$30 /lb of carbon fabric

TENSION TEST: SOME FAILED SPECIMENS

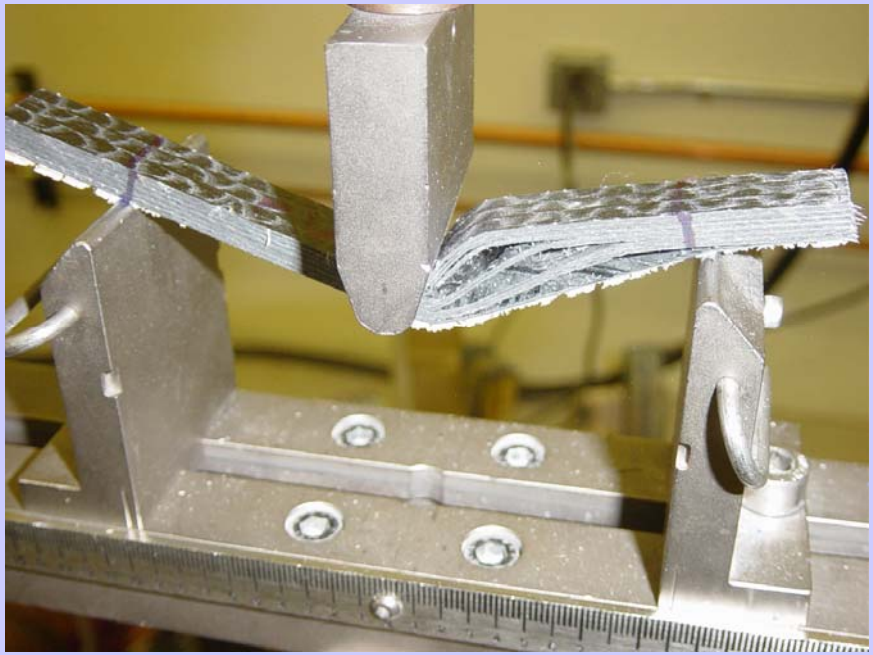


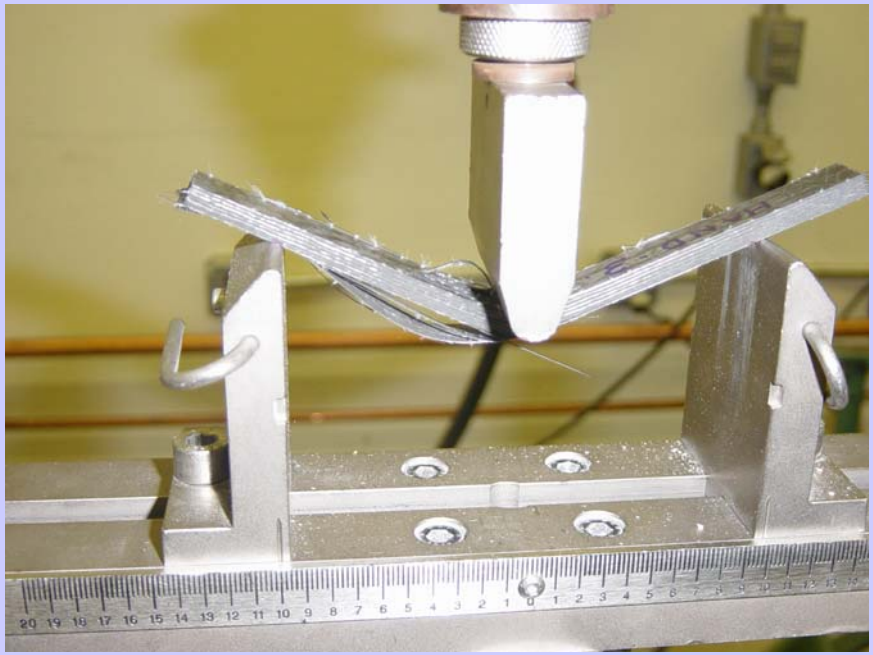
Pultruded Carbon/VE

Compression made carbon/VE

VARTM made Carbon/VE

BENDING TEST: FAILED SPECIMENS





Pultruded Carbon /VE vs. Compression molded Carbon/Epoxy

FLEXURAL PROPERTIES

3 point bending, 0.5” x 5” x 4” span

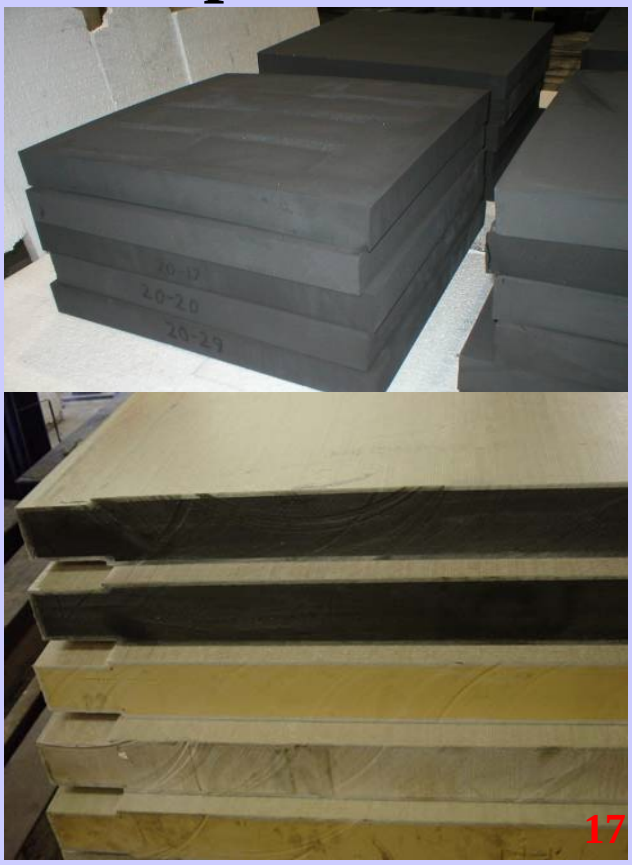
	Fiber Content wt%	Fail load/Unit width, lb/in	Flexural strength, ksi	Flexural modulus, msi
Carbon / Vinyl Ester (Pultrusion)	65.1	608 (L) 415 (T)	67.08 (L) 49.04 (T)	5.21 (L) 4.45 (T)
Carbon / Vinyl Ester (Compression)	77.5	516	87.78	6.82
Carbon / Vinyl Ester (Infusion)	51.0	689	52.75	4.24
Carbon / Epoxy (Compression)	76.3	573	98.12	7.30
Carbon / Epoxy (Infusion)	63.0	896	81.62	5.08

DEVELOPMENT OF LIGHTWEIGHT CARBON FOAM FIRE RESISTANT PANELS

GFRP composite panels using carbon foam as a core material reinforced with z-direction pins

Partners

- **GrafTech International Ltd.**
  - **Large block size**
  - **Over 100,000 ft^3 available**
  - **Available in densities from 1.5 to 35 lbs/ft^3**
- **WebCore Technologies, Inc.**
- **Fiber-Tech Industries, Inc.**
- **CFC-WVU**
- **Others**



Top: GrafTech Carbon Foam

Bottom: Pultruded GFRP Sandwich Panels with Foam Cores (CFC-WVU/BRP)

MECHANICAL PROPERTY DATA OF INFUSED CARBON FOAM GFRP PANELS

thru high temperature resin infusion process

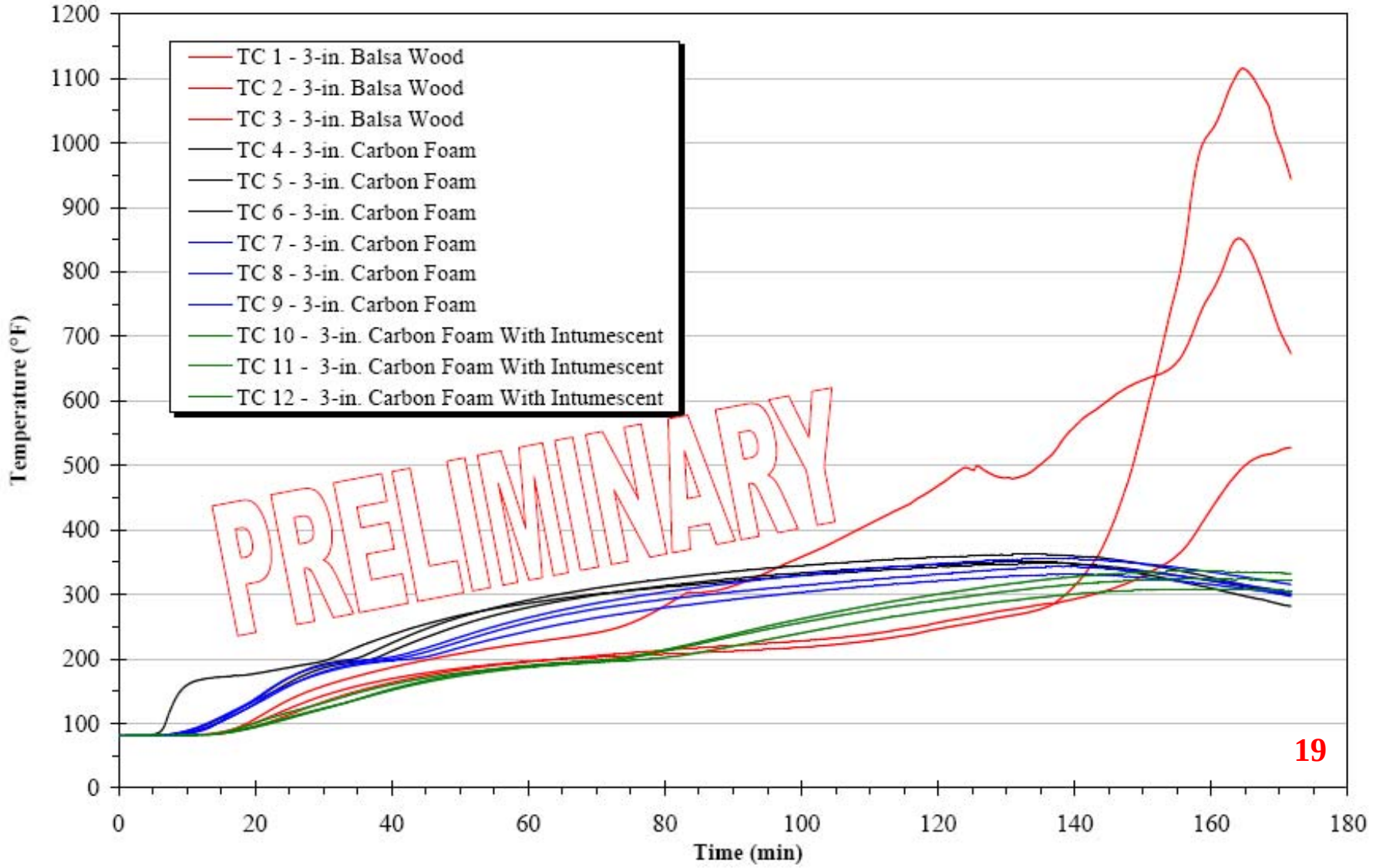
three point bending test @ span 20”	Panel thickness inch *	Load per inch of panel width lbs/in	Deflection inch	Strength ksi
1” Thick Panel	1.3125	673	0.577	21.0

*** Shell thickness 0.156 inch**

CLIENT: GRAFTECH INTERNATIONAL
SwRI PROJECT NO.: 01.11812.01.211a
TEST DATE: OCTOBER 2, 2006
TEST ID: 06-275GRA1.CSV

SOUTHWEST RESEARCH INSTITUTE FIRE TESTS

Carbon foam vs. balsa panel



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CONCLUSIONS

- **Pultruded panel is about 15-20% stronger and stiffer, and 50% lower in cost than VARTM panel**
- **Epoxy/carbon is strongly recommended, due to compatibility and durability issues with VE/carbon**
- **Large size epoxy/carbon sandwich panel may be produced thru high temperature infusion process**
- **Carbon foam is available in large quantities, at a cost that is nearly equal to balsa**