Hy-Bor® Materials for Structural Applications

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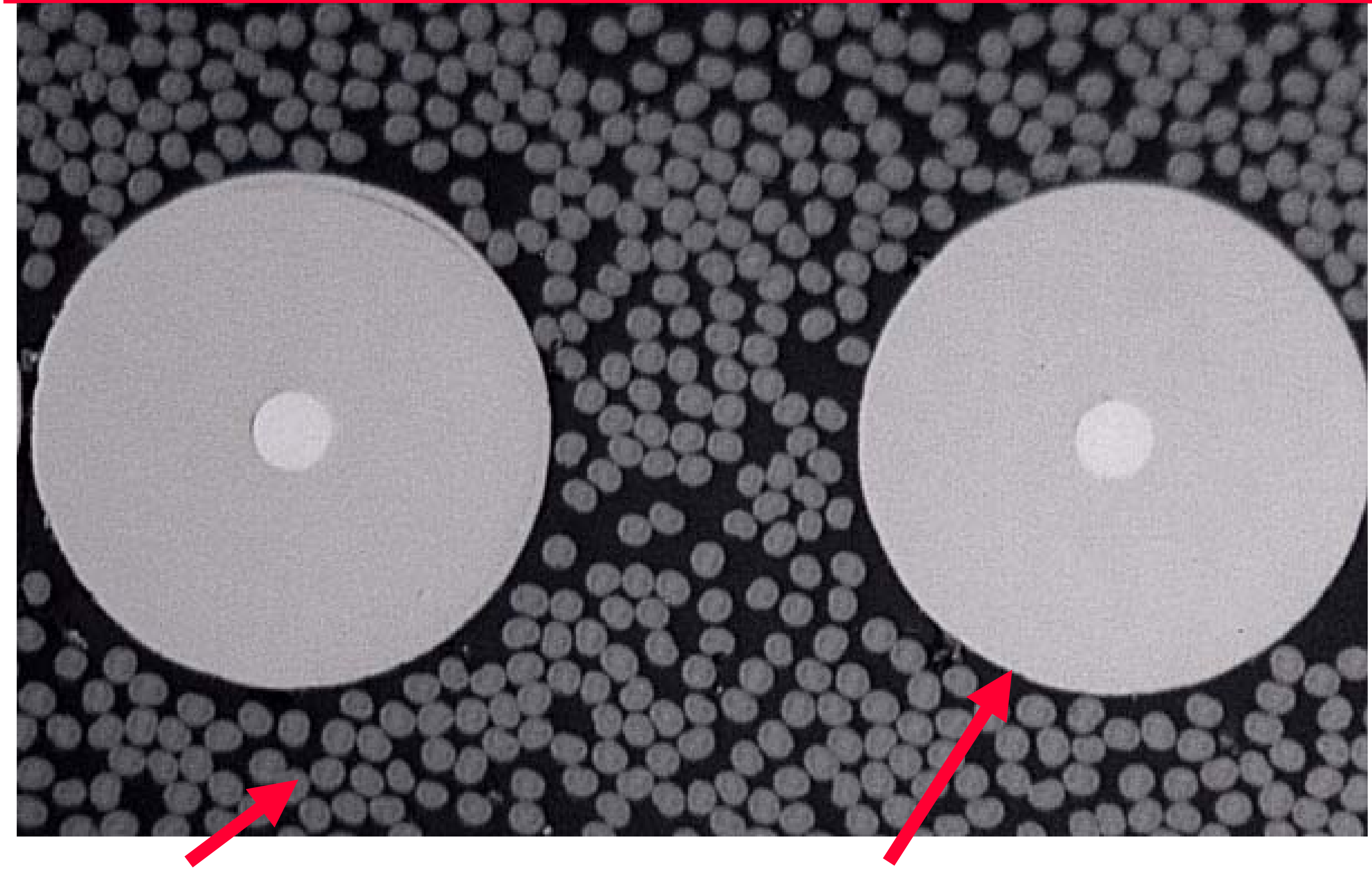
Presentation Outline

- Hy-Bor® Explained
- Designing with Hy-Bor®
- Three Potential Hy-Bor® Products
- Design Examples
- Summary

Understanding Hy-Bor®

- Hy-Bor® is a mixture of Boron and Graphite Fibers commingled as a single ply
- Individually, each material is strain limited by the fiber properties
- Commingled, each fiber contributes and shares load according to micromechanic principles
- Boron fiber improves Graphite fiber microbuckling stability

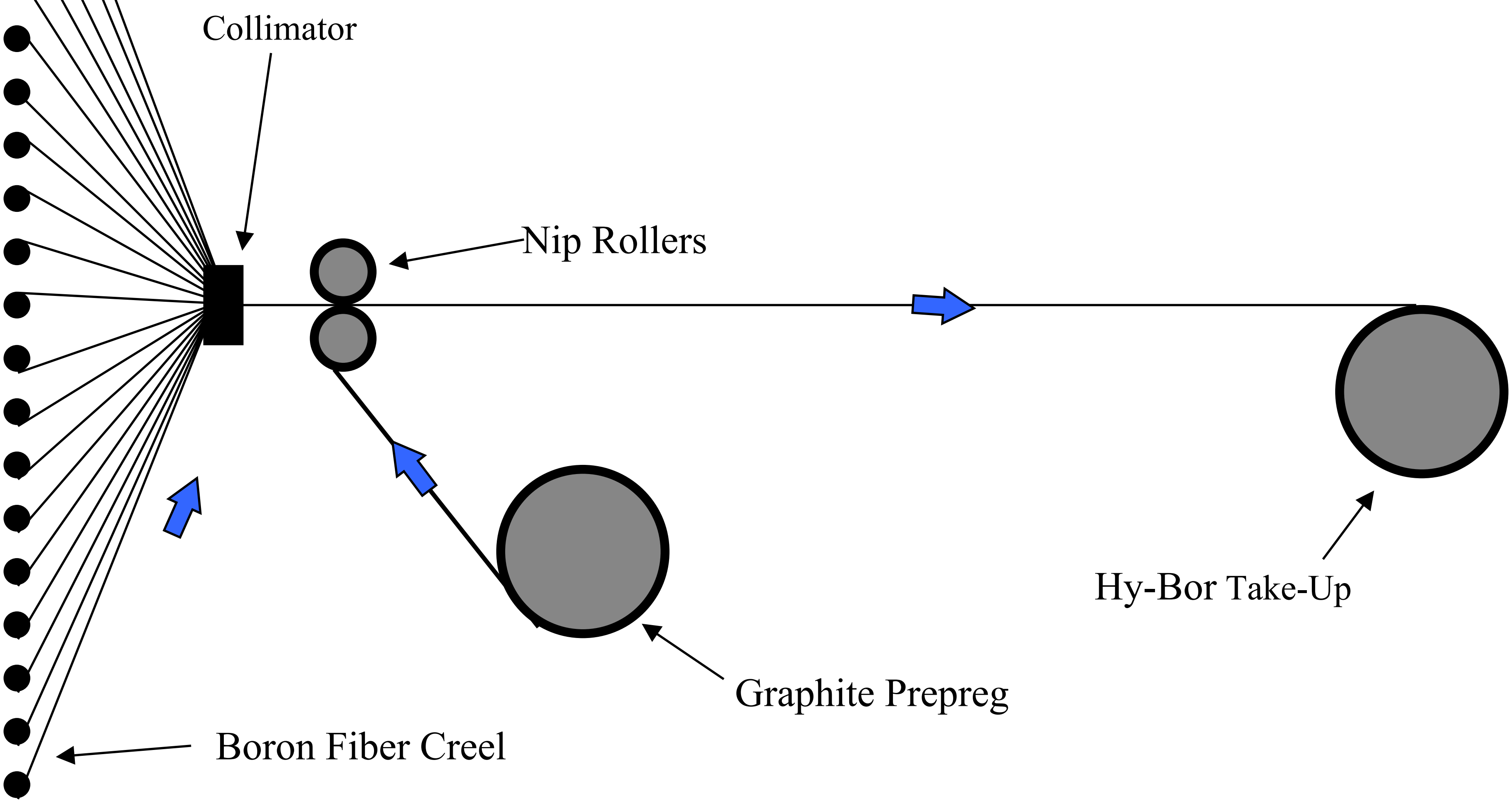
Hy-Bor® Cross-Section



Graphite Fiber - 0.0005” dia.

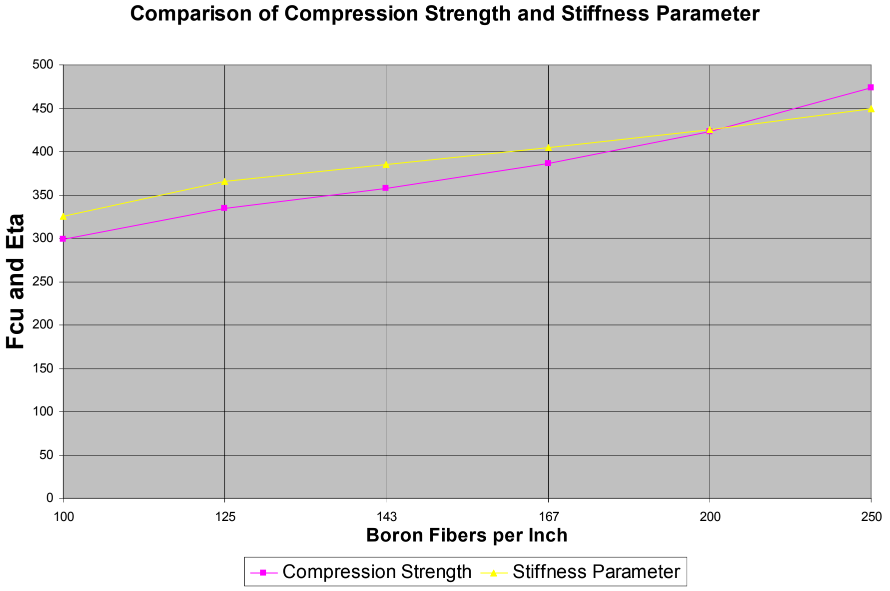
Boron Fiber - 0.004”dia.

Hy-Bor® Manufacturing Process



Compression Strength of Hy-Bor®

- Compression Strength of Hy-Bor® directly relates to Shear Modulus*
- Increasing Boron fiber count increases Fcu towards theoretical 600 ksi limit



* "The Influence of Local Failure Modes on the Compressive Strength of Boron/Epoxy Composites", ASTM STP 497, J.A. Suarez, J.B. Whiteside & R.N. Hadcock, 1972

"Influence of Boron Fiber Count on Compressive and Shear Properties of HyBor", Alliant Techsystems, J.W. Gillespie,1986

Benefits of Hy-Bor®

- Provides the Maximum Compression Strength of any continuous filament-based composite material
- Tailored to meet specific materials properties and design objectives (Graphite fiber type and Boron fiber ratio)
- Prepregged to customer resin preferences
- Analytically treated as another lamina within a laminate stack per Classical Lamination Theory
- Can be mixed with carbon plies or it can be the total laminate

Balanced Strength Laminate Design

- Typically, all graphite unidirectional lamina are compression strength limited
- High tension strength is unavailable when cyclic loads and stress limit the strength to the compression strength allowable
- Graphite fiber + Boron fiber are matched to yield improved balance between tension and compression strength and modulus
- Increased strength efficiency translates to weight and cost savings

Potential Hy-Bor® Products

- Maximum Strength Hy-Bor®
  - T800H Graphite + 200 filaments per inch Boron
- High Stiffness Hy-Bor®
  - M55J Graphite + 175 filaments per inch Boron
- High Thermal Conductivity Hy-Bor®
  - K13D Graphite + 150 filaments per inch Boron

Maximum Strength Hy-Bor® Design Properties (T800H/Boron)

Property	Expected Ave. Test Value	Pseudo-B Basis
E-11	32.2 E6 psi	29.6 E6 psi
E-22	1.75 E6 psi	1.61 E6 psi
v-12	0.25	0.25
G-12	.95 E6 psi	.87 E6 psi
ε 11-tension	.00932 in/in	.00746 in/in
ε 22-tension	.00526 in/in	.00421 in/in
ε 11- compression	.02000 in/in	.00864 in/in
ε 22-compression	.01285 in/in	.01028 in/in
ε 12-shear	.01026 in/in	.00923 in/in
α 11	1.80 ppm/F	same
α 22	16.5 ppm/F	same

Properties determined by Micro-Mechanics analysis. To be verified by test

Maximum Strength Hy-Bor® Applications

- Aircraft
  - Wing, Fuselage, Empennage
- Spacecraft
  - Launch Adapters, Struts, Deployment Booms
- Engines
  - Casings, Blades, Components
- Commercial
  - Golf Shafts, Repair Patches, Tennis Rackets, Bicycles

Design Example #1 - Struts and Tubes

- Hybrid of Maximum Strength Hy-Bor® with M55J
- $[\pm\pm21/0_2/\pm\pm21/0_2/\pm21/0/0_2/0]_S$
- Hy-Bor® = 0_2 6 plies
- M55J = ±21 & 0 12 plies

Axial Modulus	30.7 msi
Tension Strength	100 ksi
Compression Strength	95 ksi
CTE	.02 ppm/F

High Stiffness Hy-Bor® Design Properties (M55J/Boron)

Property	Expected Ave. Test Value	Pseudo-B Basis
E-11	39.6 E6 psi	36.5 E6 psi
E-22	2.00 E6 psi	1.90 E6 psi
v-12	0.25	0.25
G-12	.95 E6 psi	.87 E6 psi
ε 11-tension	.00677 in/in	.00542 in/in
ε 22-tension	.00420 in/in	.00340 in/in
ε 11-compression	.01300 in/in	.00542 in/in
ε 22-compression	.01125 in/in	.00956 in/in
ε 12-shear	.01026 in/in	.00923 in/in
α 11	1.05 ppm/F	same
α 22	16.5 ppm/F	same

Properties determined by Micro-Mechanics analysis. To be verified by test.

High Stiffness Hy-Bor® (B-M55J/RS-42)

PROPERTY	PREDICTED 175 fpi Boron	ACTUAL 167 fpi Boron
Elastic Modulus	**39.6 MSI**	**41.6 MSI**
Tensile Strength	**268 KSI**	**256 KSI**
Shear Strength	**9.7 KSI**	**9.6 KSI**

Historical Compression Strength Testing

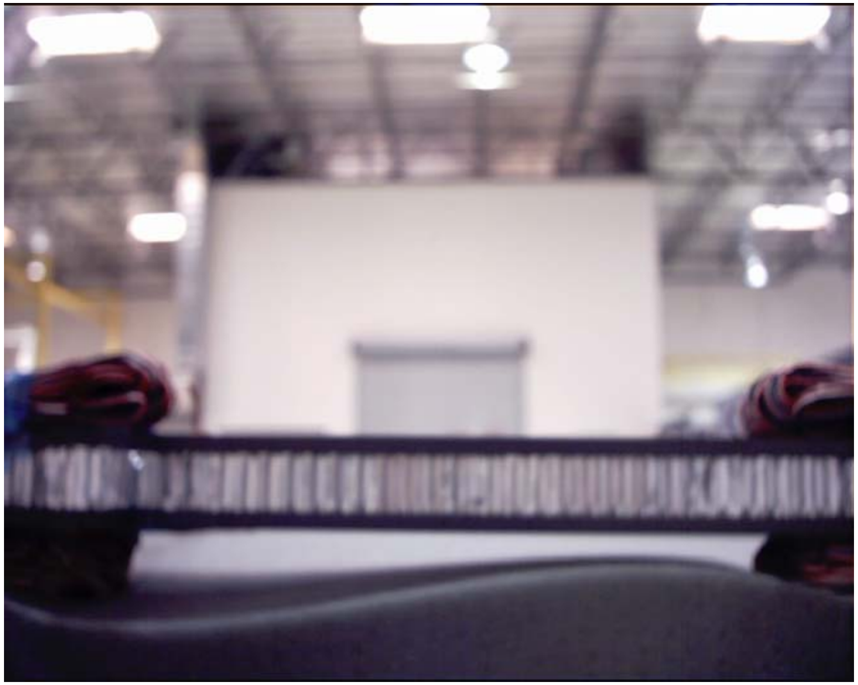
Material	Testing Facility	Test Method	Compression Strength
B/5521	Delsen (8/02)	ASTM D695	380 KSI
Hy-Bor IM-7/3501	Delsen (12/95)	Bell Test Method	414 KSI
Hy-Bor MR40/NCT-301	U of DL (8/96)	IITRI	398 KSI
B/5521	Boeing (3/96)	ASTM D695	427-463 KSI (4 batches)

High Stiffness Hy-Bor® Applications

- Aircraft
  - Flutter Critical Designs, Spar Caps, Stiffeners
- Spacecraft
  - Solar Arrays, Tank Struts, Low CTE Structure
- Engines
  - Fan Blades, Casings, Struts
- Commercial
  - Fishing Rods, Windmill Blades, Racing Yacht Mast

Design Example #2 - Aircraft Wing Skin Stiffener

- Hybrid of High Stiffness Hy-Bor® + M55J
- $[\pm45/0_4/\pm45/90/\pm45/0_4/\pm45]_N$
- HyBor = 0_4 8 plies
- M55J = ±45, 90 9 plies
- Axial Modulus 21 msi
- Shear Modulus 6.3 msi
- Tension Strength 89 ksi
- Compression Strength 98 ksi
- CTE .28 ppm/F



High Thermal Conductivity Hy-Bor® Design Properties

Property	Expected Ave. Test Value	Pseudo-B Basis
E-11	55.4 E6 psi	51.0 E6 psi
E-22	2.20 E6 psi	2.00 E6 psi
v-12	0.25	0.25
G-12	1.5 E6 psi	1.3 E6 psi
ε 11-tension	.00487 in/in	.00389 in/in
ε 22-tension	.00359 in/in	.00305 in/in
ε 11-compression	.00960 in/in	.00389 in/in
ε 22-compression	.00955 in/in	.00811 in/in
ε 12-shear	.00520 in/in	.00425 in/in
α 11	.24 ppm/F	same
α 22	16.5 ppm/F	same
k 11	250 W/m-K	same
k 22	5 W/mK	same

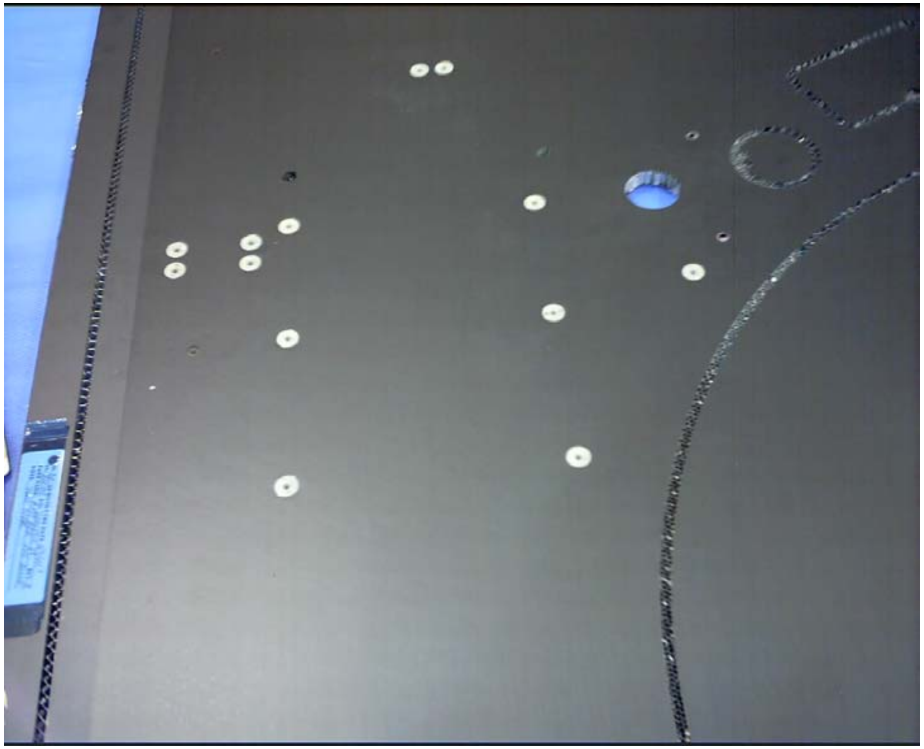
Properties determined by Micro-Mechanics analysis. To be verified by test.

High Thermal Conductivity Hy-Bor® Applications

- Any situation where high strength, high stiffness, low CTE and high thermal conductivity are design drivers
- Optical Benches, Optical Support Structure, Metering Truss
- Transponder Equipment Panels
- Scientific Apparatus, High Energy Test Structure
- Energy Production Equipment

Design Example #3 - Optical Bench

- All High Thermal Conductivity Hy-Bor®
- $[0/45/90/-45]_S$
- Aluminum Honeycomb for facesheet-to-facesheet thermal coupling
- Quasi-Isotropic Characteristics
  - Strength 71 ksi
  - Modulus 18.7 msi
  - CTE .50 ppm/F
  - Conductivity 125 W/m-K



Summary

- Commingling Graphite and Boron fibers into a single lamina provides a synergistic blend of properties unavailable from any other source
- Hy-Bor® offers a broader range of properties than Graphite prepreg to meet challenging requirements
- Your qualified resin system can be employed on all Hy-Bor® products
- Specialty Materials can provide you with data and sample material for seamless integration into your product line