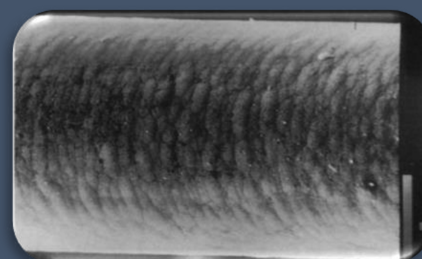
Case Studies and Composite Data

Application and performance data for boron fiber and Hy-Bor® unidirectional prepregs

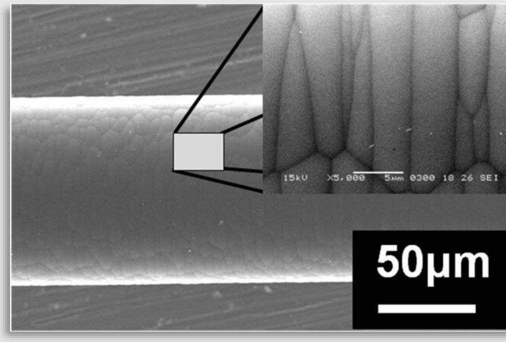
Boron is deposited via chemical vapor deposition onto a substrate within a continuous reactor.

A 4-mil monofilament boron fiber is produced from each reactor and tested.



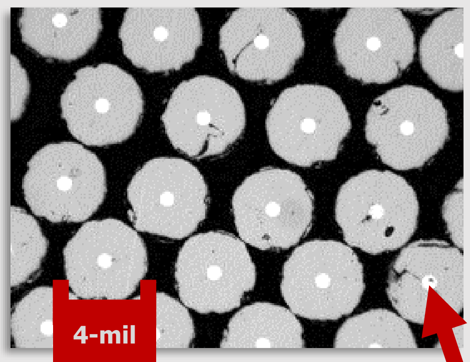
A custom creel holds Boron fiber spools and is commingled into a carbon fiber prepreg to create Hy-Bor®.

6” wide Hy-Bor® unidirectional prepreg tape (a blend of boron fiber and carbon fiber) is sold to customers.



Boron Fiber Monofilament

Tensile Strength: 4,000 MPa (580 ksi)
Tensile Modulus: 428 GPa (62 Msi)
Compression Strength: >6,000 MPa (>900 ksi)
Thermal Expansion: 4.5 ppm/^{o}C (2.5 ppm/^{o}F)



5505 Resin

Boron Fiber Prepreg

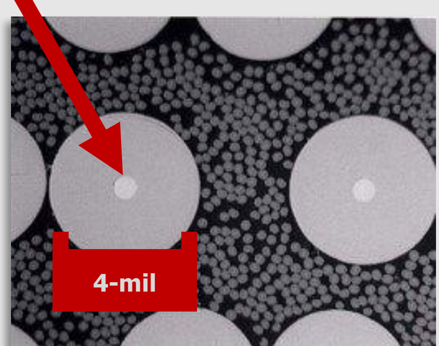
Tensile Strength: 1,655 MPa (240 ksi)
Tensile Modulus: 207 GPa (30 Msi)
Compression Strength: 2,930 MPa (425 ksi)
Fiber Volume: 50%

Tungsten Core
12 micron (0.5 mil)

Hy-Bor® prepreg (commingled with carbon fiber)

(e.g. 208 FPI Boron Fiber / MR-40 / NCT-301)

Tensile Strength: 1,900 MPa (275 ksi)
Tensile Modulus: 240 GPa (35 Msi)
Compression Strength: 2,760 MPa (400 ksi)
Fiber Volume: 58%



208 FPI Boron Fiber / MR40 / NCT301

MQ-1C Gray Eagle
MQ-9 Reaper
Wing Spar Caps
Hy-Bor® Boron+Carbon Fiber/Epoxy

High compression strength and modulus for wing loading and support.

F-15 (All Variants, including -EX)
Tail Structure
Boron/Epoxy

High CAI performance, stiffness, and toughness without galvanic corrosion for horizontal and vertical stabilizers.

SH-60 Seahawk
Rotor Blade and Stabilator
Boron/Epoxy

High compression properties and fatigue properties to increase rotor performance.

When General Atomics was asked to add 100-lb Hellfire missiles the Predator UAV wings, they needed Hy-Bor® in the wing spar caps to increase compression strength and stiffness without changing the wing's outer mold line.

Retrofit Needed

When launched in the mid-1990s, the General Atomics MQ-1 Predator unmanned aerial vehicle (UAV) was used for global reconnaissance missions and operated by the USAF and, secretly, by the CIA. Designed exclusively for observation, the aircraft did not feature weapons capability.

As a reconnaissance aircraft, the Predator could identify targets and relay coordinates to other aircraft or ships equipped with weapon systems. By 2000, however, the future was clear: to ensure enemies didn't have time to escape and evade, the Predator needed a retrofit for ordinance capacity.

The MQ-9 Reaper uses Hy-Bor® to maximize compression properties of the wing spar caps to enable higher wing loading for ordinances.

Design Limitations

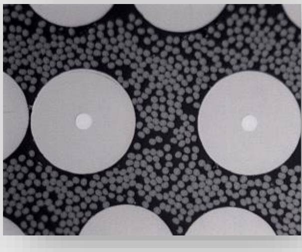
The MQ-1 wing needed more compression strength and stiffness to support the additional weight of missiles and launchers. However, the wing design needed to remain unchanged to accommodate molding and assembly tooling, and the limited volume available within the wing structure prevented designers from adding additional carbon fiber plies.

Hy-Bor® as a Solution

To support the additional wing loads, Hy-Bor® prepregs with both boron and carbon fiber were retrofitted into the wing spar cap design to increase compression strength and stiffness without negatively impacting ply thickness or airfoil shape. The modification enabled the new MQ-1C Predator variant to support four 100-lb Hellfire missiles – two on each wing – and dramatically change modern warfighting. The solution is also used in the MQ-9 Reaper which can support up to 8 Hellfire missiles.

Multifunctional Composites

Adding boron fiber to carbon fiber prepregs creates reinforced composites with increased compression strength and modulus; in high lifting and loading applications, this allows composites engineers options for decreasing ply count, reducing weight, increasing stiffness, and improving CAI performance with only one material.

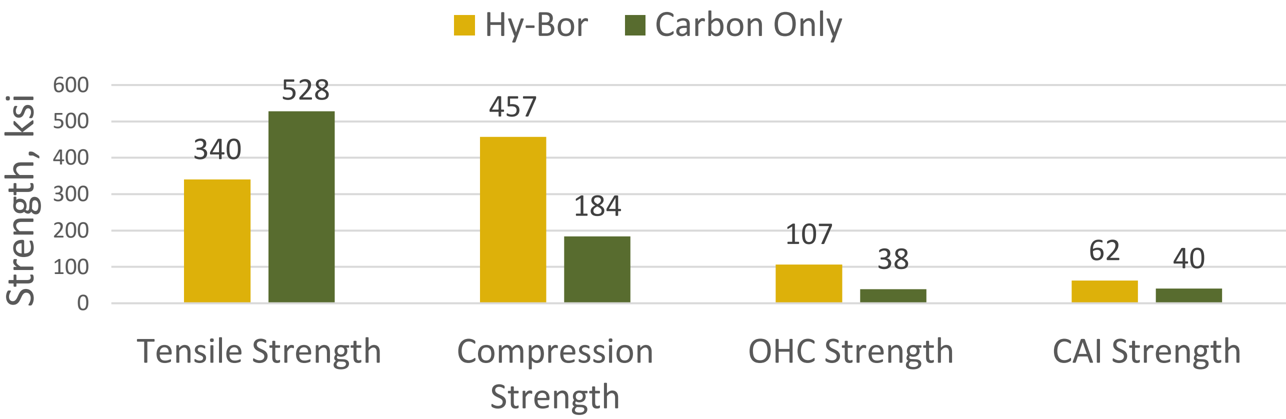


Hy-Bor® (photomic, left) is a prepreg portfolio blending 4-mil boron fiber and carbon fiber. The carbon fiber and resin system types will vary based on customer design need (bottom).

The Evolution of Hy-Bor®

The Hy-Bor® portfolio has two generations that use our 4-mil boron fiber. The first, used on the General Atomics MQ-1C Gray Eagle and MQ-9 Reaper UAS, was developed in the late 1990s and pairs MR40 carbon fiber in NCT301 epoxy resin. ***Gen 2 Hy-Bor®*** emerged in 2018 as an ongoing partnership with Toray Advanced Composites allowing customers options for advanced carbon fiber and resin systems combinations (see below).

Hy-Bor® (208 FPI/T1100/TC380) vs Carbon Only (T1100/TC380)



<u>Hy-Bor® enables:</u>

- Increase in compression properties
- Increase in flexural properties
- Improved damping behavior
- Mass reduction by decreasing ply count
- Improvement in Compression After Impact (CAI) strength
- Prevention of microbuckling and kink-band formation of carbon fiber

Hy-Bor® can be produced with many types of carbon fiber and resin systems based on your performance needs.

TORAYCA® Carbon Fiber

Standard Modulus
T700, T300

Intermediate Modulus
T800, T1100

High Modulus
M40X, M46J, M55J

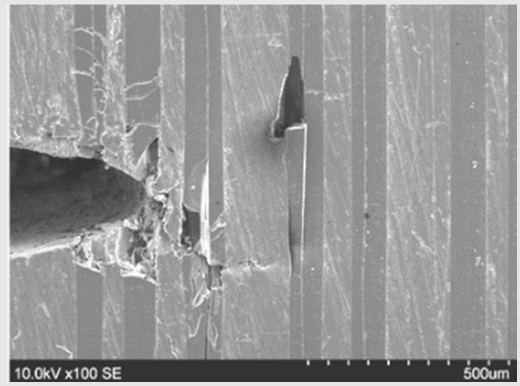
Toray Resin Systems

Toughened Epoxies (TC250, TC275-1 TC350-1, TC380)
Cyanate Esters (RS-3C, TC420, TC410)
Bismaleimides (RS-8HT)
Polyimides (RS-51)

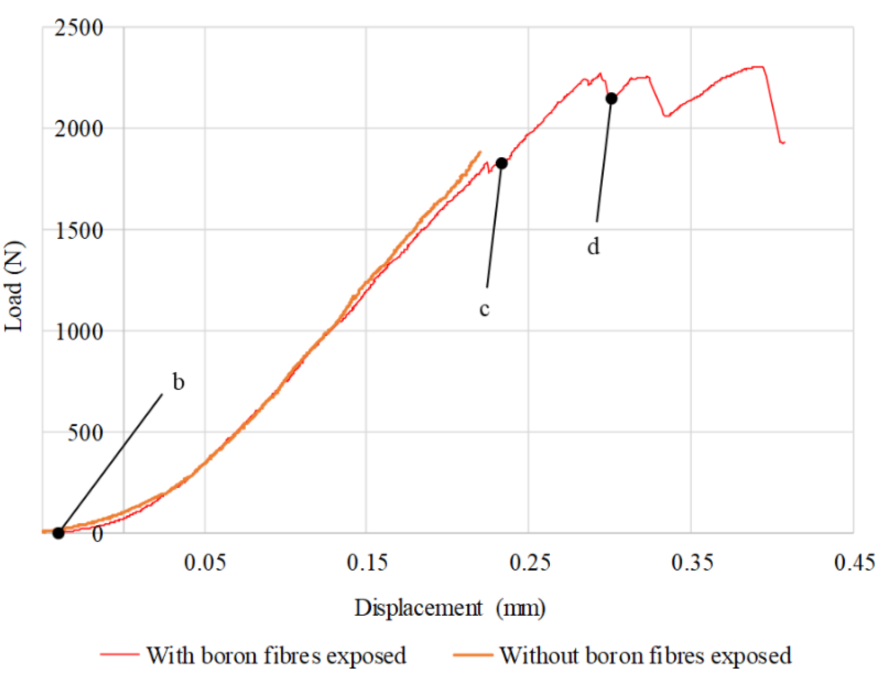
Boron fiber arrests both in-plane and out-of-plane kinkband formation to improve compression properties and mitigate microbuckling risk and protect carbon fiber from deformation.

Mitigating compression failure mechanisms

Kinkband initiation and microbuckling of delaminated plies are common compression after impact (CAI) failure mechanisms, with composite failure under compression dominated by in-plane and out-of-lane kinking due to local shear effects. Adding boron fiber to carbon fiber reinforced plastics (CFRP) improves compression performance and helps stop kinkband damage from propagating.



Hy-Bor® 152 FPI after compression test demonstrating how kinkband initiated and subsequently arrested at the boron fiber interface.



Load versus Displacement
(b) Initiation of kinkband,
(c) Progressive damage of kinkband,
(d) Carbon/Boron interface splitting

Katafiasz, et al. Compressive Failure of Boron-Carbon Fibre Hybrid Composites: A Detailed Experimental Study. ICCM23.

Bauer
AG5NT Hockey Stick
Hy-Bor®

High compression strength to strategically remove plies and provide opportunity for light-weighting.

LA Golf
Golf Club Shaft
Boron Fiber

Boron fiber is added to the club shaft to improve stiffness and damping performance.

RL Winston Fly Rods
Fishing Fly Rod
Hy-Bor®

Improved stiffness and damage tolerance provide a unique and improved feel for fly fishing.

When Bauer Hockey needed a revolutionary material to help craft their most advanced stick, they used Hy-Bor® which provided an opportunity to reduce weight while improving stick performance.

Maximizing Performance and Weight

Incremental improvements in carbon fiber tensile and compression properties make it difficult for fast-paced sporting goods equipment manufacturers to continue differentiating product offerings based on materials performance without sacrifice.

As Bauer sought a transformational step forward in their next-generation hockey stick, Hy-Bor® enabled their design engineers to both reduce stick mass while improving stick performance, a feat that generated the AG5NT and allowed Bauer to continue leading the premium market category.

Bauer's marketing team built a launch program focused on the unique, revolutionary benefit of boron fiber.

Design Criteria

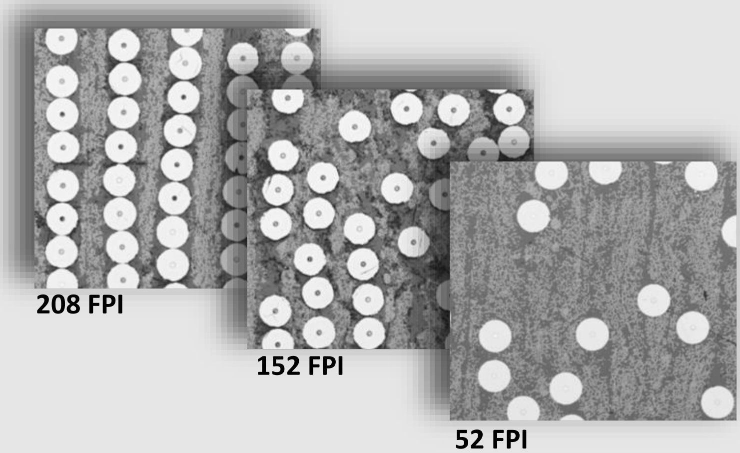
As a consumer product, cost is a primary decision factor when considering adoption of new materials. However, premium users expect a consistent evolution and product performance improvements with new product generations.

For Bauer, utilizing Hy-Bor® provided a cost-effective and significant performance advantage when used for targeted and selective reinforcement of the hockey stick to improve compression and impact strength.

Hy-Bor® as a Solution

With more than 3x improvement in compression strength, design engineers can remove multiple carbon fiber plies from a layup while substituting a boron fiber ply to both improve performance and decrease total part weight. For parts which typically see high compression loading as the primary design or fatigue factor, utilizing prepregs with boron fiber offer a powerful solution for non-incremental performance improvements.

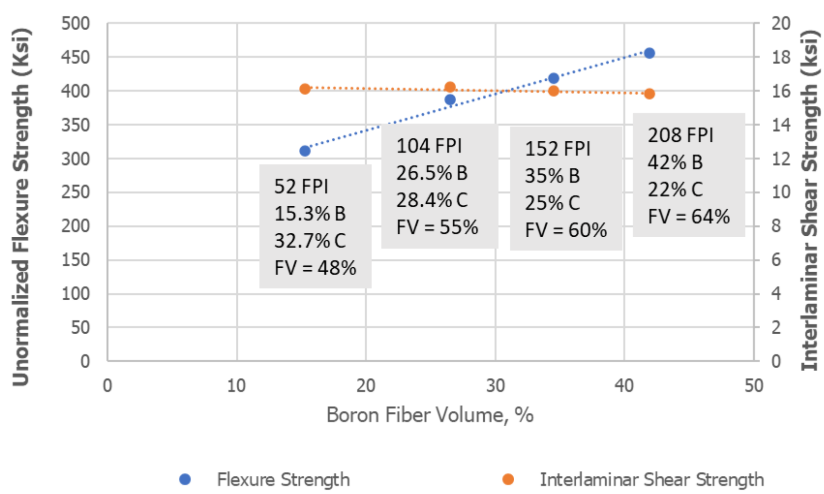
ADJUSTING BORON FPI



Hy-Bor® (photomic, left) is a prepreg portfolio blending 4-mil boron fiber and carbon fiber.

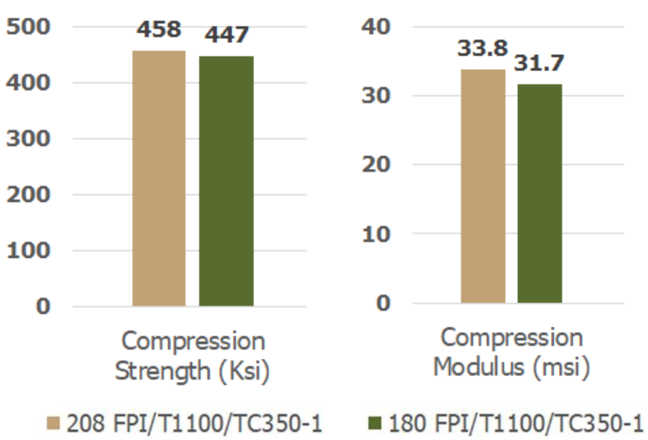
The amount of boron fiber can be tuned for targeted performance need by varying the number of fibers per inch (FPI).

Flexure Strength vs FPI for 4-mil BF/T1100/TC275



Tuning the Hy-Bor® FPI provides a linear flexure strength relationship with a stable ILSS, even at high fiber volume.

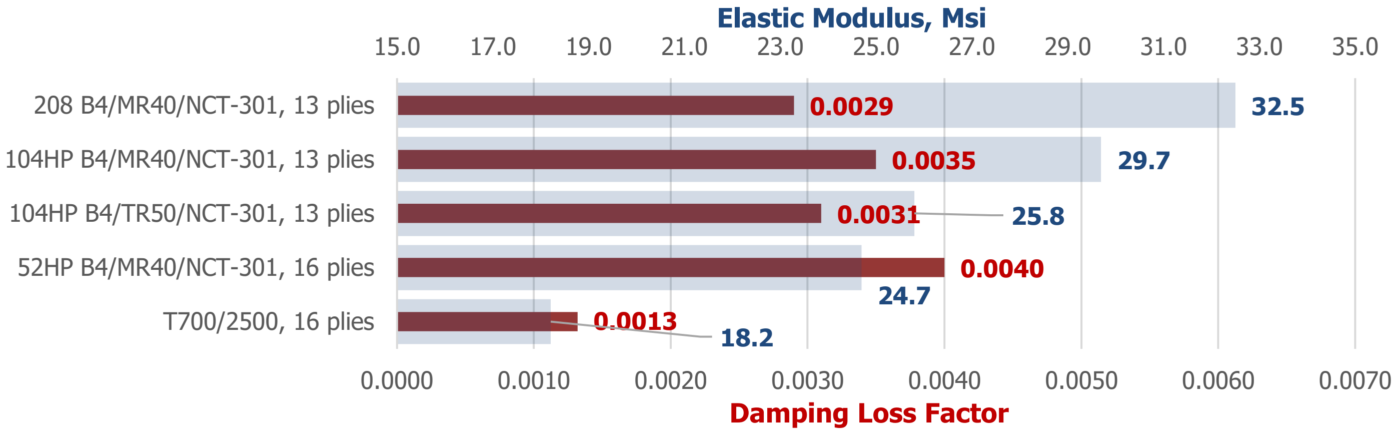
Comparing 208 FPI and 180 FPI Performance



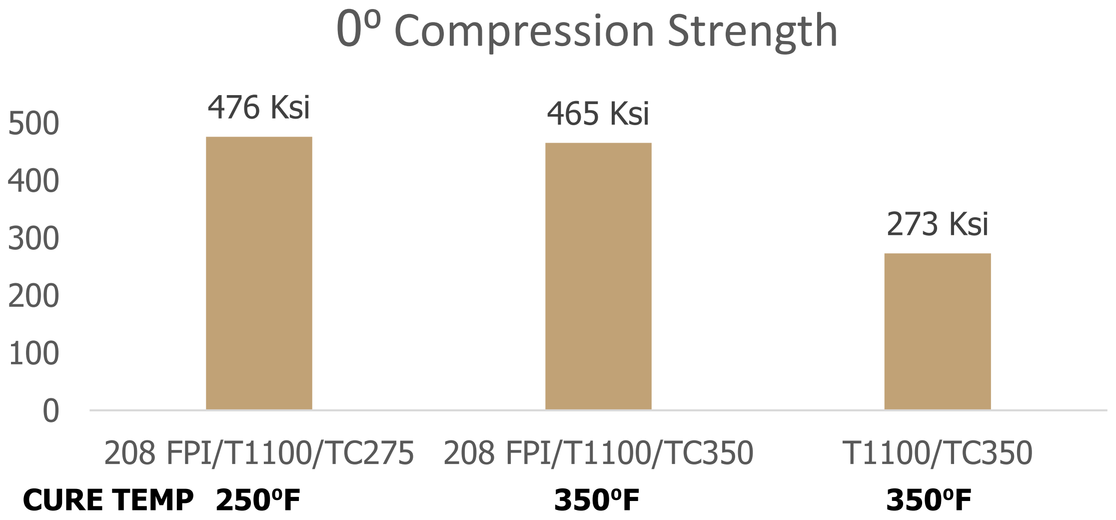
Hy-Bor® continues to demonstrate compression performance improvement at lower FPI counts.

Limited reduction of boron fiber FPI can provide similar performance at reduced weight and cost.

Damping can be tuned based on boron fiber FPI to improve handling, feel, and performance.



Performance is maintained with a variety of resin systems, including 250ºF out-of-autoclave resins.



When L3Harris needed to connect the Integrated Science Instrument Module (ISIM) to the Primary Mirror Backplane of the James Webb Space Telescope, they used boron and carbon fiber composites to maintain alignment and pointing stability down to 20K (-253ºC).

Kinematic Mounts and Composites

Kinematic mounts are used to securely and precisely hold instruments without over-constraint in a desired translational and rotational orientation. Maintaining consistent performance of these mounts is essential throughout program duration; should performance attributes change over a multi-year (or decade) space mission, these mount arms can induce alignment error.

The ISIM connects via kinematic mount to the Primary Mirror Backplane with extreme precision. Composites produced with boron fiber, M55J, and K13C2U are used for both structural performance and zero CTE tuning.

Ensuring Alignment

As the main payload aboard the James Webb Space Telescope (JWST), the ISIM required precision alignment with the mirror assembly to process light from distant galaxies.

Material choice was essential to ensure alignment for the duration of the mission. For high-precision applications, minimizing the coefficient of thermal expansion (CTE) at the end-use temperature was necessary for alignment and positioning.

Structural Support Stability

As weight is critical for satellite and other launch systems, choosing materials with multifunctional attributes is essential. These high modulus boron fiber/carbon fiber composites provide high stiffness, low obscuration, damping and survive high launch loads in a harsh radiation environment in addition to the tailored hoop CTE of zero at 20K, matching Invar while decreasing thermal stress and increasing interlaminar tension strength at the adhesive bond interface.

Satellite Systems

The unique performance of boron fiber (+CTE) and carbon fiber (-CTE) enable exquisite thermal stability in kinematic mounts, telescope structures and mirrors while maintaining the expected lightweight performance from composites when paired with a resin system with low moisture update (e.g. cyanate siloxanes).

K13C2U PITCH Carbon Fiber
CTE: -1.4 ppm/K

4-mil Boron Fiber
CTE: +4.5 ppm/K

Cyanate Siloxane Resin System

Axial Modulus: **55 Msi (379 GPa)**
Composite CTE[1]: **0.00 +/- 0.54 ppm/K**
Composite CME[2]: **0.0 +/- 3 ppm/%M**

Product	Component	Composite
Maxar WorldView 1	Secondary Mirror Tubes, Star Tracker Tubes	boron-cyanate siloxane
Maxar WorldView 2	Secondary Mirror Tubes, Star Tracker Tubes	boron-cyanate siloxane
Maxar WorldView 3	Secondary Mirror Tubes, Star Tracker Tubes	boron-cyanate siloxane
NASA JWST	Kinematic Mounts	boron-cyanate ester
NASA Nancy Grace Roman Space Telescope	Secondary Mirror Tubes/Actuator Structure	boron-cyanate siloxane

High stiffness structures with tailored CTE profiles and extremely low CME

Using multifunctional composite materials for space applications is essential to manage weight. Axial dimensional stability is required for kinematic mounts and tube structures to ensure alignment of mirror and instrument systems maintain tight tolerances.

Boron fiber will be used in the Forward Optics Assembly secondary mirror tubes aboard the Nancy Grace Roman Space Telescope (below).

Photo: NASA

[1] Coefficient of thermal expansion, axial
[2] Coefficient of moisture expansion, axial

Boron/K13C Hybrid

NASA/Chris Gunn

A combination of 4-mil boron fiber and Pitch carbon fiber (photomic, left) off the 0^{o} axis delivers structural support and near-zero CTE for space and satellite applications.

Boron fiber addition allowed **CTE tailoring to match metallic fittings** and provide the **highest axial modulus achievable in a zero CTE strut**. The boron fiber also prevents premature carbon fiber compression failure.

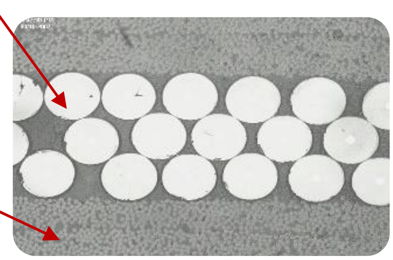
Boron/Cyanate Ester Laminate

Secondary Mirror Support and Star Tracker Tubes
Boron Fiber with K13C2U provide the highest stiffness and best-in-class CTE for mirror assemblies.

Compression strength and near-zero CTE provide tuned performance for optical and star tracker assemblies to maintain focus throughout the spacecraft's life.

Secondary Mirror Support Tubes (SMST)

Boron Fiber



UHM Carbon Fiber (off-axis)

Expert Services

The Hy-Bor® prepreg portfolio is vast and customizable depending on customers' desired composite performance attributes, such as composite strength, modulus, compression after impact, and damping behavior.

Our Expert Services team is excited to work with you to help identify and deliver optimized performance and functionality.

Design and application support:
Qualification support
Engineering assessment
Design guidance
FEM property cards
Micromechanics modeling
Design properties
Layup guidance
Material and process support

Sample support:
Recommendations
Handling assistance
Sample cutting on die press
Cured panels
Autoclave curing
Composite testing
Density measurement

End use analysis:
ATR-FTIR
Mechanical testing
SEM-EDAX
microscopy
Photomicroscopy

Equipment

Tensile Testing

Compression Testing

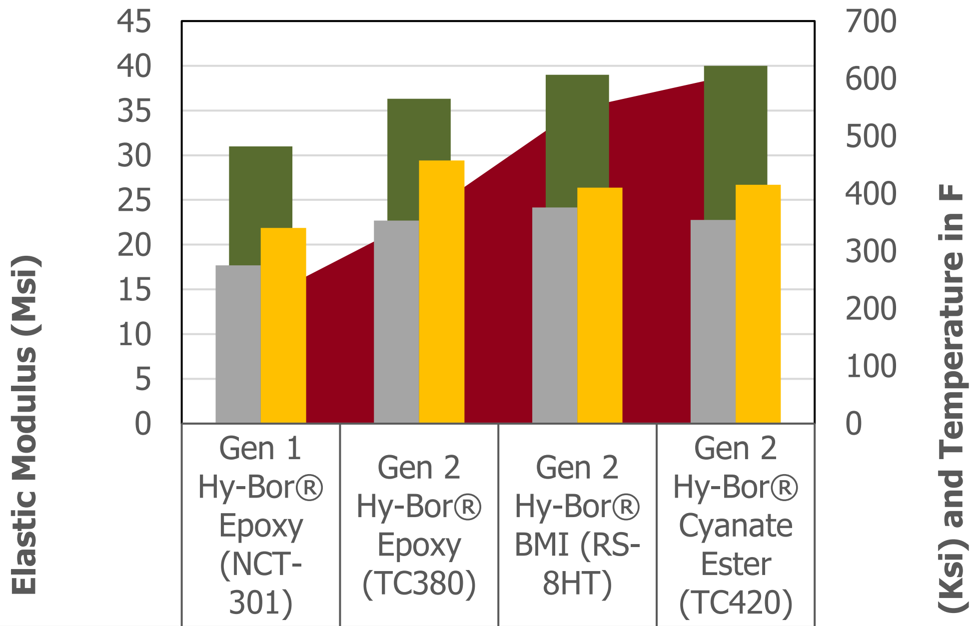
SEM-EDAX

Photomicroscopy

Die Cutting

Autoclave

ATR-FTIR



	Gen 1 Hy-Bor® Epoxy (NCT-301)	Gen 2 Hy-Bor® Epoxy (TC380)	Gen 2 Hy-Bor® BMI (RS-8HT)	Gen 2 Hy-Bor® Cyanate Ester (TC420)
Max. Temperature (F)	215	357	547	608
Elastic Modulus (Msi)	31	36.3	39	40
Tensile Strength (ksi)	275	353	376	354
Compression Strength (Ksi)	340	458	410	415

About Us

Specialty Materials produces boron fibers, silicon carbide fibers, and prepregs in Lowell, Massachusetts. We are a woman-owned small business certified by the Small Business Administration.

Specialty Materials
1449 Middlesex Street
Lowell, MA 01851-1111

Call Stephanie @
+1 978-322-1956
specmaterials.com

Specialty Materials