Toho Tenax America, Inc.
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FEIPLAR BRAZIL

"Pultrusion and Wind Energy"

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Wind Energy Market

- **Market Needs**
  - Increasing Blade Lengths
  - Retrofits
- **Raw Materials**
  - E-glass
  - S-glass
  - Carbon
- **Pultrusion in Wind Blades**
  - Benefits
  - Geometry
  - Surface Treatments
- **Logistics**
- **Conclusion**

Wind Energy Market

- **Increasing Blade Lengths**
  - Market is looking to alternate methods and materials such as carbon fiber in order to minimize weight- 20-30% reduction from glass systems
  - Reduce profile thickness for better aerodynamic efficiency
  - Retrofitting previous tower/rotor designs- longer blades need to maintain similar weight
  - Weight reduction of the rotating mass allows tower, hubs, bearings and pitch systems to be reduced in weight
- **Offshore Turbines**
  - Exceptional size capability (potential 75-100m+ blade length) due to advantages in shipping, assembly, and reduced regulatory/environmental restrictions
  - Net weight reduction and operational efficiency will be significant

Raw Material Options for Pultruded Blade Components

- **E-Glass**
  - Low cost
  - Relatively low fiber stiffness- ~70 Gpa
  - Density 2.5g/cc
- **S-Glass**
  - Higher cost than E-glass
  - Variants available with improved stiffness over E-glass- ~90 GPa
- **Carbon Fiber**
  - Fiber per-kg cost higher than glass, though reduced required volume and weight consumed due to superior fiber properties offset this to a degree
  - Density of carbon fiber- 1.8g/cc
  - Exceptional stiffness of 240+ GPa

Pultrusion in Wind Blades

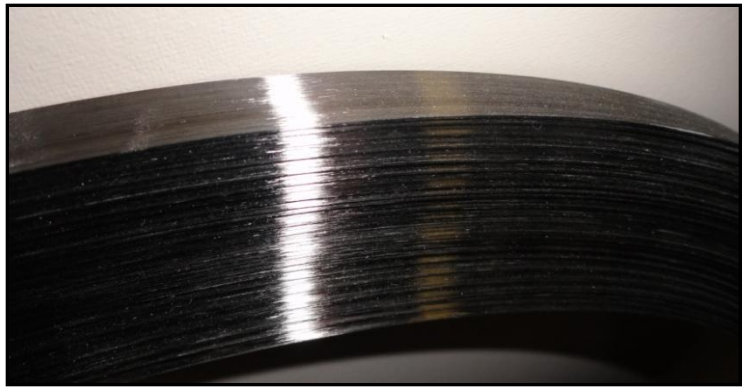
Diversified Structural Composites

- **Pultrusion Benefits**
  - Fiber property maximization
    - Highly aligned fiber, precision part geometry & straightness
    - High volume fractions possible
  - Low-cost, continuous process
  - Exceptional consistency & repeatability
  - Pre-cured, minimizing storage cost and shelf-life issues
  - Reduces exotherm in assembly layup cure process
  - Reduces tendency for “waviness” in the completed spar, increasing the overall translation of fiber properties to the finished product
  - Off-axis materials, cores, peel-ply’s etc can be incorporated into the process in a single step
  - Large profile thickness capable- reducing number of layers, reducing layup time

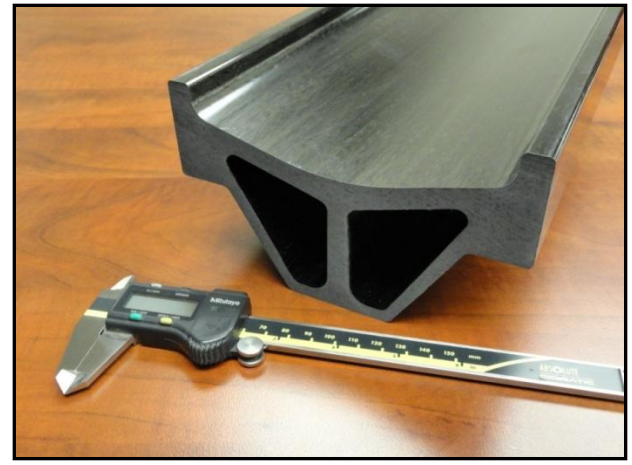
Pultrusion in Wind Blades

Diversified Structural Composites

- **Pultrusion Capabilities**
  - Constant cross-section profiles from simple to complex
  - UD profiles up to 68+% VF possible (optimal at 64-65%)
  - Section thicknesses from 0.25mm (advanced pultrusion) to 50+mm (standard pultrusion)



Spooled Pre-Cured Strip 12.7x1.9mm
(high-speed advanced pultrusion process)

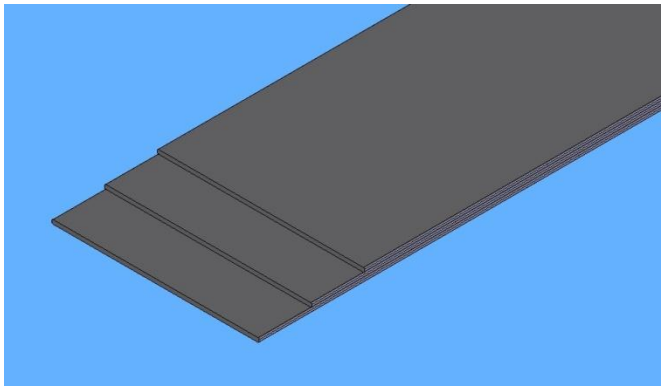


Machine component converted from aluminum to CFRP- weight reduction, increased stiffness
1300 ends of 48k Carbon (max wall thickness 38mm)

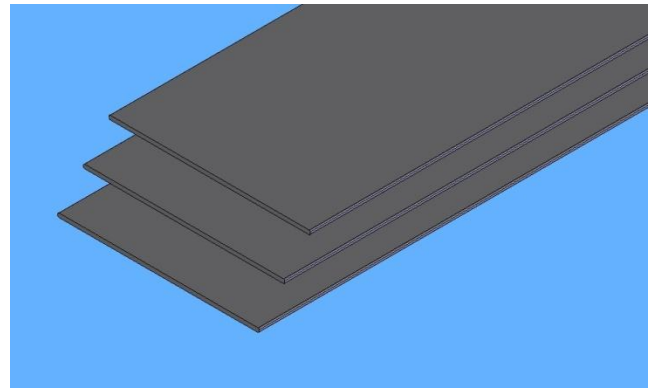
Pultrusion in Wind Blades

Diversified Structural Composites

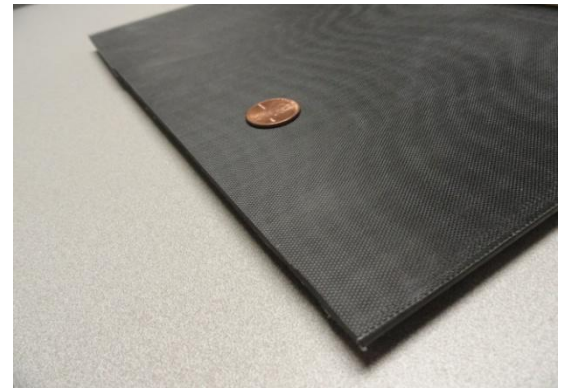
- **Concept Exploration**
  - **<u>Concept #1:</u>** Laminated Pultrusions or Pre-Cured Strips
  - Suited to construct heavy sections such as spar caps using pultrusion capable of shipping on coils



Stepped Laminates



Stepped & Staggered Laminates

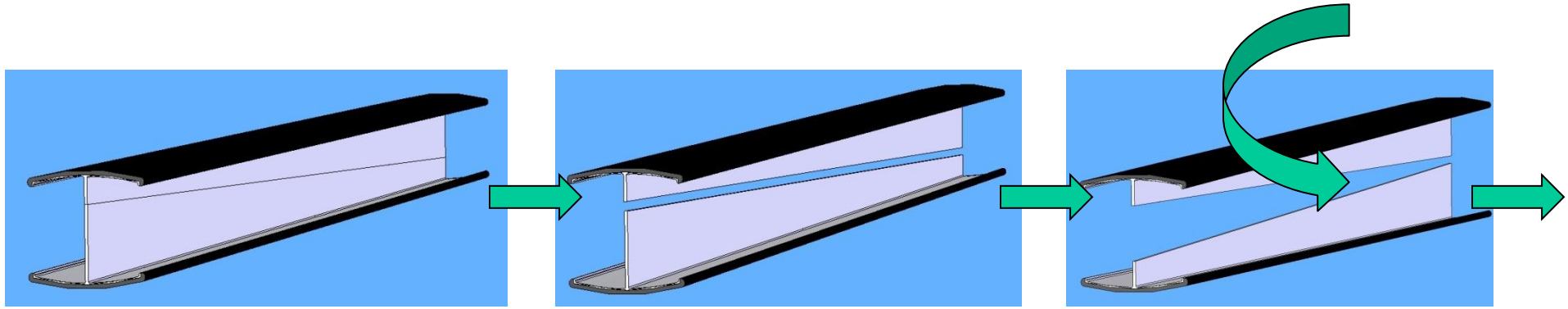


300x3mm Pultrusion with surface treatment to enhance bonding

Pultrusion in Wind Blades

Diversified Structural Composites

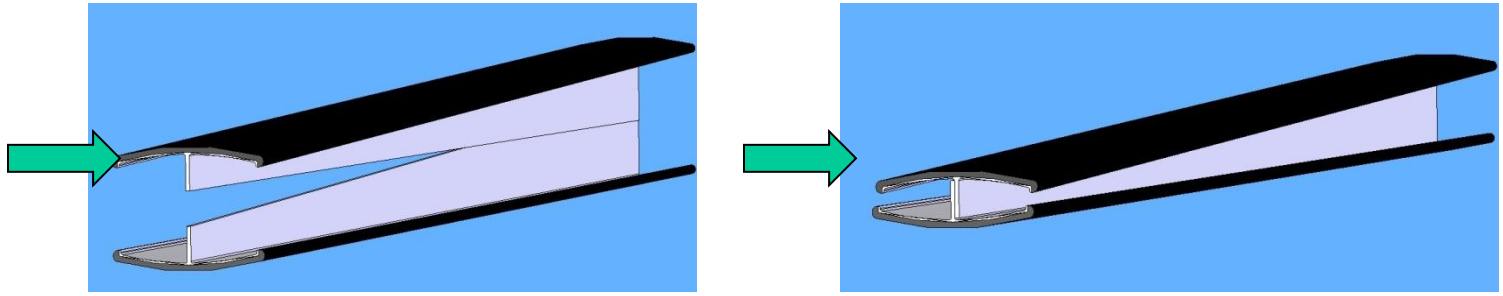
- **Concept #2:** Pultruded Spar "I-Beam" or "I-Beam" components (smaller spar sections or other locations)



Pultrusion of initial shape

Cut as necessary for geometry

Orient parts to direction desired



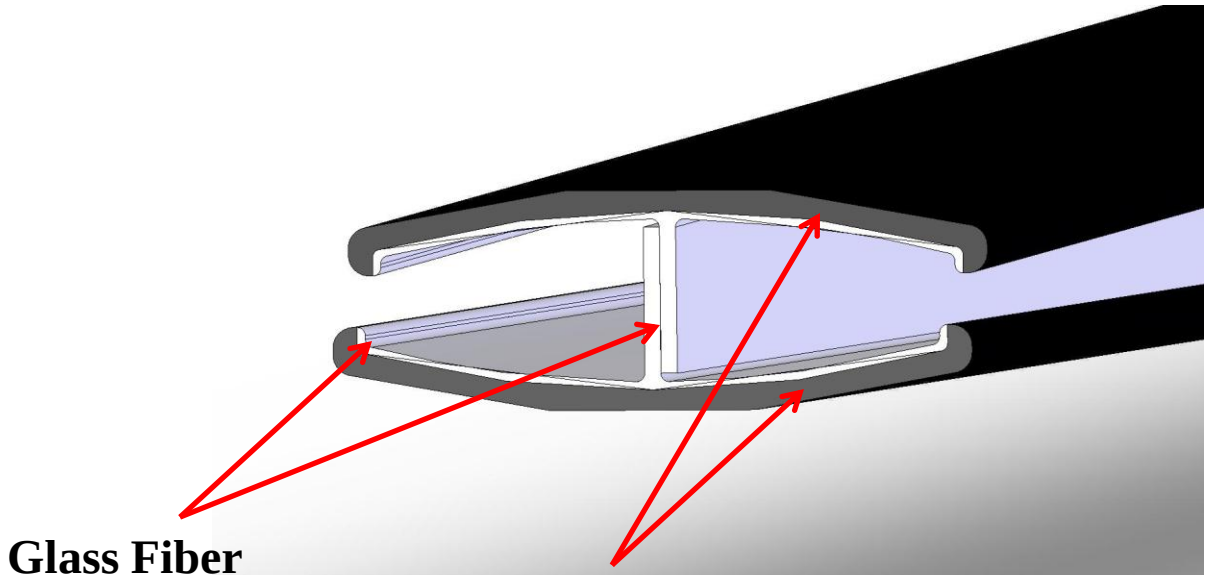
Move parts to final positions

Fit parts to final position, fasten and bond to form new tapered beam

Pultrusion in Wind Blades

Diversified Structural Composites

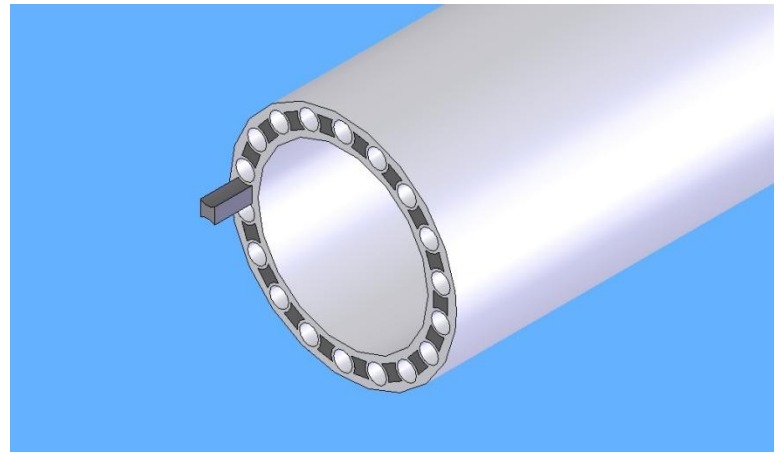
- **<u>Concept #3:</u>** "Hybrid" Pultrusion Option
  - Carbon fiber can be utilized where it is most effective
  - Lower cost glass can be used in less critical locations



Pultrusion in Wind Blades

Diversified Structural Composites

- **Concept #4:** Root & Other Locations
  - Pultruded profiles can be implemented in numerous positions of a wind blade, providing the advantages of pultrusion where most fitting
    - Maximizing fiber utilization
    - Stable geometry
    - Ability to create hollow sections (round square, oval, rectangular, custom hollow shapes to fill large volume areas)

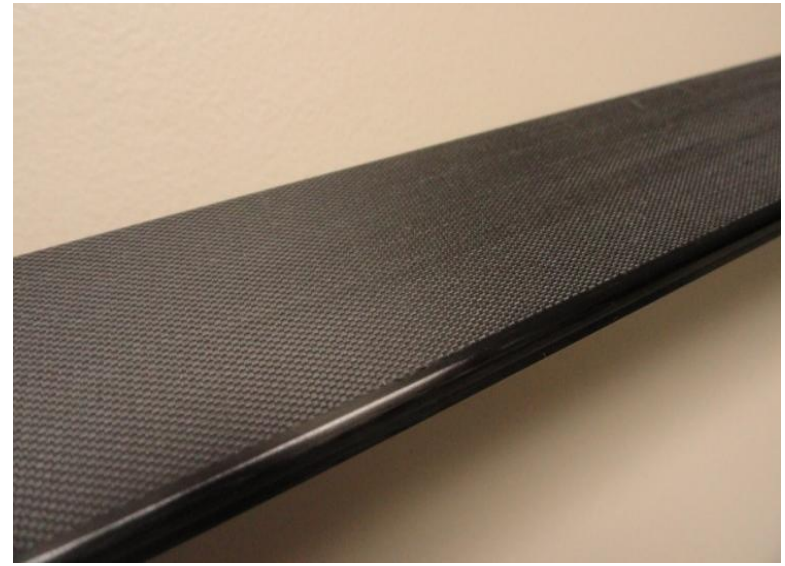


Potential usage as a tensile/compression member at the Root, or as a geometric locator or filler

Pultrusion in Wind Energy

Diversified Structural Composites

- **Pultrusion Surface Prep**
  - Peel Ply- applied at the pultrusion process before cure
    - Provides roughened surface for improved bonding
    - Removed at point of assembly, maintains cleanliness and active bonding sites
  - Mechanical Sanding or Sand Blasting- in line with the pultrusion process or as a post-process



Logistics

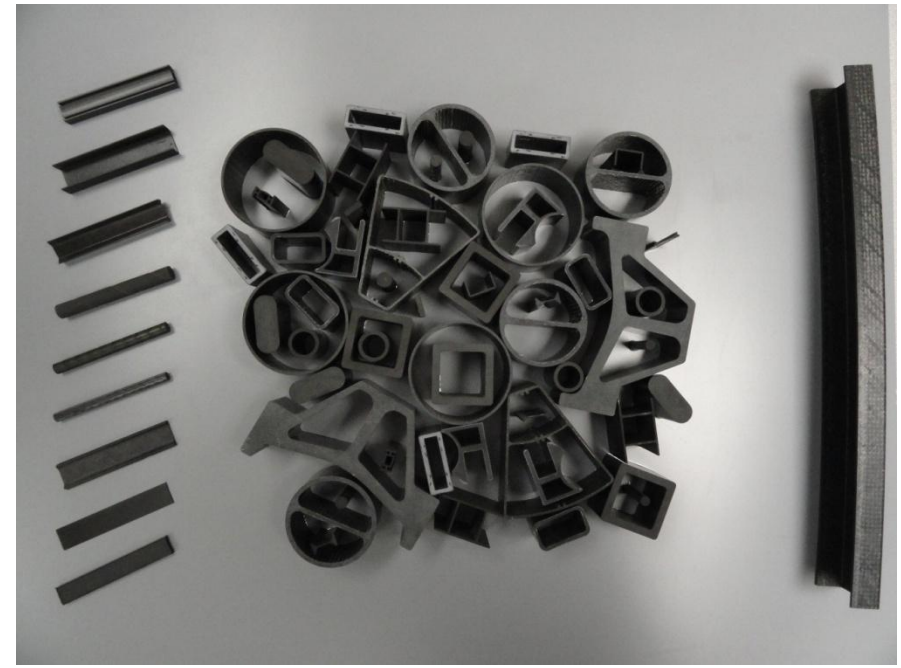
- **Continuous Coils**
  - Long lengths can be shipped efficiently
  - Dispensing system at point-of-use for length flexibility, and reduced scrap from cut drops
  - Large profile thickness capable- reducing number of layers, reducing layup time (typical coiled product ≤6mm thick without special shipping)

Logistics

- **Pre-Cut Ship Sets**
  - Cutting step eliminated at assembly site
  - Special machining (tapers, mitered cuts) can be offered by pultrusion supplier
  - Potential reduced shipping efficiency (container utilization) offset by payback on final assembly time and cost

Conclusion

- Pultrusion offers distinct advantages in ensuring fiber property utilization is maximized in the finished product
- Pre-cured profiles can be used as a "tool" in laminate construction to maintain predictable fiber placement and alignment
- The quest for ever larger blades make the use of pultrusion an attractive material to assemble large laminates



Questions ???