Panel Session 6 – “Manufacturing”

*Presented to Attendees of:*
University of Massachusetts Lowell

*Wind Energy Research Workshop*

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Anatomy of a Wind Turbine Blade (near Max Chord)

- Sandwich Shell
- Upper (LP) Spar Cap
- Lower (HP) Spar Cap
- Sandwich Shell
- Sandwhich Shell
- Sandwich Shell
- LE Shear Web
- TE Shear Web
- Sandwich Shell
- Sandwich Shell
- Sandwich Shell
- Sandwich Shell
- Sandwich Shell
- Sandwich Shell
- Trailing Edge
- Sandwich Shell
Blade Manufacturing – “What’s it Take?”

SPACE! - Physical Plant

- Factory Space
- Bridge Cranes/Heavy Lifting
- Significant Consideration of Layout/Process Flow
  - Large Molding/Assembly Operations
  - Small Parts
  - Finishing Operations
  - Material Flow thru Plant

Infrastructure

- Systems
  - Resin Storage/Plumbing for delivery
  - Vacuum Lines/Compressed Air
  - Cure Ovens (if required)
  - Finishing Operations/Dust Control
  - Root Drill/Trim
  - Automation Equipment (if used)

- Tooling/Assembly Fixtures
  - Heated vs. Ambient Cure Tools
  - Skin Molds
  - Shear Webs
  - Small Parts
    - Spar Caps, Root Preforms, balance boxes, etc.
Blade Production Requires PEOPLE

› Materials & Materials Engineering
› Structural Design
› Process/Tool Engineering
› Quality Systems/Engineering
› Sensor Development and Technologies to Positively Impact R&M
  – NDI
  – Health Monitoring
  – Control/Load Mitigation
› Transportation/Logistics
Automation for Blade Production – What’s Coming up for AMII
Automation of Blade Fabrication

- Turbine blade manufacturing consists of a labor intensive set of highly distributed manual operations.
- From pattern cutting for material kits to layup to infusion and demolding of a multiplicity of sub assemblies over a vast area and distance, automation is a challenging and expensive endeavor.
- Return on CAPEX is rapid for structures with cost of finished goods from $200 to $700/lb as opposed to $5.00 to $10.00/lb required for the energy markets.

- Automation of aerospace composite manufacturing is virtually routine with hundreds of prepreg tape machines operating across the globe.
Automation is at work in blade factories today:

- Use of x-y ply cutting for material kits, automated ply nesting software, pick and place automation.
- Limited use of material transfer systems into open molds, primarily with semi-automated or driven A-frames and gantries.
- Automated trimming and limited machine assisted surface grinding/finishing.
- Automated root trim, machine, and drill for T-Bolt installation.
- Robotic application of coatings.
Automation in Blade Finishing

› Blade molding operations account for less than 50% of total labor content.

› Finishing operations offer a brilliant opportunity for cost-effective CAPEX spending.

› Compliant grinding/finishing, scuff sanding and coating applications will become ubiquitous in the near term.

› Advances in vision systems and on the floor computational power coupled with the availability of low cost multi-axis robots makes automation of many tedious processes possible.
Automation of Blade Components a First Step

- Spar Cap components are the logical first step with root preform parts a natural extension of capability.
  - Simple Geometry.
  - Uni-directional materials for lowest possible cost of prepreg/tow prep materials.
  - “Steerable” for curvilinear spar caps in swept blade design.
  - Performance critical.

- Assurance by major machine manufacturers that layup rates approaching 1,200 kg/hr in straight run spar caps possible.
The jury is still out regarding the shape and form of future blade automation, but it is sure to come.

Longer blades, use of carbon fiber and the need to ensure lower partial safety factors for manufacturing and material variance will expedite the drive for more automation in blade layup.

Whether future automation is in the form of fiber/tow placement, prepreg or dry fabric robotic application, there are designs waiting in the wings.

TPI is intimately involved in this process and helping to shape this future.
Novel Materials for Spar Cap Assembly

› Pre-manufactured axial elements are bonded to a carrier to create a “ply-like” material for infusion.

› Used as an interleaving element in a stack of UD broad goods or as homogeneous laminating material in Spar Caps
  – Extremely high Fiber Volume Fraction
  – Eliminates potential for strength reducing waves/wrinkles

› Rapid infusion
  – Both as a “flow media”
  – And stand-alone as a homogeneous material.

In partnership with
…with Rather Amazing Properties

- Ultimate compressive strains of 2%.
- Ultimate tensile strains approaching theoretical limit of glass fiber.
- 45% higher design values for strength and 25% higher for modulus.
- Extremely low variance in results.

<table>
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<th>Test Description</th>
<th>MeanUlt Strenth (MPa)</th>
<th>Std Dev %</th>
<th>LCL (MPa)</th>
<th>Mean Max Strain (mm x 10^-6)</th>
<th>Mean Modulus (MPa)</th>
<th>Std Dev %</th>
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<td>Axial Tension (UD NCF)</td>
<td>919</td>
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<td>19,831</td>
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First Up: 9m Blade Manufacture

- This past month TPI and NEPTCO built the first Composite Rod Spar Cap Blade.
- 9m 100kW NPS-100 blade.
- To be tested as part of AMII program.
- Ultimate benefit will be in large scale glass/carbon applications for highest translation of material properties.
In the Works.....

› TPI and NEPTCO has built a full-scale (of limited length) Hybrid Spar Cap.
› Layup was 30% volume fraction Rod Packs and 70% 970gsm UD Fabric.
› Fabrication to develop infusion and cure cycle time... SHORTER and more robust.
› NO MORE WAVES.