Vacuum Infusion for Wind Blade Manufacturing
Tom DeMint, Dave Hartman, Georg Adolfs

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Abstract

- Vacuum infusion (VIP) is currently used by many blade manufacturers
  - 70% glass fiber/resin weight fractions

- Aspects of the VIP process can bring certain fabrication challenges unique to blades,
  - Glass fabric placement
  - Fabric and fiber orientation control
  - Joint fabrication

- Let’s examine some of those challenges
  - Enhance blade structural reliability
What is Vacuum Infusion Processing (VIP)?

D'Arcy's Law
Why use VIP for Wind Blades?

- Better Mechanical Properties, Lower weight vs. Hand Layup
  - Higher Fiber Content, Strength, Modulus vs. Hand Layup.
  - Typical VIP $W_f > 70\%$ (54\% $V_f$)
  - Typical HLU $W_f < 50\%$ (30\% $V_f$)

- Better reliability
  - Repeatable processing
  - Lower property variation
  - Increases reliability
  - Reduced Maintence

- Less resin usage
  - Resin prices are increasing
D’Arcy’s Law of Porous Flow

\[ \Delta P \approx \frac{\text{Resin Flow Rate}}{\text{Resin viscosity} \times \text{flow distance}} \]

- \( \Delta P \) (Pressure Drop) = 1 atm (sea level)
- Resin viscosity < 150 cp (tool temperature)
- Flow distance: \( \frac{1}{2} - \frac{1}{3} \) chord length

- Reinforcement porosity and permeability influence resin infusion fill rate
Closed Molding Process Flavors

Process and Fabric choice affects part cycle time

- **VIP**
  - Marine Hull and Deck
  - Wind Turbine Blades
  - RV Side Panels
  - Infusion time: 5-180 min.

- **CCBM**
  - Marine Hull and Deck
  - Defense Vehicle
  - Infusion time: 2-90 min.

- **Lite - RTM**
  - Marine Components
  - Auto Components
  - Infusion time: 3-50 min.

- **RTM**
  - Truck Components
  - Auto Components
  - Infusion time: 0.5-50 min.

- **Volume, Tooling Cost**
  - Low
  - 400 parts/year
  - High
CARTM™ (Channel-Assisted RTM)
Vacuum Infusion for Larger Structures
RTM for Small Complex Structures

Fiberglass Boats Length Evolution

Market Share


14' and under 14' to 16'11" 17' to 17'11"
18' to 18'11" 19' to 20'11" 21' and over
Vacuum Infusion Tooling is Simple

- VIP equipment for small parts
- Tooling conversion from Open to Closed Molding

Spray-up Tool

Attach Flange

Vacuum tight

6 inches +
Technical Flange Detail is Very Important for Proper Vacuum Consolidation

- Vacuum Bag
- Peel Ply
- Reinforcement
- Extended Flange for VIP Bag seal
- HLU tool
- Joint must be air tight
- 6 inches

Modifying HLU tooling can be tricky
Vacuum Infusion - Low Capital Investment
Process Comparison Cost Model

Example for a 5 meter length boat, production volume of 2 per day
Improvements in Fabric Design on Resin Flow Rate and Quality
Trends in Fabrics for Resin Infusion

- Woven Architecture
- Knitted Architecture
FlowTex™

Integrated Flow Channels (Path of Resin Transfer)

Integrated Flow Channels (Path of Resin Transfer)

FlowTex infuses 40% faster over the first foot.
Which type of Flow Media applies?

- **Surface medium:**
  - Suitable for small series
  - Weight-critical

- **Pros:**
  - Use of existing tooling
  - Easy for complex parts
  - Light weight, high-fiber volume parts

- **Cons:**
  - Adds installation labor
  - Added cost of disposable flow media and resin
  - Generates waste
Which type of Flow Media applies?

- **Grooved Core:**  
  - **Weight/Stiffness-Critical**

- **Pros:**
  - Fast resin flow
  - No additional flow media required
  - Works for VIP and RTM Lite

- **Cons**
  - Works only for cored laminates
  - Adds 3 to 7 % weight to the part
  - Not inexpensive
Which type of Flow Media applies?

- **Interlaminar**
  - Cost-critical

- **Pros:**
  - Integral to the part
  - Adds thickness at low fiber Wf
  - Works in VIP and RTM Lite

- **Cons**
  - Adds resin weight
Good Conformability of Single Ply
Orientation of Reinforcement

UD

TRI-axial
(with main component)

UD

BI-axial(s)

Quadraxial
(with main components)
Part Size and Complexity Requires Improvements in Materials and Processes

• Reduced Fabric Misalignment with Good Conformability
• Faster and More Consistent Resin Infusion
• Proper Training of Resin Infusion Techniques
• Automated Resin Delivery and Pre-forming of Fabrics
Fiber Alignment in Fabric Design Improves Compression Fatigue
Correct Fabric and Fiber Alignment is Important

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Methods to Enhance Blade Reliability

- Unidirectional Fabrics
  - Knits: Use **Tricot** stitch type, high stitch count
Methods to Enhance Blade Reliability

- **UD Fabrics**
Methods to Enhance Blade Reliability

- Manufacturing Details
  - No fabric bridging
  - Stagger ply drops

- Vacuum Bag pleat
Personnel: VIP Training, Process Discipline

- Biggest issue
  - CHANGE
- Implementation approaches:
  - Key team selection
  - Training
Summary: “Go with the Flow”

- Closed Molding is spreading as cost effective processes that enable the growth of composites

- New types of Fabrics, reinforcements and process aids are emerging to help the Wind Energy market as it grows

- As Wind market grows, biggest challenge may be in finding, training, and retaining skilled VIP labor