Intelligent Manufacturing of Hybrid Carbon-Glass Fiber-Reinforced Composite Wind Turbine Blades

Dr. Bob Minaie
Department of Mechanical Engineering
Wichita State University
bob.minaie@wichita.edu
(316) 978-5613

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Resin Transfer Molding (RTM)

- Fiber reinforcement is placed in the mold.
- The mold is closed and clamped.
- Resin is injected into the mold cavity under pressure.
- The resin cures.
- The part is removed from the mold.

The driving force in RTM is pressure. Therefore, the pressure in the mold cavity will be higher than atmospheric pressure.

In contrast, vacuum assisted methods use vacuum as the motive force, and the pressure in the mold cavity is lower than atmospheric pressure.

Supported by the Department of Energy
DOE DE-FG36-08GO88149
If the pressure in the mold is *higher* than atmospheric pressure, it is... Resin Transfer Molding (RTM)

If the pressure in the mold is *lower* than atmospheric pressure, it is... Vacuum-Assisted RTM (VARTM)
Why Process Modeling?

• Reduce manufacturing costs and time by minimizing trial-and-error procedures during process design.
• Evaluate injection strategies.
• Optimize locations of gates and vents.
• Predict filling issues including dry spots.
• Estimate filling time.
• Predict degree of cure and curing time.
• Predict temperature distribution and heat concentrated areas.
• Process optimization.
Materials

**Resin**
- Polyester resin
- Viscosity for isothermal model: 0.1 Pa.S
- Viscosity for non-isothermal model:

\[
\eta = C_0 \times e^{\left(\frac{C_1}{T}\right)} \times \left(\frac{C_2}{C_2 - \alpha}\right)^{(C_3 + C_4 \alpha)}
\]

**Reinforcement Fibers**
- One Continuous Fiber Mat (CFM) layer on top and one on bottom with each layer being 1 cm thick.
- One layer of the core material (balsa wood) with a thickness of 2 cm.
- One layer of biaxial glass fiber mat with a thickness of 1 cm in sandwich areas and a thickness of 3 cm in other areas.

**Permeability**
Permeability orientation for all the fibers is defined as \(K_1\) in the longitudinal direction of the blade, \(K_2\) in the transverse direction, and \(K_3\) is in the through-thickness direction.
Geometry of the Wind Turbine Blade

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Isothermal Filling
Isothermal Filling

Filling pattern at 363 s

Filling pattern at 1485 s

Dry Spots

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Curing After Isothermal Filling
Degree of Cure

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Curing After Isothermal Filling

Degree of Cure

Degree of cure at 14,840 s
Curing After Isothermal Filling
Temperature Distribution

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Curing After Isothermal Filling
Temperature Distribution

Temperature at 15,240 s

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Non-Isothermal Filling
Temperature Distribution
Non-Isothermal Filling

Filling pattern at 525 s

Temperature at the end of filling

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Curing After Non-Isothermal Filling
Degree of Cure

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Curing After Non-Isothermal Filling

Temperature Distribution

Temperature

Time : 36 s.

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Curing After Non-Isothermal Filling

Degree of cure at 2,268 s

Temperature at 15,228 s

Supported by the Department of Energy
DOE DE-FG36-08GO88149
Summary

- Parameters such as preform permeability and temperature can significantly affect filling pattern and curing during manufacturing of wind turbine blades using vacuum-assisted resin transfer molding process.
- Process modeling could result in cost-effective manufacturing of defect-free wind turbine blades with desired properties while minimizing production engineering iterations.