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

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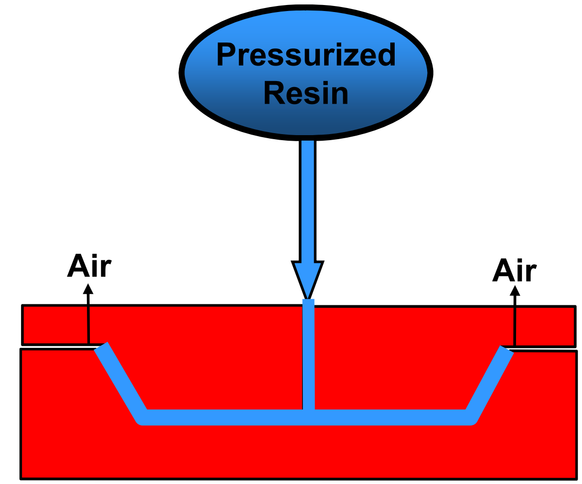
Resin Transfer Molding (RTM)

- 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.



RTM Process

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RTM or VARTM?

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)

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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.

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Materials

SUSTAINABLE ENERGY SOLUTIONS

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.

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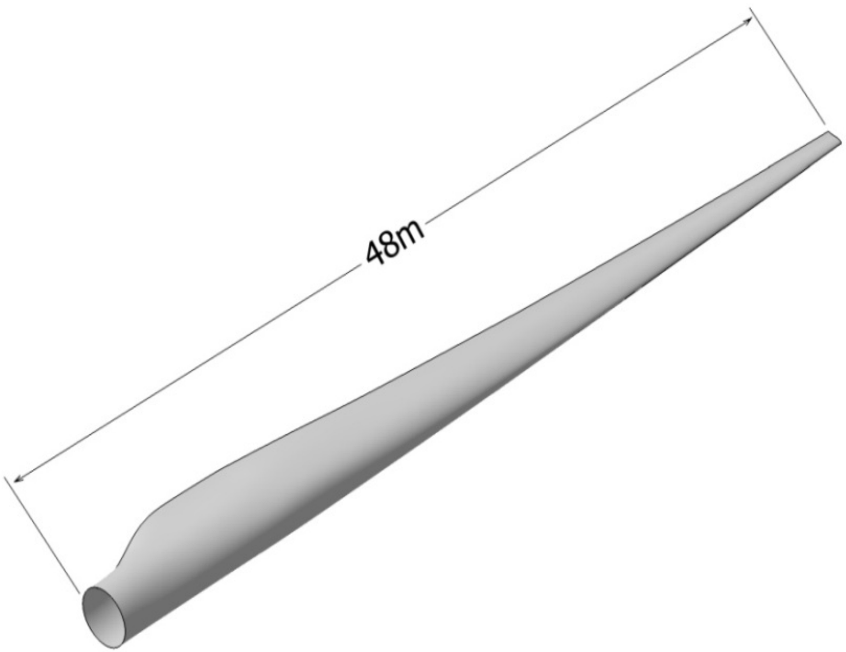
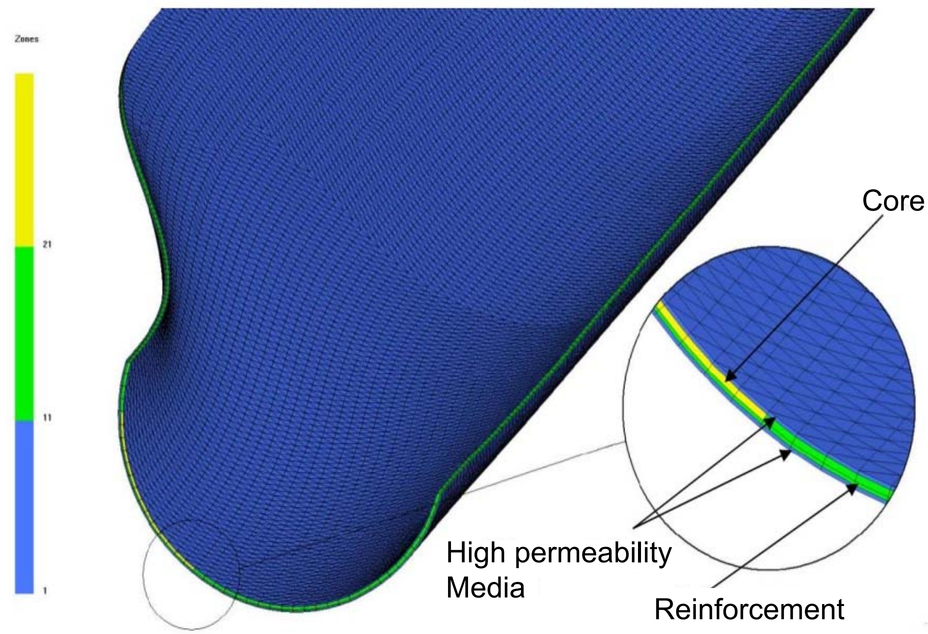
Geometry of the Wind Turbine Blade





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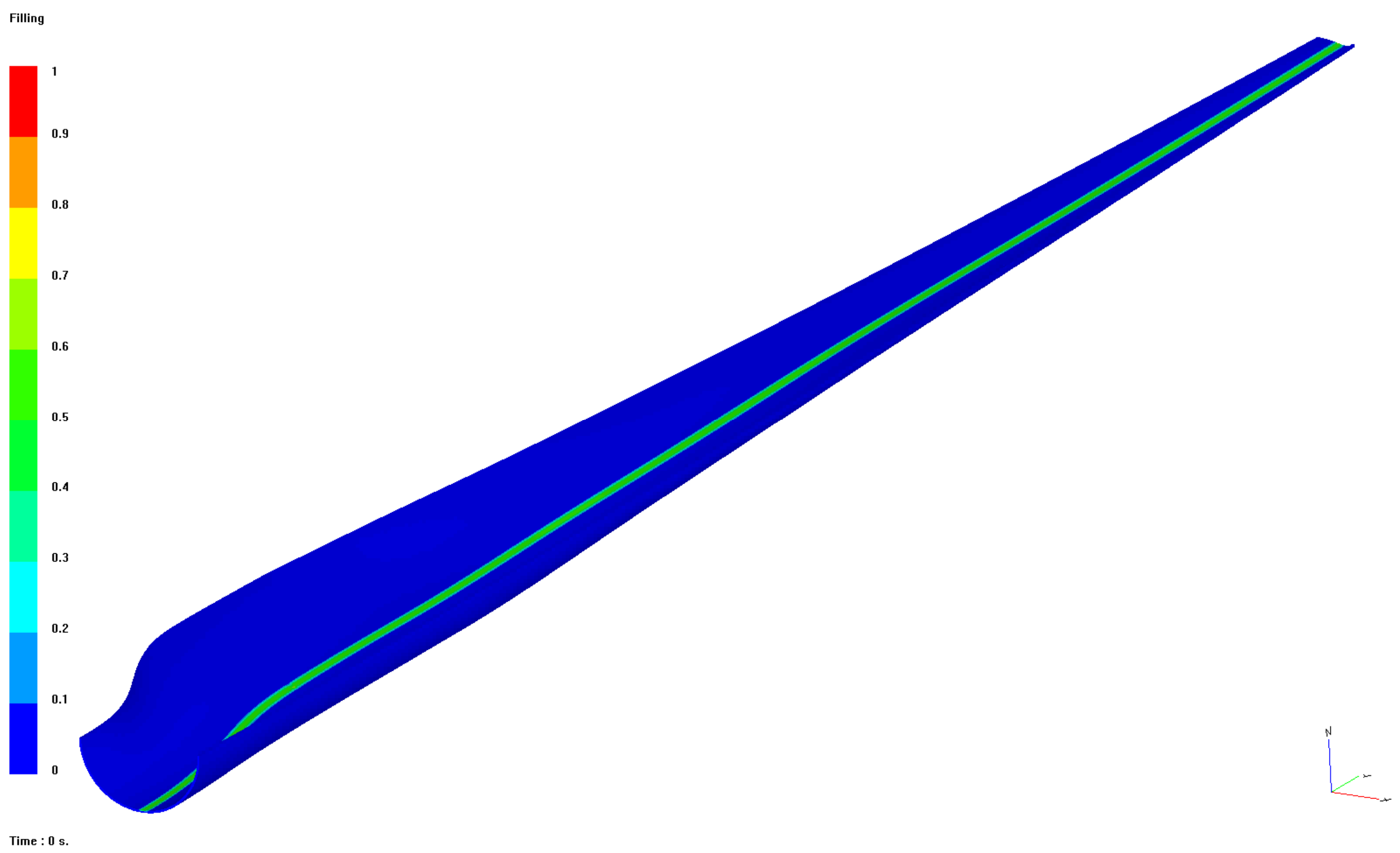
Isothermal Filling



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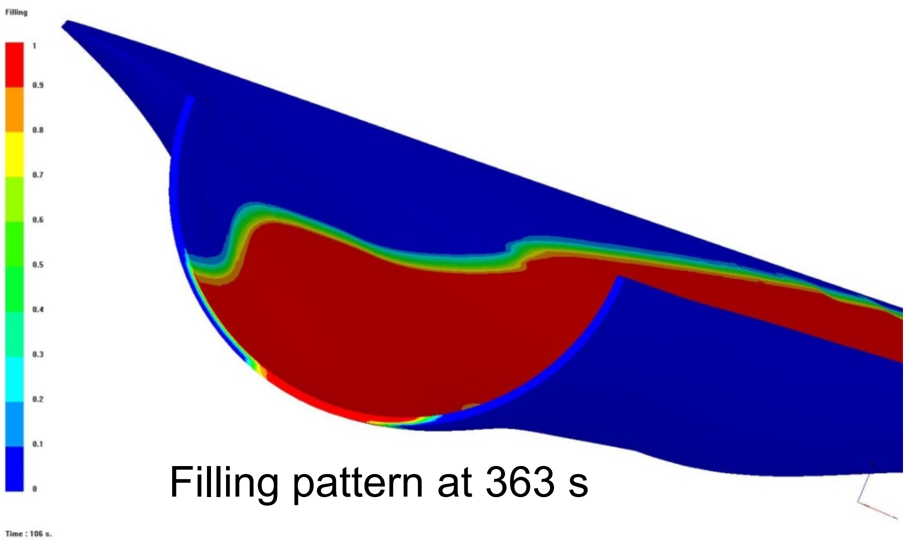
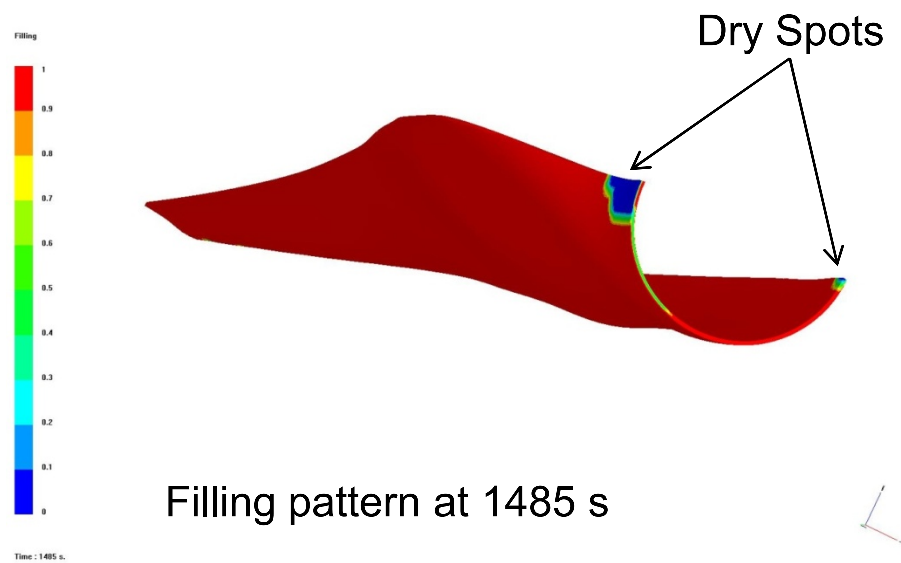
Isothermal Filling



Filling pattern at 363 s



Filling pattern at 1485 s

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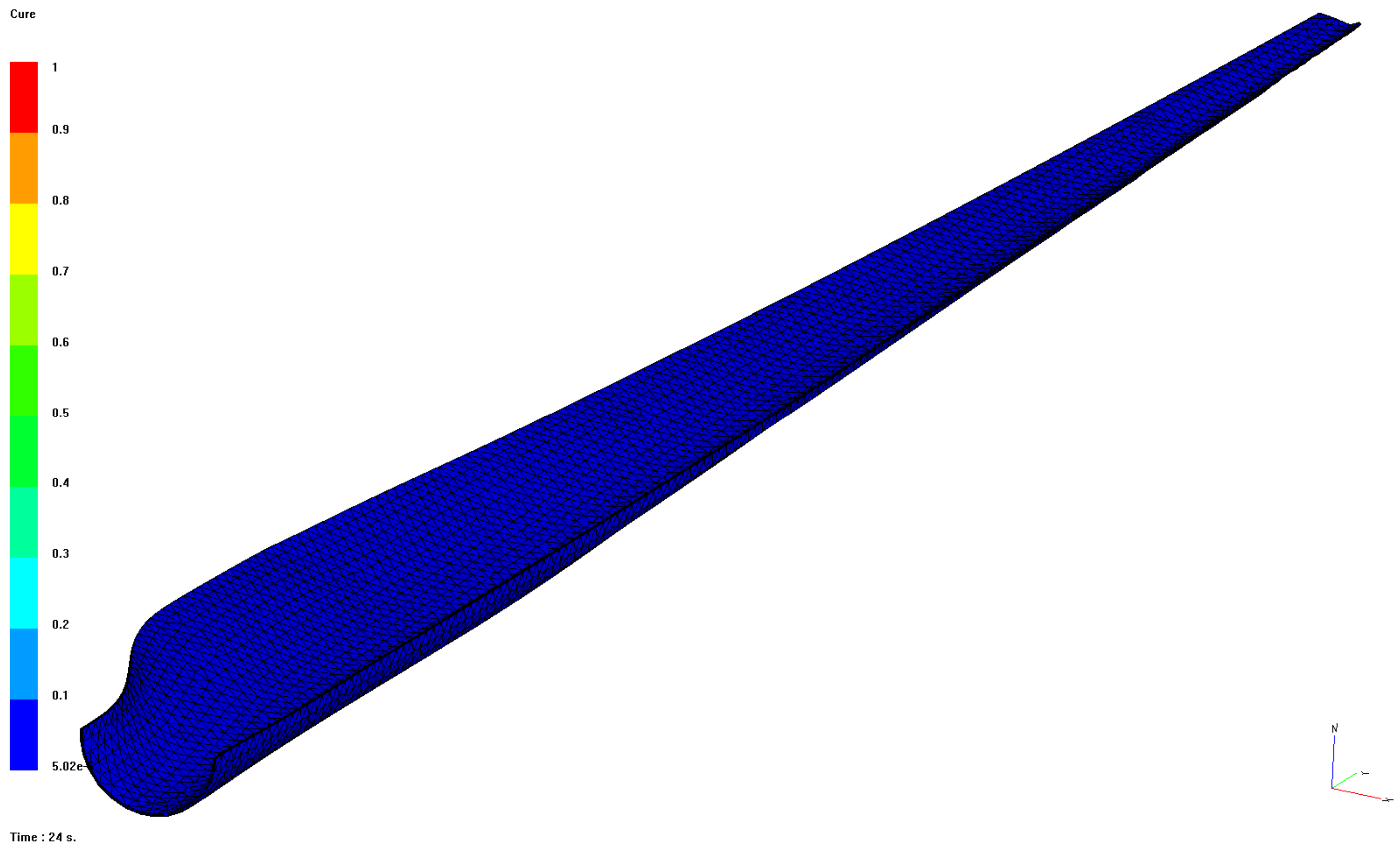
Curing After Isothermal Filling

Degree of Cure



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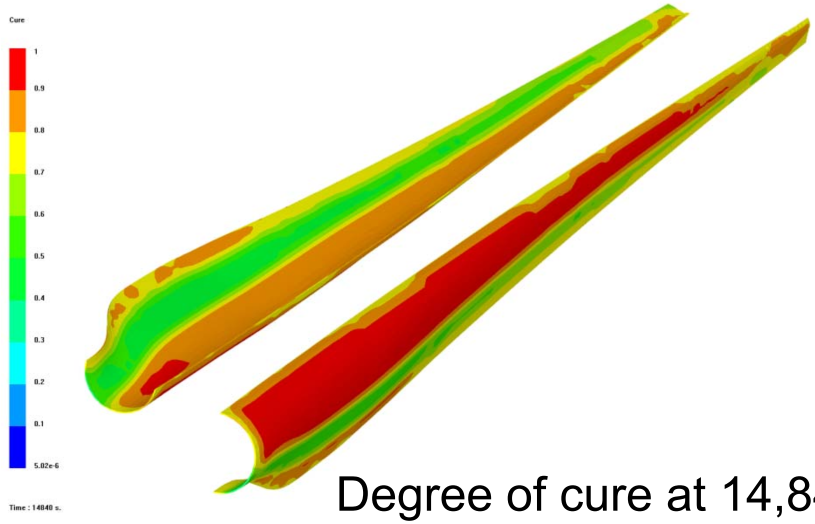
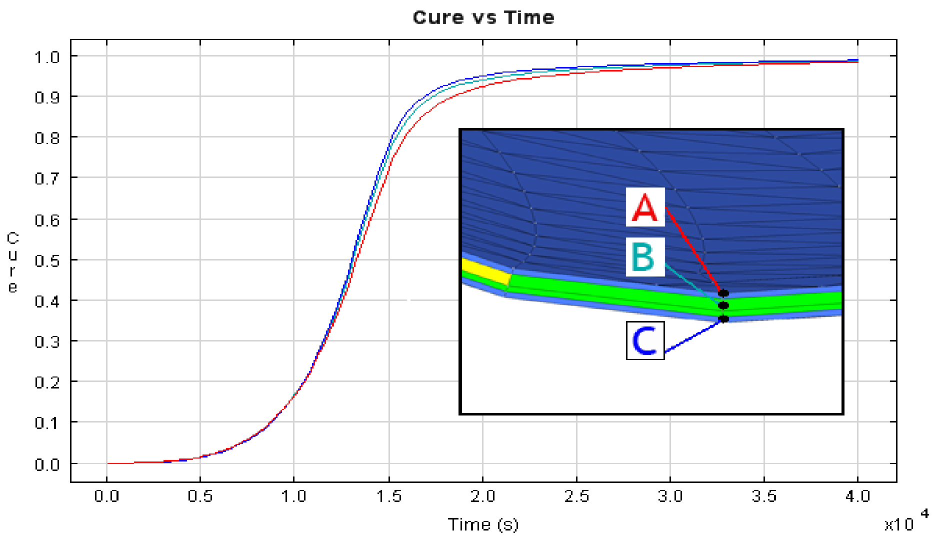
Curing After Isothermal Filling

Degree of Cure



Degree of cure at 14,840 s



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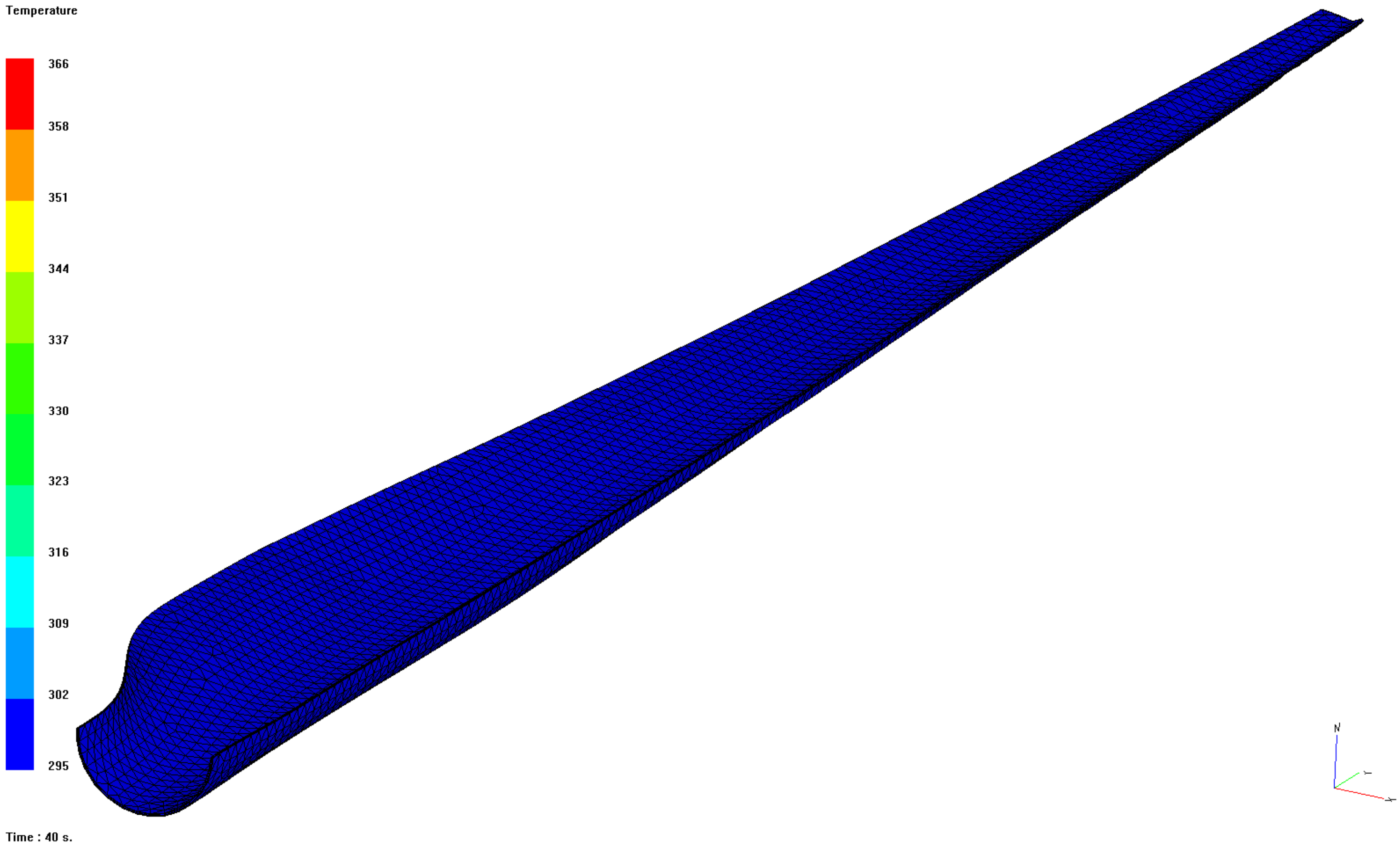
Curing After Isothermal Filling

Temperature Distribution



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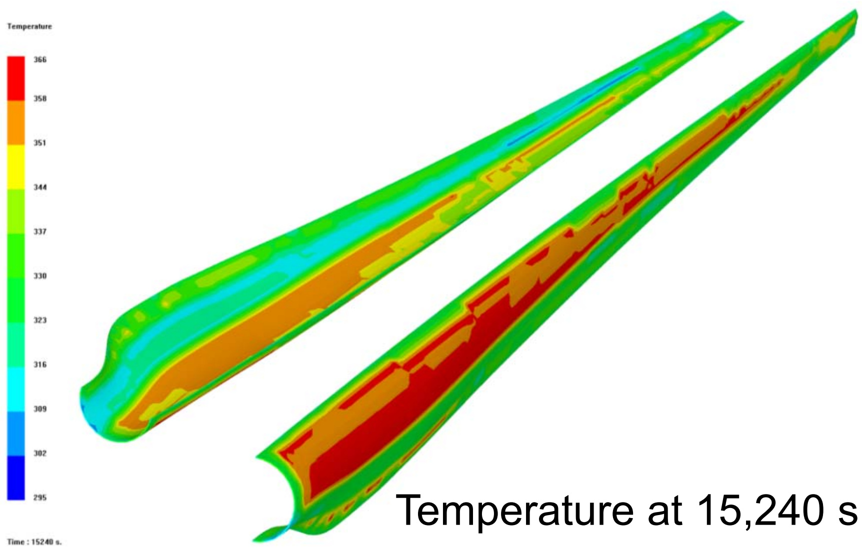
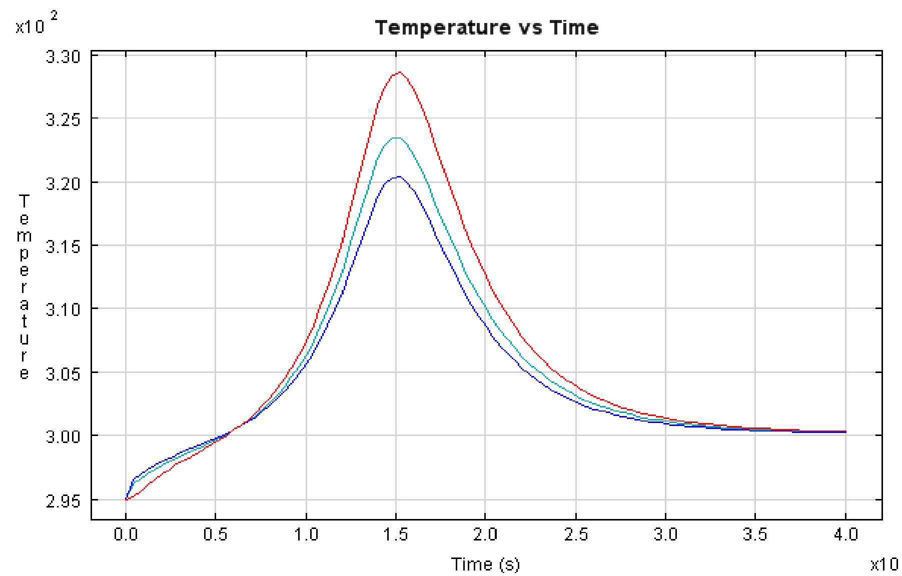
Curing After Isothermal Filling

Temperature Distribution





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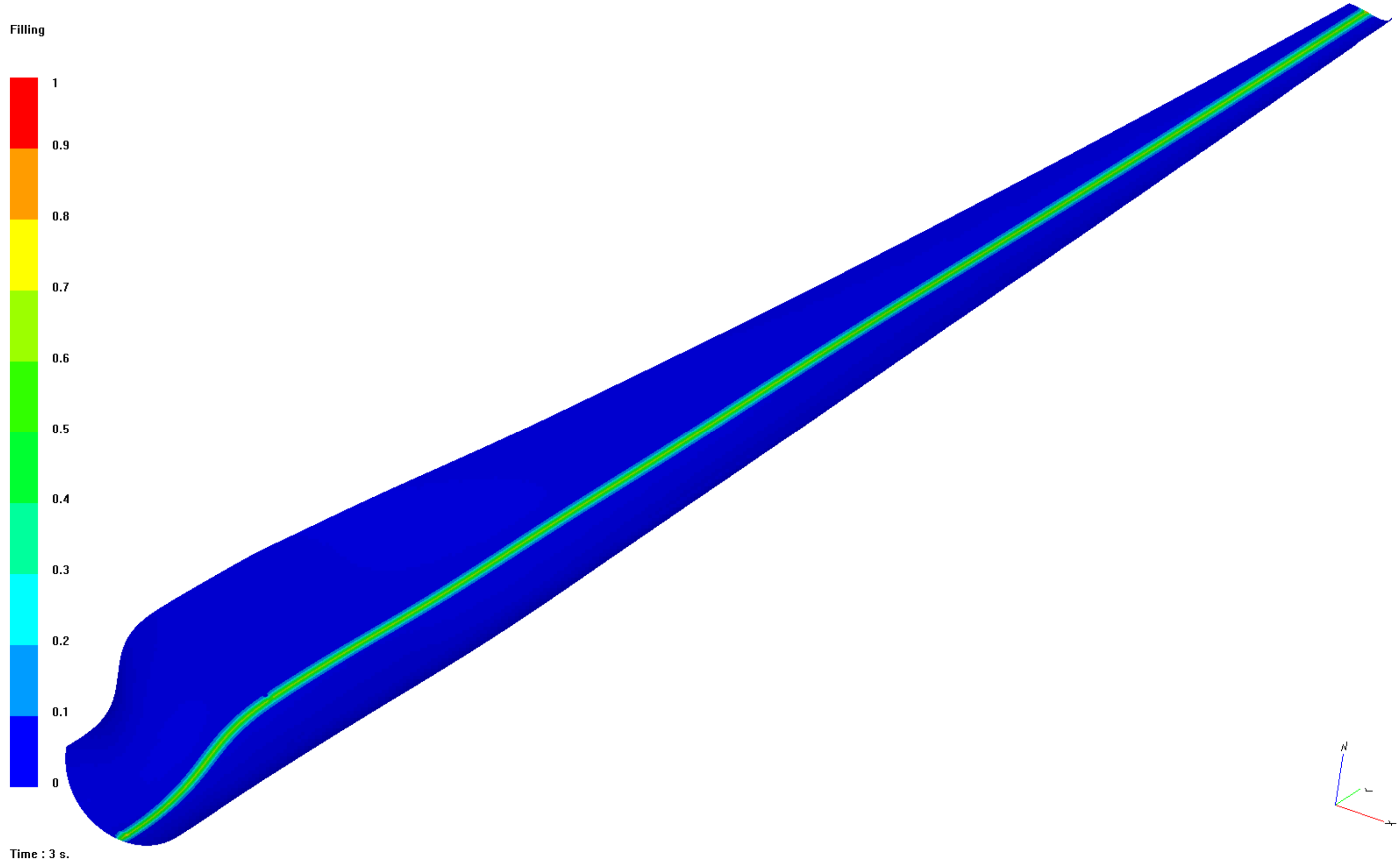
Non-Isothermal Filling



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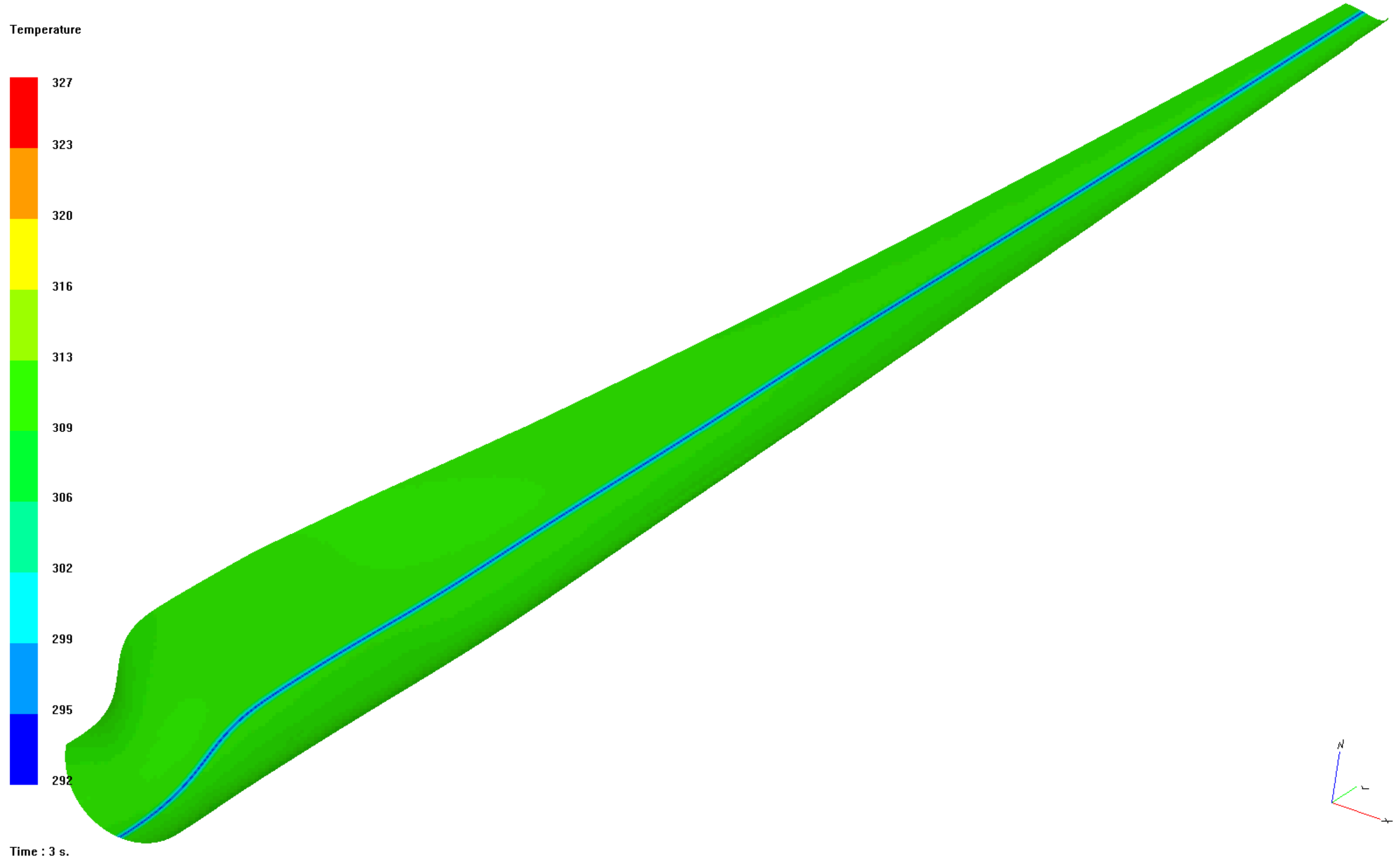
Non-Isothermal Filling

Temperature Distribution



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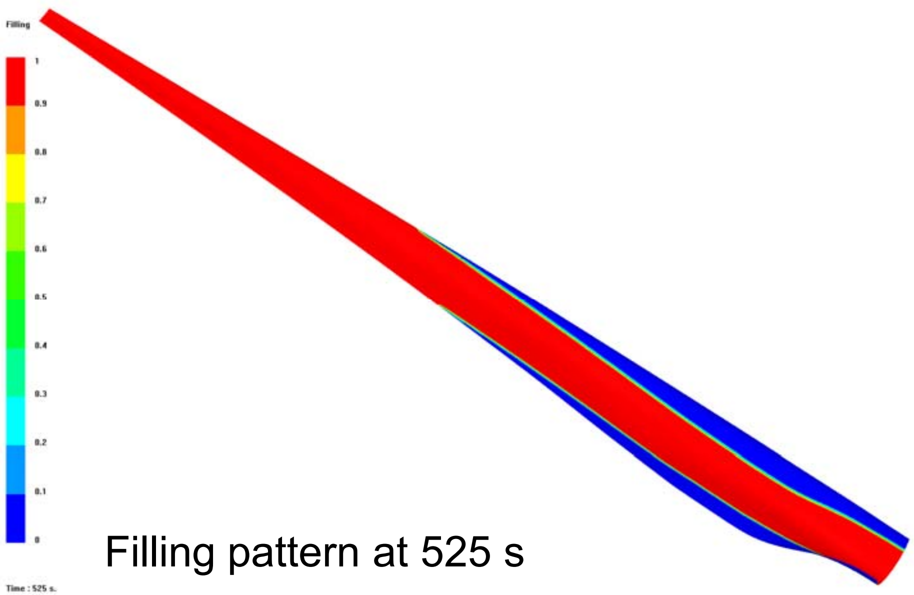
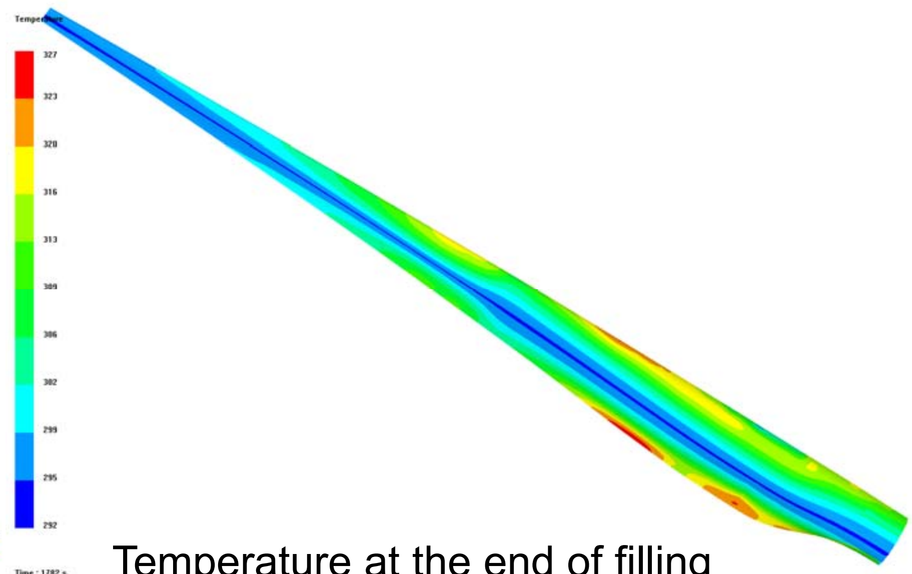
Non-Isothermal Filling



Filling pattern at 525 s



Temperature at the end of filling

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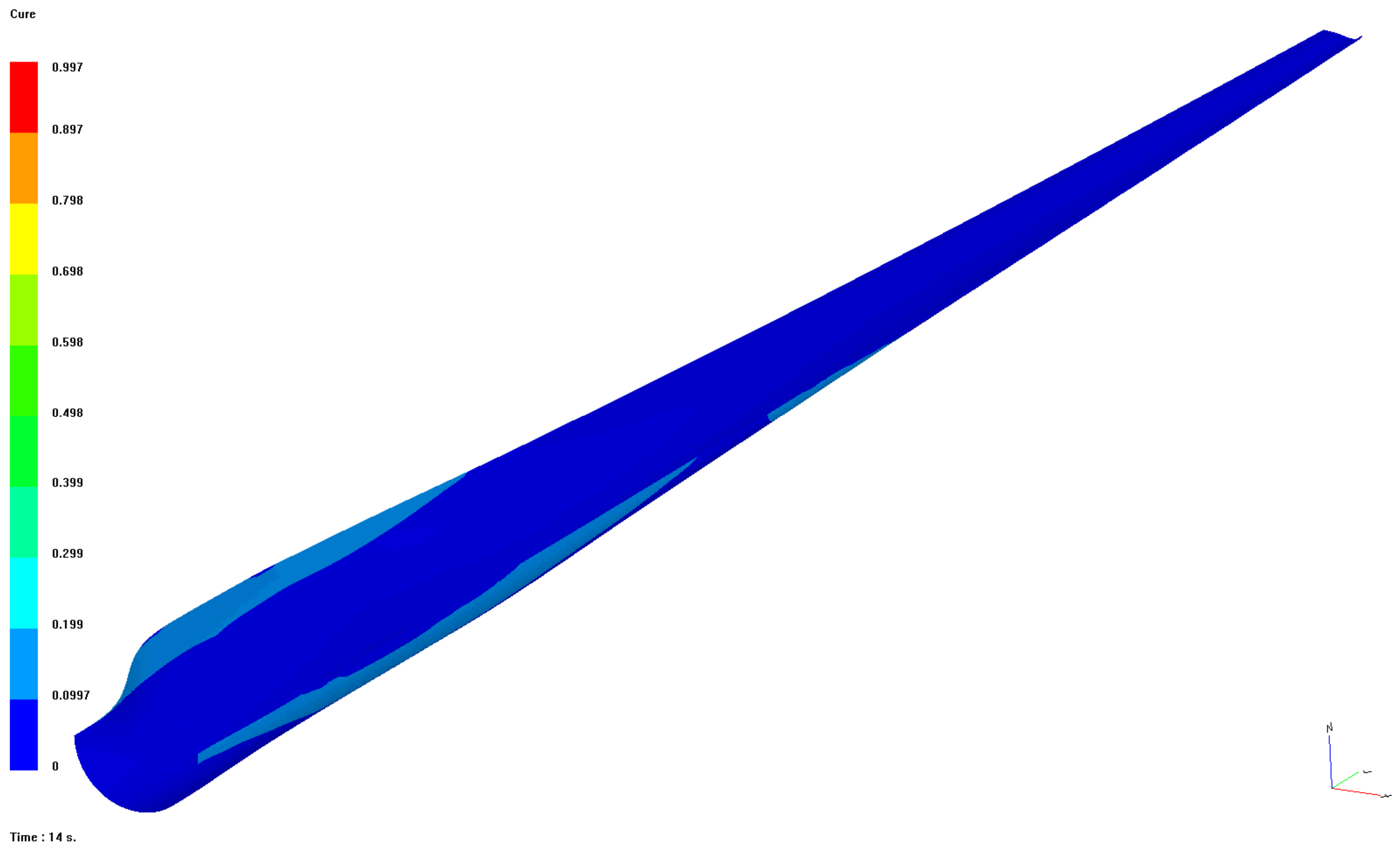
Curing After Non-Isothermal Filling

Degree of Cure



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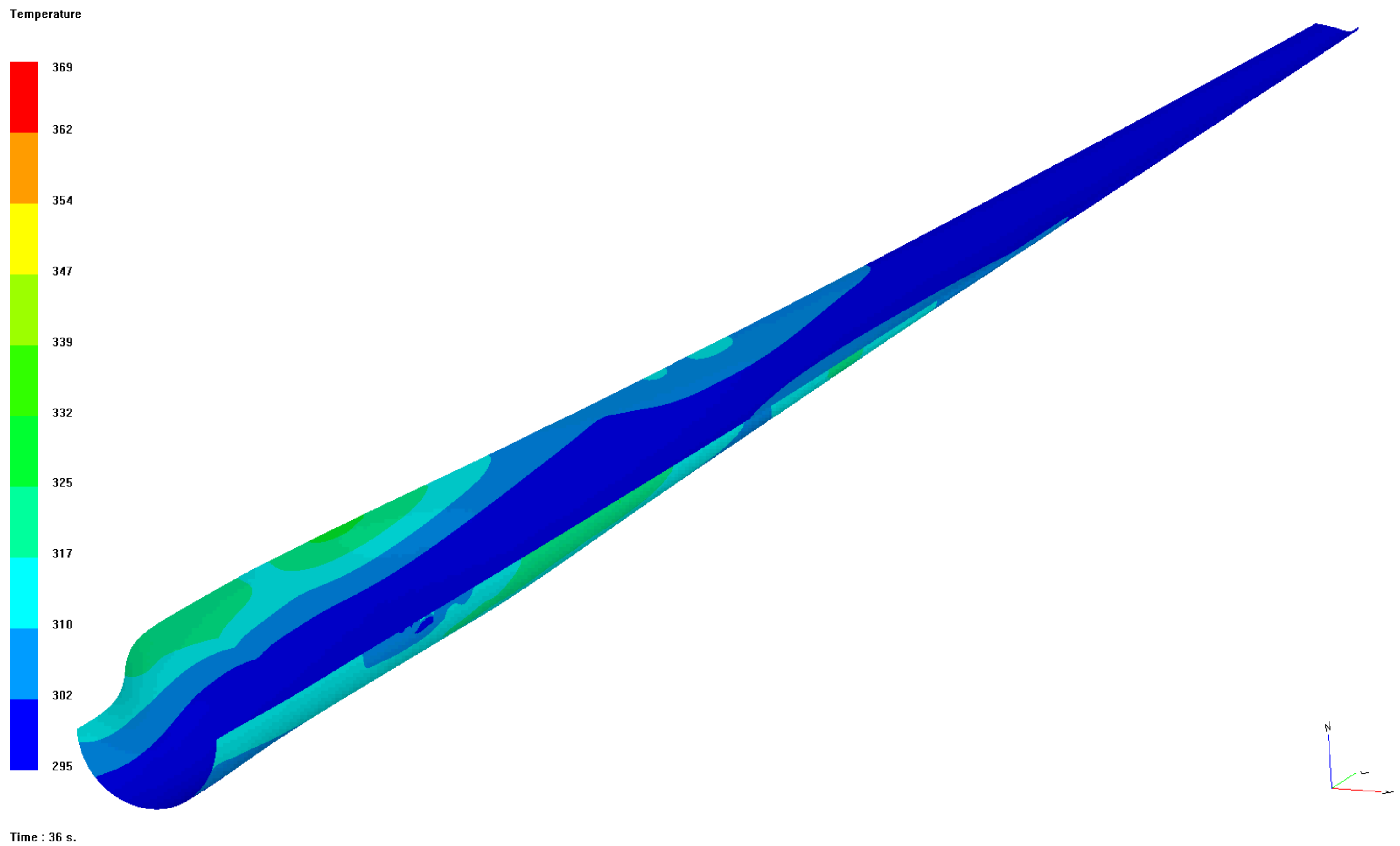
Curing After Non-Isothermal Filling

Temperature Distribution



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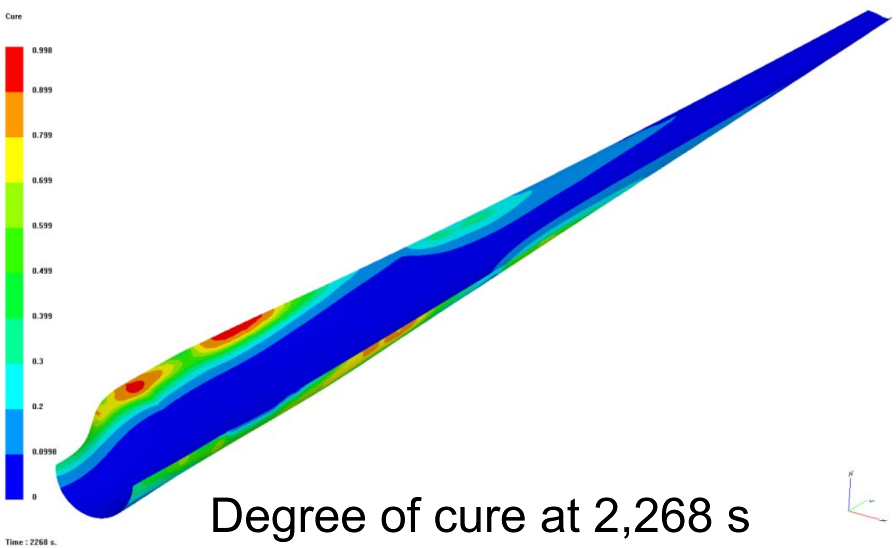
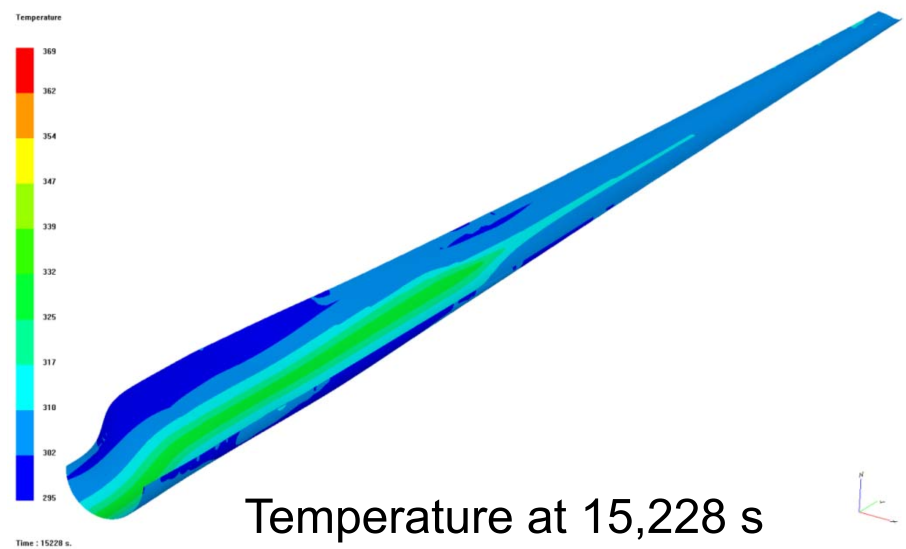
Curing After Non-Isothermal Filling

SUSTAINABLE ENERGY SOLUTIONS



Degree of cure at 2,268 s



Temperature at 15,228 s

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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.

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