Additive Manufacturing of Wind Turbine Blades Using Thermoplastic Composite Material
Big Area Additive Manufacturing Used to 3D Print a Wind Turbine Mold

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Today, ORNL is a leading science and energy laboratory.
The Manufacturing Demonstration Facility at ORNL

Core Research and Development
- R&D in materials, systems, and computational applications to develop additive manufacturing

Industry Collaborations
- Cooperative research to develop and demonstrate advanced manufacturing to industry in energy related fields

Education and Training
- Internships, academic collaborations, workshops, training programs, and course curriculum for universities and community colleges.

Supported by DOE’s Advanced Manufacturing Office

Neutron scattering: SNS and HFIR
- World’s most intense pulsed neutron beams
- World’s highest flux reactor-based neutron source

Advanced Materials
- DOE lead lab for basic to applied materials R&D
- Technology transfer: Billion dollar impacts

Leadership-class computing: Titan
- Nation’s most powerful open science supercomputer

Advanced Manufacturing
- Novel materials
- Advanced processing

SmartManufacturingSeries.com
BAAM vs. Conventional AM

Big Area Additive Manufacturing (BAAM) is an innovative process capable of producing large parts quickly and more cost effectively than conventional additive manufacturing.

**Conventional Additive Manufacturing**
- Small (<1 cubic ft)
- Slow (< 5 ci/hr)
- Expensive (~$100/lb)
- Takes days to go through 1 kg spool

**Big Area Additive Manufacturing**
- Large (> 1000 cubic ft)
- Fast (>2500 ci/hr)
- Cheap (<$5/lb)
- One machine can go through a Gaylord in one day
Partnership with CRADA

ORNL and Cincinnati Incorporated collaborate to create commercial large-scale systems

Partnership to establish US-based large-scale AM equipment manufacturer

- Targets tooling lead time and cost reduction
- Based on existing ORNL gantry system
- Cincinnati providing >$1M in cost share for year one
- Interest from multiple automotive, aerospace, and tooling industries
The Carbon Fiber Technology Facility has developed a method for producing industrial-grade structural carbon fiber and flame-retardant fibers from commercially available acrylic precursor materials.

- **Vehicle Lightweighting**: Reduce vehicle weight by using carbon fiber throughout body and chassis.
- **Wind Energy**: Build turbine components and longer blade designs for applications in wind energy.
- **Gas Storage**: High-strength, lightweight pressure vessels for storage of gas.
- **Recreational Equipment**: Next-level performance for sporting goods and recreational equipment.

Exhibits properties equal to or exceeding conventional carbon fibers.

- Increase in capacity greater than 3x over traditional conversion process equipment.
- Power reduction up to 60% per unit vs. traditional conversion techniques.

Scalable process for producing low-cost carbon fiber.
Carbon Fiber-Reinforced ABS

- Low-cost desktop systems are used to develop materials for large-scale applications
- Second phase carbon fiber-reinforced ABS has demonstrated a 2-3x increase in strength and a 4-7x increase in stiffness
- Reinforced polymers allow high resolution and low distortion printing
- Performance of low-cost printers equivalent to higher-cost industrial systems when using reinforced materials
Material Strength

Strength [Ksi]

13% CF-ABS Spec = 11.4 Ksi

ABS Spec = 5.83 Ksi

σ_u [Ksi]

0-0  90-90  0-0  90-90  0-0  90-90

ABS  13% CF-ABS  13% CF-ABS (w/ z-tamping)
Material Elasticity

Young's Modulus [Msi]

13% CF-ABS
13% CF-ABS (w/ z-tamping)

E [Msi]

ABS

ABS Spec = 0.327 Msi

Spec = 1.12 Msi
AM Wind Turbine Blade Mold

ORNL partnered with TPI Composites to 3D print an entire wind turbine blade mold from a composite material made of carbon fiber and ABS thermoplastic.
Traditional Blade Mold Manufacturing

- Expensive (> $1M per mold)
- Time consuming to produce (several weeks to months from CAD drawings to creation)
- Uncustomizable
- Requires hours of manual labor

### Traditional 50 m Mold

<table>
<thead>
<tr>
<th>Fabrication takes a total of 27 weeks</th>
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<tbody>
<tr>
<td>• 12 weeks: fabricate plug</td>
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<tr>
<td>• 3 weeks: setup and inspect to confirm shape</td>
</tr>
<tr>
<td>• 6 weeks: layup shell, attach frame, demold from plug</td>
</tr>
<tr>
<td>• 6 weeks: Electrical connections, cure, QA, shipping prep</td>
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1 pair of main plugs – reliable for 6 to 10 molds. On pair of molds typically reliable for 1,000 blades

Wires are embedded into the fiberglass surface by hand during mold fabrication to heat the surface
AM Wind Turbine Mold

3D Printed 50 m Mold

Based on 13 m mold results, a 50 m mold can be designed, printed and finished in only 20 weeks
• 12 weeks: print mold sections
• 4 weeks: glass and finish mold sections
• 4 weeks: attach frame, install heaters, QA, shipping prep

No plugs are needed. Direct CAD to mold

Air passages are incorporated into the design of the mold to accommodate heated air which is cycled throughout the mold

Cost effective – Fast – Customizable – Less post-processing
Wind Turbine Mold Sections Design
Final Wind Turbine Mold Sections
Time-lapse of BAAM Wind Turbine Mold Section Fabrication
Questions?

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