Thermoplastic Wind Turbine Blades and Recyclable-by-Design Materials

Robynne Murray
August 31, 2022
Team: Ryan Beach, David Barnes, Nic Rorrer, Erik Rognerud, David Snowberg, Derek Berry, and many more
Introduction

**Problem:** Large composite structures like wind turbine blades have traditionally been made of materials that are costly and challenging to recycle.

**Impact for wind turbines:** Could be over 50 million metric tons of waste by 2050 from blades.

**Today’s talk:**

- Thermoplastic blade materials
- 13m blade manufacturing and validation
- Techno-economic analysis
- Recyclable-by-design anhydride development

Source: Elsevier / University of Cambridge
NREL has been researching thermoplastic composites (using Elium resin) as well as novel recyclable-by-design materials to address this challenge.

Thermoplastic composites gaining interest in wind industry.

- **Reduce cycle time and energy consumption**
- **Can be thermally joined**
  - Eliminates adhesive bonds, increasing strength and reliability
- **Can be reformed**
  - Enables easier repair and maintenance
- **Can be recycled at the end of their life span**
- **On-site manufacturing becomes a viable option**
• Thermoplastic composites compared to thermoset composite materials at a coupon scale
• Thermoplastics are within 5% strength and modulus compared to epoxy
13 m blade manufacturing and validation
13-m Epoxy blade

- DOE WETO Project: National Rotor Testbed (NRT)
  - 13-m blades made using traditional epoxy resin and fiberglass to go on SNL SWiFT turbine
  - ORNL 3D printed molds
  - TPI Composites fabricated 4 blades
    - 3 to fly at SWiFT site
    - 1 to NREL for structural validation

Photo Credit: https://energy.sandia.gov/energy/renewable-energy/wind-power/wind_plant_opt/
• Identical thermoplastic blade manufactured with Elium resin in the CoMET at NREL using the same tooling
  – Different fiberglass, adjusted layup using NuMAD to match stiffness and thickness to 5%
  – Different adhesive (PMMA adhesive chosen based on lap shear testing)
Static strength testing
- Flatwise displacement 3-7% higher
- Edgewise displacement 10-15% higher
- Strains within 10%
- Differences attributed to differences in adhesive and fiberglass (less stiff adhesive)
Fatigue method: Damage Equivalent Load
  – Accelerated loading $1 \times 10^6$ (1 million) cycles using resonant fatigue testing
Fatigue load comparison

- Dynamic mechanical analysis (DMA) to compare damping characteristics of epoxy and thermoplastic blades
- First 3 natural frequencies within 3% of NRT
- Structural damping 5-7x higher = reduced loads in field operation

- How does structural data impact design?
- Are there other tests we should be doing to better inform blade and turbine design?
Techno-Economic Analysis

- Breakdown of blade manufacturing cost for a 61.5-m thermoplastic blade
  - Thermoplastic blade costs 4.7% less than an equivalent epoxy blade
  - Mainly driven by reduced tooling costs
  - Material costs more per kg, with economies of scale, the cost can go down further
• Thermoplastics can be a drop in replacement for non-recyclable epoxy resins
• Still a lot of research to do to understand the full value proposition
  – Thermal welding
  – Thermoforming
  – Repairs

• Need to understand science and cost of recycling these blades - have not recycled the 13m thermoplastic blade
Recyclable-by-design materials at NREL
Recyclable epoxy

• Resins that can undergo exchange reactions -> composite materials can be recycled and thermomechanical properties modulated

• NREL developed a novel bio-derivable epoxy-anhydride resin with reversible crosslinks to enable recycling ("RBD resin")

• ROI 20-59 and patent application submitted

• Techno-economic and supply chain analysis of feedstocks shows lower GHG and potentially less expensive than traditional epoxy materials

• NREL working on characterization and validation of this new material for wind turbine blades
Wind materials testing

- **Manufacturability:** Infusion of RBD resin into glass and carbon fiber in the CoMET
  - Cure cycle same as traditional epoxy material
  - Similar viscosity to traditional epoxy
  - Promising!.. balance between strength and flexibility
  - SEM imaging shows possible sizing incompatibilities
Recycling

- Currently depolymerizing panels (at room temperature and 100g+ scale)
- TGA results indicate no detrimental effect to the CF sizing post depolymerization
- Residual resin MAY further aid re-use due to exchange reactions
Thank you!