

# Dimensional Stability and Creep Performance of Glass Fiber Reinforced Thermoplastic Polyurethane (GFRTPU)

as a Recyclable Alternative to  
Fiberglass Epoxy Composites  
for Wind Turbine Blade Applications

By: Olivia Snell



From A Healthy Win, Jennifer, 2022, MIT (News  
<https://news.mit.edu/2022/wind-health-impact-1202>). CC BY  
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From Thousands of old wind Turbine Blades Pile Up in West Texas, by Russell,  
2023, Texas Monthly  
([www.texasmonthly.com/news-politics/sweetwater-wind-turbine-blades-dump/](http://www.texasmonthly.com/news-politics/sweetwater-wind-turbine-blades-dump/)).  
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# Introduction

## Year 1 Foundation

In my first project, after discovering that wind turbine blades are made from non-recyclable fiberglass epoxy resin I examined the tensile strength and strain of GFRTPU as a recyclable alternative. I found GFRTPU's tensile strength is comparable to fiberglass epoxy, with a higher elastic modulus (lower elastic strain under load).

## Year 2 — This Project

While increased stiffness suggests less deformation under stress, the relationship between quasi-static mechanical properties and creep at elevated temperatures remained unknown. This project examines GFRTPU's durability and long-term dimensional stability through two tests. 1st: Elevated Creep Testing which gives data for the Findley Power Law calculation. 2nd: Electric Tensile Testing, which gives data for Stress Relaxation calculation.

## Collaboration

Samples of Elastollan® R3000 were obtained from BASF Corporation. Dr. Kevin Walsh provided access to the electric tensile testing machine and guided the testing procedures.



Photo taken of finalist by finalist's parent, Laura Walker



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# Research Question & Hypothesis

Can glass fiber-reinforced thermoplastic polyurethane (GFRTPU) match or exceed the creep resistance and thermal stability of fiberglass epoxy resin for wind turbine blade applications?

## Hypothesis

**Based on Year 1:** GFRTPU's strain is better than fiberglass epoxy resin and tensile strength is comparable. The glass fibers improve creep resistance.

If GFRTPU's creep and thermal resistance are comparable to or better than fiberglass epoxy resin, **then GFRTPU should be considered a viable alternative material for wind turbine blades.**

### Creep Explanation:

Think of creep as a bookshelf where the plank holding the books is your blade, and the books are your constant load. After time, you may see a bend. This bend is deflection, and from deflection you can measure creep.



Photo taken by finalist



Photo taken by finalist

### GFRTPU Advantages

- ✓ Impact resistant
- ✓ Less prone to delamination
- ✓ High strength-to-weight ratio
- ✓ Excellent fatigue resistance
- ✓ UV & weather resistant
- ✓ **FULLY RECYCLABLE**



Photo taken of finalist  
by finalist's parent,  
Laura Walker

# Methodology

1

## Cut Samples

GFRTPU sheets (4"×5") cut to ASTM D638-14 Type I specs using table jigsaw and scribe. 44 samples prepared. (ASTM D638 was referenced in ASTM 2290-17 for test specimens for tensile creep measurements).

2

## Measure Dimensions

Gauge length (G), gauge width (W), and gauge thickness (T) measured in mm per ASTM D5947 using metric caliper.

3

## Sample Preparation

Samples labeled numerically; gauge length marked with permanent pen. Hex nuts positioned just outside gauge marks.

4

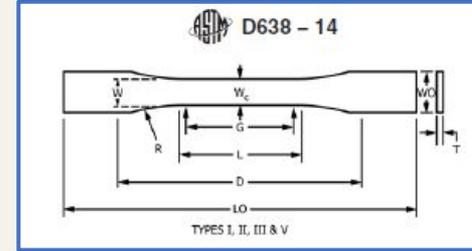
## Load Assembly

5 identical loads: 1 carriage bolt (5/16"×4"), 7 hex nuts (1/2"), 1 hex nut (3/8"). Each load weighed and recorded. (~5.5oz of load measured, used on all 8 creep tests)

5-7

## Creep Testing

Two samples tested at room temp (68°F) 7 days + 3 samples at moderate (120–140°F) + 3 samples at high temp (160–200°F). Deflection measured at 30 min, 1hr, 2hr, 4hr, 8hr intervals on pizza stone in convection oven. These temperatures tested replicate conditions during wind turbines blades would experience during operations.



ASTM International. (2014). Standard test method for tensile properties of plastics (ASTM D638-14). <https://doi.org/10.1520/D0638-14>

Note: The ~5.5oz was not used to replicate the exact forces on a full-scale turbine blade — it was specifically chosen to produce measurable deflection while keeping samples within their elastic region.



Photo taken by finalist



Photo taken by finalist

# Methodology — Calculations

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## UTS Load Calculation- for electric tensile testing

Calculated 70% UTS target force: Mean UTS  $\times$  0.7  $\rightarrow$  stress (psi).  
Force = Stress  $\times$  Area. Each sample: 236 lbf target.

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## Tensile Machine Operation

Sample installed in grips; "PEAK AUTO" mode enabled. Load applied to ~236 lbf; readings at 1, 5, 10, 30 min, 1, 2, 4, 8, 14–16 hr.

## Creep Strain

10–11

Deflection converted from fractions to decimals. Creep strain:  $\epsilon = \Delta L / L_0$  (deflection  $\div$  gauge length). Calculated in decimal and %.

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## Standard Deviation

Mean and SD calculated across all 11 samples: mean  $\rightarrow$  deviations  $\rightarrow$  squared  $\rightarrow$  mean  $\rightarrow$  square root.

13

## Findley Power Law

$\epsilon(t) = \epsilon_0 + a_0 \times t^n$  | Solver minimized SSR (GRG Nonlinear, Multistart).  $R^2 = 1 - (SSR/TSS)$ . Repeated for each sample and temperature.

## Findley Power Law- Industry standard for predicting long term creep behavior

$$\epsilon(t) = \epsilon_0 + a_0 \times t^n$$

$\epsilon_0$  = instantaneous strain      $a_0$  = creep coefficient  
 $n$  = time exponent              $t$  = time (hours)

## Stress Relaxation Explanation:

Think of a stretched rubber band — if you hold it at a fixed length, the force it pulls back with gradually decreases over time. That's stress relaxation: under constant deformation, a material slowly reduces the internal force needed to maintain that shape. I measured this in GFRTPU using an electric tensile testing machine."

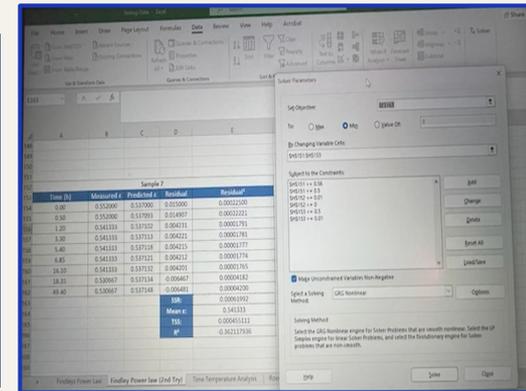


Photo taken by finalist

# Creep Testing Data Tables, Graphs & Results (1st Test)

## Creep Testing — Findley Power Law

### Creep rate coefficient ( $a_0$ ):

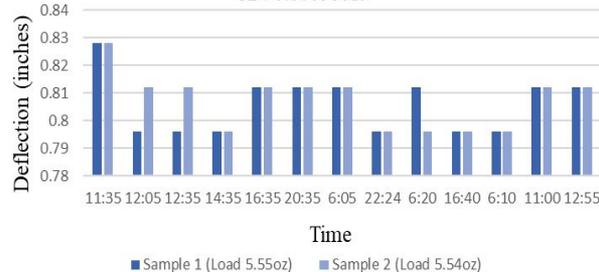
- Room temp & 120–140°F: **effectively ZERO**
- 160–200°F:  **$0.003 \pm 0.0043$**

Low  $R^2 \approx 0$  = **superior dimensional stability** — constant strain vs. progressive deformation in epoxy.

Table created by finalist using Microsoft Excel

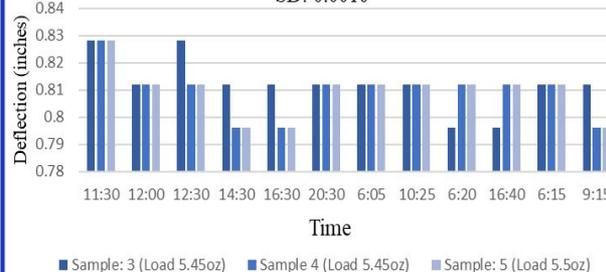
Findley's Power Law Analysis ( $\epsilon_0, a_0, n, R^2$ ) + Elevated Creep Strain					
Standard Deviations (68,120-140,160-200°F)					
<u>Temperature Condition</u>	<u>Creep Strain</u>	<u>Instantaneous Elastic Strain (<math>\epsilon_0</math>)</u>	<u>Creep Rate Coefficient (<math>a_0</math>)</u>	<u>Time-Dependency Exponent (n)</u>	<u>Percentage of Variance (<math>R^2</math>)</u>
Room Temperature	$0.537 \pm 0.0005$	$0.537 \pm 0.0004$	$0.000 \pm 0.000$	$0.088 \pm 0.041$	$0.000 \pm 0.000$
Elevated Temperature (120-140°F)	$0.540 \pm 0.0008$	$0.540 \pm 0.0008$	$0.000 \pm 0.000$	$0.07 \pm 0.0366$	$0.000 \pm 0.000$
Elevated Temperature (160-200°F)	$0.541 \pm 0.0006$	$0.541 \pm 0.0006$	$0.003 \pm 0.0043$	$0.0496 \pm 0.032$	$0.370 \pm 0.306$

Room Temperature Samples (1,2)  
Deflection Measurements  
Temperature (~68°F)  
SD: 0.00058019



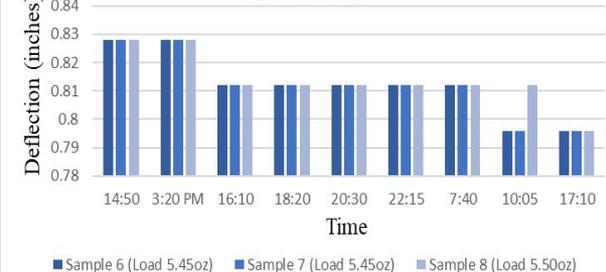
Graph created by finalist using Microsoft Excel

Elevated Temperature Samples (3-5)  
Deflection Measurements  
Temperature (~120-140°F)  
SD: 0.0010



Graph created by finalist using Microsoft Excel

Elevated Temperature Samples (6-8)  
Deflection Measurements  
Temperature ~160-200°F  
SD = 0.31288



Graph created by finalist using Microsoft Excel

# Electric Tensile Data Tables, Graphs, & Results (2nd Test)

## Stress Relaxation Testing

Actual stress level:

55–61% UTS (target: 70%) due to cross-sectional variation

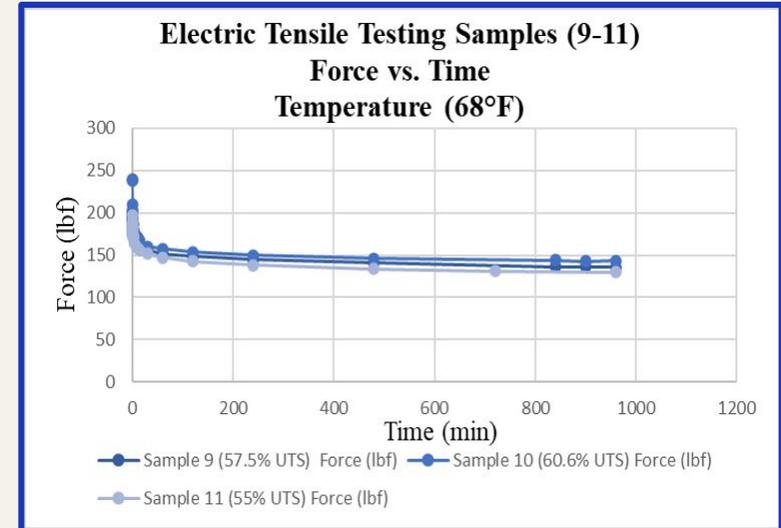
Result: **42.3% ± 2.3% over 16 hours**

Low CV confirms **reproducible, predictable behavior** — controlled stress redistribution across all samples.

- Two complementary tests, creep and stress relaxation, because in a real wind turbine blade two phenomena occur simultaneously. Testing both together provides a complete picture of long-term material behavior that neither test could provide alone.

Electric Tensile Testing Analysis		
	Standard Deviation	Coefficient of Variation (CV)
<b>Percent Stress Relaxation (%):</b>	42.3 ± 2.3	6.63
<b>Initial Stress (psi):</b>	6586 ± 83.3	1.549
<b>Final Stress (psi):</b>	3800 ± 157.8	5.086
<b>Stress Drop (psi):</b>	2786 ± 152.4	6.7
<b>Actual % UTS:</b>	57.70% ± 2.3%	4.86

Data table created by finalist using Microsoft Excel



Graph created by finalist using Microsoft Excel

# Discussion — GFRTPU vs. E-Glass/Epoxy

## Creep Compliance

E-glass/epoxy: 13.6× increase over 10 years, requiring TTSP modeling.  
 GFRTPU: virtually zero increase with CV as low as 0.11% at elevated temperatures (160–200°F)

## Thermal Stability

E-glass/epoxy: ~11% creep strain increase; recycled: ~23%.  
 GFRTPU: only 7.4% increase.

## Viscoelastic Behavior

E-glass/epoxy exhibits nonlinear stress-dependent acceleration near  $T_g$  (glass transition temperature). GFRTPU maintained predictable linear behavior at constant load.

## Long-Term Prediction

E-glass/epoxy requires complex TTSP + Arrhenius modeling. GFRTPU's stable data eliminates need for extrapolation entirely.

## Recyclability

Recycled E-glass/epoxy: 305% higher creep rates, 28% lower flexural strength — effectively single-use. GFRTPU: full thermoplastic recyclability.

## Safety Factor

Findley  $a_0 \approx 0$  across all samples confirms 23.6× safety factor from Year 1 will NOT degrade over 20–25 year blade service life.

GFRTPU data was compared against published literature of E-glass/epoxy composites (type of fiberglass epoxy resin).

## Material Comparison Summary

Property	GFRTPU	E-Glass/Epoxy
Time-Dep. Deformation	MINIMAL ( $a_0 \approx 0$ )	SIGNIFICANT (13.6×)
Thermal Sensitivity	LOW (7.4%)	HIGH (11–23%)
Long-term Stability	EXCEPTIONAL	Moderate
Recyclability	YES 	NO 

# Conclusion & Further Research

The comprehensive creep and stress relaxation testing of BASF Elastollan® R3000 demonstrates that GFRTPU possesses exceptional dimensional stability that fundamentally distinguishes it from traditional fiberglass epoxy composites. The Findley Power Law confirmed creep rate coefficients approaching zero — meaning the 23.6× safety factor established in Year 1 will not degrade over the blade's entire 20–25 year service life.

- ✓ **Creep coefficients  $\approx 0$**   
Virtually zero time-dependent deformation
- ✓ **7.4% thermal increase**  
vs. double digits for epoxy across 62°F
- ✓ **Safety factor preserved**  
23.6× will NOT degrade due to creep
- ✓ **Fully recyclable**  
Thermoplastic — melted and reprocessed repeatedly
- ✓ **Recycled epoxy fails**  
305% higher creep, 28% lower strength
- ✓ **Predictable behavior**  
Eliminates need for TTSP complex modeling
- ✓ **Long-term reliability**  
Consistent performance over 20–25 year life
- ✓ **Dual benefit**  
Superior performance + circular economy

## YEAR 1

Tensile Strength & Strain  
23.6× safety factor established

## YEAR 2

Creep & Thermal Stability  
 $a_0 \approx 0$  · Safety factor confirmed stable

## YEAR 3 (Planning)

Recyclability & Fatigue Testing — reprocess fractured samples, retest tensile strength to quantify any performance loss.

# Economic + Environmental Comparison

**2.2M tons**

US Blade Waste by 2050

**78%**

Landfilled Under Business-as-Usual

**305%**

Higher Creep in Recycled Epoxy

## Policy & Global Action

Germany, Netherlands, Austria & Finland have banned landfilling blades. European wind industry committed to full ban on Jan 1, 2026. Countries are using blades as playgrounds (Netherlands), bike shelters (Denmark), and bridges (Ireland) — all expensive workarounds for a material never designed with end-of-life in mind.

**GFRTPU closes the loop:** melt → reprocess → new blade. Not a workaround — a solution.

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