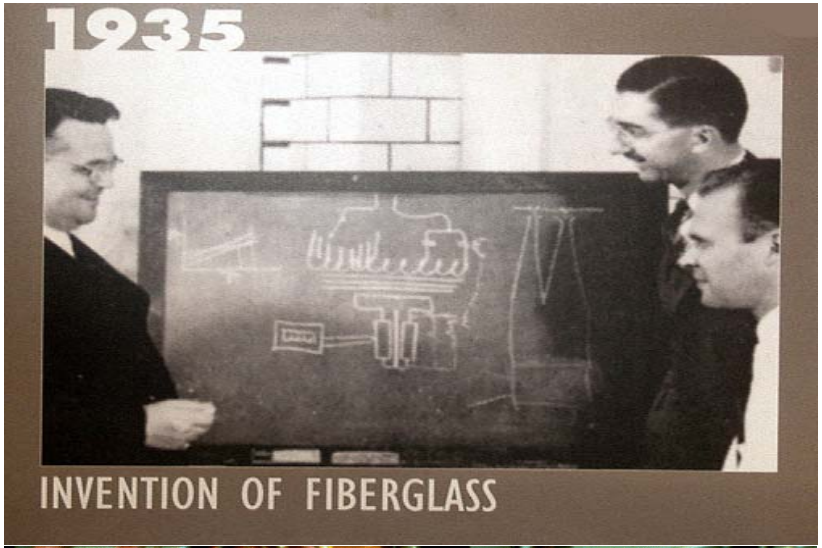
2006 Wind Turbine Blade Workshop Materials and Manufacturing Research

Advances in Material Technology

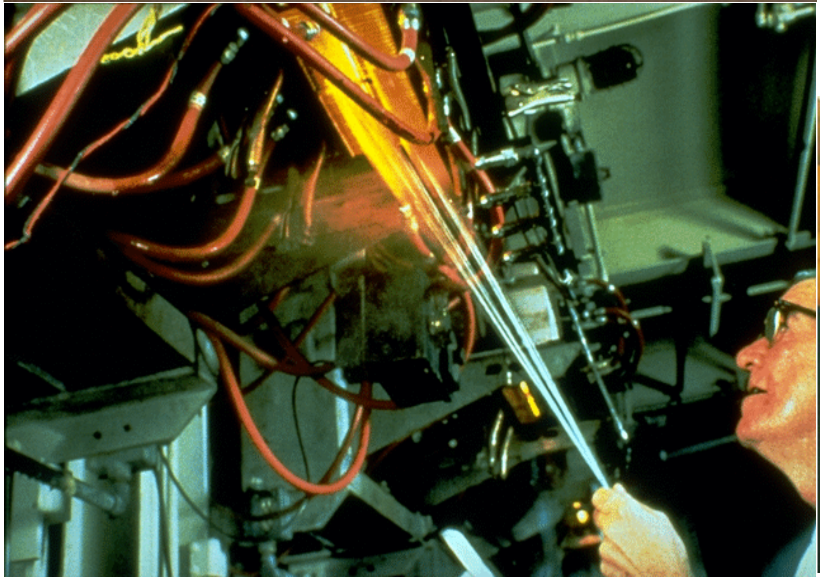
David Hartman
April 19, 2006

INNOVATIONS FOR LIVING™

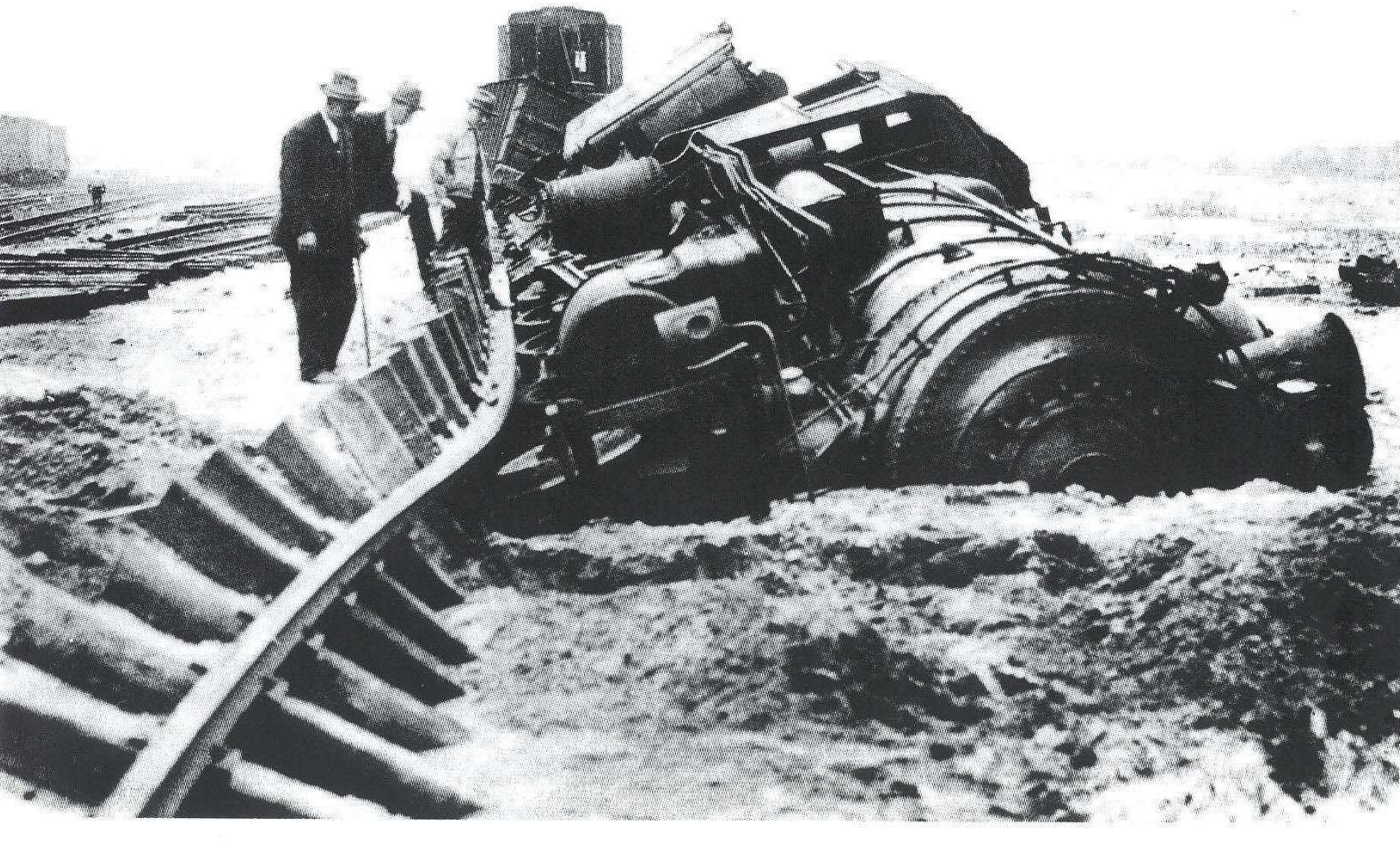
Innovation in Fiber Technology



- In 1938: E-glass
- In 1968: S-2 Glass®
- In 1980: ECRGlas®
- In 1997: Advantex®
- In 2006: HiPer-tex™



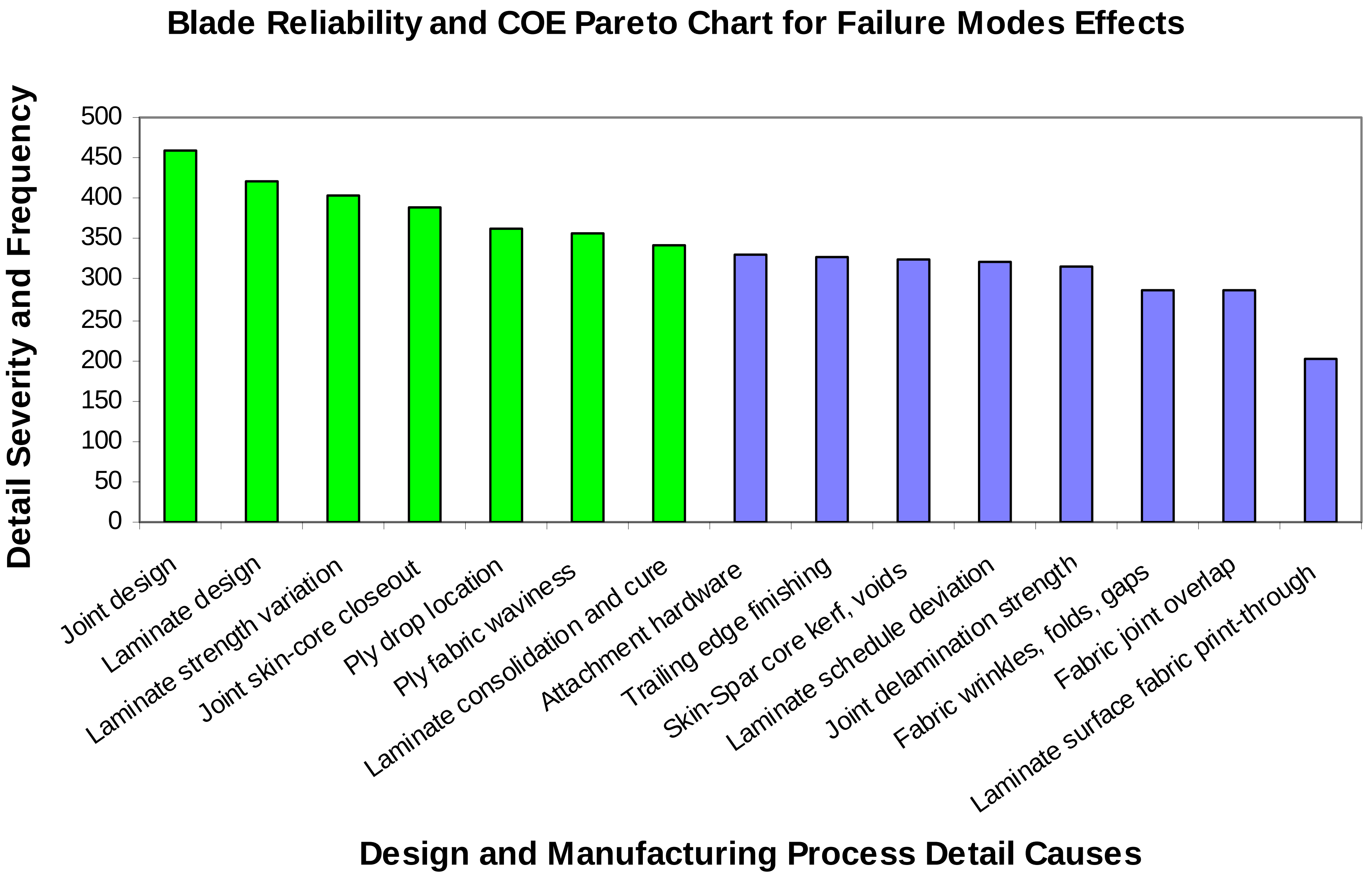
Time to get the train back on track…



Design Drivers for Utility-Scale Blades

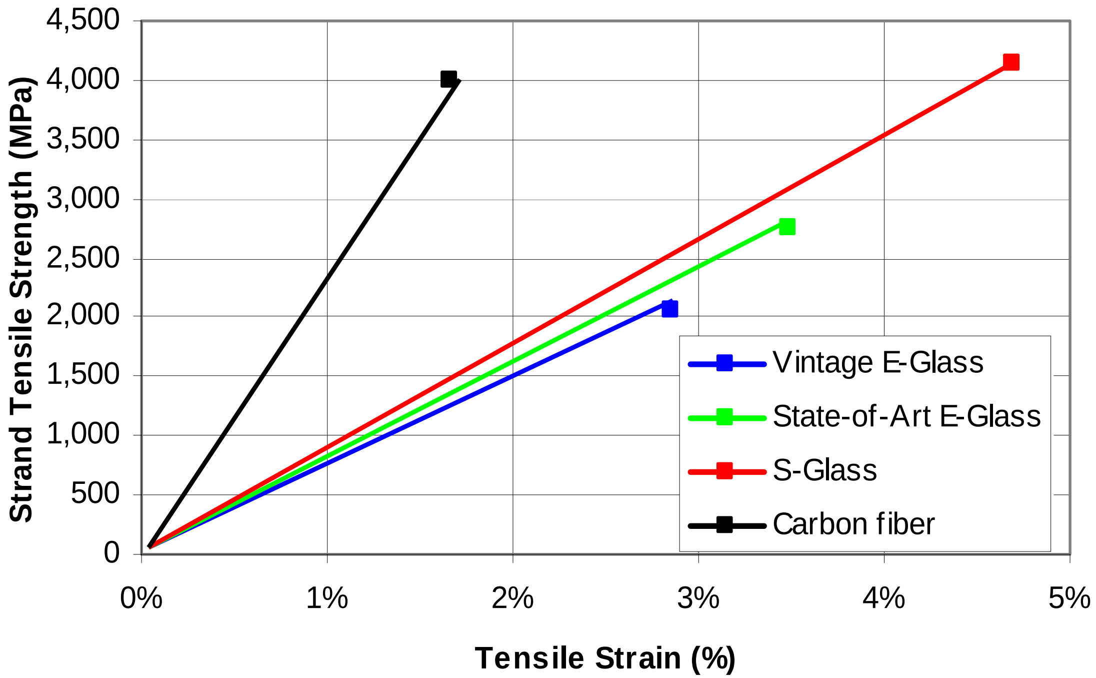
- **Maximum blade swept area at minimum weight and cost**
  - Inertial bending loads reduced with lower weight
  - Reduce transportation costs
  - Reduce labor and material costs
- **Cost effective materials and manufacturing**
  - Design and process FMEA of defect severity and occurrences
  - Automation and process flow
  - Resin infusion with integration of large parts
- **Deflection**
  - Curved back edge or pre-bent blade designs
  - Increase energy capture with passive or active load mitigation
  - Materials with higher modulus for spar cap stiffness
- **Ultimate strength**
  - Improved materials with lower variation
  - Reduced knock-down factors
- **Fatigue strength**
  - No failures for 30 year life with improved damage tolerance
  - Inspection and maintenance of damage accumulation every 3 years

Improvement in Blade Reliability and COE



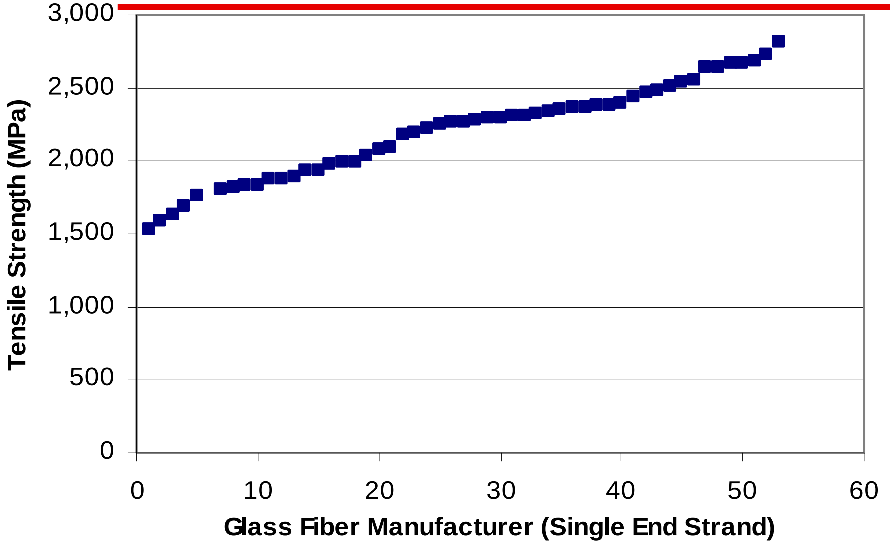
Improvement in Material Performance

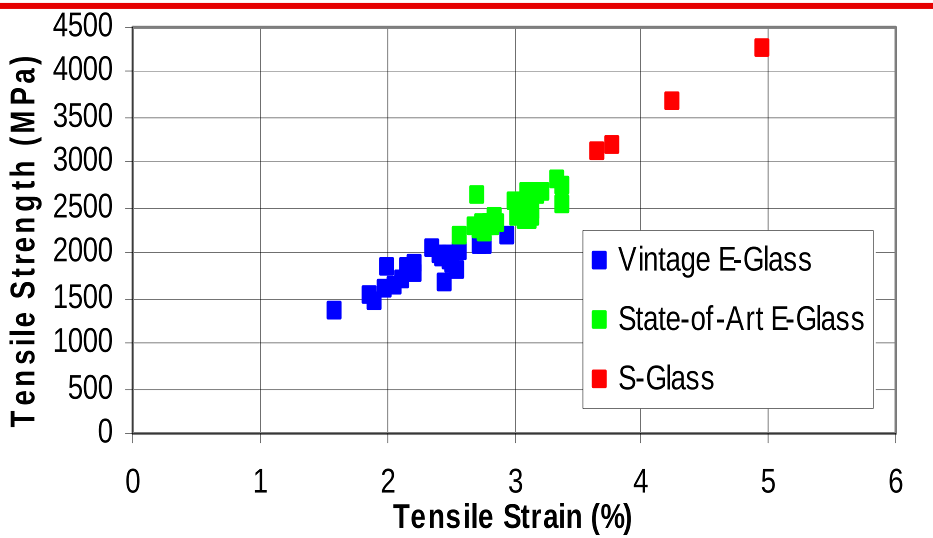
- Increased Resin Matrix Fracture Toughness
- Increased Glass Fiber Strength and Fatigue Performance
  - Glass Composition and Homogeneity
  - Fiber/Strand Alignment
  - Fiber/Matrix Adhesion
- Use of High Performance Fibers

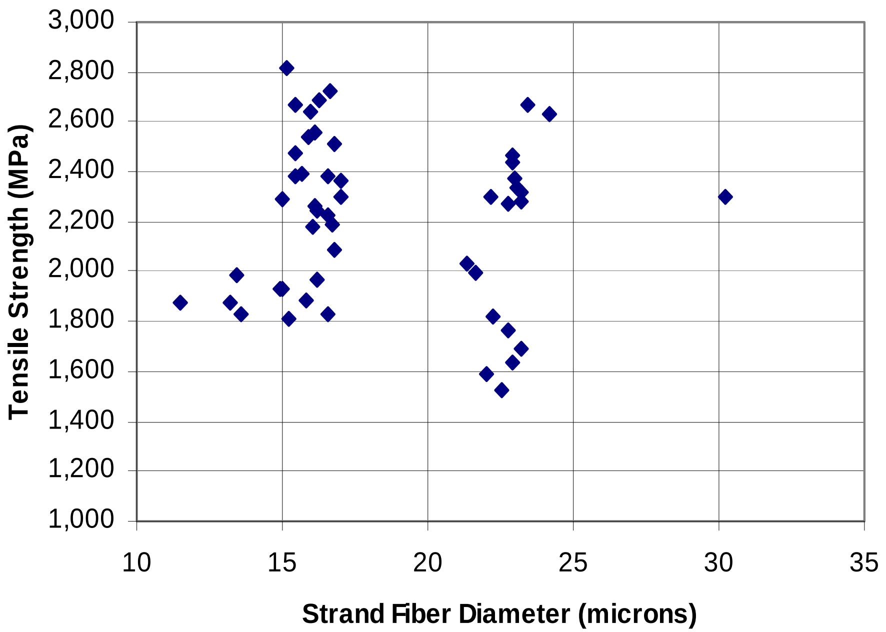


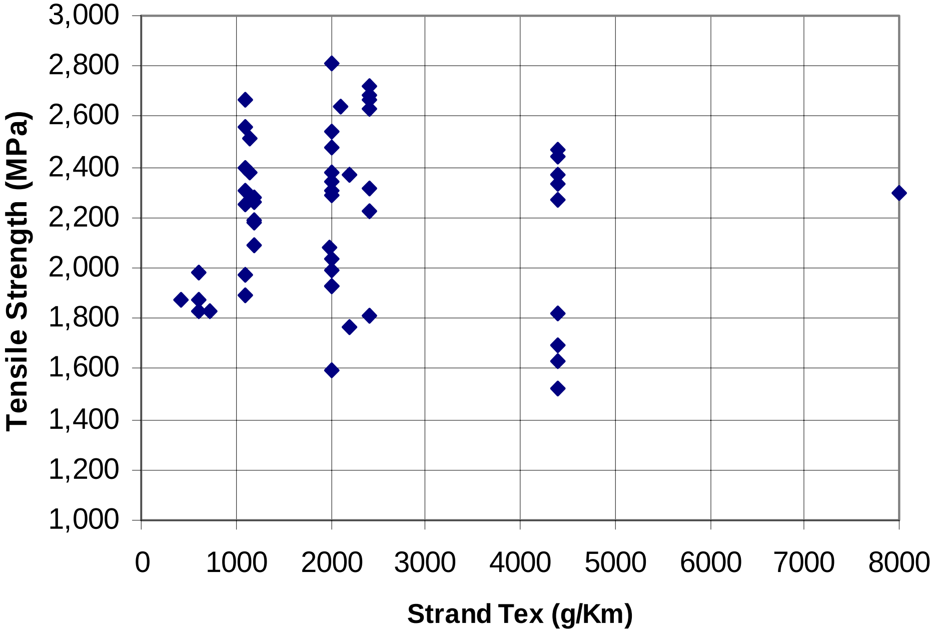
Used by Permission Owens Corning

Evolution of Higher Strength Glass Fibers

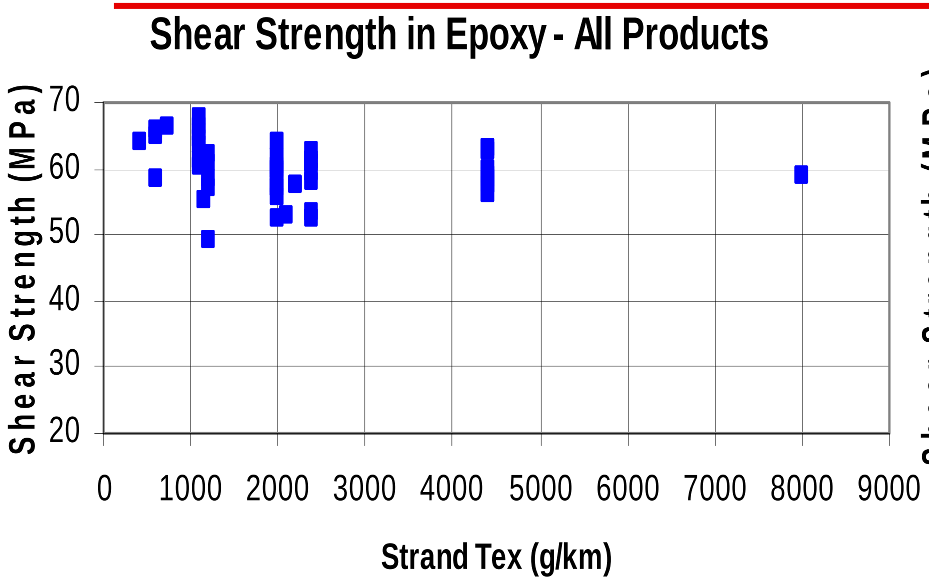


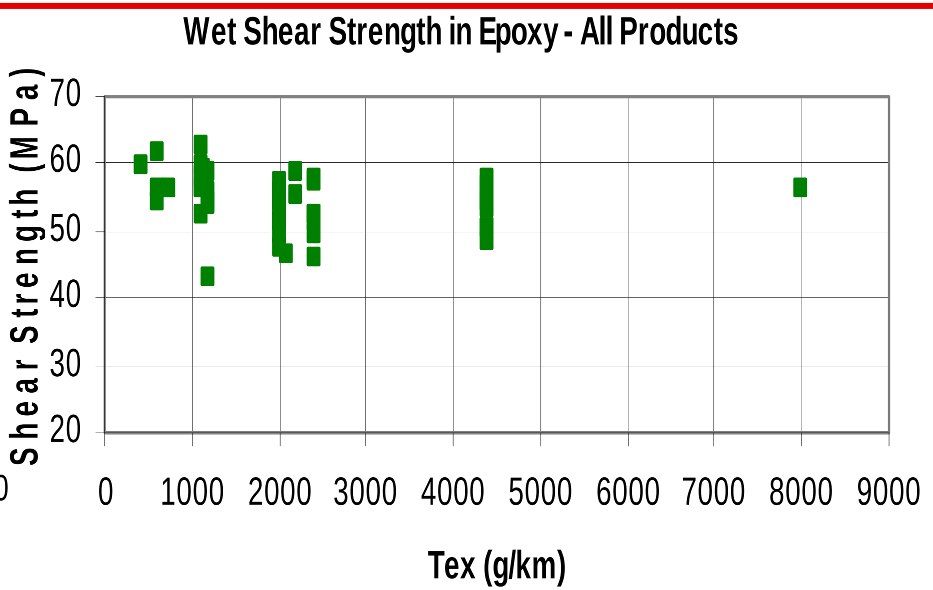


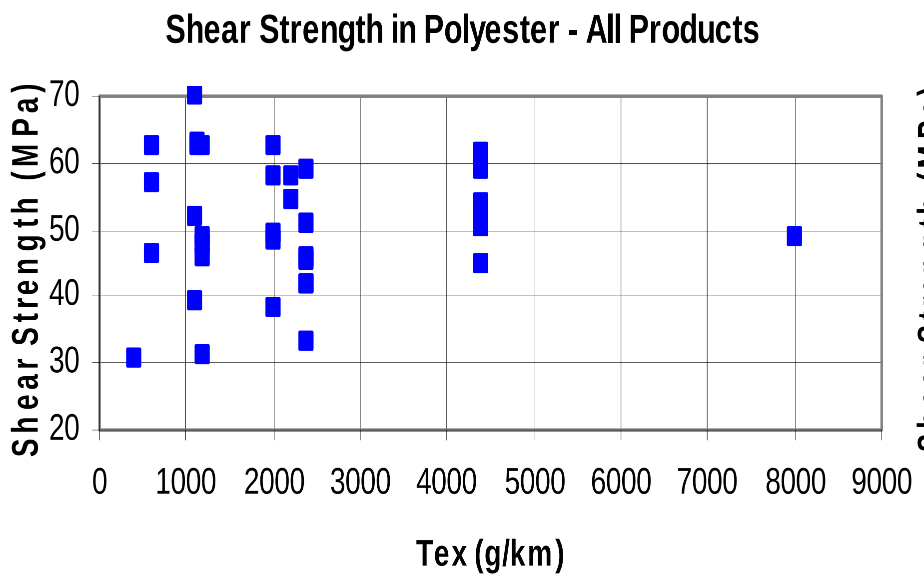


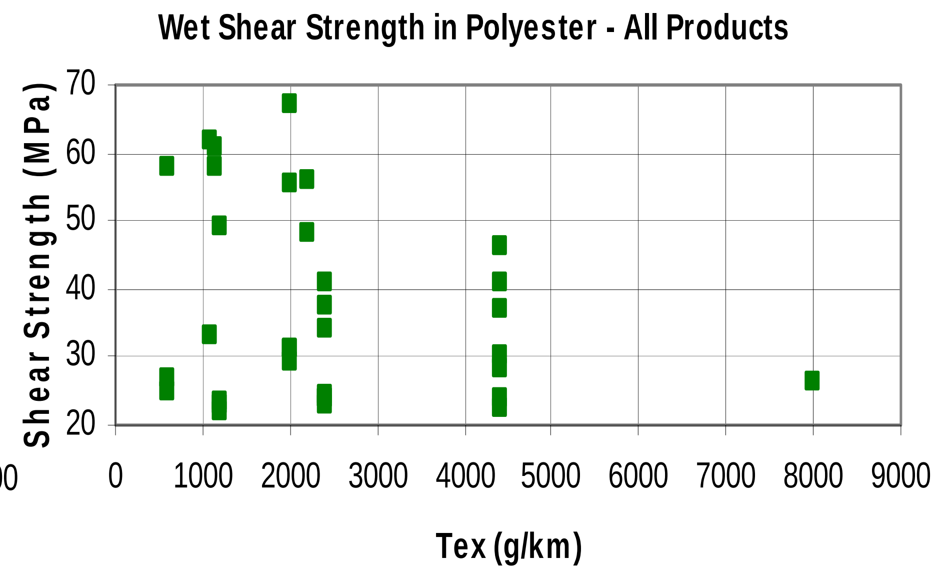


Glass-Resin Adhesion Hot/Wet Retention









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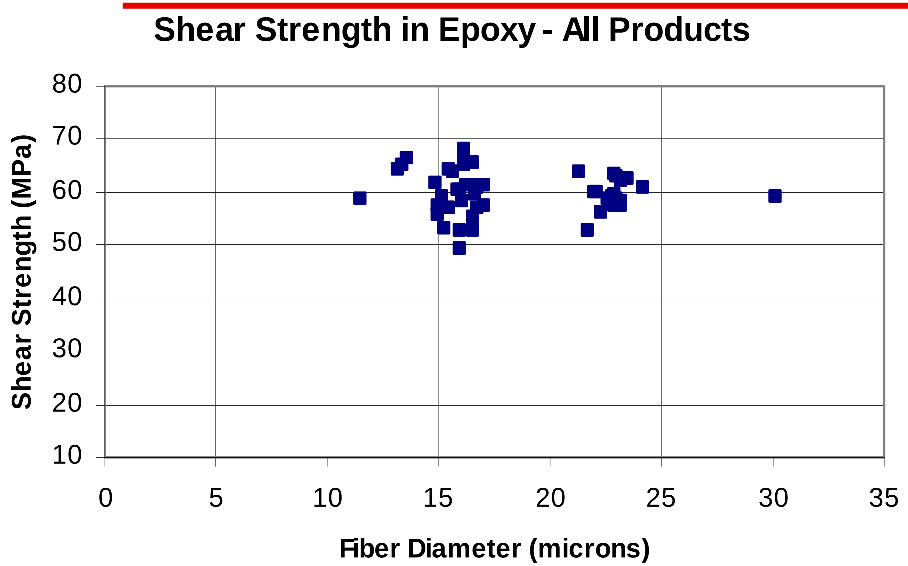
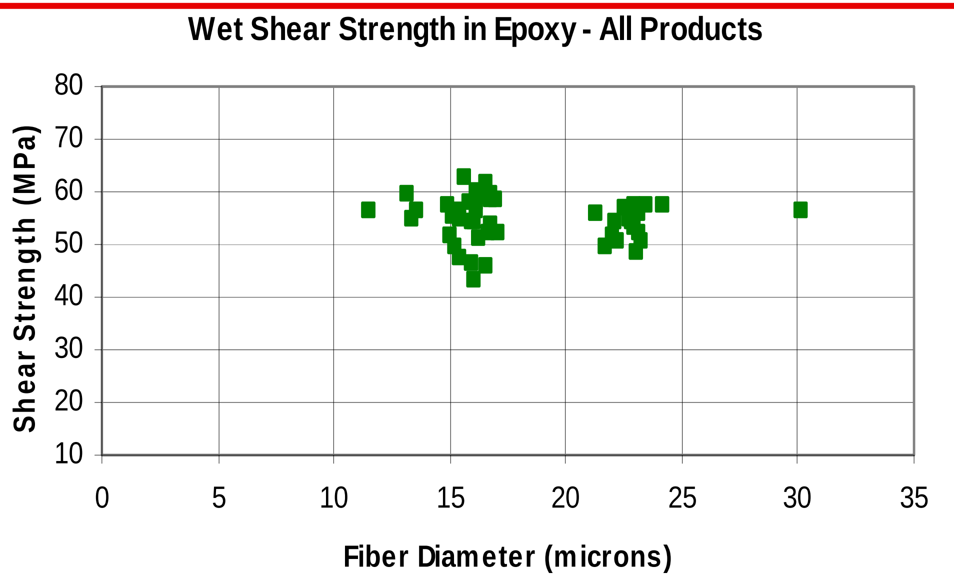
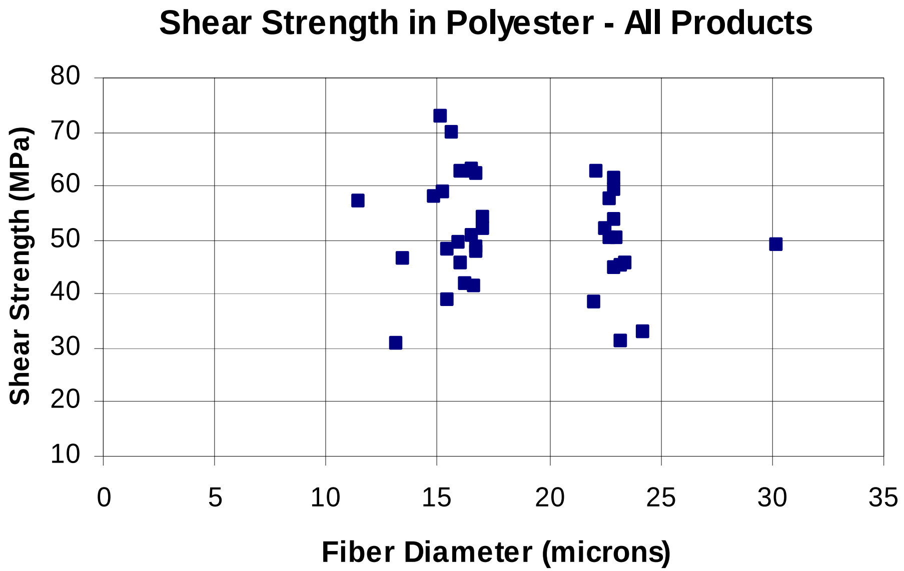
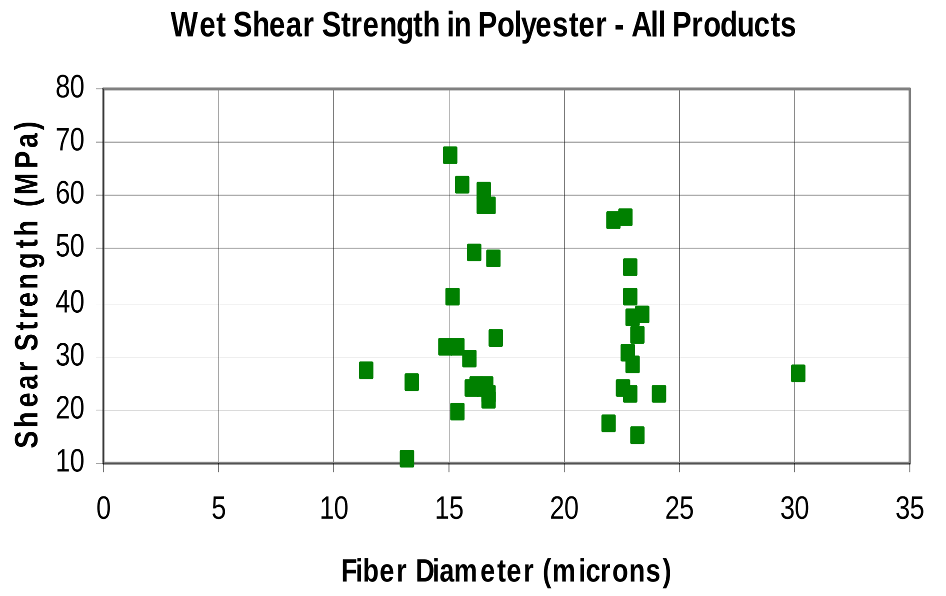
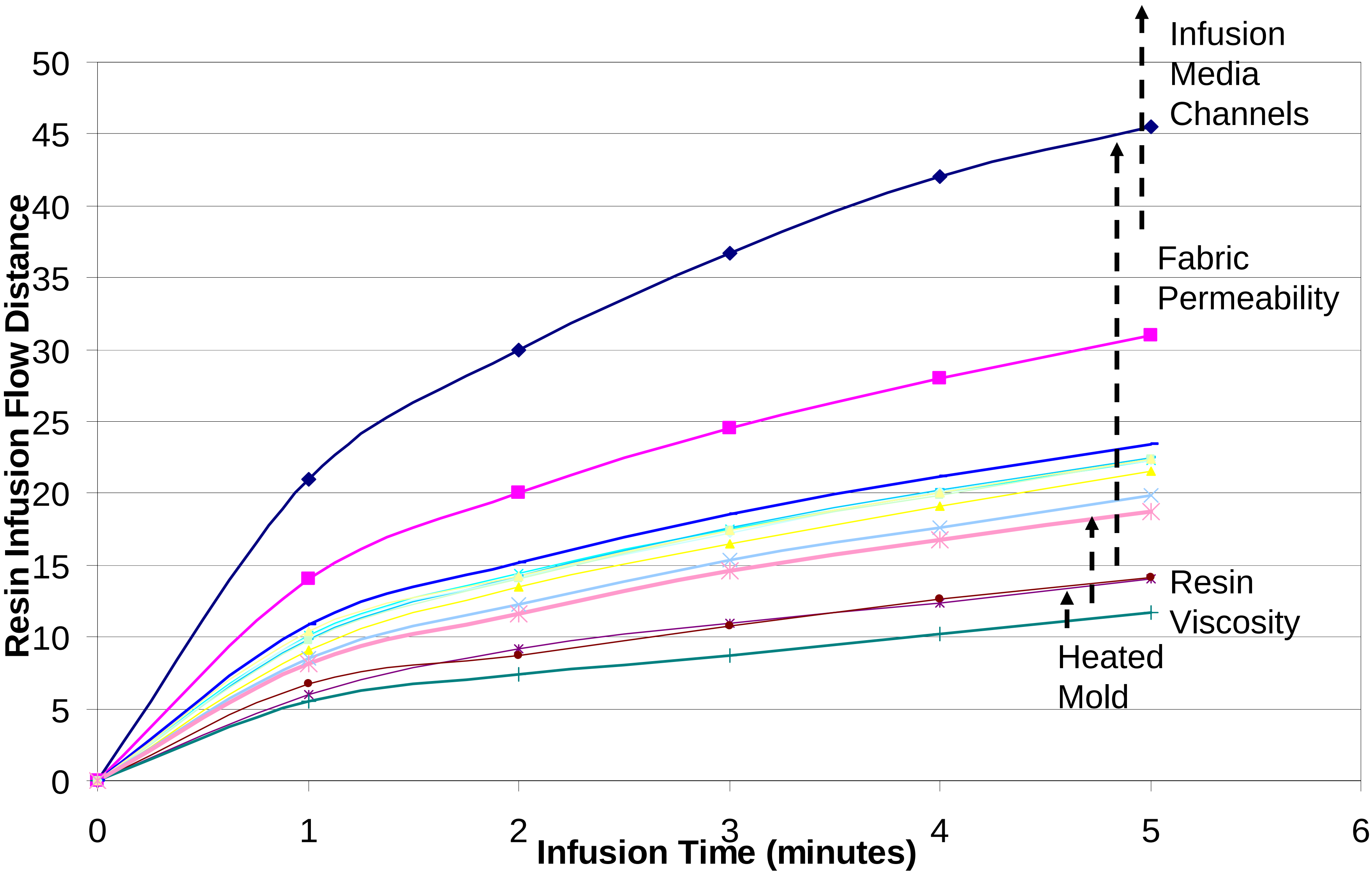








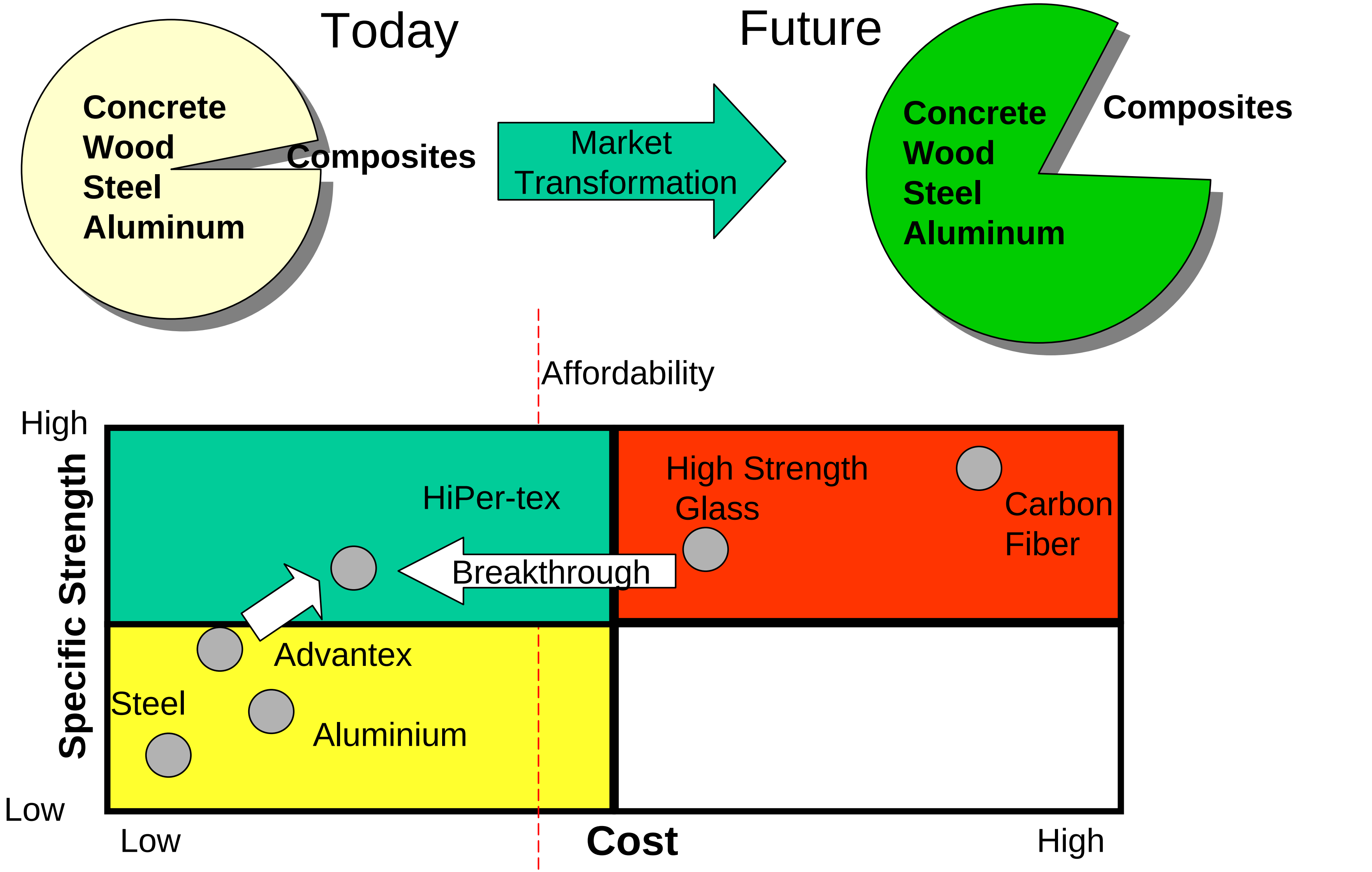
Improvements in Fabric Design on Resin Infusion Flow Rate and Quality



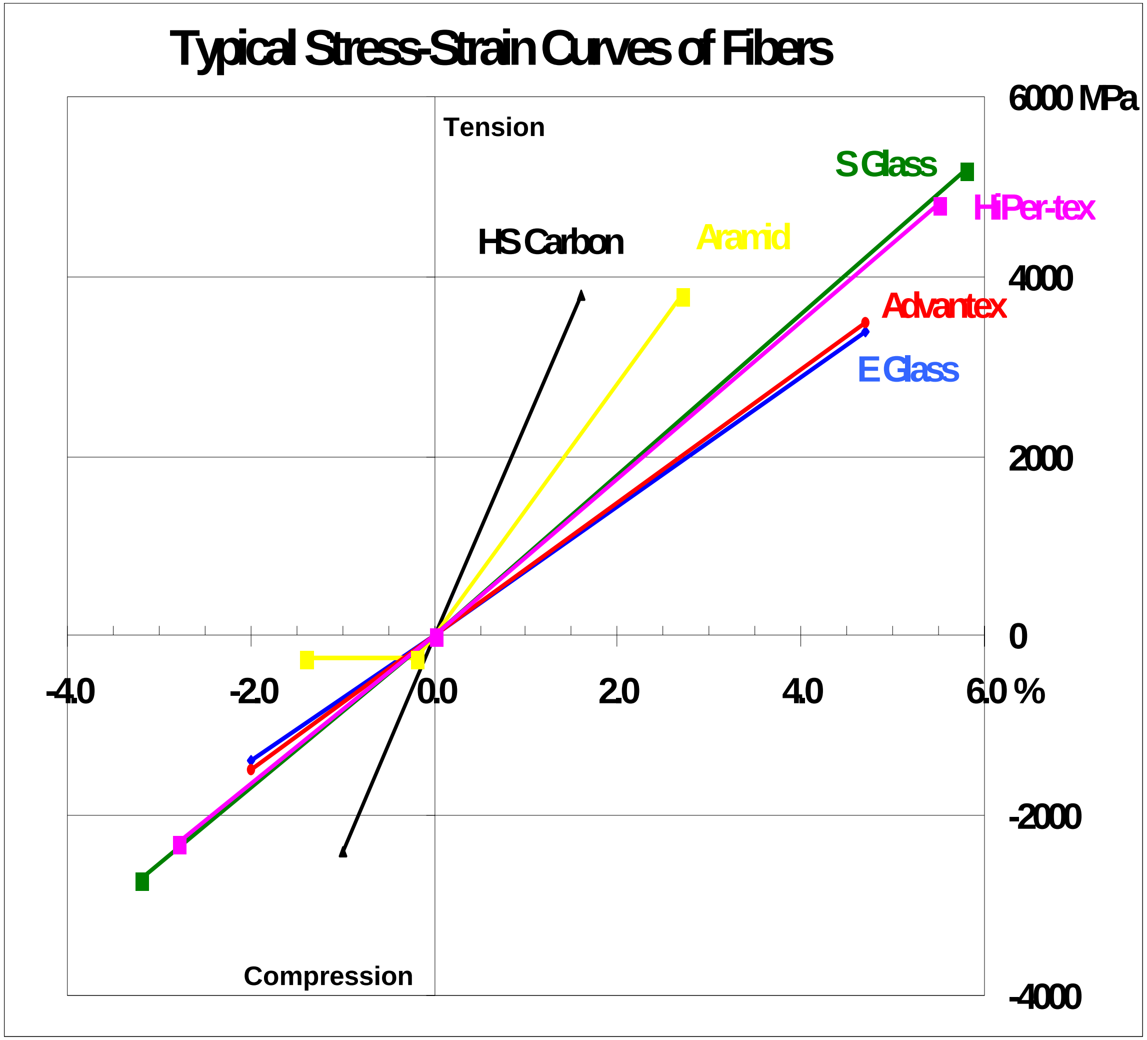
To Improve Blade COE and Reliability

- Owens Corning introduces HiPer-tex™ WindStrand™ in 2006
- HiPer-tex is a family of breakthrough reinforcements
  - New glass formulation
  - New melting technology
  - New fiberizing technology
  - New sizing technology
  - High capacity platform
- HiPer-tex WindStrand SE2350M2 is a single end reinforcement engineered for epoxy prepreg and resin infusion of wind blades with higher modulus, strength, fatigue resistance and corrosion resistance than Advantex
- WindStrand meets DIN 53811 available in 600, 1200 and 2400 tex
- WindStrand fabrics available uniaxial C1000 and biaxial CDM1250

HiPer-tex™ is a Breakthrough Improvement in Cost Performance



HiPer-tex WindStrand™ Performance



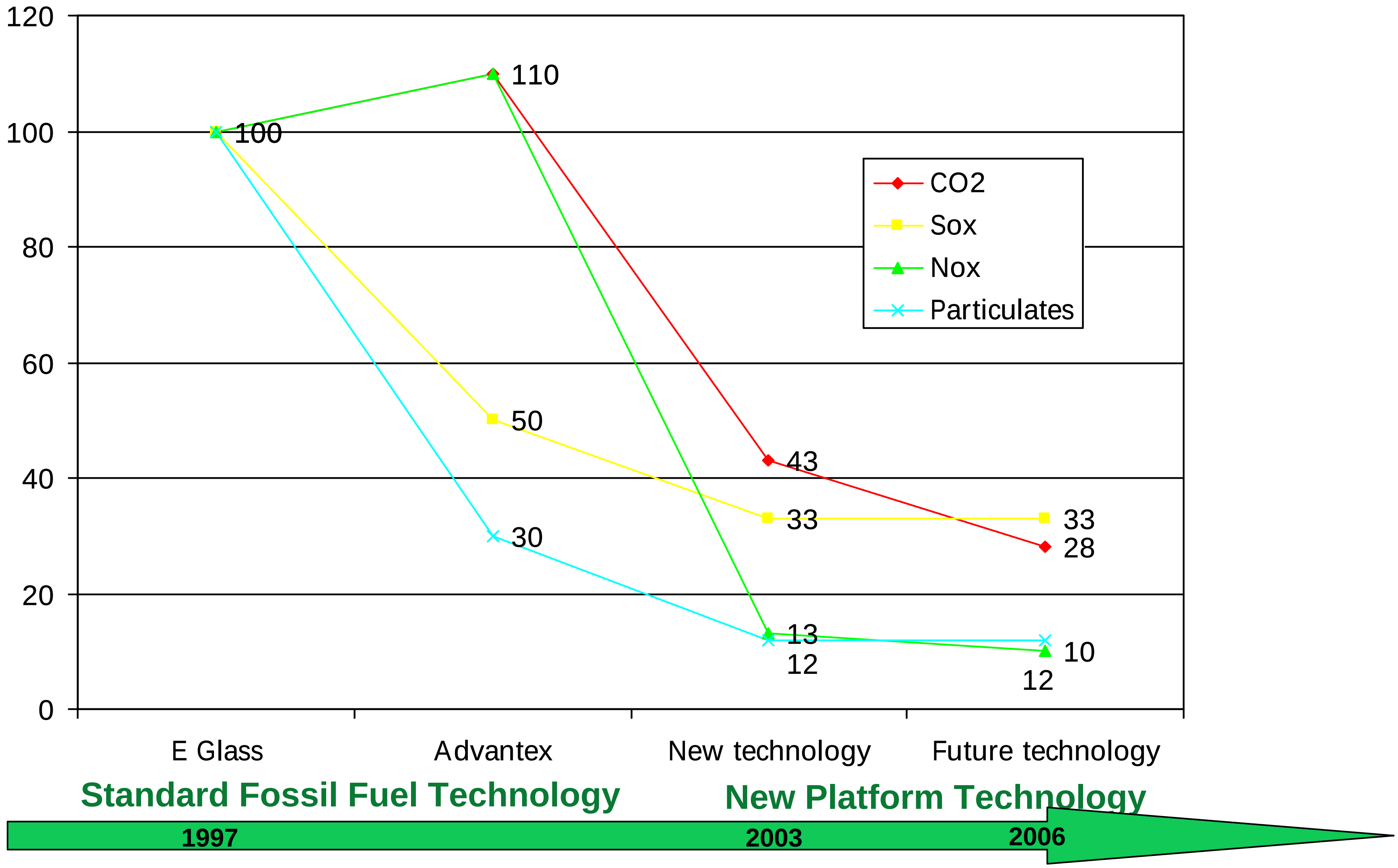
Improvement over Advantex

- 35% higher strength
- 17% higher modulus
- Better impact energy
- Better fatigue properties
- Superior corrosion resistance
- Higher temperature resistance
- 30% better CTE

Improvement over other high performance fibers

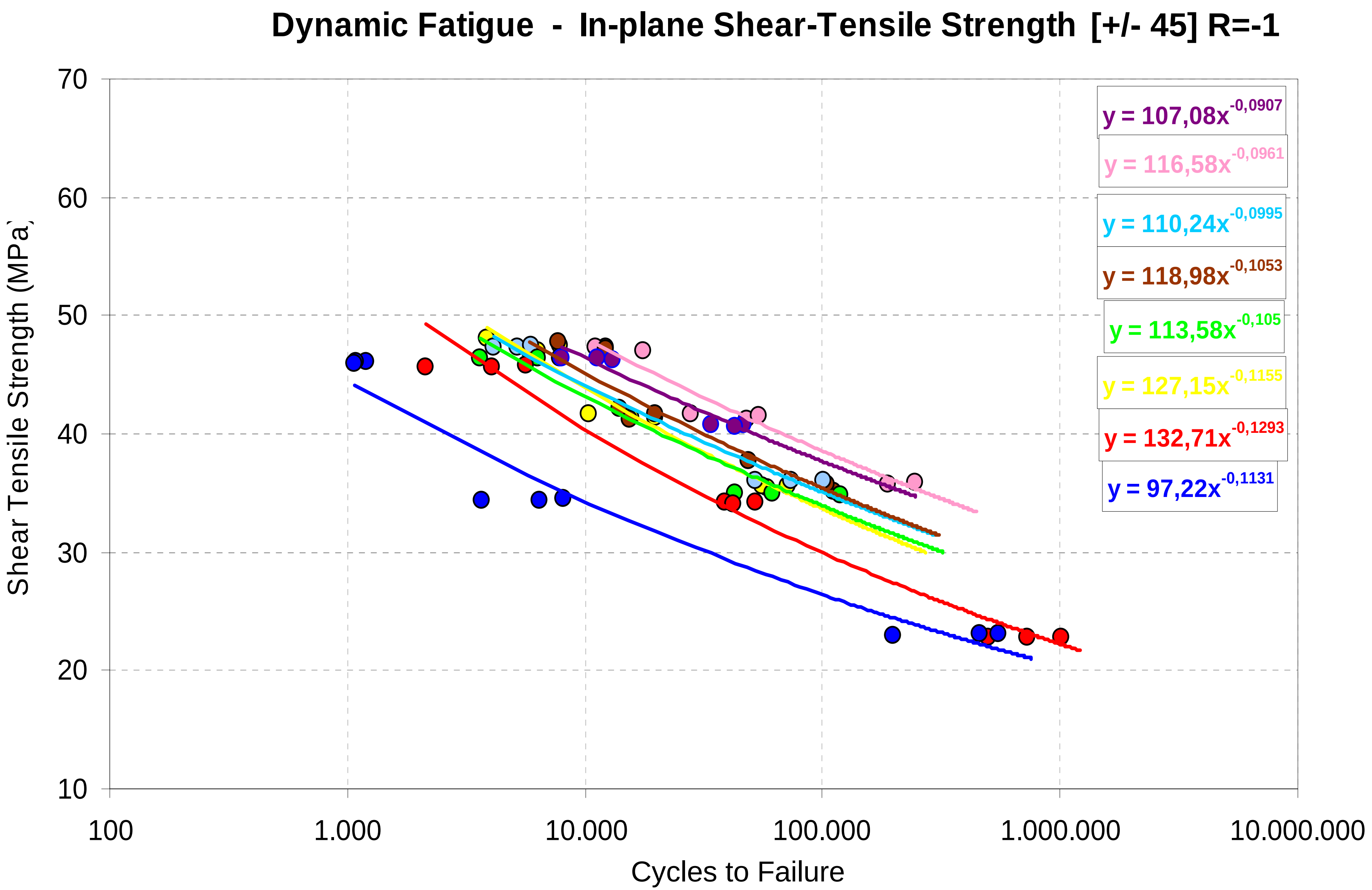
- Affordable
- Higher volume

Fibers Produced With Smaller Environmental Footprint on our Planet

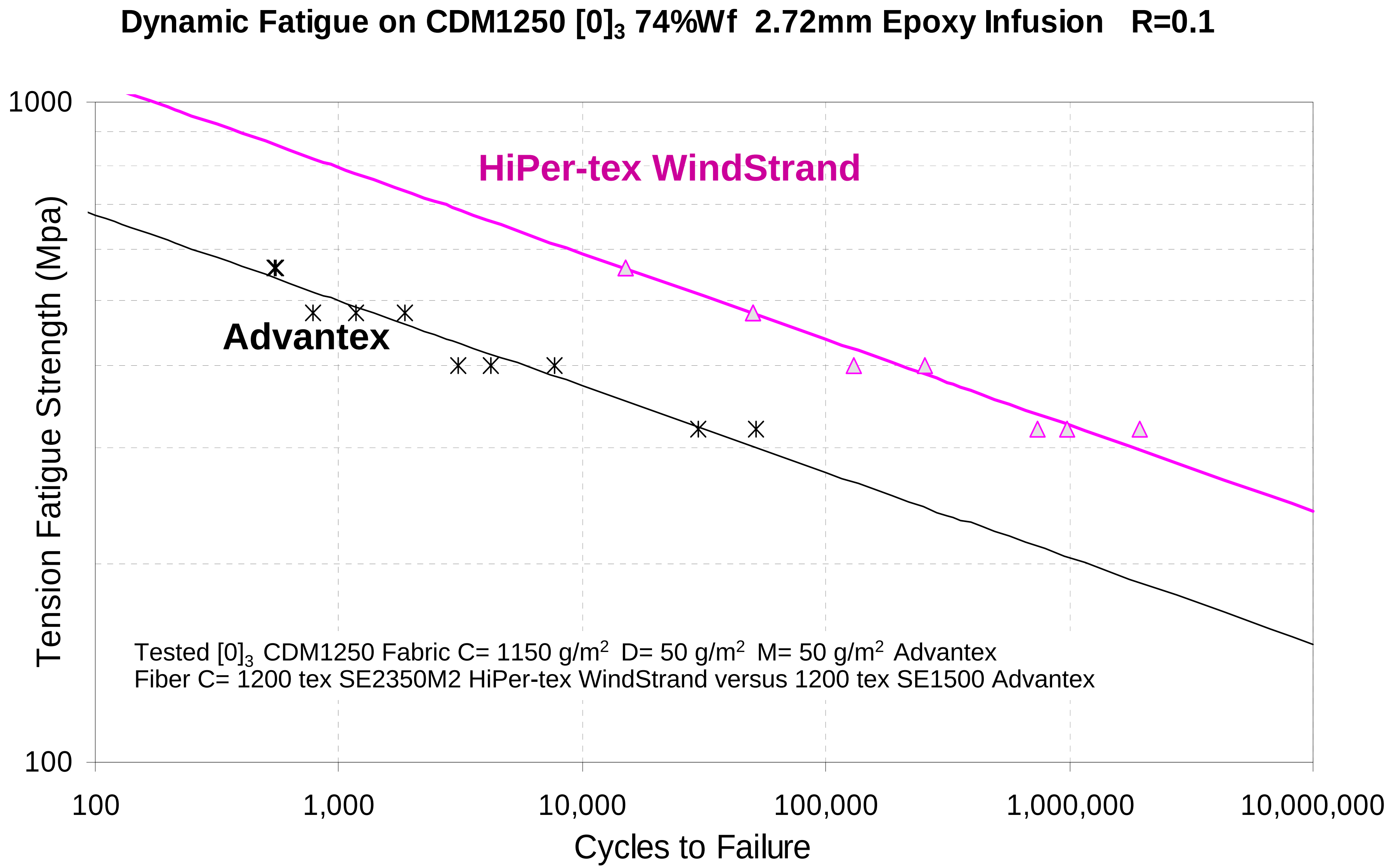


Significant reduction in CO2 and air pollutants emission

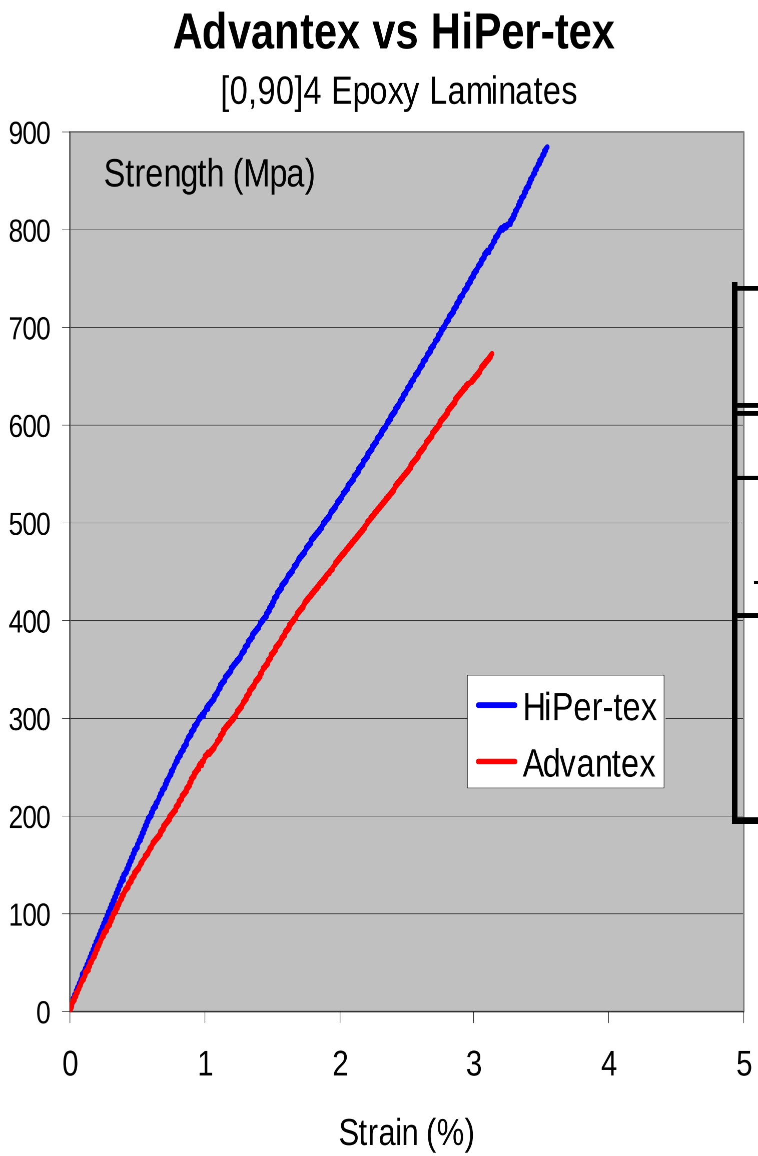
Glass-Resin Adhesion Improves Fatigue



HiPer-tex Improves Fatigue Strength



HiPer-tex Biaxial Epoxy Laminates



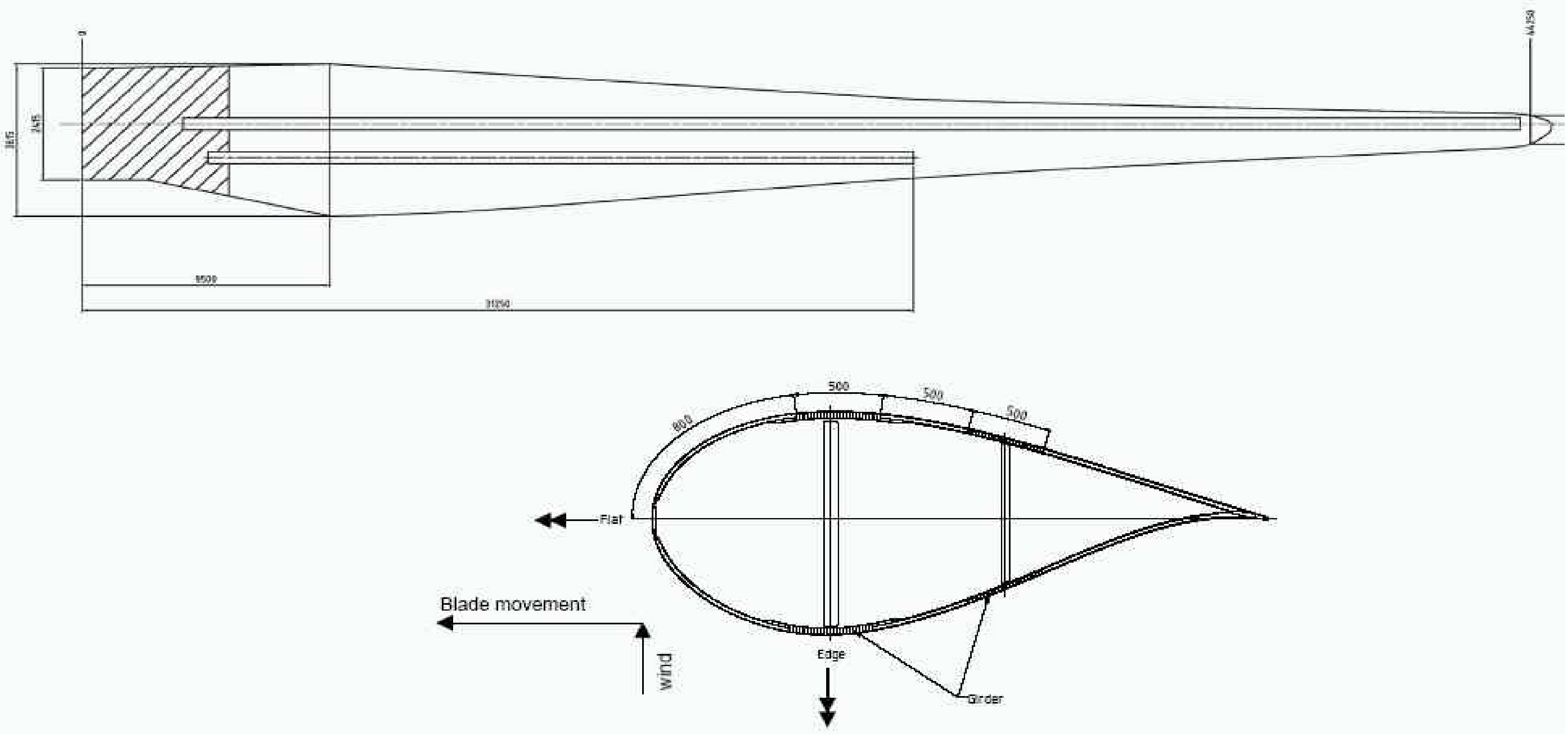
Property	Advantex	HiPer-tex	Change (%)
Fiber weight content (%)	78.5	78.6	0%
+-45° Tensile shear (MPa)	132.6	135.4	2%
+-45° Tensile modulus (GPa)	14.2	15.3	8%
0-90 Tensile strength (MPa)	673	885	32%
0-90 Tensile Modulus (GPa)	27.1	32.2	19%
Strain Energy (J/cm3)	11.4	16.6	46%

HiPer-tex CTC Analysis
NO144 Rotor Blade Specification

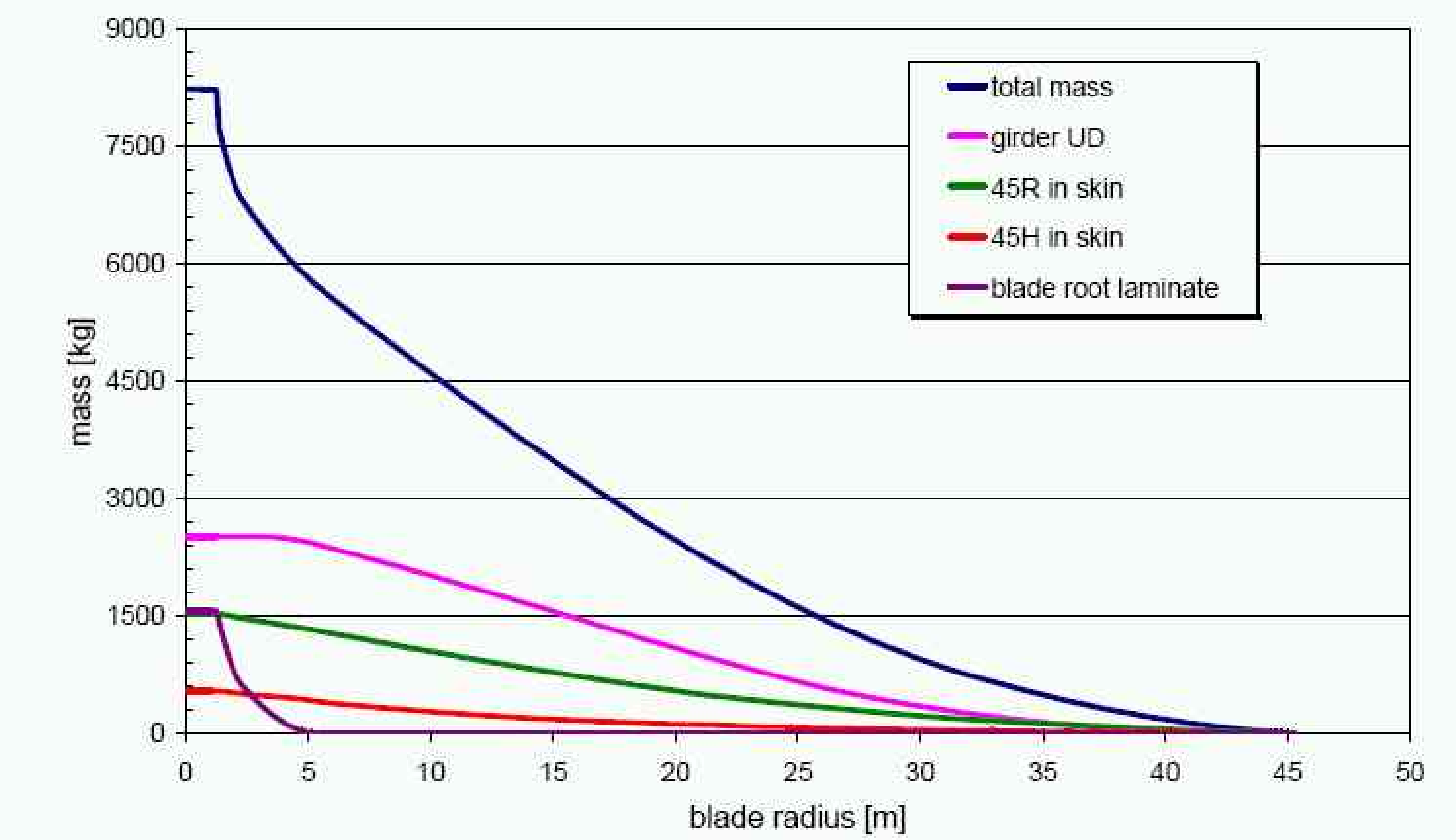
- Designed for 2.5 MW, wind class 2
- Meets Germanischer Lloyd regulation
- E Glass / Epoxy Basis
- Vacuum Infusion production technique
- 44 m blade length
- Blade mass 7900 kgs (excl. steel parts)
- Fatigue is dominant design criteria

NO144 Blade Structure

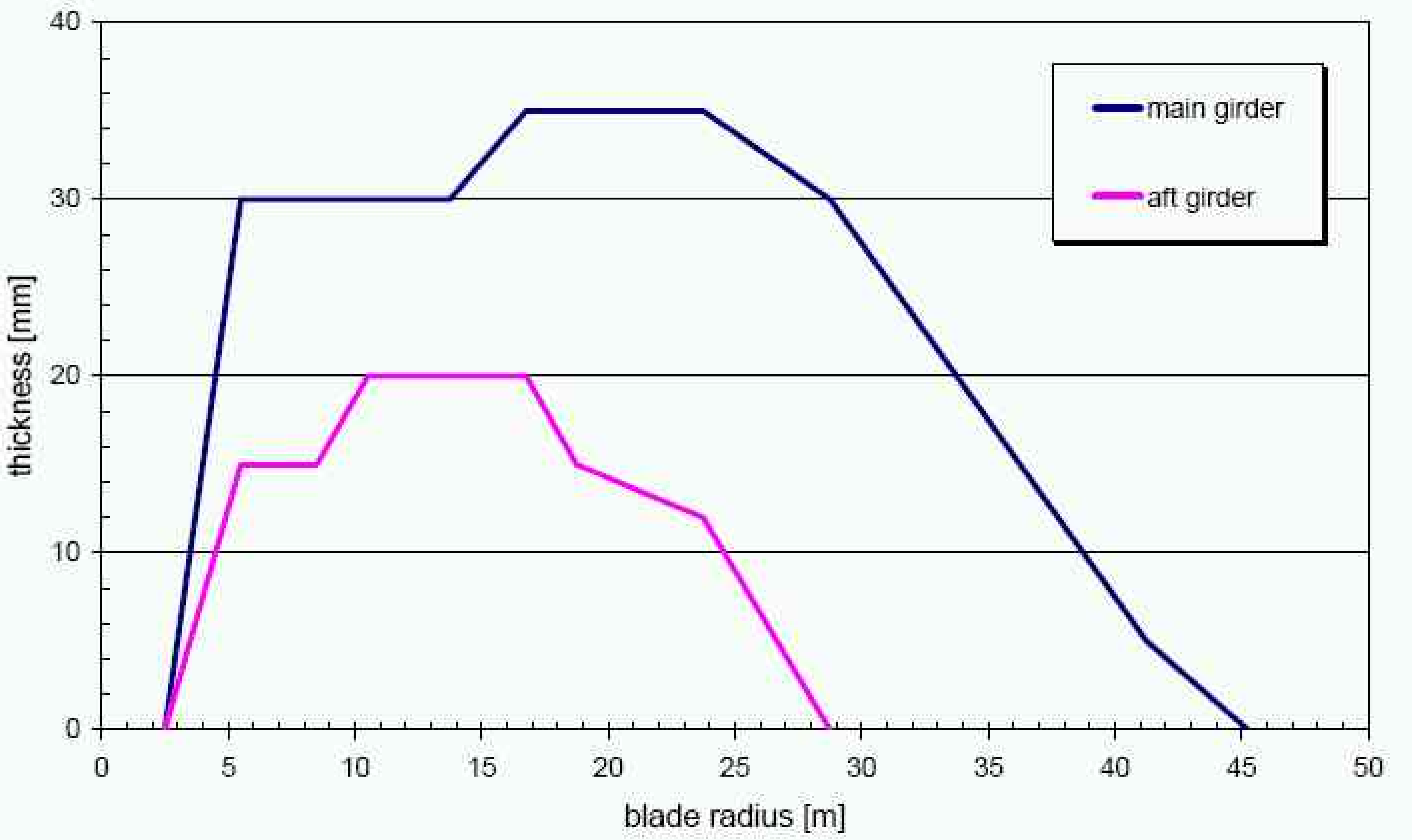
- Discrete girder design
- For Girders 0° tape (91.4% in UD, 8.6% in transverse)
- For Skins biaxial laminate with core sandwich



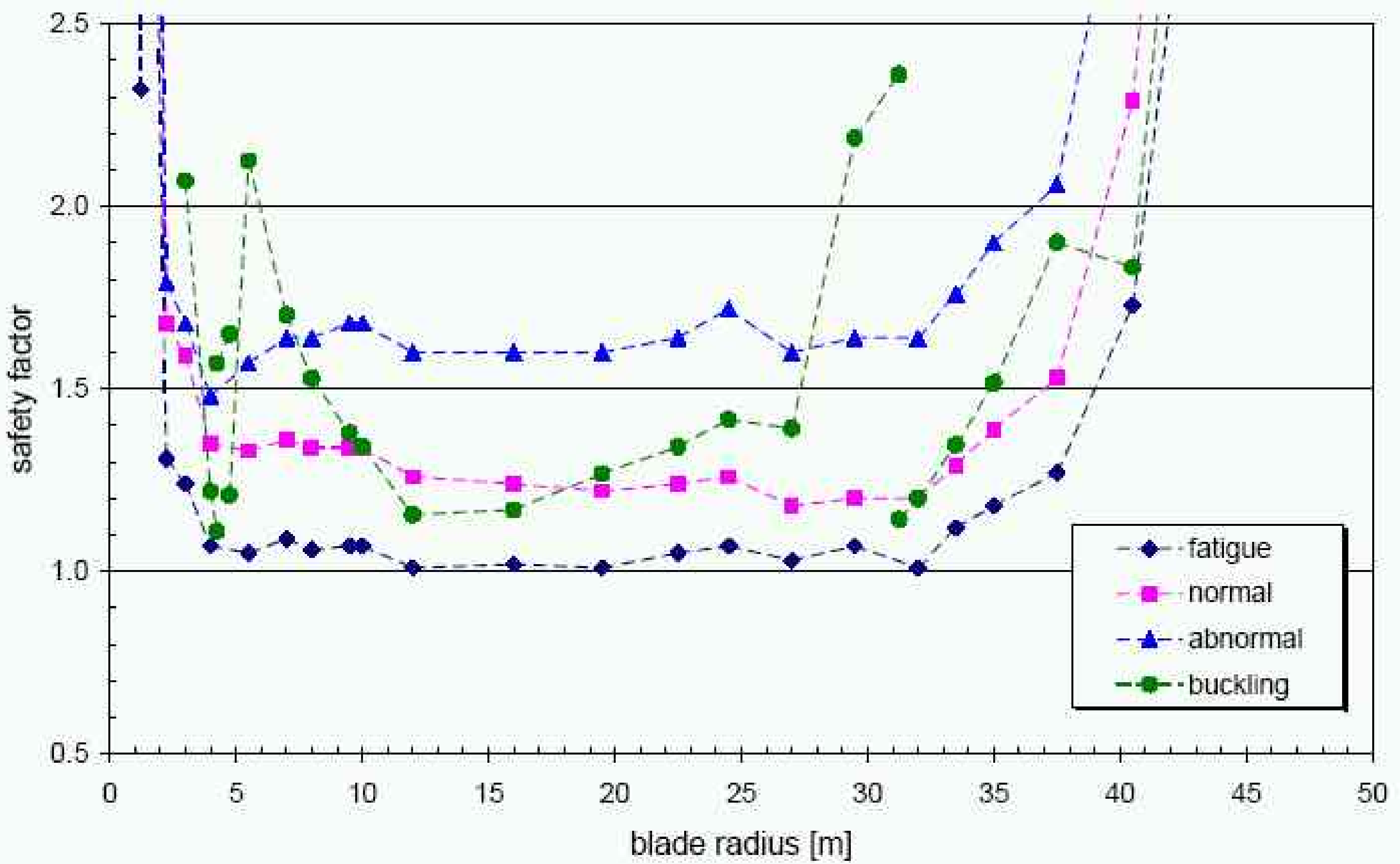
Mass Distribution Along Blade Length



Girder Thickness for the NOI44



Safety Factors Along Blade for NO144 Baseline and Design Criteria



NO144 Section Analysis

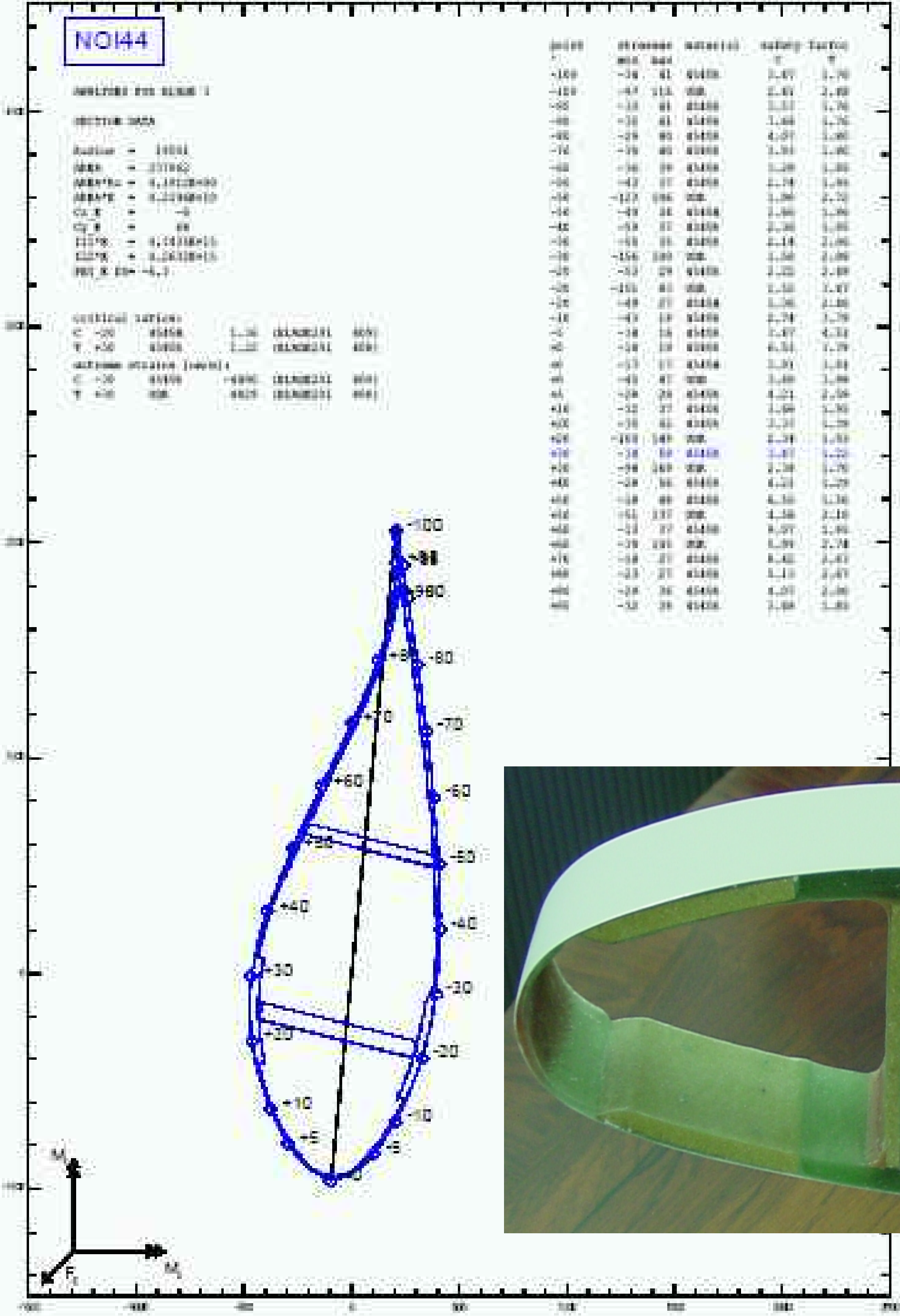


Figure 6: FOCUS output for strength validation (normal cases, blade 3)

HiPer-tex WindStrand Performance

- Enables blade manufacturer to reduce blade weight by up to 10%
- Enables up to 6% longer blades with no increase in weight
- Provides opportunity to translate benefits into more power
- Ultimately results in a lower cost per kWh