PPG Industries

Empowering Wind

Influence Of Fiber Glass Sizings and Resin Selection on Laminate Performance

Sandia Blade Workshop

May 13, 2008

Technology Leader

- The world's leading supplier of paints, chemicals, optical products, and specialty materials.
- Among the world's two largest suppliers of fiber glass and coatings.
- Traded on the New York Stock Exchange with sales in 2007 of $11.2 Billion.
- Industries served: automotive, aerospace, shipbuilding, architecture, packaging, optics, industrial and consumer products.
- Invests more than $300 million annually in research and development.

Global Resource

- Global supplier with 150 production facilities in more than 60 countries
- Established support network in sales, distribution and field technical service
- Tailored products delivered anywhere on any scale
- Speed of solution & speed of industrialization – from product conception to development to commercialization to you

What does fiber glass sizing bring?

- **To the blade designer/end user**
  - Strength/stiffness
  - Fatigue/durability
  - Optimized for resin of choice
- **To the blade builder**
  - Wetting/infusion
  - Part quality
  - Fabric conformity
- **To the fabric producer**
  - Low fuzz/abrasion
  - Even tension
  - Multiple resin compatibility

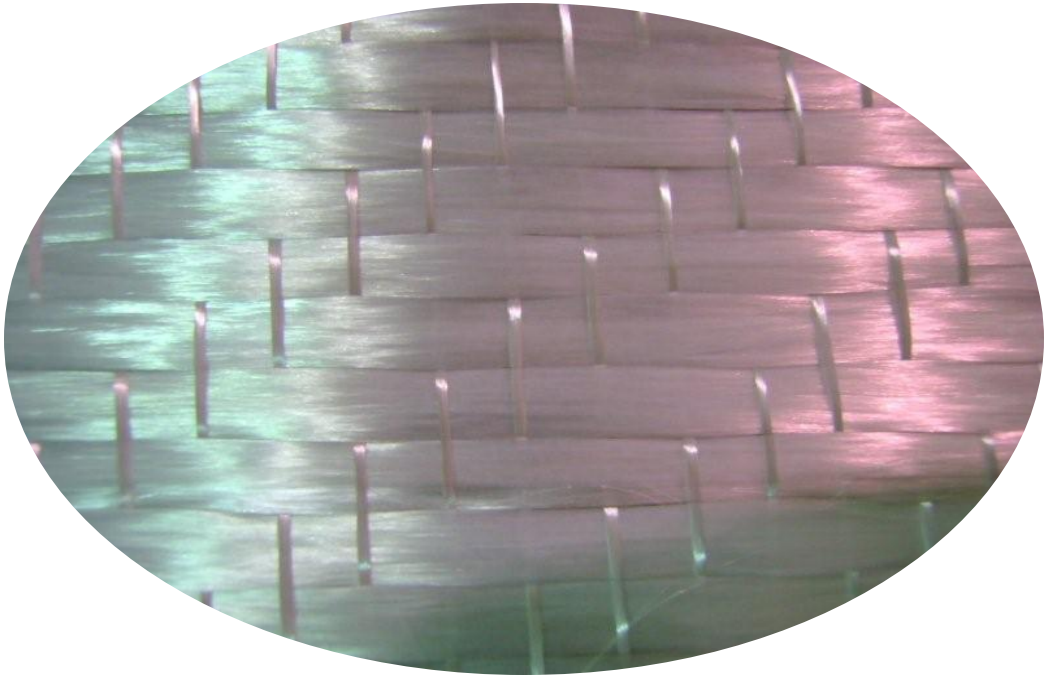
The World of Sizing

Blades on the order of 50 meters in length

Meters

The World of Sizing

Fabrics on the order of 1–2 meters wide



Meters

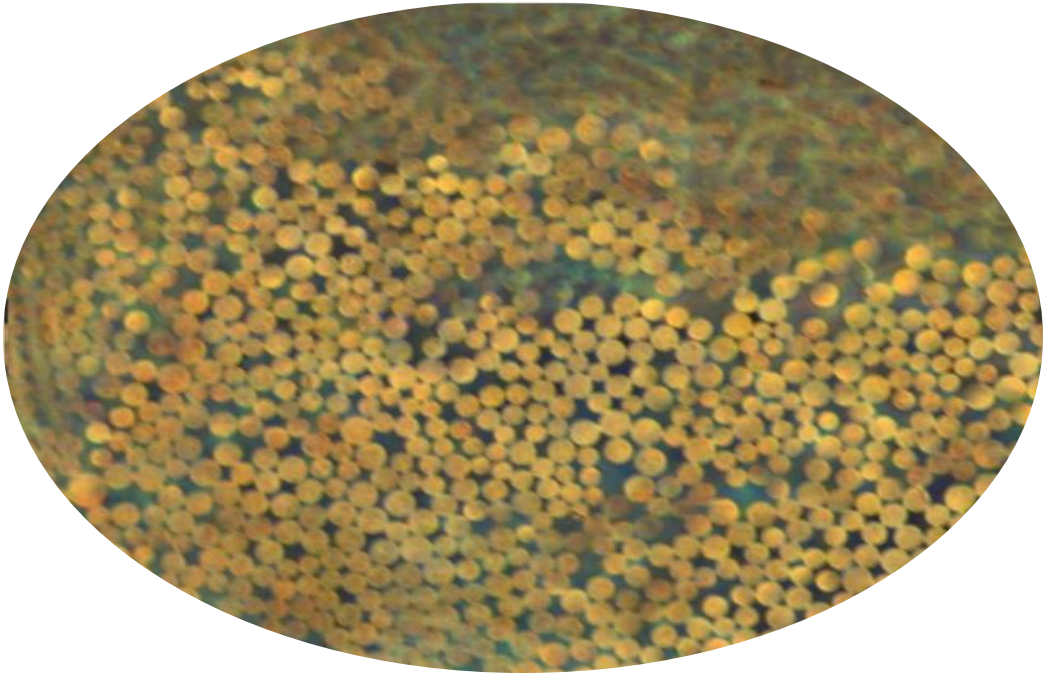
The World of Sizing

Rovings on the order of 300-2400 tex

Meters

The World of Sizing

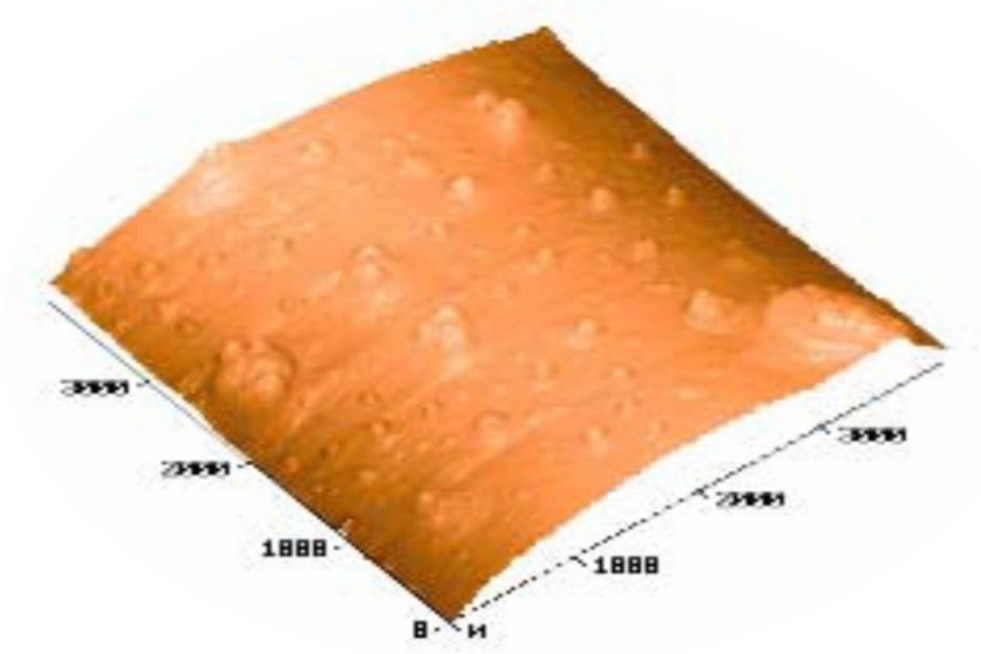
Fibers on the order of 17 microns diameter

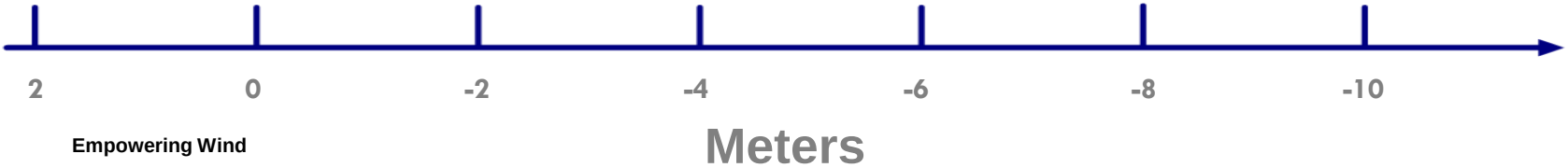


Meters

The World of Sizing

Sizings on the order of 50 nanometers

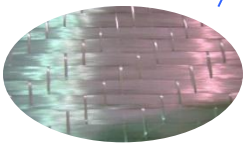




The World of Sizing

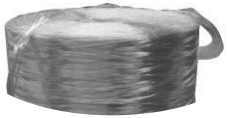
Needs at the 50 meter level

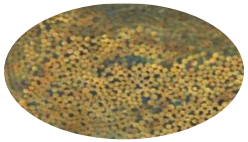
Infusion, fatigue, weight



Needs at the 1 meter level

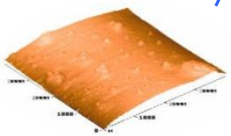
Fabric processing





Needs at the 1 mm level

Fiber processing



Design on a nano scale

2 0 -2 -4 -6 -8 -10

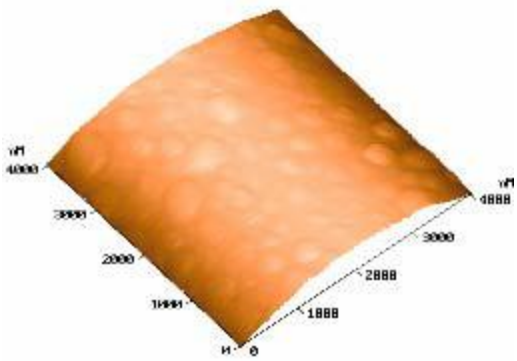
Meters

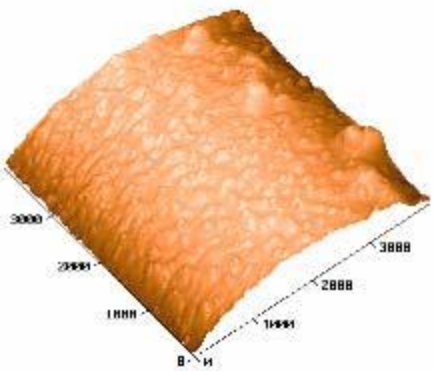
Empowering Wind

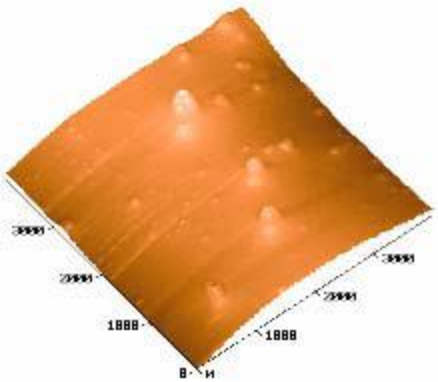
Typical Sizing Components

- **Coupling agents**
  - Organosilanes
- **Film-formers**
  - Critical to wetting
  - Critical to processability
- **Process Aids**
  - Fiber to fiber
  - Fiber to metal/ceramic

Sizing at the Surface
AFM Images

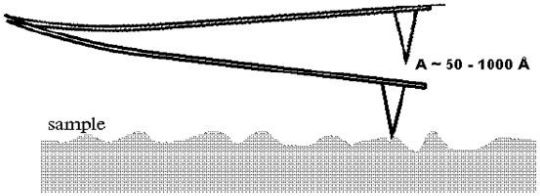




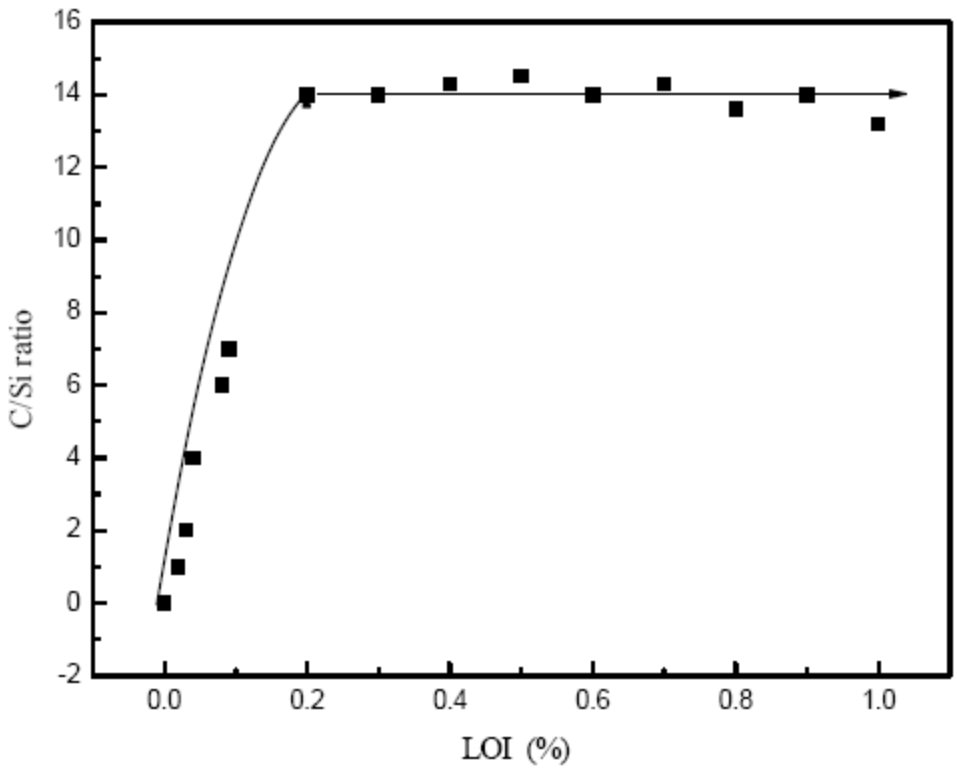


LOI = 0.091% **LOI = 0.16%** **LOI = 0.64%**

Typical coverage images for direct roving products used in wind blade fabrics



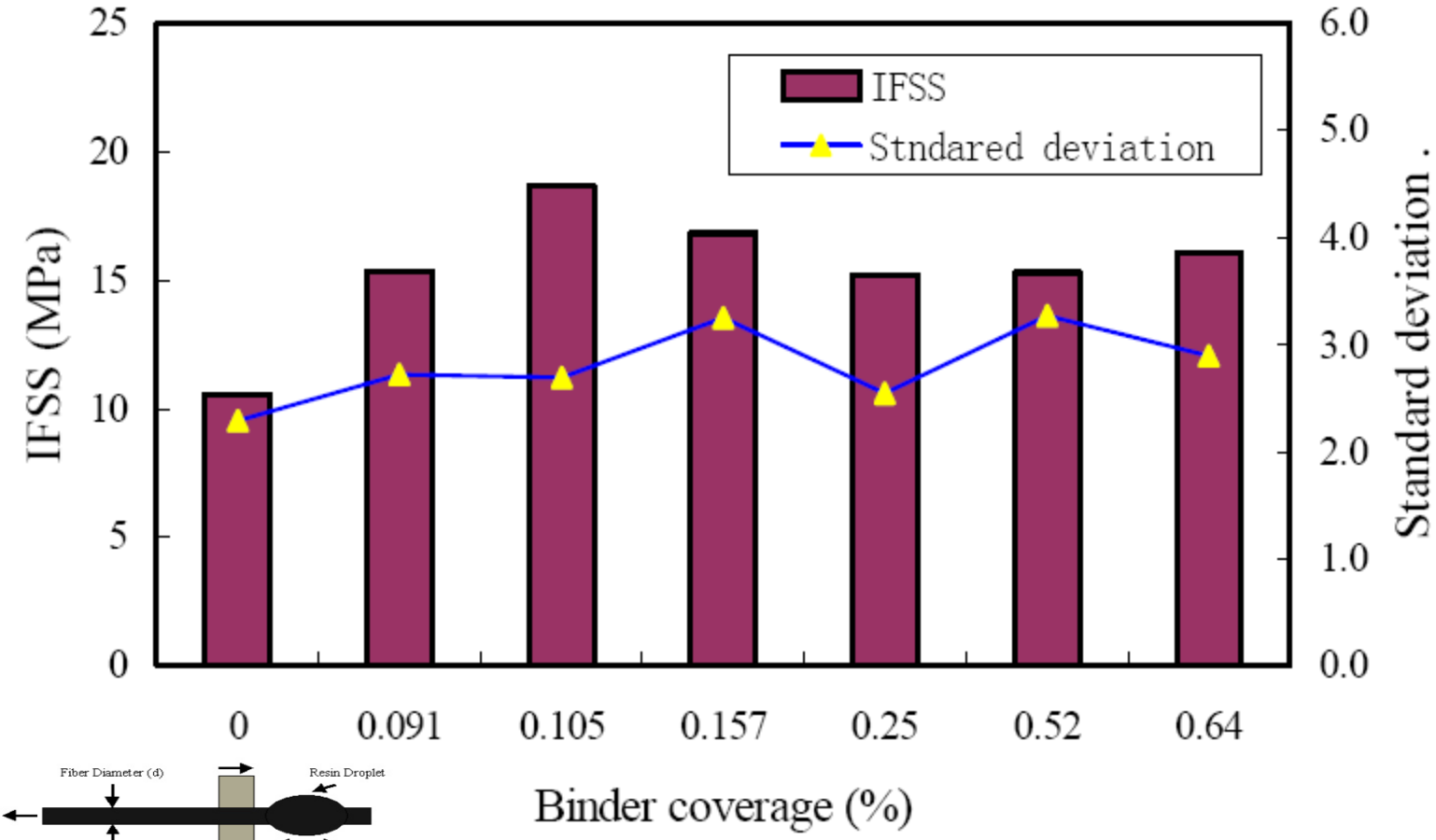
Sizing at the Surface Coverage Analysis

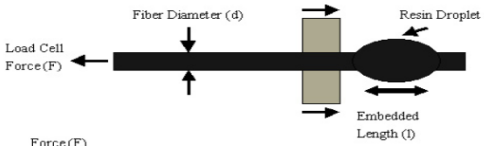


Complete coverage at ~0.20% sizing level

Calculated from XPS analysis of C/Si ratios

Sizing at the Surface Adhesion





Sizing at the Surface Conclusions

- Typical Sizing LOI ~ 0.5%
- Surface coverage is achieved at ~ 0.2%
- Adhesion is maximized at ~ 0.1%
- Additional sizing is typically needed for processing

Screening Methods

- Processing characterization
- Strand wetout characterization
- Filament wound cylinders
  - Short beam shear (SBS) tested per ASTM D2344
- % Retention after accelerated ageing
- % Voids

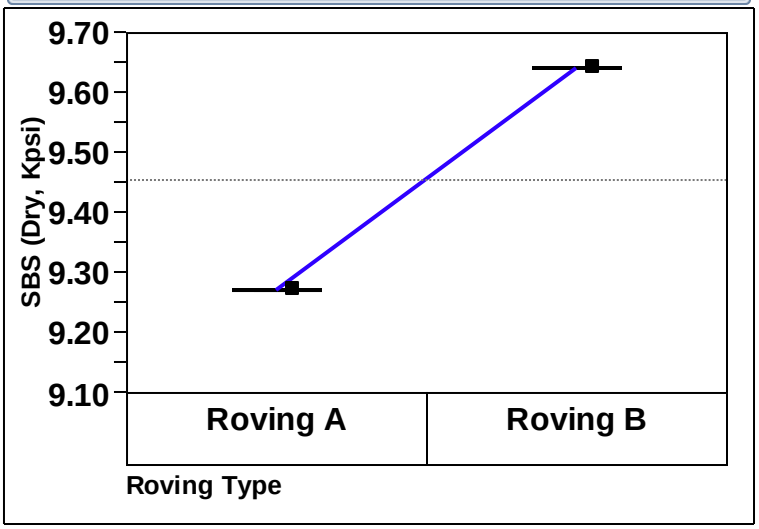
Epoxy Matrix Resin

Short Beam Shear (SBS)

Dry

Variability Gage Matrix Resin=Epoxy

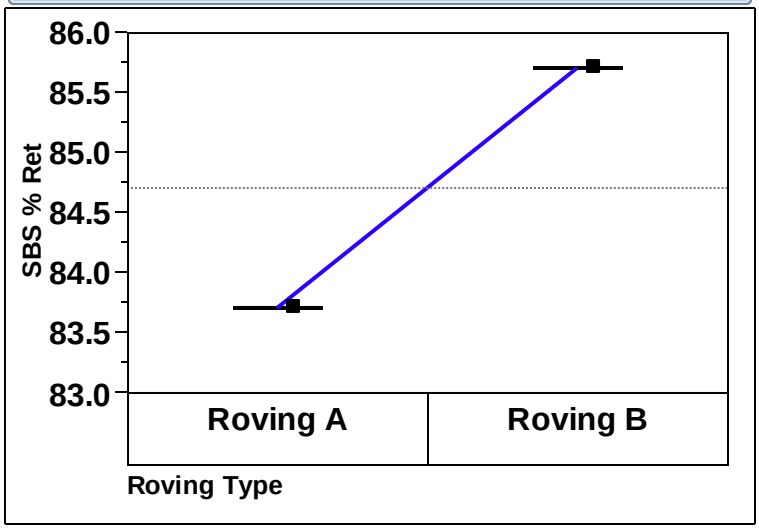
Variability Chart for SBS (Dry, Kpsi)



% Retention

Variability Gage Matrix Resin=Epoxy

Variability Chart for SBS % Ret



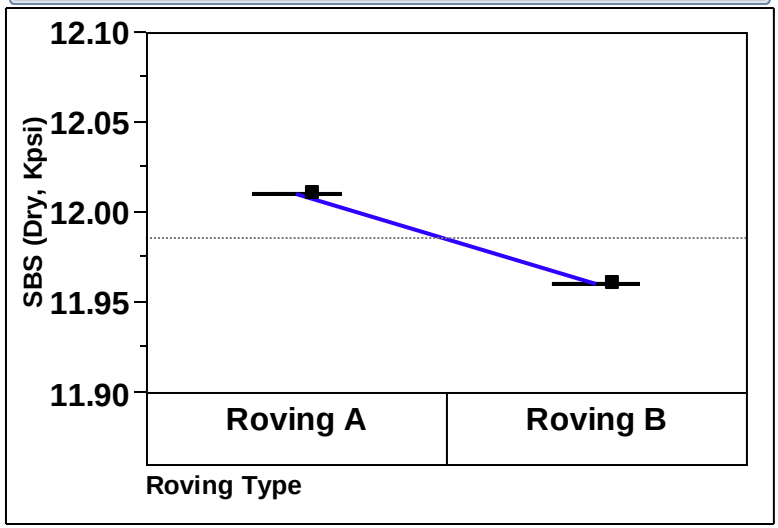
Vinyl Ester Matrix Resin

Short Beam Shear (SBS)

Dry

Variability Gage Matrix Resin=Vinyl Ester

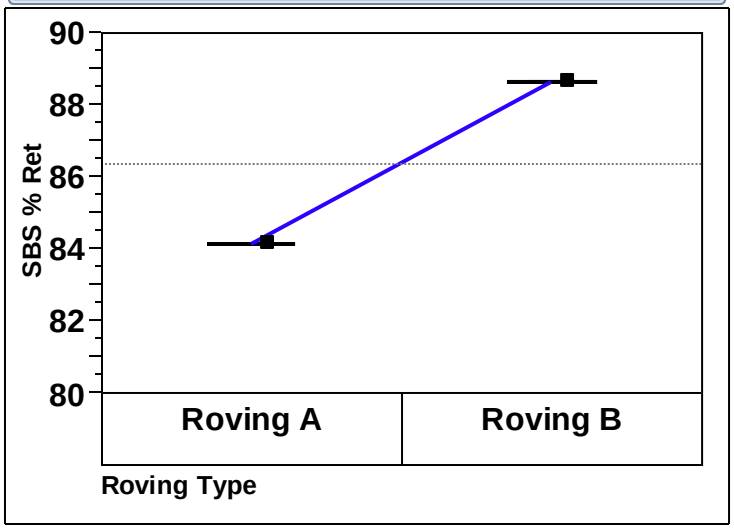
Variability Chart for SBS (Dry, Kpsi)



% Retention

Variability Gage Matrix Resin=Vinyl Ester

Variability Chart for SBS % Ret

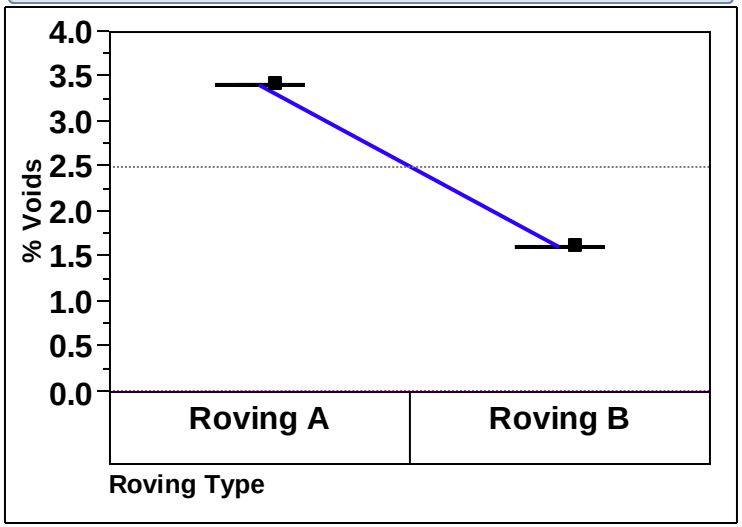


Epoxy Matrix Resin

Voids

Variability Gage Matrix Resin=Epoxy

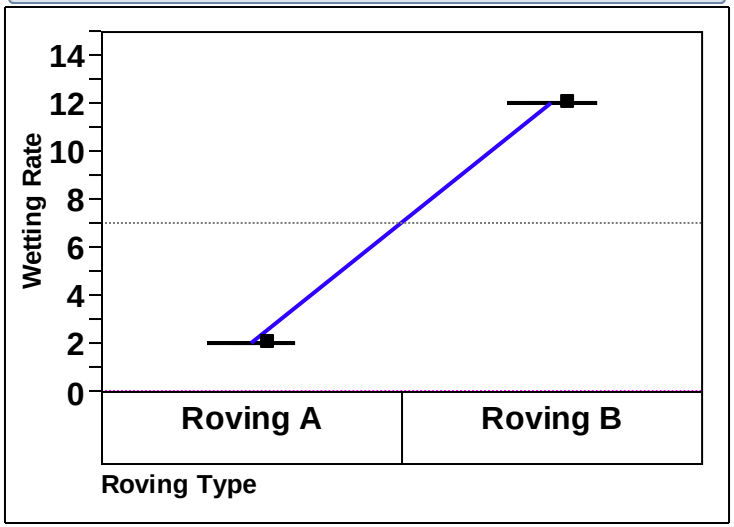
Variability Chart for % Voids



Wetting Rate

Variability Gage Matrix Resin=Epoxy

Variability Chart for Wetting Rate

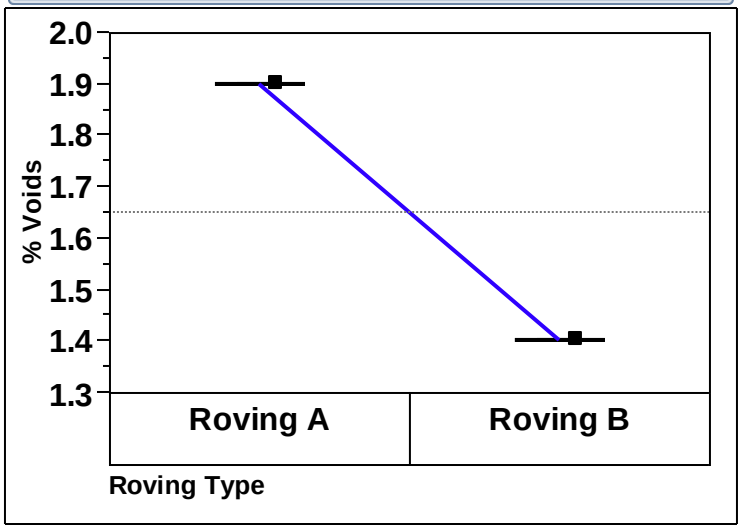


Vinyl Ester Matrix Resin

Voids

Variability Gage Matrix Resin=Vinyl Ester

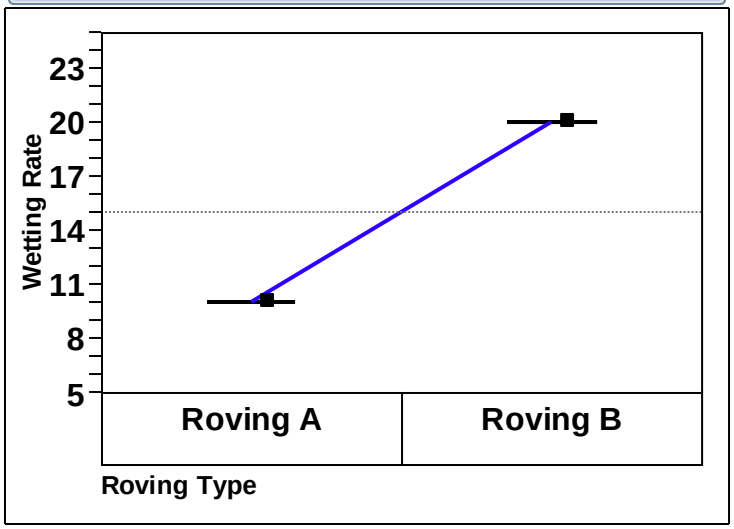
Variability Chart for % Voids



Wetting Rate

Variability Gage Matrix Resin=Vinyl Ester

Variability Chart for Wetting Rate



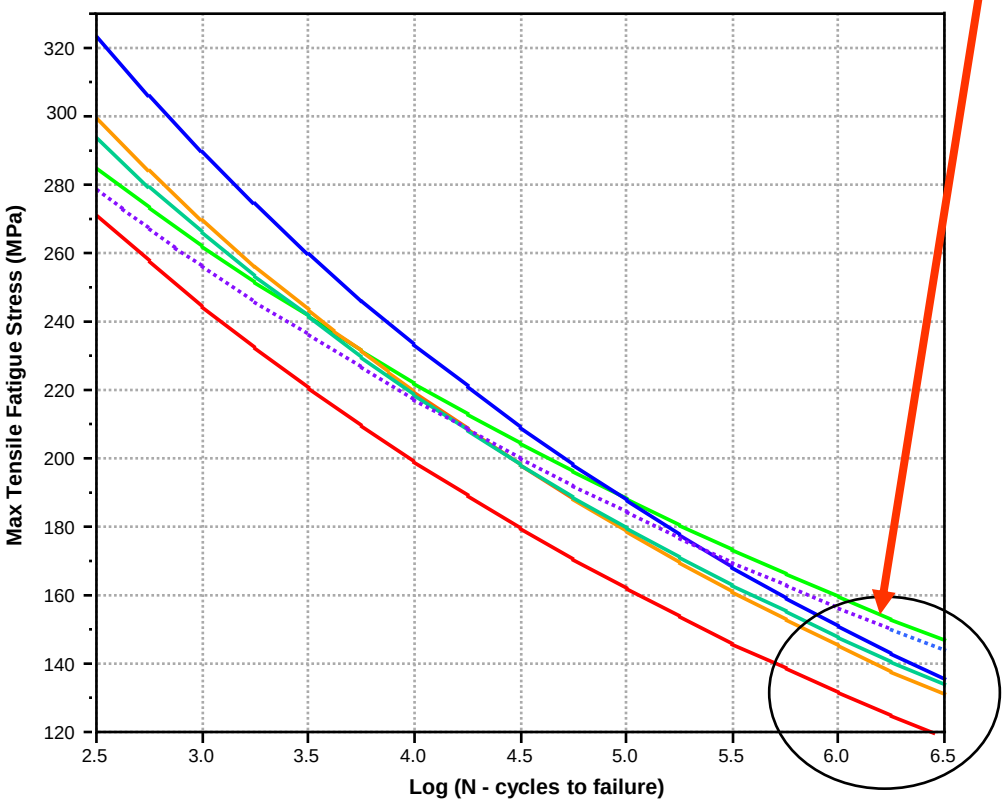
Basic Mechanical Properties

- Static properties provide direction
  - Adhesion
  - Wetting
  - Laminate quality
  - Strength/stiffness

Long Term Properties

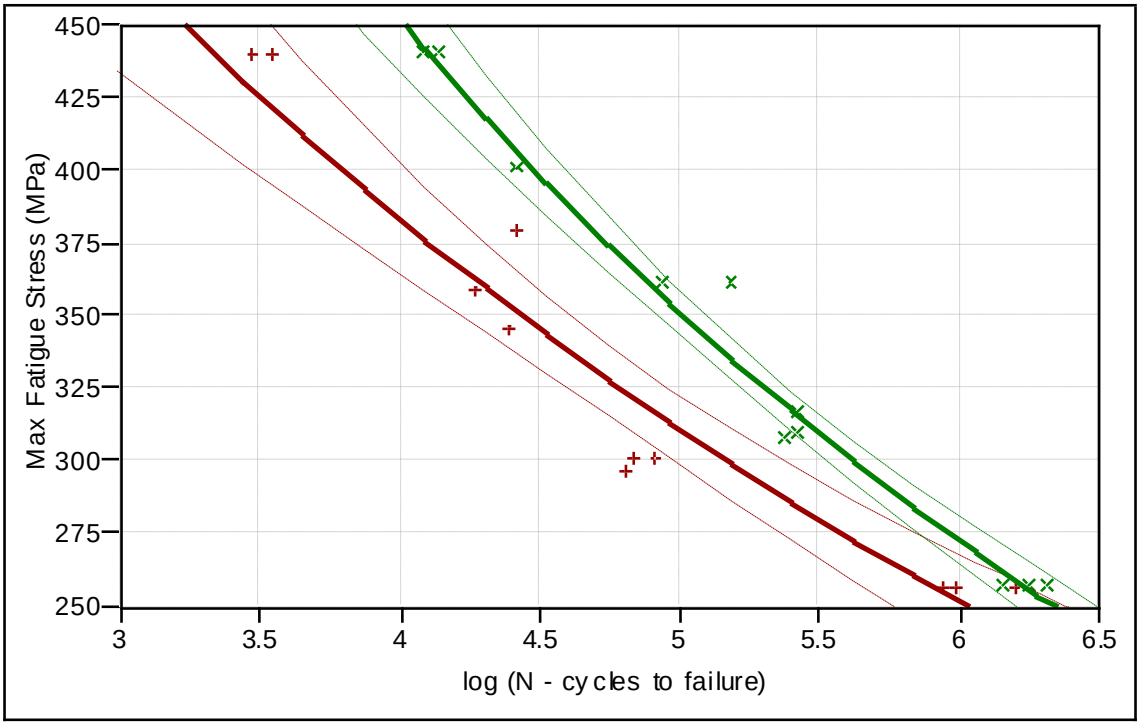
- Focus on fatigue
- Infused laminate attributes
- Processing rates

Epoxy Fatigue Performance



- High cyclic fatigue performance @ low stress critical to turbine flexing

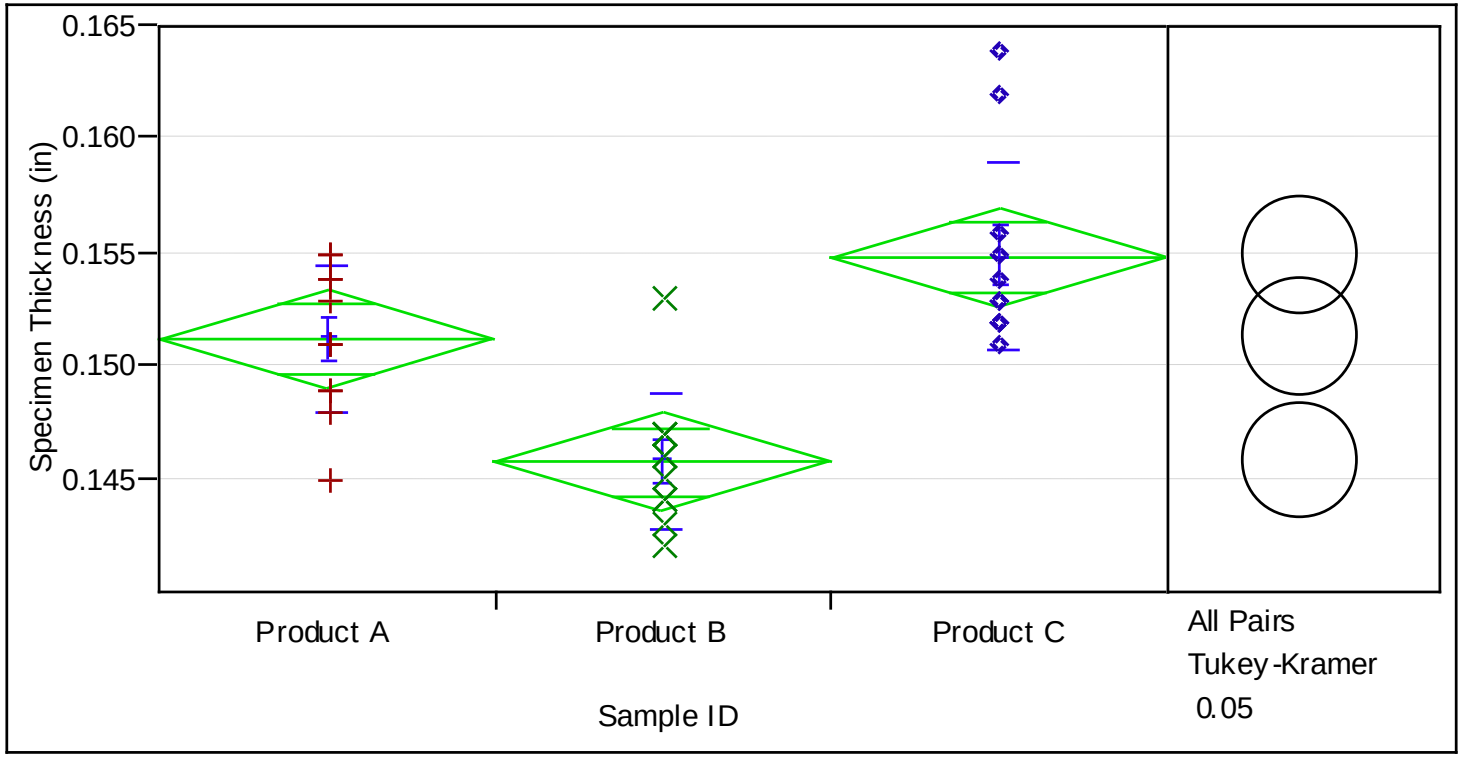
Epoxy Fatigue Performance



Transformed Fit Log Sample ID=="Product A"
Transformed Fit Log Sample ID=="Product B"

- Epoxy laminates include 3 inner layers of L1200 g/m² unidirectional fabric using 2400 tex input and 2 outer layers 810 g/m² +/-45 fabric
- Dumb-bell shape 250 mm x 25 mm tensile specimen for static and fatigue testing
- Tensile fatigue testing @ R (min/max) = 0.1
- Testing frequency = 5Hz

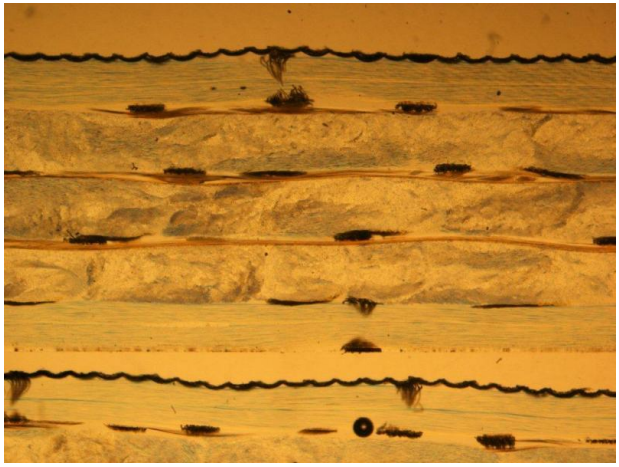
Thickness Effects



Panel thickness varies by product type – effect of resin demand due to sizing differences

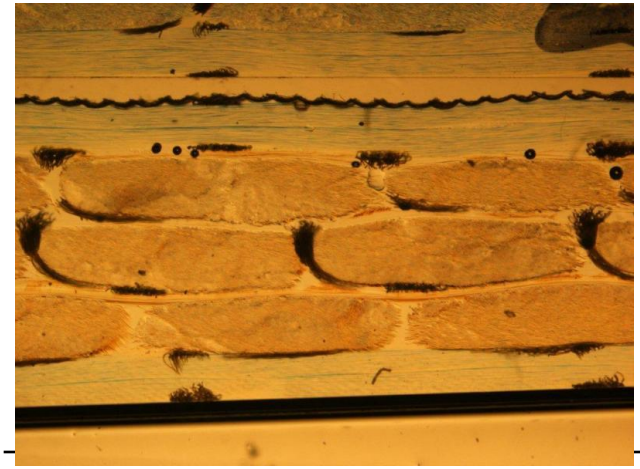
Laminate Sections
Roving Bundle Effects

A



B

C



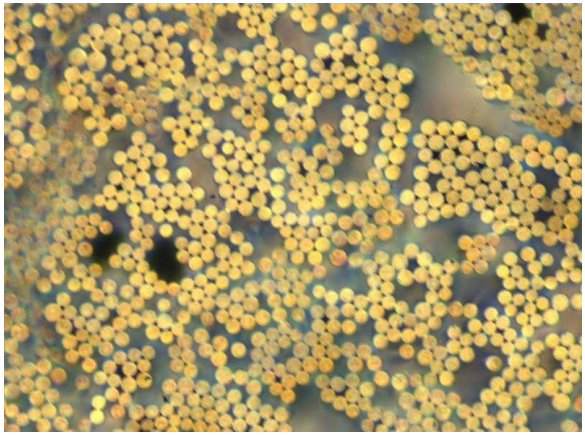
Optical microscopy

Note differences in A/B vs C

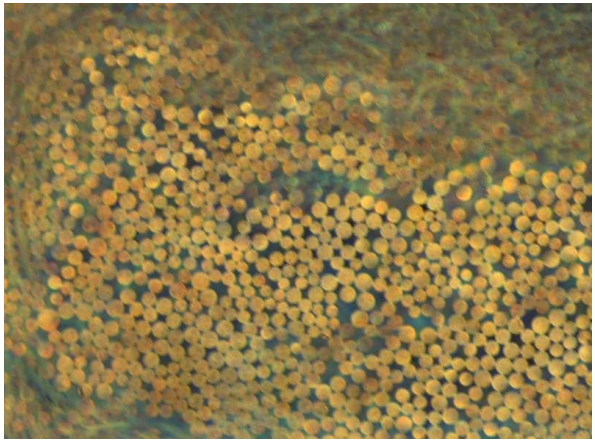
- **A very well spread**
- **B has some resin boundaries**
- **C more pronounced boundaries**

Laminate Sections
Filament Distribution

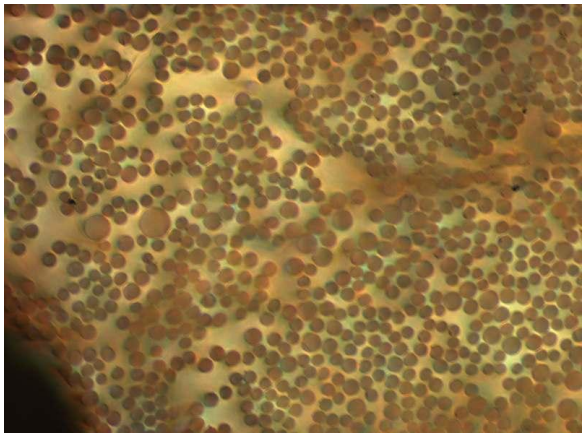
A



B



C



Optical microscopy

Note differences in A/B vs C

- **A has pronounced resin areas**
- **B very uniform**
- **C large diameter fibers**

Summary

- Sizing composition is critical to meeting performance requirements
  - Blade designer
  - Blade builder
  - Fabric convertor
  - Fiber producer

Proven Products

Blades – PPG Fiber Glass

- Products tailored to manufacturing process and application
- Unique chemical sizings (coatings) enhance fiber glass/resin bonds for maximum fatigue performance, rapid and complete wet-out
- Innovation in design and fabrication – strong, light weight and cost-efficient
- Extensive experience in manufacturing fiber glass reinforcements for composites