Wind Turbine Blade Trends & Issues

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Wind Turbine Blade Workshop

Albuquerque, New Mexico

February 24-25th, 2004

Presentation Overview:

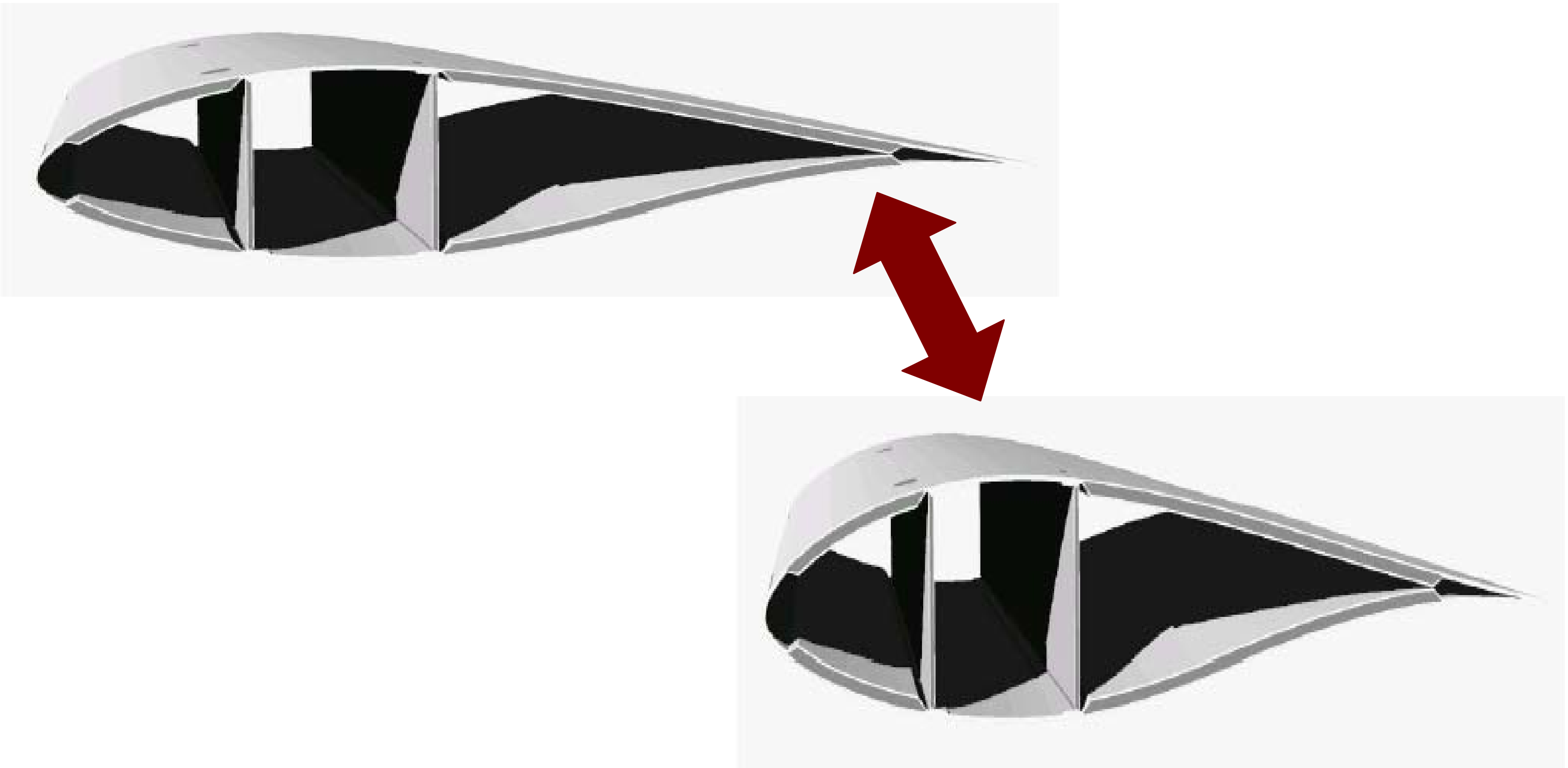
- Major Wind Turbine Blade Components
- Modifications Affecting Stiffness & Stability
- Infusion Processing - New Materials
- New Fiberglass Products Being Developed
- Proposed 60+ meter Blade Assembly
- Questions

Wind Turbine Blade Components:

- Traditional composite sandwich laminates are designed for out of plane loading. However Wind Turbine Blade laminates experience in-plane loads for both the blade surfaces and shear webs.
- Inertial loads will increase as blade lengths and weights continue to grow contributing to greater shear loading.
- Decreasing overall blade weights will reduce blade loading.
- Much emphasis is given to reducing weight by focusing solely on the reinforcing fiber as a “solid laminate” rather then treating the sandwich laminate as one entity.
- More than 65% of a large wind turbine blade’s surface area is a sandwich laminate.

External Modifications: (Macro)

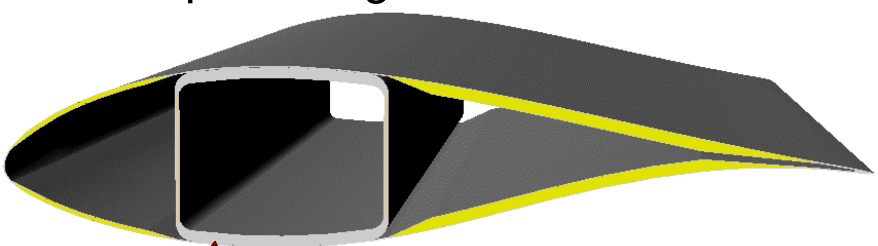
- Changing the overall blade profile is one way to modify stiffness & stability but may impact a blades aerodynamic performance



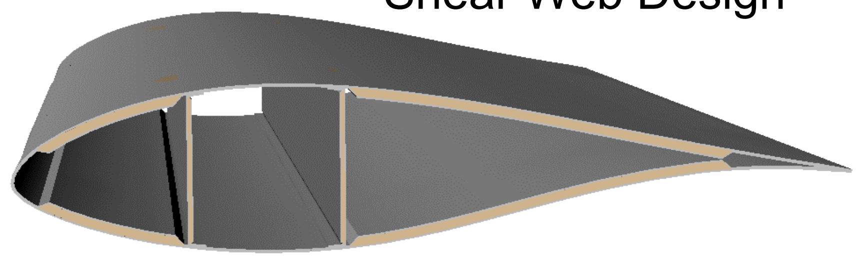
Internal Modifications:

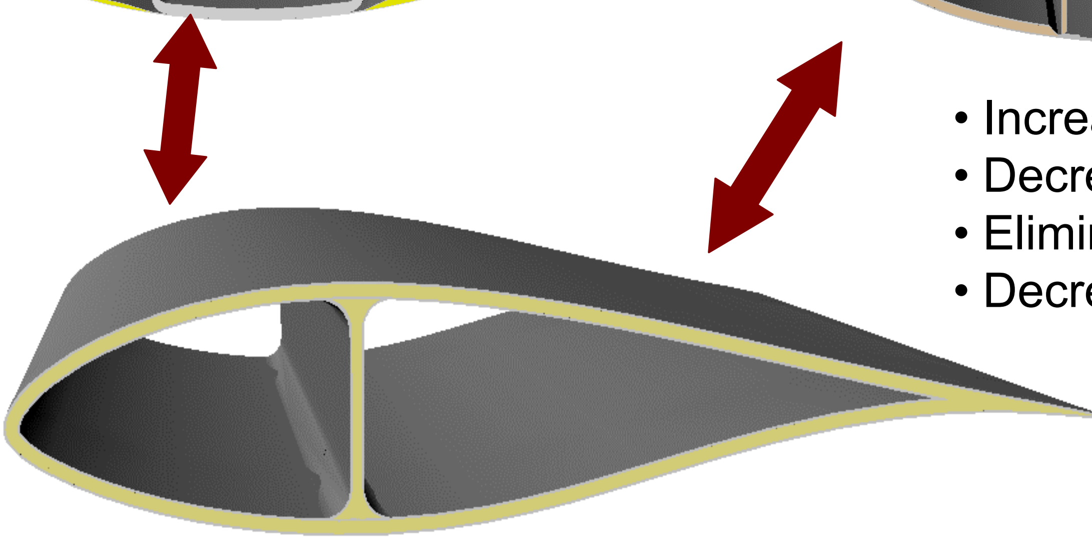
- Modifying the internal laminate or web components is another way to enhance stiffness & stability without changing the blades cross sectional "footprint". This is a favorable approach since it does not impact a blade's aerodynamic performance. ***Result:*** Decreased blade loading

Central Spar Design



Shear Web Design





- Increased the use of core materials
- Decreased the number of webs
- Eliminated the spar
- Decreased blade weight

New "Optimized" Blade Design

Material Modifications: (Micro)

$$K = \frac{K_0}{1+\pi^2\theta\left(K_0 - \frac{4}{3}\left(1+\frac{b^2}{a^2}\right)\right)} \quad \textit{for } 0 \le \pi^2\theta \le \frac{4}{3}\left(1+\frac{b^2}{a^2}\right)$$

Where K_0 is the value of the buckling coefficient of an ordinary plate with $\theta = 0$.

$$K_0 = 9 + \frac{17b^2}{3a^2} \qquad (5)$$

The critical shear buckling load, P_{xy}, is calculated through:

$$P_{xy} = \frac{K\pi^2 D}{(1+\nu^2)b^2} \qquad (6)$$

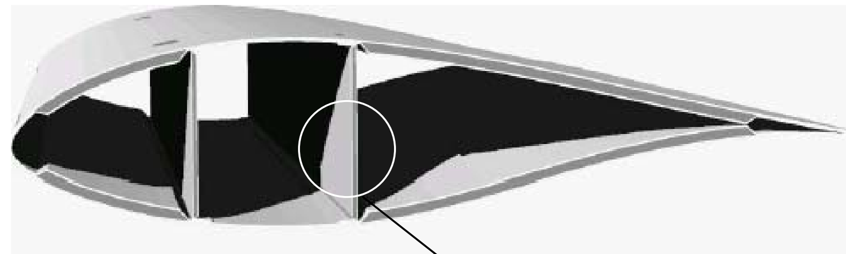
Table 1 Sandwich lay-up for reference shell panel.

Laminate Modulus, E_f*	15.0 GPa
Laminate Thickness, t_f	2.0 mm
Core Modulus, E_c	60.0 MPa
Core Shear Modulus, G_c	22.0 MPa
Core Thickness, t_c	20.0 mm

*Properties assumed to be quasi isotropic

Table 2 Sandwich lay-up for reference stiffener panel.

Laminate Modulus, E_f*	15.0 GPa
Laminate Thickness, t_f	4.0 mm
Core Modulus, E_c	60.0 MPa
Core Shear Modulus, G_c	22.0 MPa
Core Thickness, t_c	10.0 mm



- Increase Core Thickness/Density
- Increase Reinforcing plies
- Change fiber orientation
- Change reinforcing fiber material

Shear Buckling: (Web)

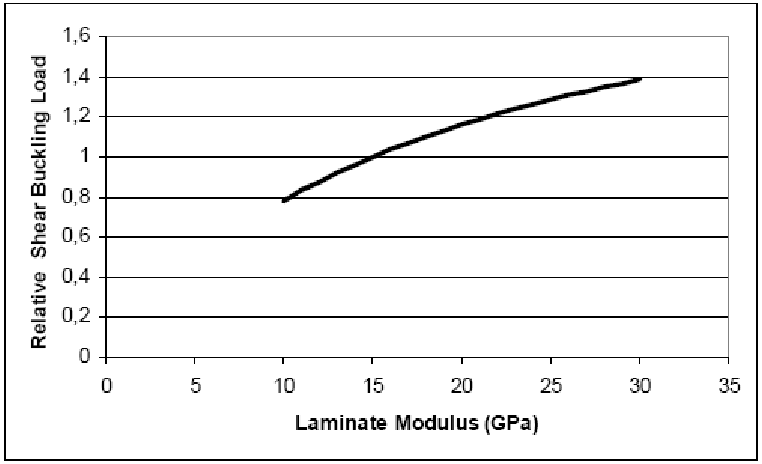


Figure 6 Influence of laminate modulus on critical shear buckling load.

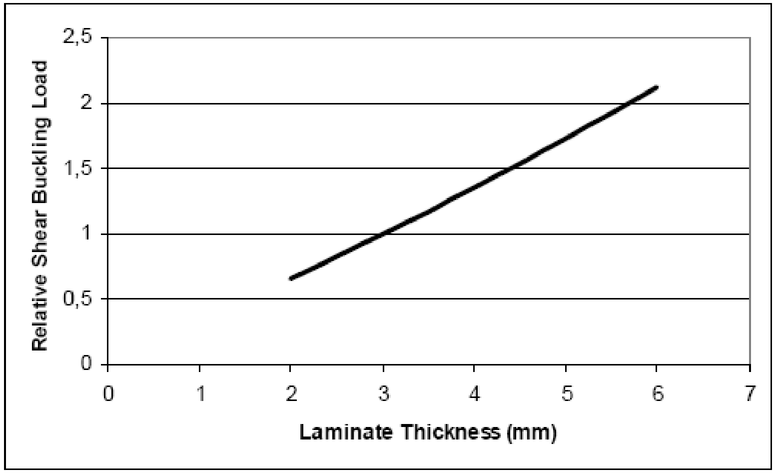


Figure 7 Influence of laminate thickness on critical shear buckling load.

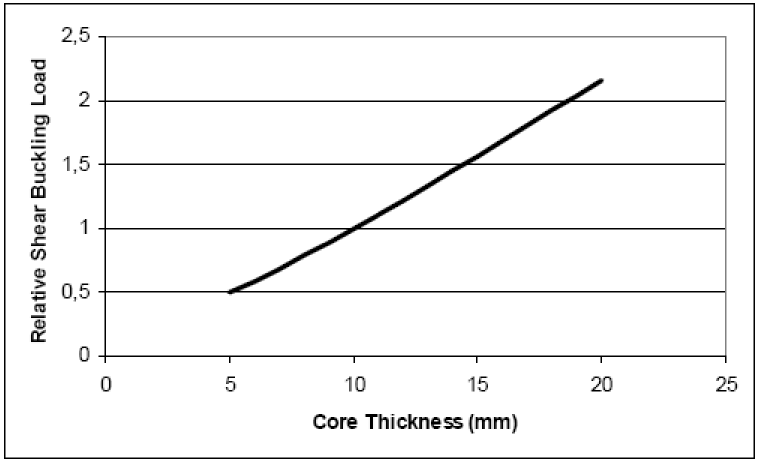


Figure 8 Influence of core thickness on critical shear buckling load.

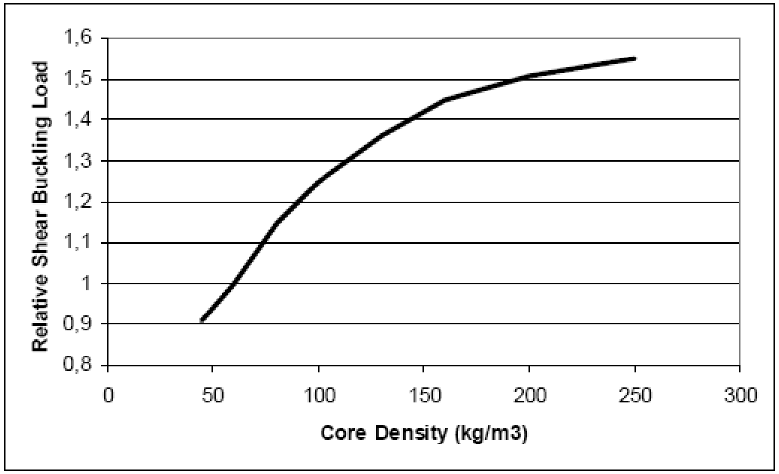


Figure 9 Influence of core density on critical shear buckling load.

Material Modifications: (Micro)

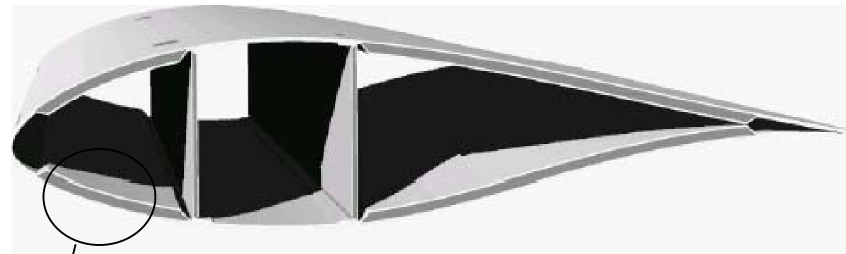
$$K = \frac{(1-\nu^2)b^2}{\pi^2 D} P_{cr} = \left(\frac{mb}{a}+\frac{a}{mb}\right)^2 \left(1+\pi^2\theta\left[\left(\frac{mb}{a}\right)^2+1\right]\right)^{-1}$$

Critical Buckling Load- P_{cr}

where K is the buckling coefficient
a and b is the length and width of the panel
D is the flexural rigidity
S is the shear stiffness

and θ is the shear factor, which for isotropic laminates equals:

$$\theta = \frac{D}{b^2 S(1-\nu^2)}$$



- Increase Core Thickness/Density
- Increase Reinforcing plies
- Change fiber orientation
- Change reinforcing fiber material

General Buckling: (Blade Surfaces)

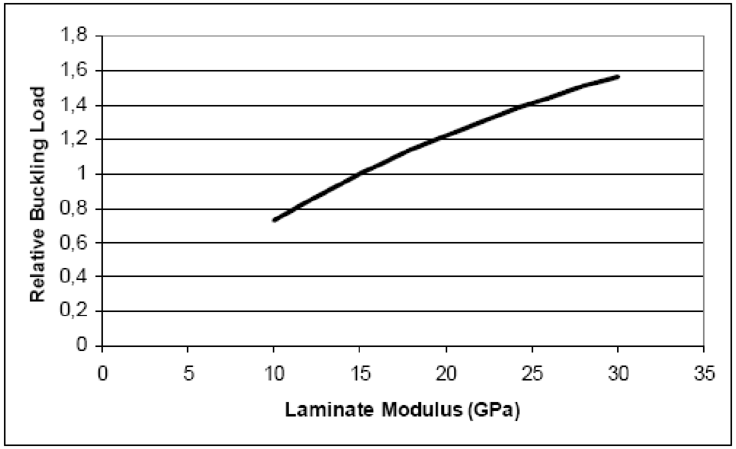


Figure 2 Influence of laminate modulus on critical buckling load.

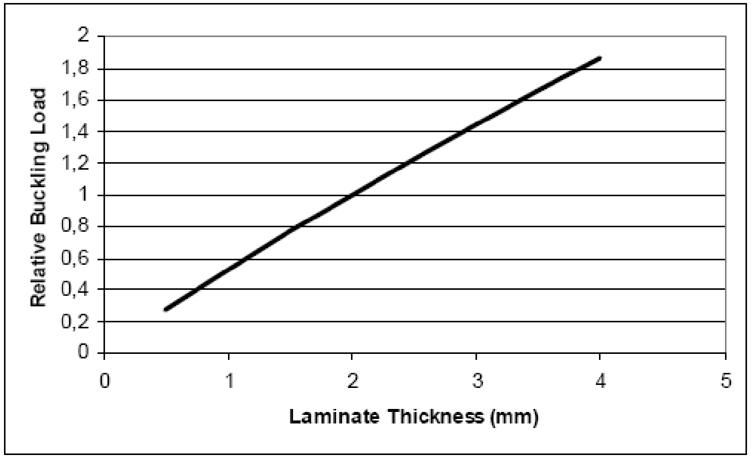


Figure 3 Influence of laminate thickness on critical buckling load.

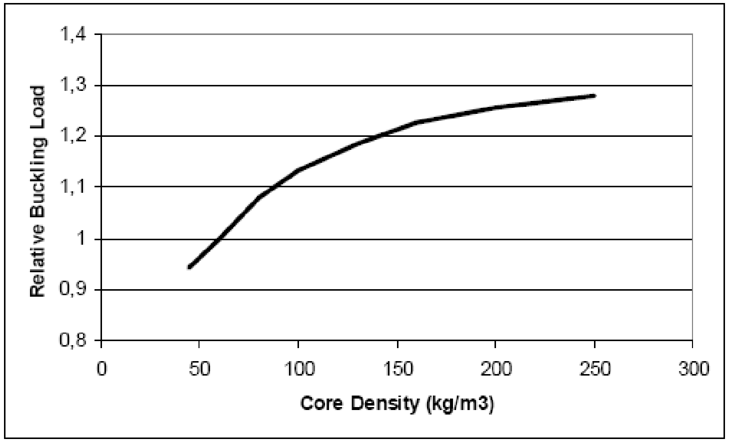


Figure 4 Influence of core density on critical buckling load.

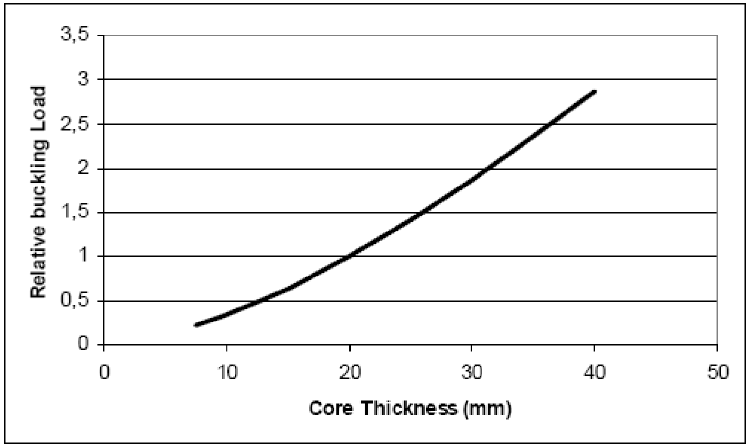
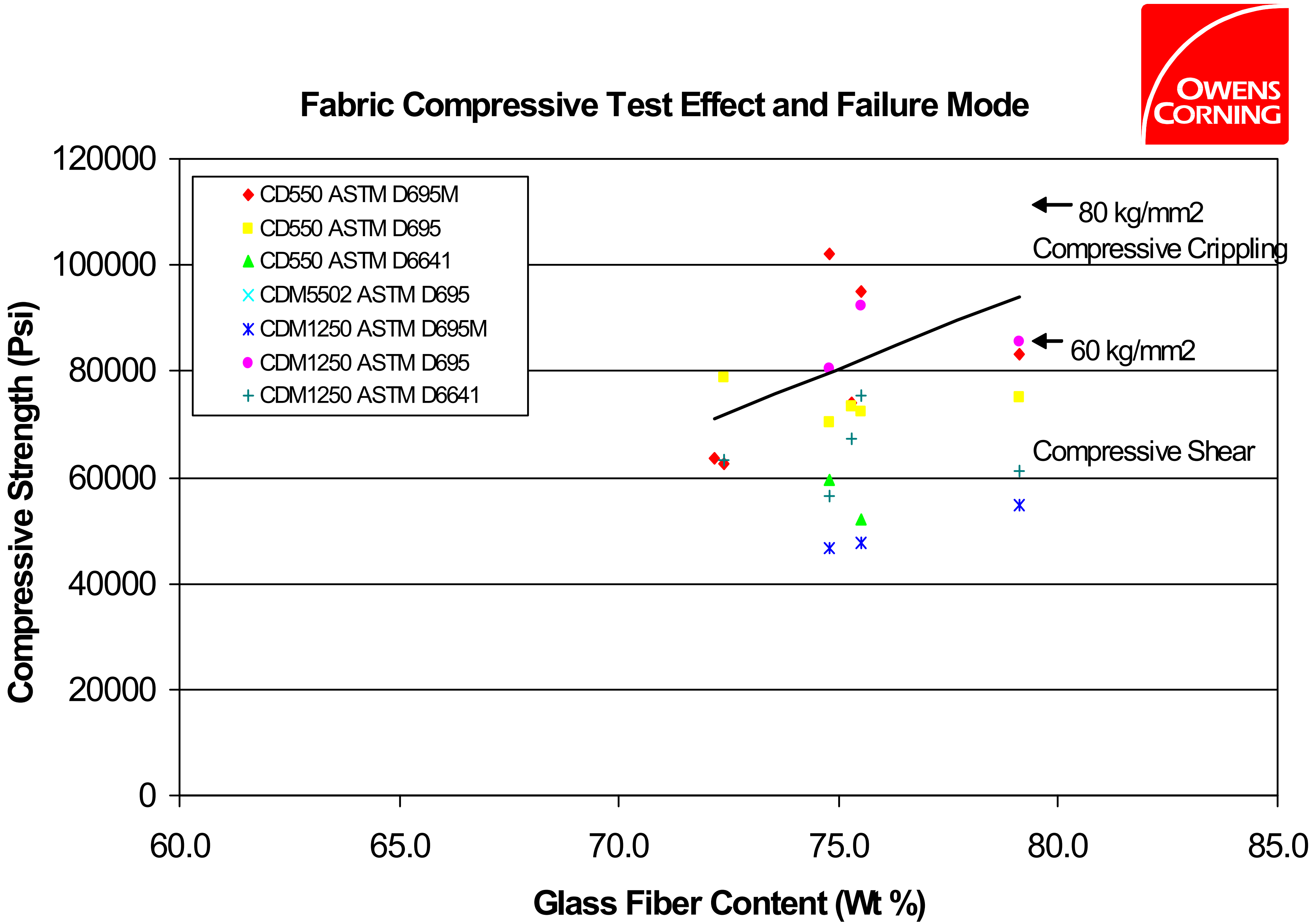


Figure 5 Influence of core thickness on critical buckling load.



Fabric Compressive Test Effect and Failure Mode
OWENS CORNING
CD550 ASTM D695M
CD550 ASTM D695
CD550 ASTM D6641
CDM5502 ASTM D695
CDM1250 ASTM D695M
CDM1250 ASTM D695
CDM1250 ASTM D6641
80 kg/mm2
Compressive Crippling
60 kg/mm2
Compressive Shear
Compressive Strength (Psi)
0
20000
40000
60000
80000
100000
120000
60.0
65.0
70.0
75.0
80.0
85.0
Glass Fiber Content (Wt %)

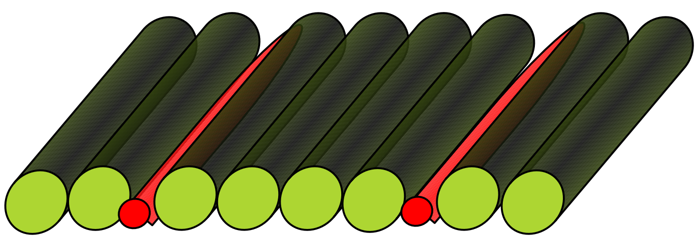
Effect of Manufacturing on Blade Weight:

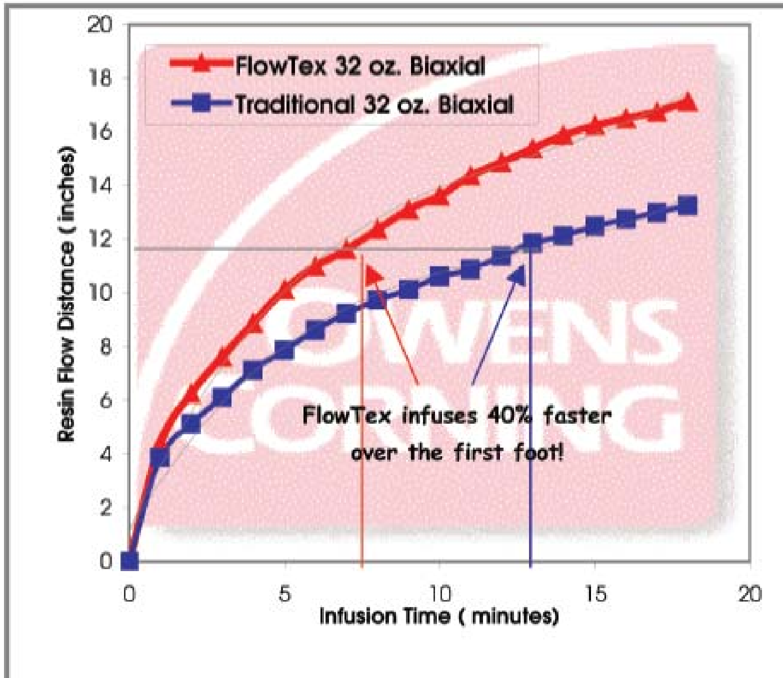
New Infusion Fabrics from Knytex:

• New Flowtex© line of fabrics decrease infusion time for many closed molding processes.

• Flow channels are incorporated directly into the Knytex© fabric eliminating the need for a disposable infusion media.

• Knytex© fabrics are available bonded to eliminate fiber crimping.



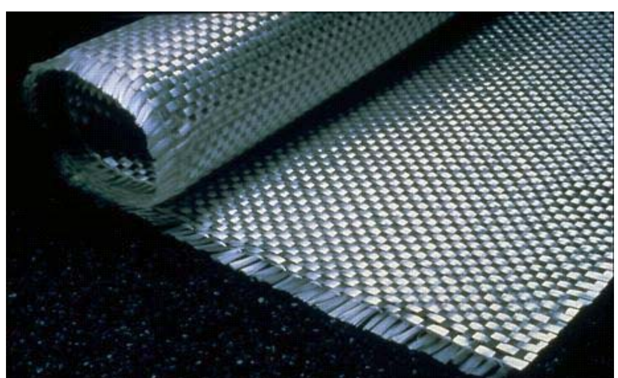


New Fiberglass Developments:

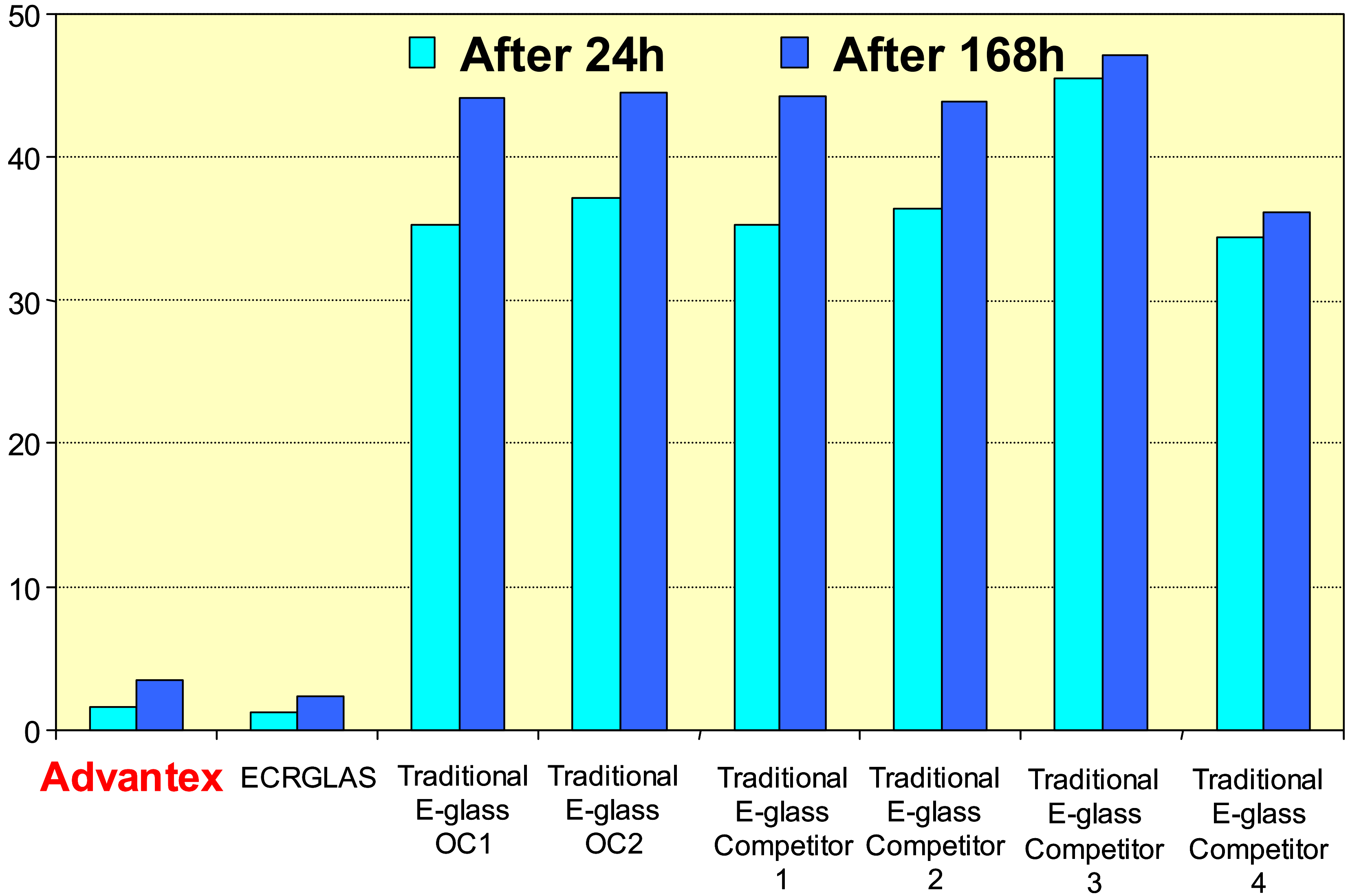
- Advantex© : New fiberglass chemistry combining the properties of traditional E-glass with the enhanced performance characteristics of E-CR glass. Patented Technology by Owens Corning.
- New SE 1200 ***polyester*** & SE 1500 ***epoxy*** Single End Rovings for weaving and infusion processing of Wind Turbine Blades.
  - Enhanced Fatigue Characteristics

Environmental Advantages of Advantex© Fiberglass:

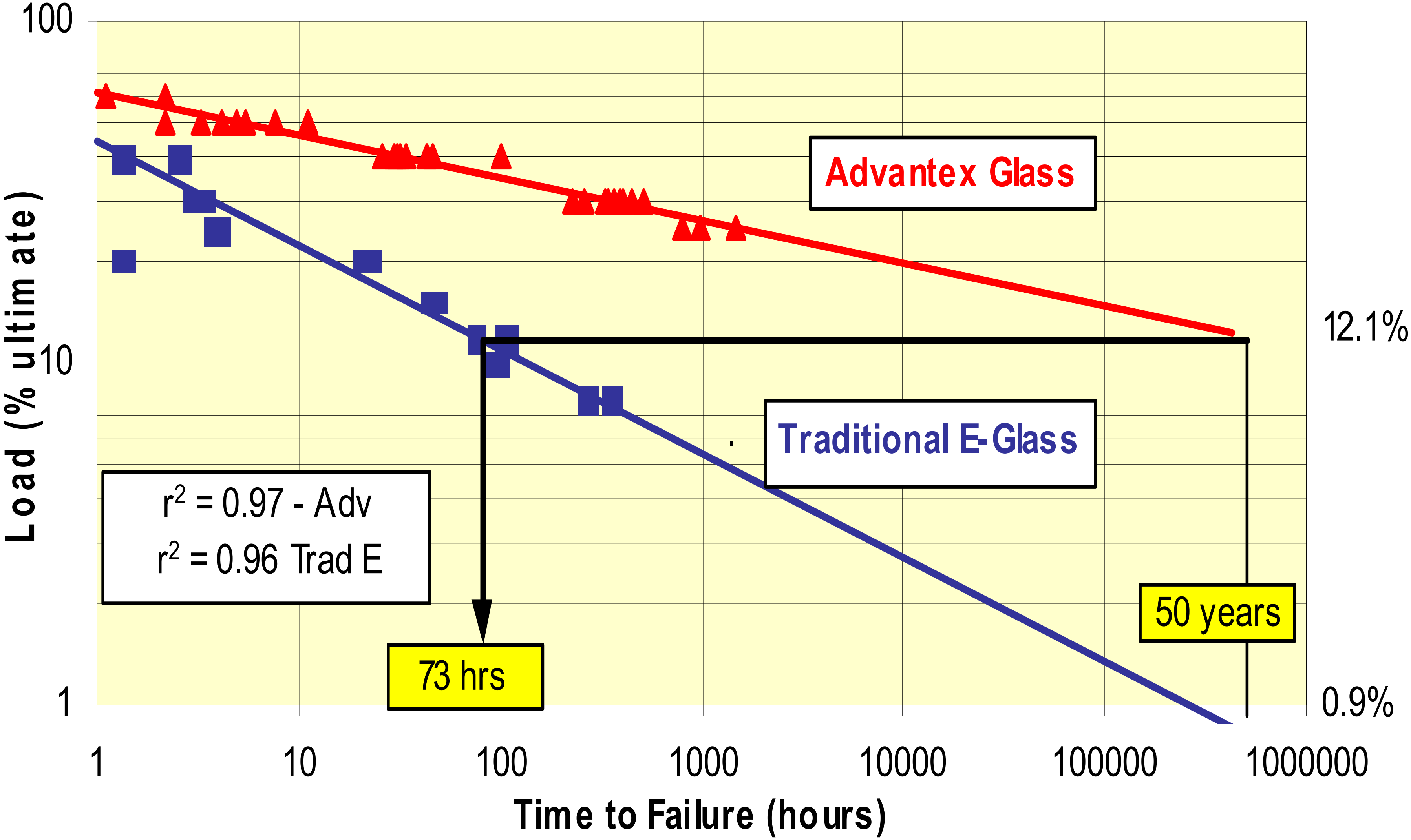
- About 100,000,000 lbs of glass are used each year to build wind turbines blades
- Advantex© fiberglass production reduces emissions:
  - Boron 85% reduction
  - NOx 80% reduction
  - Fluorine 90% reduction



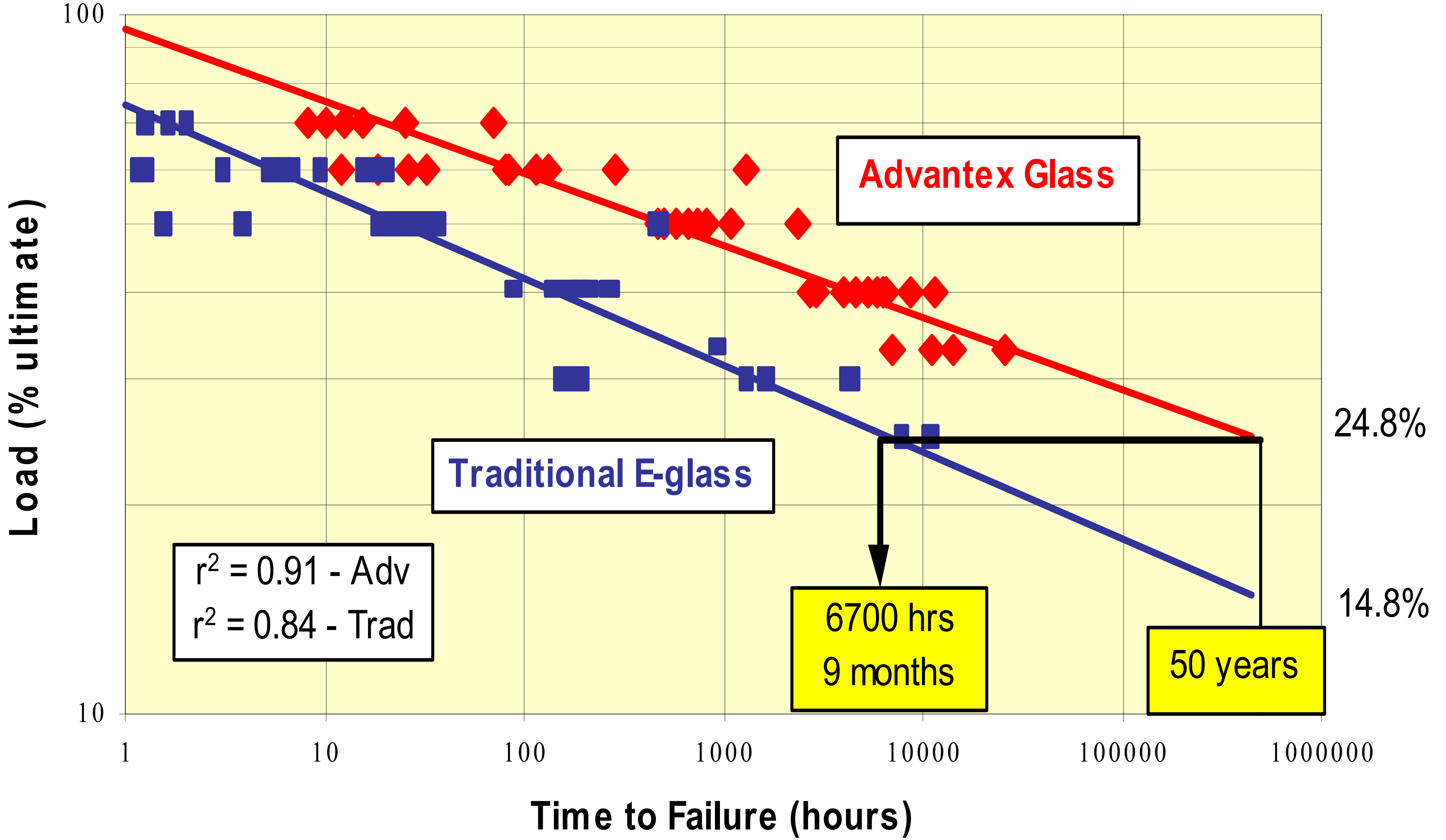
Advantex® Corrosion Resistance: % Weight Loss



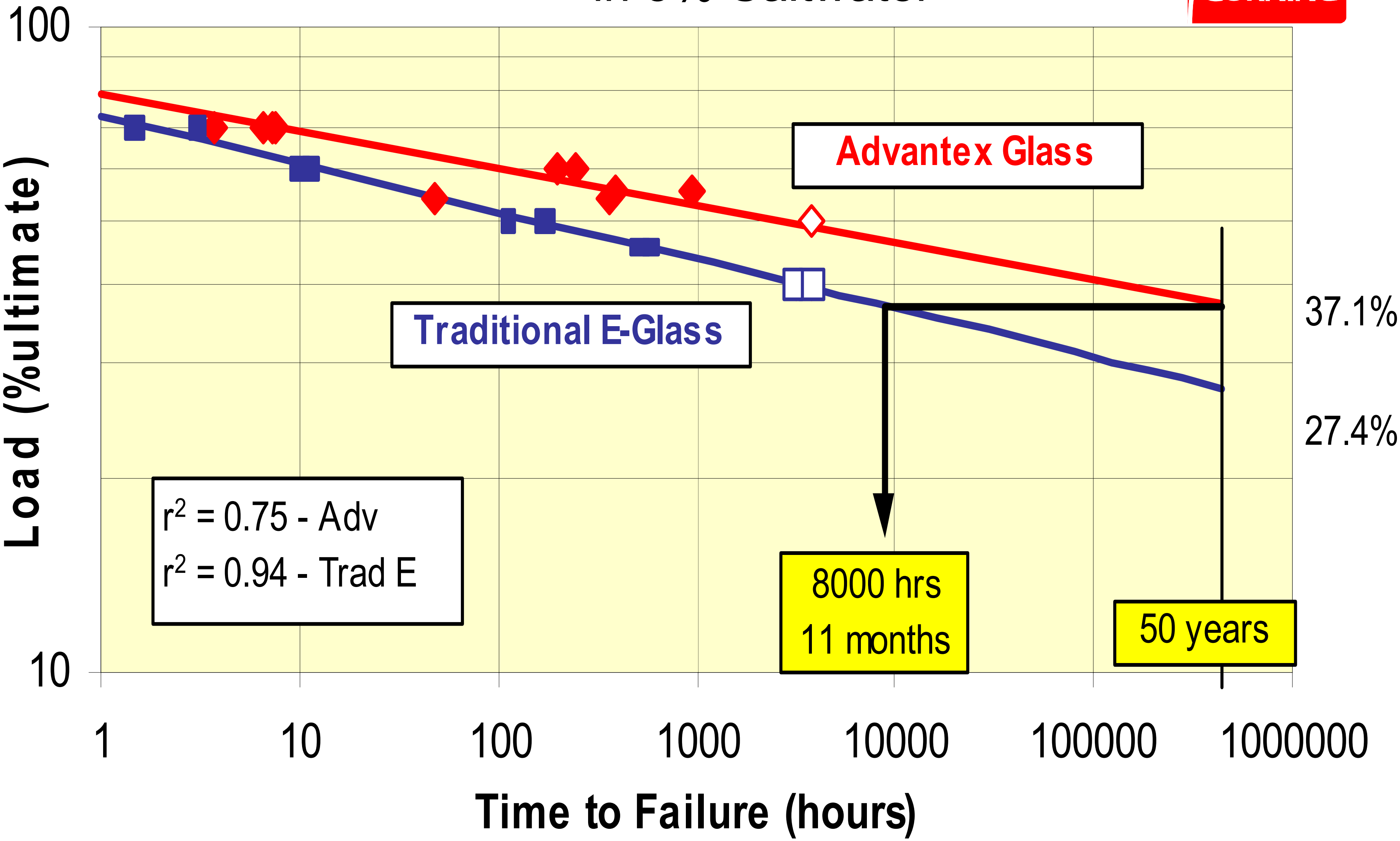
Creep-Rupture of Composite Rods in 1 Normal Acids (HCl - H_2SO_4)



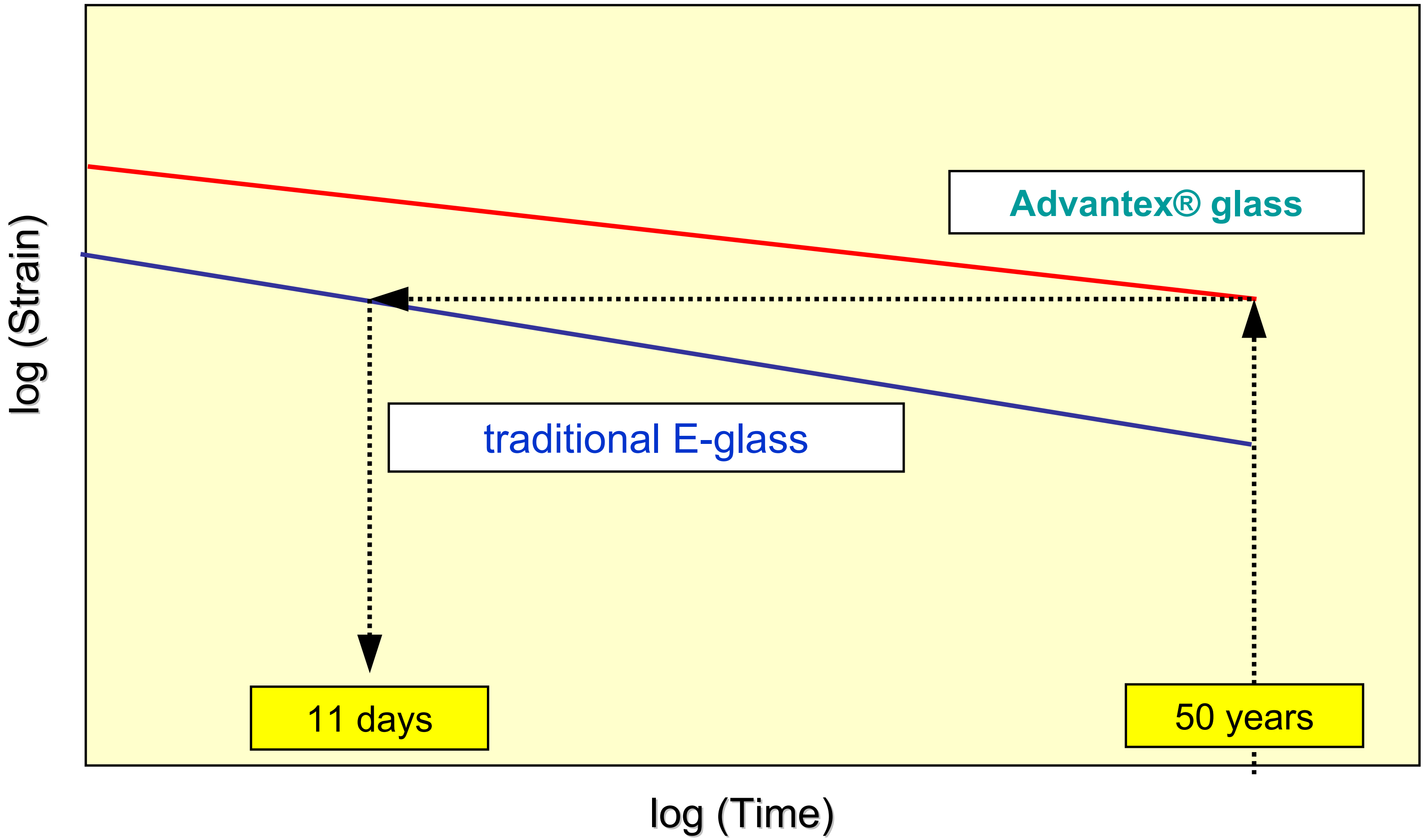
Creep-Rupture of Composite Rods in Cement Extract (pH 12.6)



Creep-Rupture of Composite Rods in 5% Saltwater



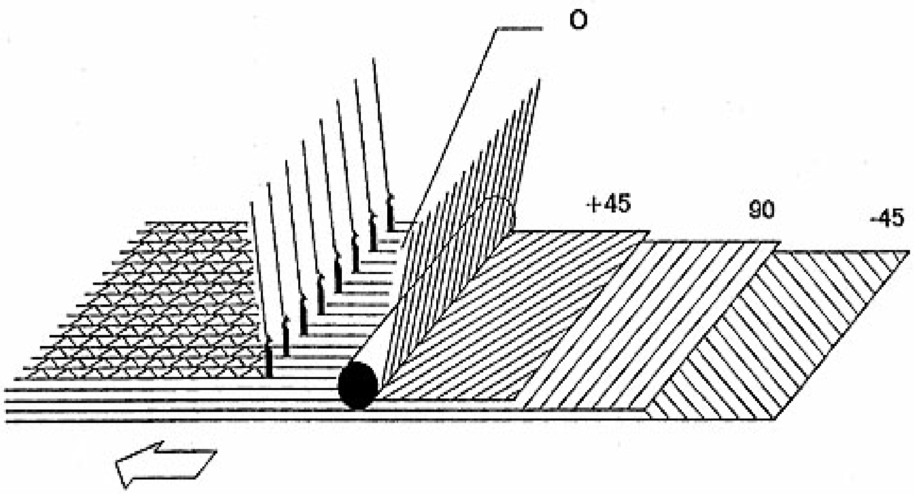
Strain-Corrosion of GRP pipe rings in 5% H_2SO_4

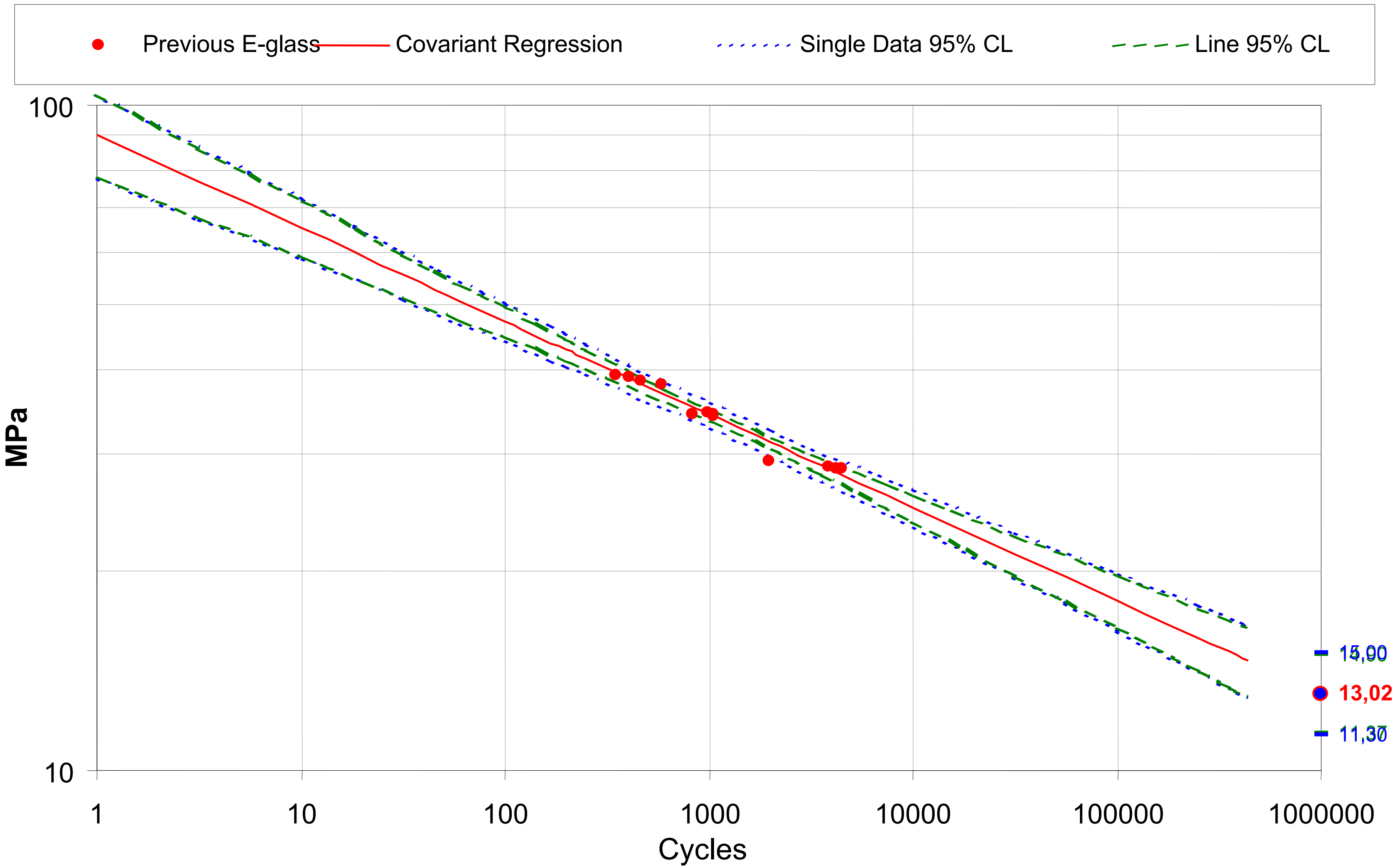


New SE 1500 Single End Roving:

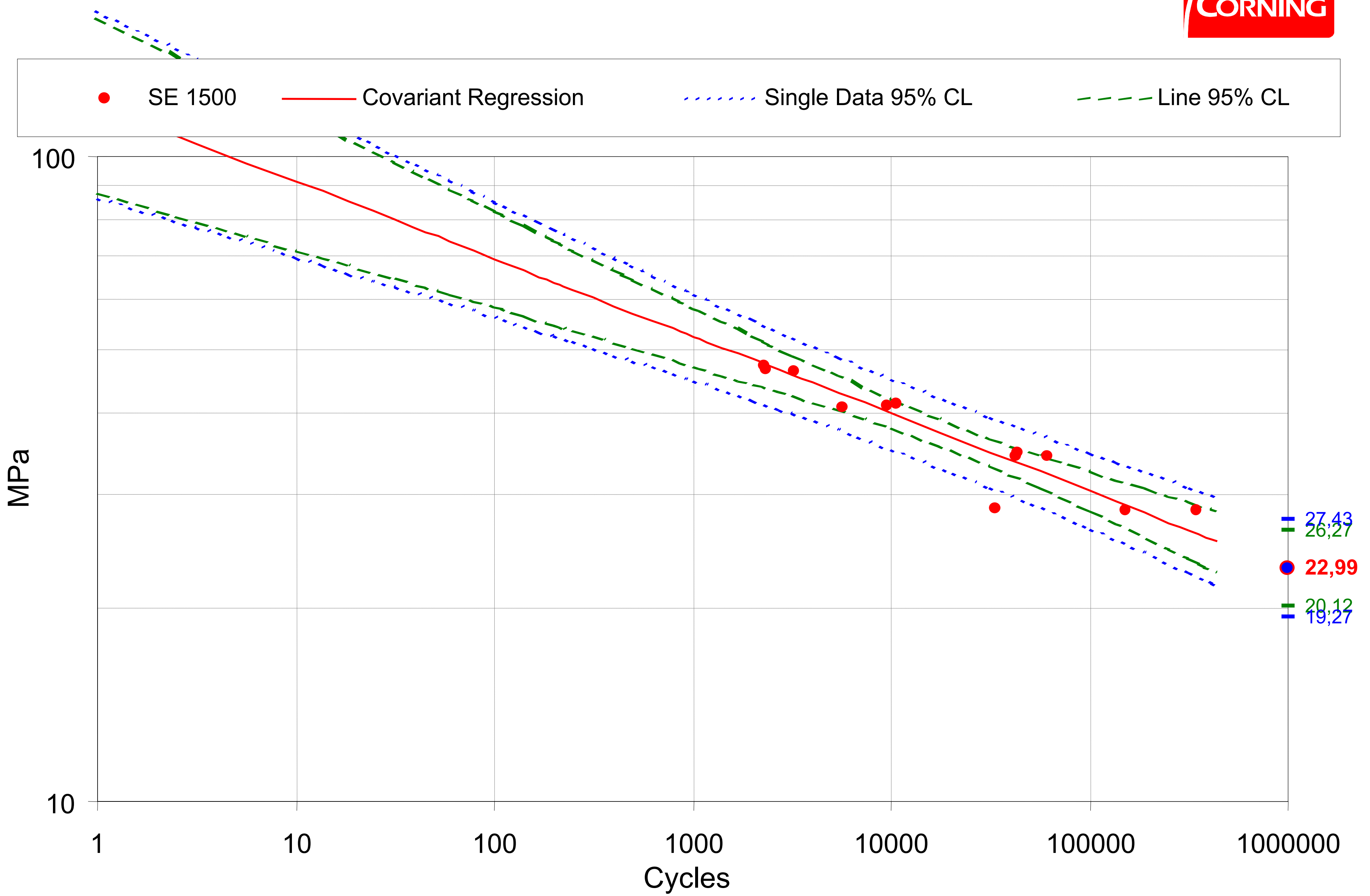
Fatigue Properties Laminate Comparison: +/- 45^0

Product	Extrapolated Stress at 10^6 cycles (MPa)	Glass content (%)
Previous E-glass	**13**	**71**
New SE1500	**23**	**71**





Previous E-glass
Covariant Regression
Single Data 95% CL
Line 95% CL
100
10
MPa
1
10
100
1000
10000
100000
1000000
Cycles
15,00
14,90
13,02
11,37
11,30



SE 1500
Covariant Regression
Single Data 95% CL
Line 95% CL
100
10
MPa
1
10
100
1000
10000
100000
1000000
Cycles
27,43
26,27
22,99
20,12
19,27

New SE 1500 Single End Roving:

Tensile Properties: +/- 45^0 Laminate

Product	Strength (MPa)	Modulus (MPa)	Elongation %	Glass content (%)
Previous E-glass	86.8	14,132	11.34	71
New SE 1500	**149**	**13,766**	**17.9**	**71**

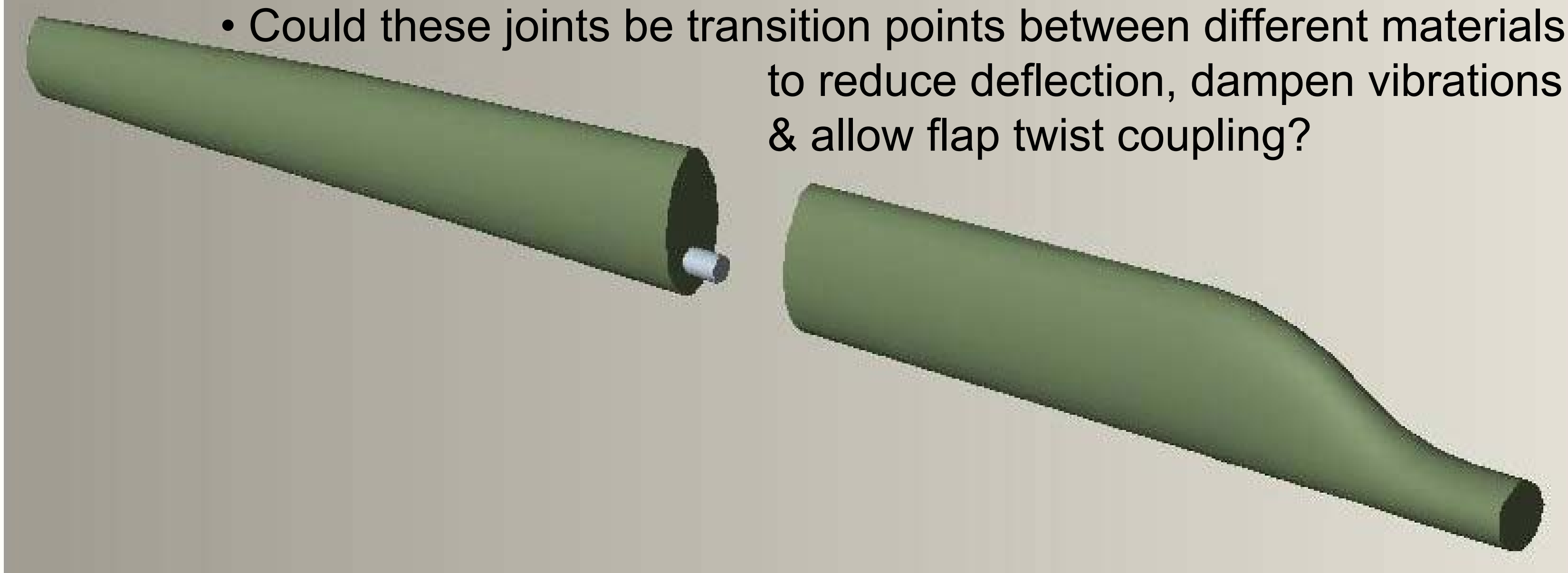
Compressive Properties: +/- 45^0 Laminate

Product	Strength (MPa)	Modulus (MPa)	Elongation %	Glass content (%)
Previous E-glass	98	3,729	2.34	71
New SE 1500	**111**	**4,512**	**1.83**	**71**

New Ideas For 60+ m Blade Assembly

OC is looking to develop new ways to produce larger blades in order to achieve the following goals:

- Cost effective ransportability of 60+ meter blades on 1 truck
- On-site assembly of either 2 or 3 piece blades
- Ability to design stiffness and torsional response into blade
- Eliminate the need for length wise joining of blade halves
- Could these joints be transition points between different materials to reduce deflection, dampen vibrations & allow flap twist coupling?



Thank you to the following suppliers for their assistance & technical support:

Blade Buckling Information Supplied by:

Peter Norlin - DIAB

Title: Optimised Usage of Foam Core Material in Rotor Blades

REFERENCES

1. Fagerberg Linus, Wrinkling in sandwich panels for marine applications, Report 2001-17, KTH, Stockholm, Sweden
2. Zenkert. Dan, The handbook of Sandwich construction. EMAS Ltd, UK, 1997
3. Divinycell, Technical Data Sheet, H-grade, DIAB, Laholm, Sweden

Fabric Test Data Supplied by:

David Hartman – Owens Corning

Advantex & SE 1500 Test Data Supplied by:

Byrd Hennessee – Owens Corning