Blade Cost and Weight Reduction using TYCOR® W Engineered Cores

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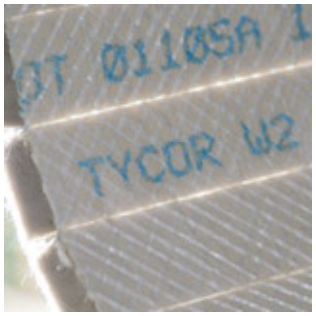

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Wind Turbines – Dual Use Technology

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WebCore Company Overview

Miamisburg, Ohio, USA

- Founded in 1991
- ISO 9001-2008 registered manufacturer of TYCOR® fiber-reinforced core ("FRC") products for sandwich construction
- FRC products are characterized by composite web construction
- ~30 full time employees; Development and Engineering staff of 15
  - Sandwich Core Development
  - Customer Support
  - Sandwich Application Development
- Current markets: Wind Energy; Marine; Transportation; Industrial; Infrastructure

Interior Structure of Molded TYCOR® Core

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TYCOR® FRC in Wind Turbine Blades

- TYCOR® FRC used in manufacture of large-blade shear webs (2+MW turbine) since July 2008
- Two-year effort to optimize FRC technology for the needs of blade design and manufacturing
  - Low cost
  - Low weight
  - Structural performance
  - Processing

Shear webs with TYCOR® FRC

⇒ *Result: TYCOR® W product line for utility-scale wind turbine blades*

⇒ *TYCOR W is an enabler for important blade cost and weight reductions*

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AGENDA

- Nature of Sandwich Construction and Core Materials in Blades
- Description of TYCOR® W Product Line
- TYCOR® W Properties Compared to Other Cores
- Blade Level look at Weight and Cost Impact of TYCOR® W

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Sandwich Construction in Large Blades

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- **<u>Large Blade Design</u>: Characterized by extensive sandwich shell construction**
- **<u>Function of Core and Sandwich Construction</u>: Stabilize highly-loaded laminates against deformation and buckling**
- **<u>Preferred Attributes of Core Material</u>: 1) Stiff, especially transverse shear stiffness; 2) Light weight; 3) Low cost**

<u>Comparison of Leading Blade Core Materials</u>

Core Material	Advantages	Disadvantages
Low-density (60-70 kg/m^3) Rigid Foam (PVC, SAN)	• Light weight • Affordable at low densities	• Low stiffness • More expensive than balsa
Medium-density (155 kg/m^3) End-Grain Balsa	• Low cost • High stiffness	• Heavier than foam • Subject to processing irregularities • Availability problems

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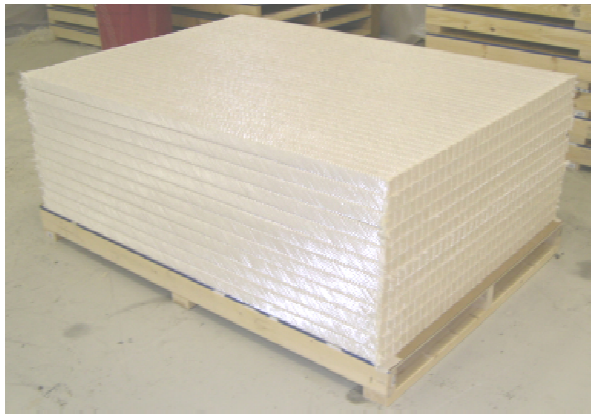
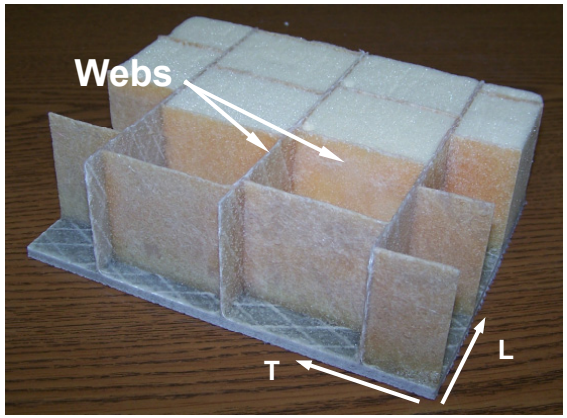
TYCOR® Fiber Reinforced Core (FRC) Technology

- **TYCOR® FRC *Preforms* – TYCOR® FRC sheets are *preforms* made with dry fiber and foam. Final mechanical properties of TYCOR are achieved by infusion molding.**
- **FRC Input Materials**
  - **Closed cell polyisocyanurate foam (~30 kg/m^3)**
  - **Glass fiber reinforcements (E-glass roving, mat)**
  - **Binders**
- **Mechanical Properties – Dominated by stiff composite webs. Foam contributes only ~2% to 8% of stiffness in molded TYCOR® W**
- **Property Representation – For engineering purposes, FRC can be represented in terms of equivalent homogeneous (smeared) properties**
- **Patents - Patents and patent applications in key international markets**



TYCOR Preform Sheets

- **Face layup**
- **Infusion molding**



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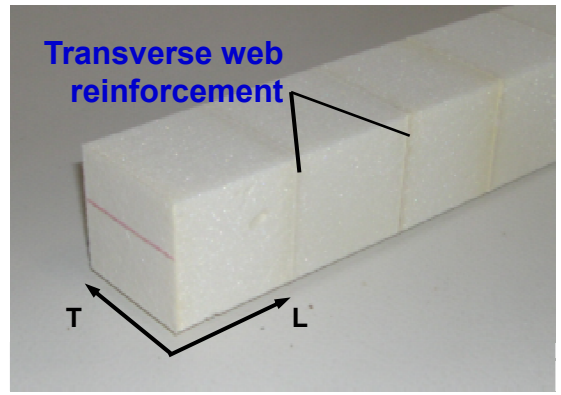
Construction and Web Architecture

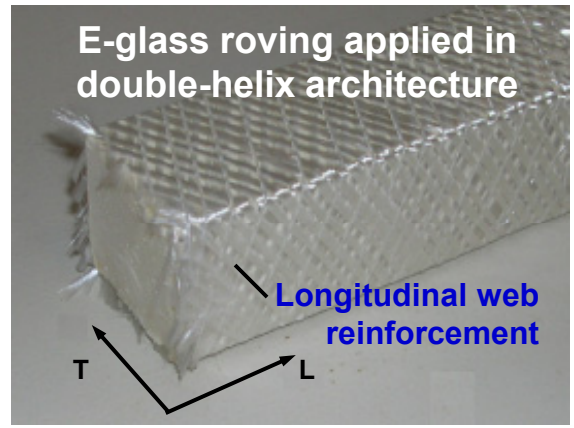
- Foam lamination process
- Cutting processes

Precursor Strip with Transverse Webs



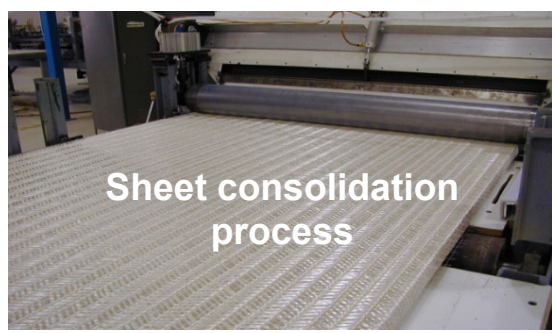
- Winding process

Wound Strip

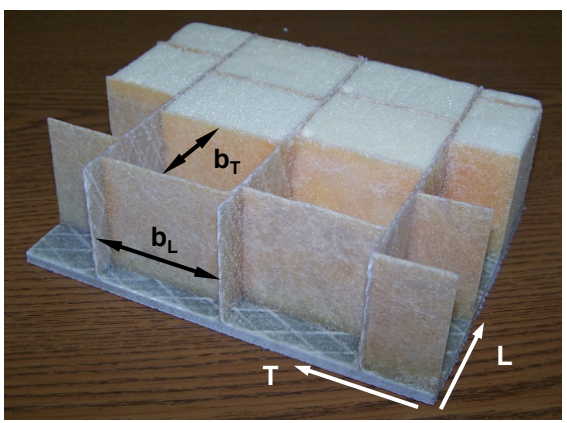


- Multiple strips

Consolidated Sheet



- Face layup
- Infusion molding



Composite Web Structure
(Face and foam removed for visibility)

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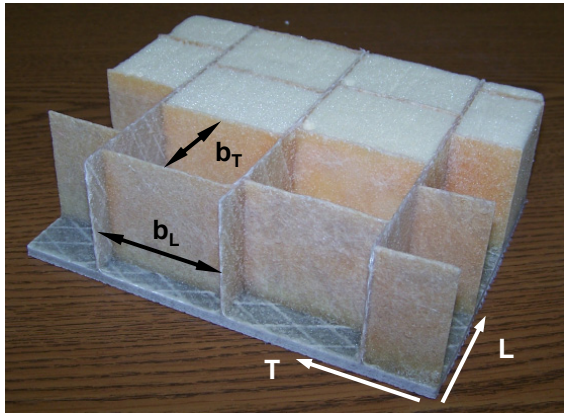
FRC Property Engineering

- **Strength and stiffness can be engineered using many design variables**
  - **Type of input foam**
  - **Thickness of input foam**
  - **Weight of laminated glass mat**
  - **Type of laminated glass mat**
  - **Spacing of wound-glass webs**
  - **Weight of glass roving for winding**
  - **Winding pattern (number of ends, winding angle)**

⇒ ***Provides a technology platform for producing a wide range of engineered core designs targeting customer needs***



Web Structure

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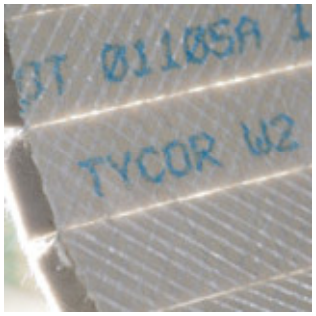
TYCOR® W Core for Wind Turbine Blades



- <u>Standardized</u> product family, optimized for blade application with respect to *Transverse shear modulus, Cost, Weight, and Processing*
  - Designed to roughly span the performance regime between low-density PVC foam and balsa
- Four current designs in product family (W1, W2, W3, and W4) based on a fixed set of web reinforcement designs
  - Two different weights for L-web reinforcement
  - Two different weights for T-web reinforcement
- Thickness Range
  - Any thickness from 12mm to 78mm
  - Cut tolerance ±0.13mm (± .005")
- GL Type Approval in process – August 2010

Design Space by Web Construction

	L-Web	T-Web
TYCOR W1	Light	Light
TYCOR W2	Light	Heavy
TYCOR W3	Heavy	Light
TYCOR W4	Heavy	Heavy

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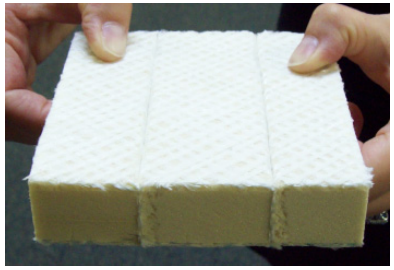
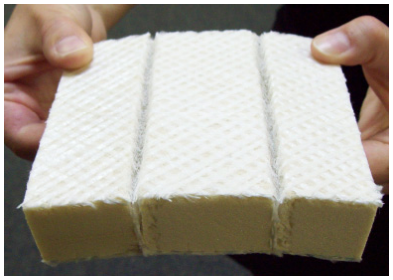
TYCOR® W FRC Processing

- **Contourable:**
  - Patent-pending feature: Sheet is consolidated on two sides, but allows conformability in one direction
  - General flexibility before infusion allows mild conformability in second direction
- **Large Sheet Size:**
  - Up to 1.2 × 2.4 m (4 × 8 ft.) sheet size
  - Sheet size is tailorable

  ⇒ *Increased kitting yield*
  - Dimensional stability and large piece size minimizes tolerance buildup, improves placement accuracy in blade layup

  ⇒ *Improved infusion performance*





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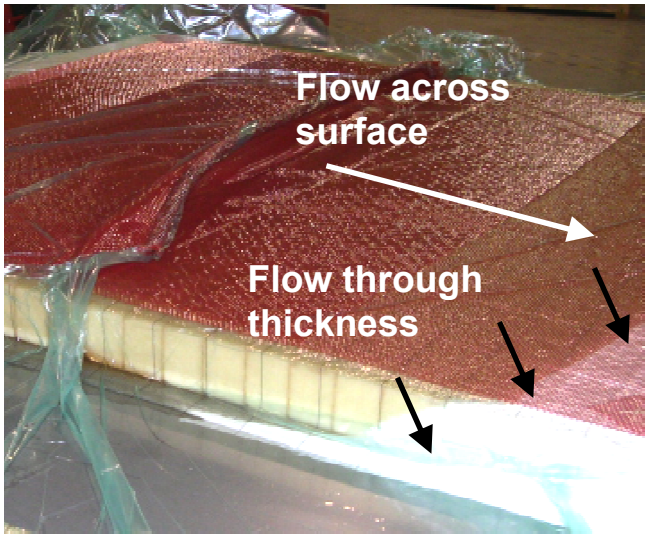
TYCOR® W FRC Processing

- **<u>High Durability</u>:**
  - **Two-sided consolidation provides excellent durability for core kitting, shipping, handling, and mold loading (compared to single-side scrim consolidation)**

- **<u>Infusion Core</u>:**
  - **Dry-fiber webs in FRC provide natural through-thickness porosity for vacuum infusion with one-side feed. No special treatment required (e.g. perforations)**



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Properties of TYCOR® W Core

- **Statistical transverse properties of 25.4mm TYCOR W molded with Hexion 135i epoxy resin, six-specimen samples**
- **Comparisons with supplier-published data for:**
  - **60 kg/m^3 PVC foam (Alcan Airex® C70.55) average values**
  - **155 kg/m^3 balsa (Diab ProBalsa® PB, "Average" and "Minimum" values)**

Statistical Properties of TYCOR W with Epoxy Resin, 6-Specimen Samples

TYCOR Core Design	Transverse Shear Modulus ASTM C273/C273M-07				Transverse Shear Strength ASTM C273/C273M-07				Z Compressive Strength ASTM C365/C365M-05		Z Compressive Modulus ASTM C365/C365M-05		Z Tensile Strength ASTM C297/297M-04	
	L		T		L		T							
	Average MPa	COV (%)	Average MPa	COV (%)	Average MPa	COV (%)	Average MPa	COV (%)	Average MPa	COV (%)	Average MPa	COV (%)	Average MPa	COV (%)
W1	74.8	2.1	33.2	4.1	1.13	2.1	1.11	2.7	2.09	8.3	123	6.1	1.59	8.6
W2	81.4	2.3	68.7	4.1	1.59	7.7	1.66	3.9	3.37	4.5	151	6.3	1.90	9.7
W3	110.6	3.3	32.5	1.4	2.17	4.3	1.04	2.5	2.42	5.2	158	5.0	1.86	4.0
W4	107.8	1.0	71.8	2.1	2.10	7.0	1.88	2.4	3.28	5.7	210	12.4	2.64	3.5

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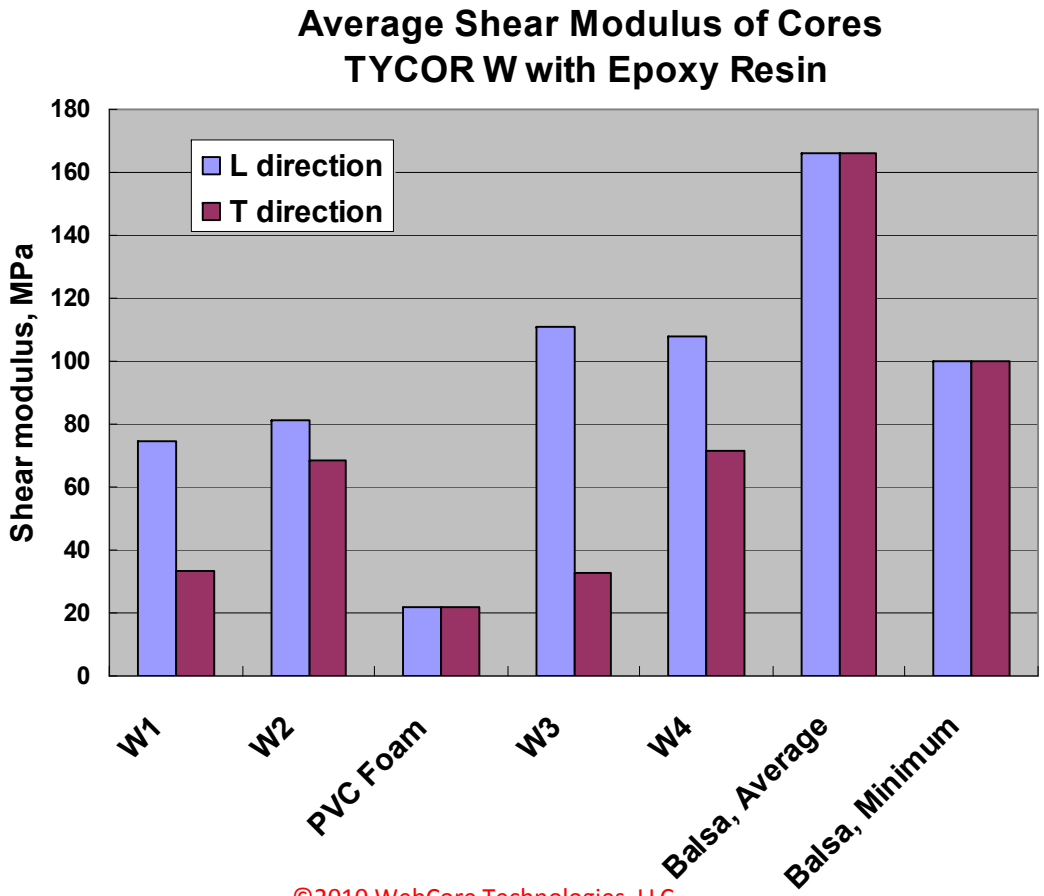
Transverse Shear Modulus

- **<u>Transverse shear modulus</u> is a key performance parameter for core materials**
  - **Affects blade resistance to global buckling (assessed analytically)**

⇒ ***TYCOR W family spans from greater-than-foam to vicinity of balsa "minimum" properties***



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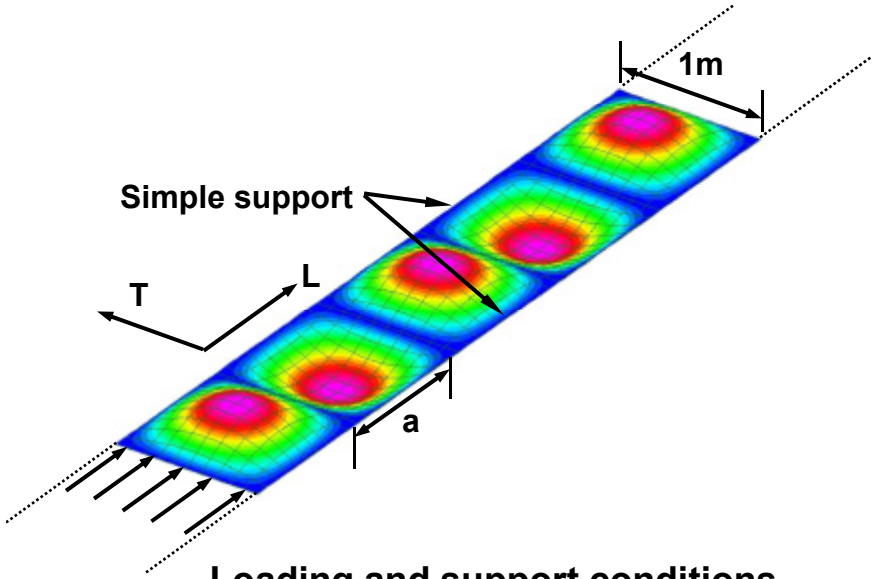
Flat-Panel Buckling Analysis
Uniaxial Compression of Sandwich Laminate

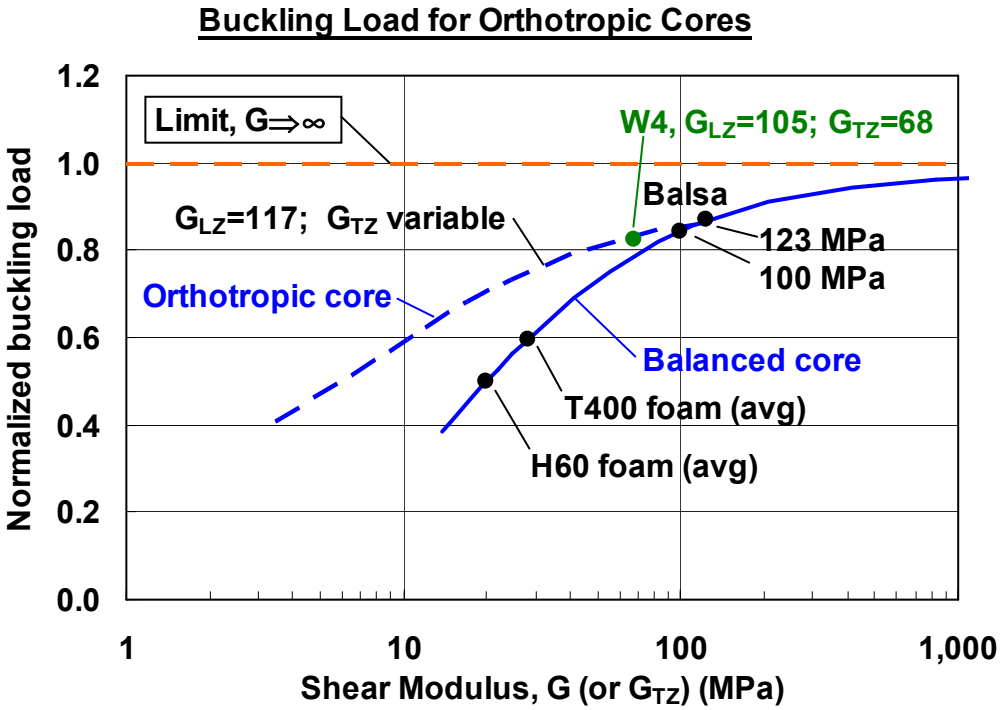
- **Goal:** Simulate a strip of *blade skin*, explore effects of transverse shear moduls
- **Analysis method:** Double-Fourier series solution for thin-faced sandwich
- **Laminate:** Core thickness=37mm, Face thickness=2.6mm of E-TLX 3300 ([0/±45]), Width b=1m

⇒ ***W4 FRC performs similarly to balsa***

⇒ ***Optimal core design may be orthotropic (reduced minor shear modulus) with only small effect on buckling load***



Loading and support conditions, buckling mode shape



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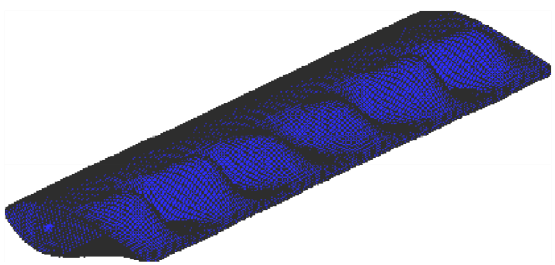
Core Thickness Optimization for Buckling

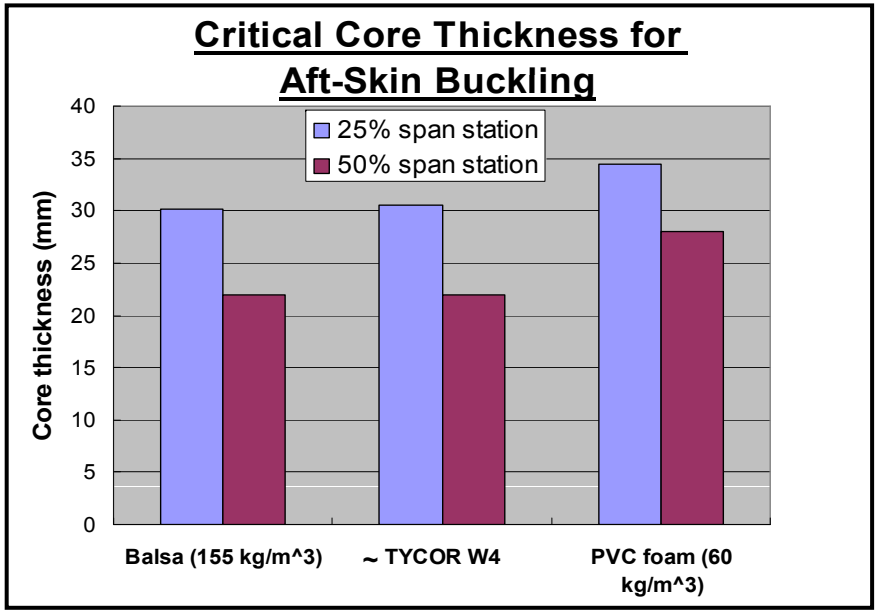
- Design-for-Buckling Study in collaboration with *Global Energy Concepts* (now *DNV Renewables*)
- Fiberglass blade, 43.5m long, 2.5MW turbine
- Optimize core thickness for critical buckling design margin
- Core properties: Balsa "minimum" properties Diab ProBalsa PB (G=100 MPa); PVC foam average properties ALCAN Airex C70.55 (G=22 MPa)
- Results for aft-skin buckling, 25% and 50% span station

⇒ *With geometric effects of blade structure, critical core thickness for W4 is nearly identical to balsa.*

⇒ *PVC foam requires ~5mm increased thickness compared to balsa and W4 FRC.*



Typical aft-skin buckling mode, flapwise bending load



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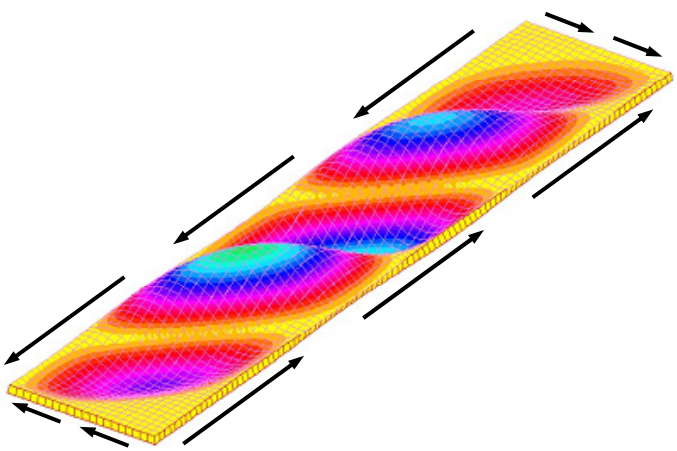
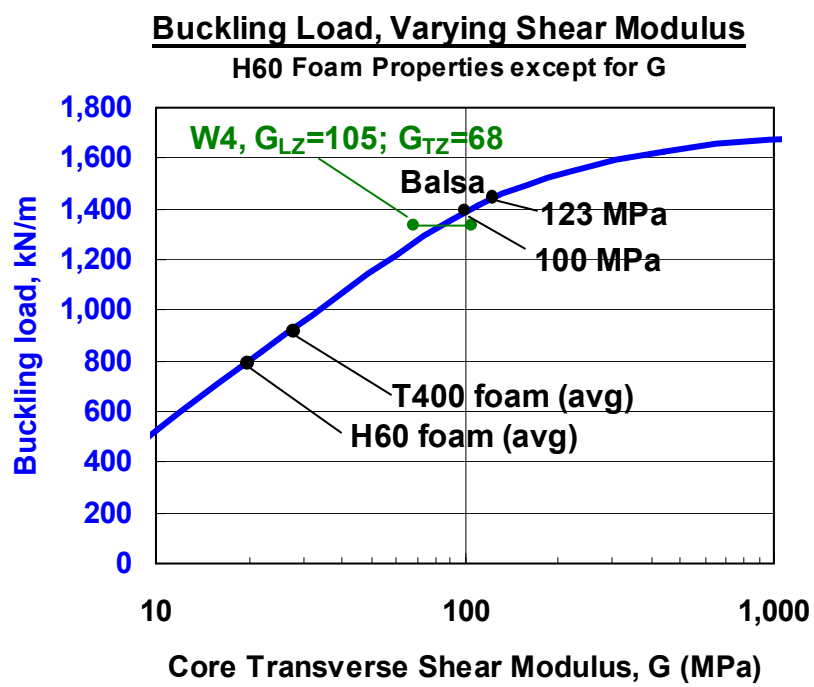
Flat-Panel Buckling Analysis
In-Plane Shear of Sandwich Laminate

- Simulate a Shear-Web laminate under in-plane shear using FEA
- Rectangular panel, simple edge support, 1m wide by 5m long
- Demonstrate sensitivity of buckling to transverse shear modulus of core, G
- Core thickness=50mm, Face thickness=1.5mm, +-45° E-glass reinforcement

⇒ ***Higher modulus core materials (balsa, TYCOR W) can be used al lower thickness than low-density foams to achieve minimum buckling margin***



Loading configuration and typical buckling mode shape



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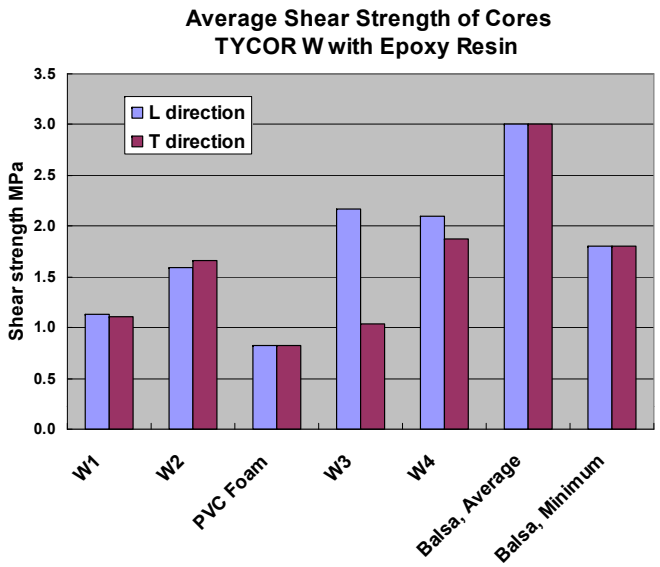
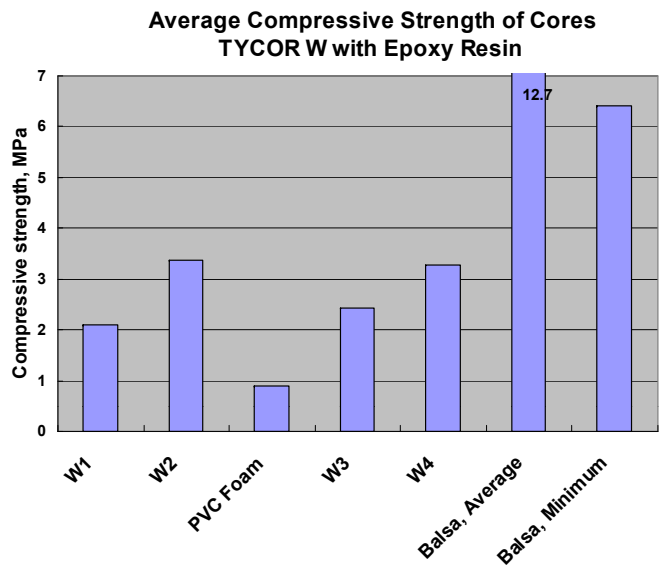
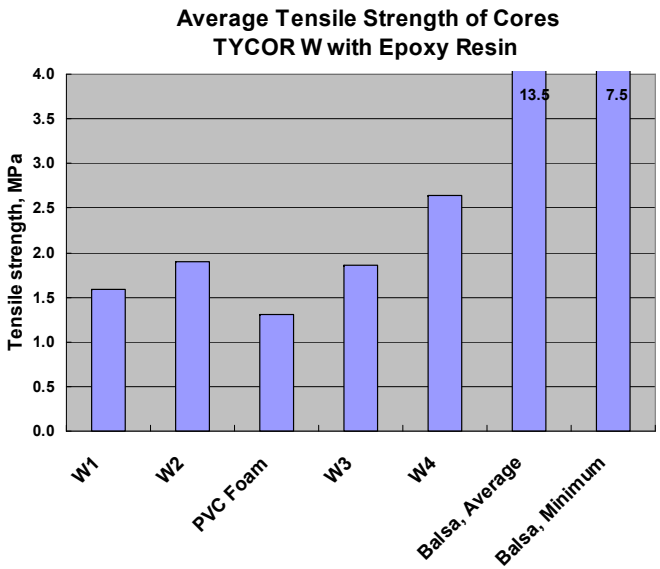
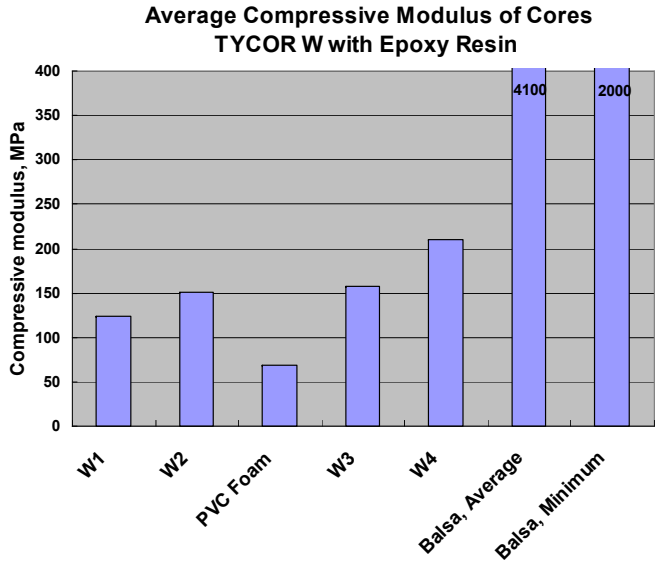
Additional Mechanical Performance Parameters









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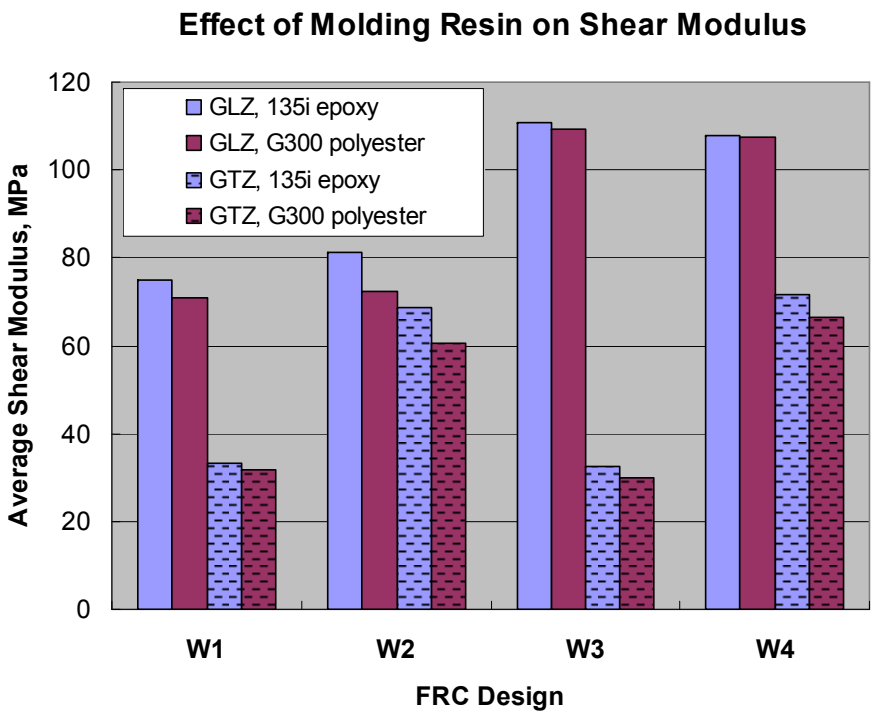
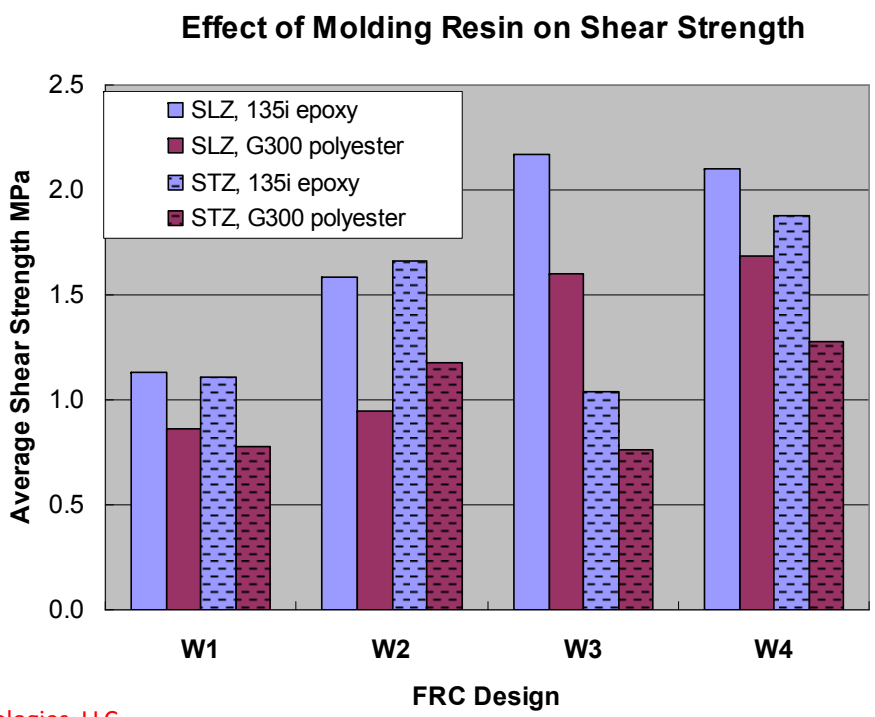
Effect of Molding Resin on FRC Mechanical Properties

- TYCOR® W1, W2, W3, and W4 FRC properties measured with:
  - Hexion 135i epoxy
  - Ashland Aropol G300 polyester
- Small effect on transverse shear modulus (6%)
- Moderate effect on transverse shear strength (29%)

⇒ ***Development of design allowables must account for molding resin selection***





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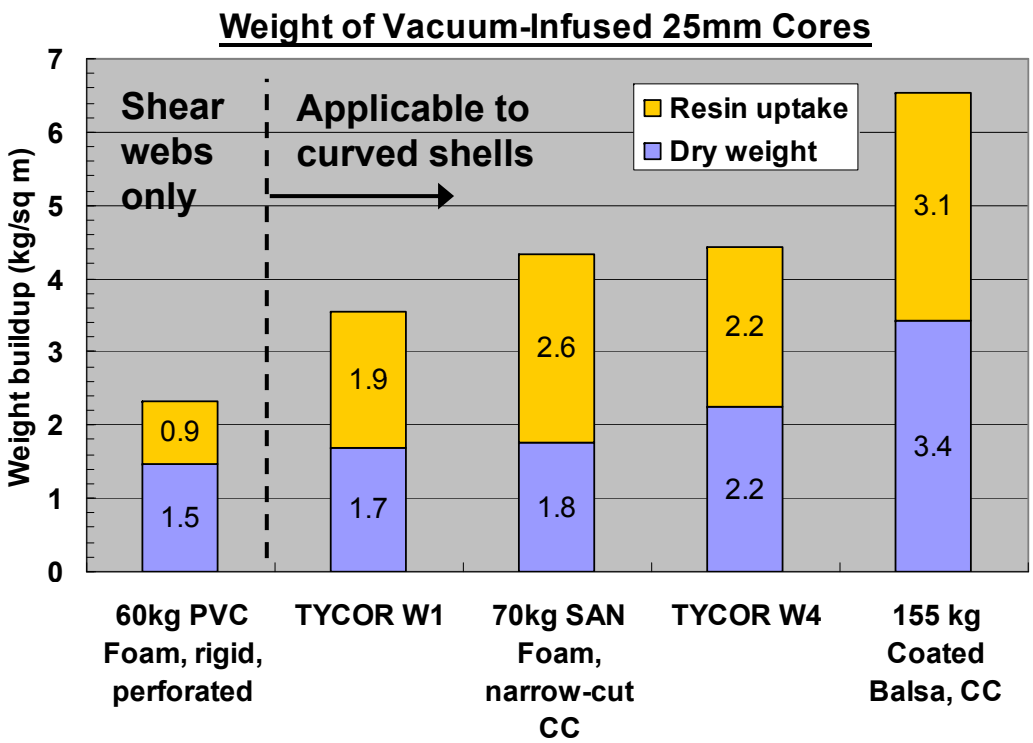
Weight Comparison – Constant Core Thickness

- 25mm contour cores (no added facing) were molded with vacuum infusion to determine infused weight build-up. (25mm rigid foam interpolated from 50mm data using weight model)
- Contourable cores:
  - ⇒ *W1 FRC weighs less than SAN foam*
  - ⇒ *W1 and W4 both absorb less resin than SAN foam or balsa*
  - ⇒ *W4 FRC weighs 1/3 less than balsa*



70 kg/m³ SAN foam

- 0.9mm cuts on 30mm centers

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Weight and Cost Analysis – 40m Blade Shells

- **GOAL: Assess FRC weight and cost impact on the basis of a blade**
- **Bill of Materials: Use BOM for shells of ~40m blade**
  - **~150 m^2 core, <10mm to 40mm**
  - **Consider only 90% of core >10mm for FRC application**
  - **Consider core materials on equal thickness basis (No accounting of design-for-properties)**
- **Weight Basis**
  - **Infusion weight data for flat-molded 25mm cores (shown earlier)**
  - **Apply mathematical weight models for scaling to different thicknesses and curvatures**
- **Core Price Basis**
  - ***Coated CC Balsa*: Market data for large volume price, average of three data points per thickness**
  - ***CC Foam* (60-70 kg/m^2): 20% above Balsa**
  - ***W1 and W4 FRC* – Manufacturer-suggested retail price**
- **Total Cost = Core Cost + Resin Cost**
  - **Assume equal kitting yield**

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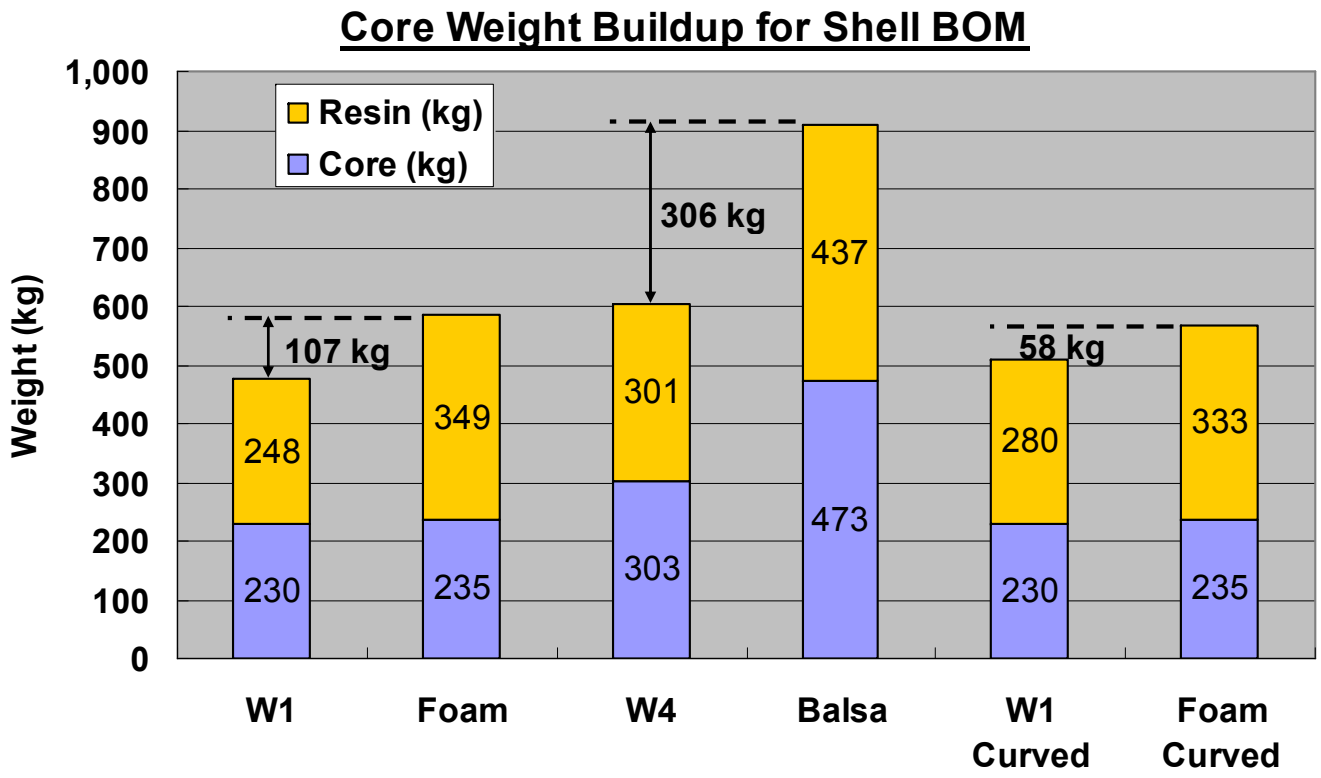
Weight Impact – 40m Blade Shells

- **W4 vs. Balsa: 306 kg reduction (shells only)**
- **W1 vs. Foam: 107 kg reduction**
  - **Curvature Simulation (impacts resin uptake): 2.5m average radius of curvature, W1 opening, Foam closing: 58 kg reduction**



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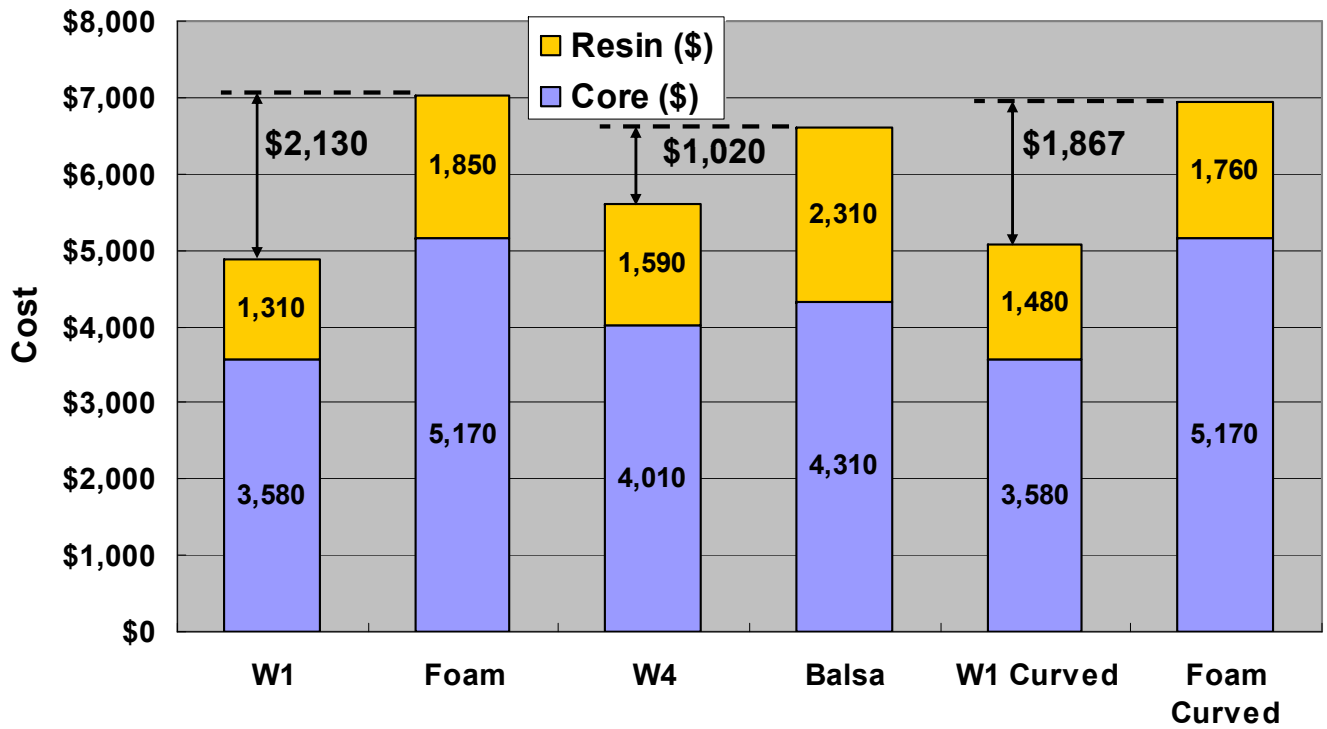
Cost Impact – 40m Blade Shells with Epoxy Resin

- **Resin price: $5.30/kg ($2.40/lb)**
- **W1 vs. Foam: $2130 reduction (30%)**
  - **Curvature Simulation (impacts resin uptake): 2.5m average radius of curvature, W1 opening, Foam closing: $1867 reduction (28%)**
- **W4 vs. Balsa: $1020 reduction (15%)**
  - **Additional FRC savings with increased kit yield**

Core+Resin (Epoxy) Cost Buildup for Shell BOM



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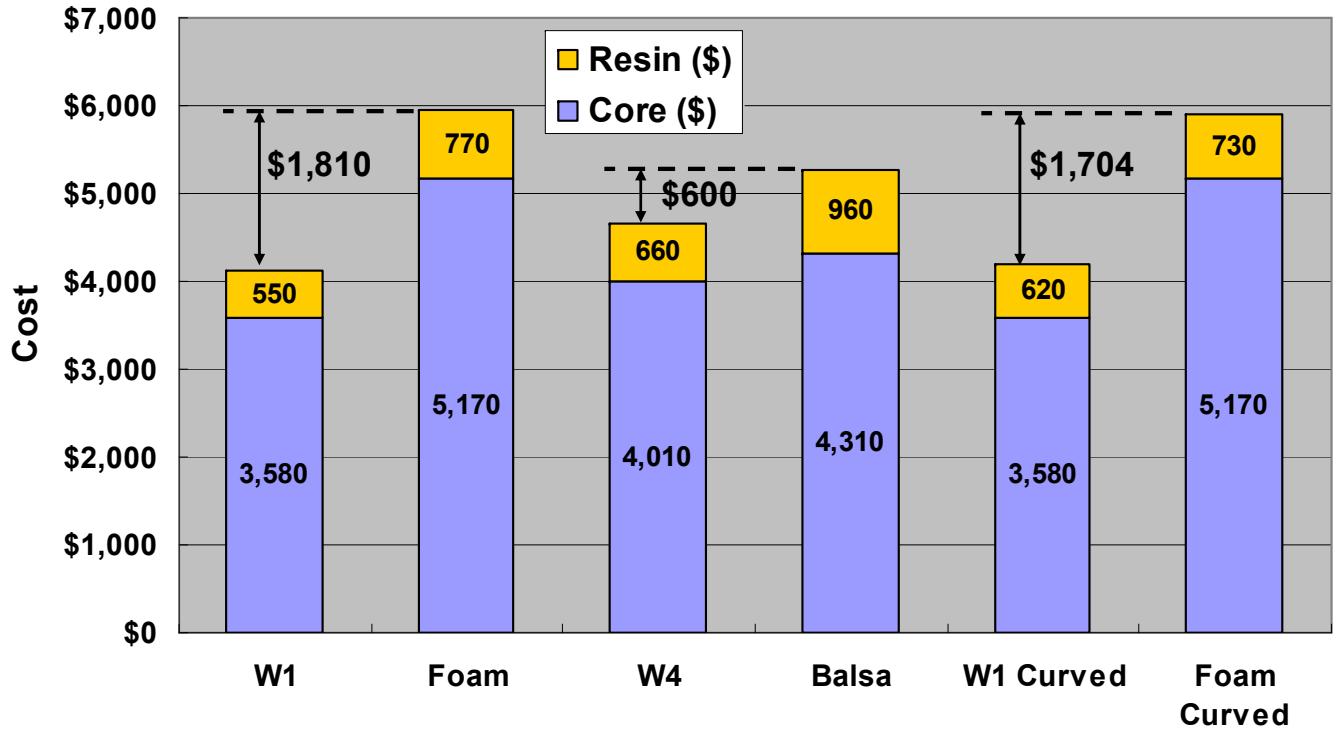
Cost Impact – 40m Blade Shells with Polyester Resin

- **Resin price: $2.20/kg ($1.00/lb)**
- **W1 vs. Foam: $1810 reduction (30%)**
  - **Curvature Simulation (impacts resin uptake): 2.5m average radius of curvature, W1 opening, Foam closing: $1704 reduction (29%)**
- **W4 vs. Balsa: $600 reduction (11%)**
  - **Additional FRC savings with increased kit yield**

Core+Resin (PE) Cost Buildup for Shell BOM



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FRC Impact Summary

FRC BENEFITS

- Material Cost Reduction (40m Shell example)
  - ~$2000/blade compared to foam
  - ~$600-$1000/blade compared to balsa
- Weight Reduction (40m Shell example)
  - ~300kg/blade compared to balsa
  - ~60-100kg/blade compared to foam
- Improved Processing
  - Variable sheet size for improved yield
  - Improved layup fit – reduce infusion problems
  - Better handling than single-side-scrim contour cores

FRC CONSIDERATIONS

- Discrete reinforcement spacing requires consideration in testing
- Core properties are resin dependent (just as with solid laminates)
- Thickness transitions can not be machined currently
- Shallow edge bevels may require separate material

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WebCore Manufacturing Status

Miamisburg, Ohio, USA

- *ISO 9001-2008 registered (2009)*
- *100+ consecutive weeks of on-time TYCOR® order delivery*
- *510k m^2 (5.5M ft^2) current annual production capacity*
- *Committed to global supply*
- *Overseas manufacturing planned 2012*
- *Low capital investment required for additional plants or production lines*

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Concluding Remarks

- **TYCOR® W family of Fiber-Reinforced Core (FRC) products has been established for the wind energy market.**
  - **Dry preform sheets for vacuum infusion molding**
  - **4 standard designs (W1, W2, W3, W4)**
  - **Any thickness from 12mm to 78mm**
  - **GL Type Approval of TYCOR® W1-4 expected August 2010**

⇒ Compared to medium density balsa and low density rigid foams, TYCOR® W FRC provides a superior mix of (i) Low Cost, (ii) Light Weight, and (iii) High Shear Modulus.

VISIT OUR BOOTH!

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