‘TORAY’

Relevant Issues of Carbon Fiber for the Emerging Wind Market

Toray Carbon Fibers America, Inc.
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Sandia Blade Workshop
Feb. 24, 2004
1. Toray Industries and Toray CFA Company Information
2. CF Forms and Applications
3. CF Technical Issues for the Wind Market
4. CF Commercial Issues for the Wind Market
Summary of Toray Industries, Inc.

- Founded: January, 1926
- Employees: 35,700
- Net Sales: 1015.7 billion yen (US $8.2 B)
- Business Domain:
  - Fibers and Textiles: 39.0%
  - Plastics and Chemicals: 22.4%
  - IT Related Products: 13.3%
  - Housing and Engineering: 13.4%
  - Pharmaceuticals & Medical Products: 4.5%
  - New Products & Other Business*: 7.4%

  (*Includes Carbon Fiber)

Note: As of March 31, 2002 (US$ 1.0 = 124 yen)
Toray's R&D Focus

Approx. 40 billion

Approx. 2,800

(Fiscal Year)

(Consolidated)

Approx. 2,800

( *determined)

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**Toray’s Activities for Advanced Materials**

**Advanced Materials**

**Foundation Businesses**
- Nano-structured Materials
- Environmentally Friendly Materials
- New Functional Materials

**Expanding Businesses (3 Growth Areas)**

**Information and Telecommunications**
- Circuit Materials
- Advanced Display Materials
- High Performance Films

**Environment, Safety and Amenity**
- Composite Materials
- Water Treatment
- Alternative Energy

**Life Sciences**
- Drug Discovery
- Innovative Therapy
- Bio/Nano-bio Materials
- Carbon fiber composites are a core technology
- Committed to and seeking new business opportunities in ACM market

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Established May 1997 in Decatur, AL
First production began April 1999
90,000 sq. ft. on 50 acres, approximately 100 employees
Sales offices in Dallas, LA and Atlanta
Products manufactured at Decatur plant:
  Regular and intermediate modulus fibers
  T600S, T700S, T700G, T800S, M30S, M30G
  Tow Sizes: 12K, 18K, 24K
• Strong technical work over the past 30 years
• Focus on new technology to reduce costs and improve performance

• Numerous facilities in Japan
• CFA Technical Center
  - Opened Jan 2004 in Decatur, AL
  - Current capabilities:
    1. Basic materials testing
    2. Analysis (SEM, optical)
    3. Composite fabrication
  - Future capabilities:
    1. CF development line
    2. Other composite fabrication processes as needed
1. Toray Industries and Toray CFA Company Information

2. *CF Forms and Applications*

3. CF Technical Issues for the Wind Market

4. CF Commercial Issues for the Wind Market
TORAYCA Carbon Fiber Forms

Fabrication Methods
- Filament Winding
- RTM, Infusion
- Autoclave
- Sheet Wrapping
- Compound

Applications
- Pressure Vessel
- Auto, Marine
- Aircraft
- Golf Shaft
- PC Housing

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Industrial Applications

- Pressure Vessel (CNG, SCBA, Hydrogen)
- Civil Eng. & Infrastructure (Bridge, Construction)
- Marine (Boat, Sailcloth)
- Energy (Windmill, Fuel Cell)
- Offshore Oil (Drill Riser, Tendon)
- Compound (PC Casing)
- Others
Industry trend of increasing turbine size (blade length) has recently led to CF becoming economically feasible.

Toray and Soficar supported European market for CF blade development.

A number of companies have announced plans for using CF:

- Vestas V90 (3.0 MW)
- NEG Micon NM92 (2.75 MW)
- DeWind D8 (2.0 MW)
- Nordex (5 MW)
- REPower (5 MW) with LM 61.5m blade
1. Toray Industries and Toray CFA Company Information

2. CF Forms and Applications

3. **CF Technical Issues for the Wind Market**
   a. Categories of CF – Aerospace vs. Commercial
   b. Factors influencing composite properties
   c. Compression strength of CFRP

4. CF Commercial Issues for the Wind Market
Carbon fibers are generally categorized in various groups:

1. Tensile Strength - 500 to over 900 ksi
2. Tensile Modulus - Standard (33 Msi)
   - Intermediate (40-45 Msi)
   - High (> 45 Msi)
3. Tow Size - Small tow vs. large tow (1K to 48K)
4. Sizing Type - Resin compatibility
5. Application - Aerospace vs. commercial

- No industry-wide accepted categories
- Typically, categories do not capture relationship of fiber properties to composite properties
1. Performance - Aerospace applications require demanding fiber properties to provide balanced composite properties

2. Qualification - Aerospace testing requirements and lengthy qualification are major cost drivers for aerospace fibers

3. Change Control - Aerospace fibers are under restrictive change control clauses, preventing utilization of cost-down technologies

4. Quality - Both aerospace and commercial applications require high quality standards, including performance and processing. Aerospace has higher quality testing standards.

5. Tow Size - Both aerospace and commercial applications require cost effective fiber forms

Toray products include:

Aerospace: T300, T700G, T800H, T800S

Commercial: T600S, T700S
• TORAYCA fibers are available in a wide range of properties
• TORAYCA fibers are known for high quality and high performance
• Typical commercial fibers include T600S, T700S and M30S

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The mechanical performance of composites, on a material level, are greatly affected by many variables, including the following (not limited to):

**Material**
1. Fiber type - Tensile strength, modulus and adhesion characteristic
2. Fiber form - Unidirectional, fabric (stitched, woven), chopped
3. Resin type - Resin strength, modulus, and adhesion

**Process**
4. Fiber volume and fiber alignment
5. Fiber and resin distribution
• Composite tensile strength is improved with higher strength fibers
• Composite compression strength is not significantly improved with higher strength fibers

Note: Toray #2500 Epoxy Resin. Normalized to 60% Fiber Volume
Effect of Fiber Form and Resin on Composite Properties

- Data normalized to 55% fiber volume where applicable
- All data tested from unidirectional fiber forms

- Prepreg (UD) form provides best composite properties
- Epoxy resin provides higher properties vs. vinyl ester resin
- Recommend T600S based UD epoxy prepreg for wind market as most cost-effective form

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Compression Strength of CFRP

• Widely accepted that compression strength (strain) is the design driver for wind market

• On a fiber level, compression strength does increase with tensile strength (loop test method)

• On composite level, compression strength is below theoretical translation

• Reduced translation is an effect of fiber buckling due to:
  – Fiber anisotropy ($E_f/G_f$)
  – Resin modulus
  – Others (alignment, etc)
Theoretical Compression Strength of CFRP

- Toray conducted low temperature flexural test to access the potential compression strength of CFRP

- Bending strength of T800H was improved to 2.6 GPa (377 ksi) from 1.7 GPa (247 ksi)

- Result can be roughly predicted by modified Rosen’s equation:
  \[ \sigma_c = \frac{G_m}{(1-V_f + G_m V_f / G_f)} \]

- Improvement due to increase of resin modulus, which improved shear stability

- Higher compression strength of CFRP could be possible with new technology

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• General long-term trend of lower carbon fiber price over 30 year history
• CF supply-demand and exchange rates effect market price in short-term

Reference: Toray Data and High Performance Composites, July/August 2000
History of PAN Carbon Fiber Market

### Introductory Period
1971-83
- Marginal Application
  - Fishing Rod
  - Aircraft Secondary Structure

### Initial Growth Period
1984-93
- Application Expanded
  - Tennis Racket
  - Golf Shaft
  - Aircraft Primary Structure

### Expansion Period
1994-
- Industrial Uses take off
  - Energy related
  - Transportation
  - Civil Eng’s & Construction

**Applications**
- Development of Golf Shaft, Fishing Rod
- Secondary Structure for B-757 & B-767
- Tennis Rackets & Golf Shafts Bodim
- Primary Structure for A-320
- Aircraft Business Recession
- Primary Structure for B-777
- Industrial Market take off (CNG, Infrastructure)

**Remarks**
- High Performance
- Product Grade Variety
- Fabrication Development
- Cost Reduction
- Larger Scale Structure

**Graph Details**
- 1000 ton / Year
- 1970 to 2005 timeline
- Development of Golf Shaft, Fishing Rod
- Secondary Structure for B-757 & B-767
- Tennis Rackets & Golf Shafts Bodim
- Primary Structure for A-320
- Aircraft Business Recession
- Primary Structure for B-777
- Industrial Market take off (CNG, Infrastructure)
- Wind Turbine

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Worldwide PAN Carbon Fiber Capacity

- Unit: Amount/year  - Announced figures by year end 2004
- Large tow CF capacity may be used for oxidized PAN fiber

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<th>Tons</th>
<th>M lb.</th>
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<td>SGL-Aldila</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>33,800</strong></td>
<td><strong>74.4</strong></td>
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- Toray is the world’s largest PAN CF supplier
- Toray is the only CF supplier to expand in 2004

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Future CF Demand from the Wind Market

• Annual installed wind turbine capacities are predicted to be 10-15 GW in 2010
• CF usage estimated at roughly 1 ton/MW (design dependent)
• If…
  ☐ 25% turbines use CF ➝ 2500-3750 ton CF demand
  ☐ 50% turbines use CF ➝ 5000-7000 ton CF demand

• Toray’s current production machine technology is 1800 ton/yr, the largest in the world
• Toray is committed to support future wind business, provided business feasibility
1. Toray leading global CF supplier, providing high-quality commercial and aerospace fibers

2. Toray’s committed technical focus will further strive to improve performance and reduce costs

3. T600S based UD epoxy prepreg recommended for wind blade application

4. In the future, CFRP compression strength could be improved with new technology

5. Toray’s future CF expansion dependent on business feasibility

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