The Future of High Capacity Carbon Fiber Production

Presenter: James Fry
Applications Engineer, Harper International
Introduction

Challenge: Carbon fiber applications for ground transportation exert market pressure towards increased capacity and lower cost.

How can our industry meet the demand?
Agenda

• About Harper
• Automotive Materials Usage
• Current Carbon Fiber Production Lines
• 10,000 Tons Per Year Carbon Fiber Lines
  • Space Requirements
  • Energy Consumption
  • Technical Challenges
About Harper

- Headquartered outside of Buffalo, NY
- An Employee-Owned Company
- Onsite Technology Center
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration
About Harper

- Established Leader in Thermal Processing Systems
- Key Partner in Advanced Materials Scale Up

Primary Technical Focus:

- New / Challenging / Advanced Material Processing
  - 200°C – 3000°C
  - Batch and Continuous processing
  - Precise atmospheric controls
  - High purity requirements
  - Complex gas-solid interactions

Harper Pilot Line at Oak Ridge National Laboratory
Technology Focus

Focus on Processing System Solutions for...

Materials:
- Fibers & Filaments
- Metal Oxides & Powders
- Technical Ceramics
- Energy Materials
- Nano Materials
- Rare Earths
- Graphene

Applications:
- Sintering
- Drying
- Calcination
- Reduction
- Controlled oxidation
- Carbonization
- Carburization
- Solid-solid reaction
- Gas-solid reaction
- Purification
- Metalizing
- Debinding
- Parts processing
- Phase transformation
Thermal Processing Systems

Custom Advanced Systems for High Temperature Processing

Range of Sizes:
• Research Scale
• Piloting Systems
• Full Scale Production

Design Expertise:
• Rotary Tube
• Pusher Tunnel
• Belt Conveyor
• Vertical
• Slot
• Elevator

Comprehensive Solutions:
• Material Handling
• Waste Gas Treatment
• Control Systems
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Historical PAN-based Carbon Fiber Supply

Worldwide Nominal PAN CF Capacity

Source: Growth Opportunities in the Global Carbon Fiber Market 2011-2016, Lucintel, 2011
Global Carbon Fiber Capacity vs Automotive Material Demand

Material Comparisons

Source: http://www.aluminiumleader.com/economics/world_market/
Global Carbon Fiber Capacity vs Automotive Material Demand

Material Comparisons

Source: https://www.worldsteel.org/Steel-markets/Automotive.html/
The Drive For Efficiency

USA Corporate Average Fuel Economy Mandates
1975-2025

The Drive For Efficiency

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The Drive For Efficiency

USA Corporate Average Fuel Economy Mandates
1975-2025

Example – C7 (2014+) Corvette Stingray

Every roof and hood – CFRP
→ 8.2kg CF per Coupe
37,288 Vehicles (71% Coupes)
→ ~261 tons CF

2014 General Motors
• 6.03 Million Vehicles
  → 49,000 Tons CF

2014 Ford
• 6.3 Million Vehicles
  → 51,000 Tons CF

2014 Volkswagen AG
• 10.1 Million Vehicles
  → 82,000 Tons CF

2014 Global Industry
• 87.9 Million Vehicles
  → 718,000 Tons CF

What If

Sources: plasancarbon.com; corvetteblogger.com; GM, Ford, and VW Annual Reports
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Carbon Fiber – Current Production Lines

1500 to 2500 Tons Per Year
3 Meter Processing Width

3 Meter Wide Harper Oxidation Oven Section
Current Production Lines – Floor Space Requirements

Up to 300 meters long
Harper Estimated Cost Structure

Cost of Manufacturing (CF) Based on 1500 TPY 12k (90min, 90s, 90s RT)

- Energy ~10% of total
  - Oxidation = 30-40%
- ~6 MW total consumption
- $4MM USD per year (energy)
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Step Change – From 2,500 to 10,000

Carbonization Line Productivity

- 2000 f/mm 10 m/min
- 2500 f/mm 10 m/min
- 3000 f/mm 10 m/min
- 2000 f/mm 15 m/min
- 2500 f/mm 15 m/min
- 3000 f/mm 15 m/min
- 2000 f/mm 20 m/min
- 2500 f/mm 20 m/min
- 3000 f/mm 20 m/min
# Today vs Tomorrow

<table>
<thead>
<tr>
<th>Production</th>
<th>2,500 TPY</th>
<th>10,000 TPY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament Density</td>
<td>2500 f/mm</td>
<td>3000 f/mm</td>
</tr>
<tr>
<td>Line Width</td>
<td>3 Meters</td>
<td>5 Meters</td>
</tr>
<tr>
<td>Line Speed</td>
<td>10 m/min</td>
<td>20 m/min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tow Type</th>
<th>Tow Spacing (mm)</th>
<th>Number of Tows</th>
<th>Tow Spacing (mm)</th>
<th>Number of Tows</th>
</tr>
</thead>
<tbody>
<tr>
<td>12k</td>
<td>4.6</td>
<td>650</td>
<td>3.8</td>
<td>1300</td>
</tr>
<tr>
<td>24k</td>
<td>9.2</td>
<td>325</td>
<td>7.6</td>
<td>650</td>
</tr>
<tr>
<td>48k</td>
<td>18.4</td>
<td>162</td>
<td>15.2</td>
<td>325</td>
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</tbody>
</table>

**Dual Tow Bands May Be Necessary**
Dual Tow Bands

Parallel Oxidation

Shared Carbonization

Single Plant

- Shared Controls
- Common Utilities
- Common Creels / Winders
- Etc...
10,000 Tons Per Year Line – 48k Tow

~310 meters long

Oxidation
3 Stacks, 15 Passes per Stack
26m Pass Length
1170m Total Heated Length

Carbonization, Each Furnace
10 Zones
20m Heated Length
10,000 Tons Per Year Line – Energy Consumption

Power Consumption
10,000 Tons Per Year Single CF Line

- Ovens 1483
- LT 1933
- HT 2244
- Abatement 1320
- Auxiliary 9735

16.7 Megawatts!
1500 TPY, 6MW = 30 kw/kg
10,000 TPY, 16.7MW = 12.5 kw/kg
### Technical Challenges

<table>
<thead>
<tr>
<th>Today</th>
<th>Tomorrow</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,500 TPY</td>
<td>10,000 TPY</td>
<td>400%</td>
</tr>
<tr>
<td>3 meters wide</td>
<td>5 meters wide</td>
<td>167%</td>
</tr>
<tr>
<td>10 m/min</td>
<td>20 m/min</td>
<td>200%</td>
</tr>
<tr>
<td>2,500 filaments/mm</td>
<td>3,000 filaments/mm</td>
<td>120%</td>
</tr>
</tbody>
</table>

For Faster Speed & Greater Precision...

- Better Process Stability
- Oxidation Oven Stability

“Focus on the Bottleneck”
PAN Oxidation

“Like toasting a marshmallow on a camp fire.”
-Dr. Renee Bagwell

- Achieve uniform thermal processing
- Prevent runaway exotherm
- Key: airflow uniformity
  - Straight
  - Smooth
  - Even
Harper Oxidation Oven Flow Pattern

- Inlet Nozzle
- Collector Plenum
- TOWS
- INLET NOZZLES
- BASE ASSEMBLY
- DOOR
- ACCESS DOOR BLOWER
- ACCESS
- FILTER
- HEATER
- ACCESS DOOR EXTERNAL
- BLOWER
Oxidation – Unstable Airflow

Inlet Nozzle

Collector Plenum

Tow Processing Volume

Flow Just Downstream of Heater

Fan Inlet
Harper Oxidation Oven – Stable Airflow

Inlet Nozzle

Collector Plenum

Tow Processing Volume

Flow Just Downstream of Heater

Fan Inlet
Harper Oxidation Oven - Stable Data

Velocity at Center Nozzles of 3 Meter Oven

144 points (every 200 mm at each nozzle)
Mean = 3.35 m/sec
St. Dev. = 0.07 m/sec
C.V. = 2.2%
Harper Oxidation Oven – Safety Features

<table>
<thead>
<tr>
<th></th>
<th>3000 Filaments/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Width</td>
<td>5 Meters</td>
</tr>
<tr>
<td>Line Speed</td>
<td>20 m/min</td>
</tr>
<tr>
<td>Production</td>
<td>10,000 TPY</td>
</tr>
</tbody>
</table>

448kg PAN in Each Zone
= 878,000 kJ Energy
= 25 Liters Gasoline

Water Injection

Deflagration Management
Furnaces

Length OK
• Harper Has Furnaces >18m in Operation

Width is Challenging
• Multiple Vent Ports?
• Dual Muffles?

Harper LT: ~5.2 meter wide tow system in final assembly,
Two (2) muffles 2.6 meter each
Conclusions

Adoption of CFRP as an automotive material will force **rethinking of plant configuration.**

16.7 Megawatts!
1500 TPY, 6MW = 30 kw/kg
10,000 PTY, 19.2MW = **12.5 kw/kg**

**Precision equipment** will be paramount to success.

Significant **cost savings** will be realized.
Thank You!

Visit us at harperintl.com
or stop by booth Hall 6, Booth C56