TenCate Thermoplastic Composites

- **TenCate Advanced Thermoplastic Composites**
  - Locations: Morgan Hill, CA; Camarillo, CA; Burlington, ON, Canada; Nijverdal, Netherlands; and Guangzhou, China
  - Products: Tape, fabric, laminates and parts
  - Applications include aerospace, defense, pipe, foot wear, recreational, medical and orthotics, and consumer electronics
  - Unidirectional tape impregnation technologies
    - Slurry for aerospace applications
    - Melt for high performance industrial applications
  - Annual Capacities
    - Tape: 600,000 lbs aerospace quality by June 2017, 800,000 lbs by 3Q 2018
    - Laminates: >1M lbs in 2017
    - Parts: >10M pieces in 2017
International Thermoplastic Composite Partnerships

• Grow the thermoplastic composites business through cooperation and technology development

• TPRC formed in partnership with Boeing, Stork Fokker, TenCate and University of Twente focusing exclusively on thermoplastic composite processing
• TAPAS consortium formed with Airbus, Fokker, TenCate and the University of Delft focusing on thermoplastic fuselage activities
• TenCate is a Tier 2 member of AMRC (Advanced Manufacturing Research Center, University of Sheffield) focusing on thermoplastic tape placement, bonding and machining activities.
• TenCate is a member of the National Composites Center (NCC) in Bristol, UK that is involved in thermoplastic processing
• Outstanding working relationships with Victrex (PEEK), Hexcel (carbon fiber) and Arkema (PEKK)
Markets for Thermoplastic Composites

- Aerospace
- Defense
- Aircraft seating and interiors
- Weapon systems
- Jet engine components
- Pumps (vanes, housings)
- Truck liners and shirts
- Compressors (blades, plates)
- Pulp and paper (doctor blades)
- Shoe inserts
- Oil pipe, frac packers, bridge plugs, antenna shields
- Water pipe
- High speed motors, generators and flywheels
- Wear rings and bearings
- Consumer electronics
Current TP Tape Products

- High Quality TP Tapes using PEEK, PEKK, PAEK, PPS & PEI
  - AS4, AS4A, AS4D, AS7, IM7, S2 and other fibers
  - Excellent wet out, fiber resin distribution and interface: 90° Flex Strength = 20-25 ksi
  - Low void content (<0.5%) and excellent dimensional uniformity; CAI = 38-52 ksi
  - Multiple aerospace qualifications
## TenCate TP Prepregs and Key Properties

<table>
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<tr>
<th></th>
<th>PEEK/AS4</th>
<th>PAEK/AS7</th>
<th>PEKK/AS4D</th>
<th>PEI/AS4</th>
<th>PPS/AS4</th>
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<tr>
<td><strong>Tg</strong></td>
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<td>147°C</td>
<td>159°C</td>
<td>215°C</td>
<td>90°C</td>
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<tr>
<td><strong>Tm</strong></td>
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<td>305°C</td>
<td>337°C</td>
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<td>285°C</td>
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<tr>
<td>CAI (ksi)</td>
<td>40-52</td>
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<td>44</td>
<td>-</td>
<td>38</td>
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<td>Resin Cost</td>
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<td>5</td>
<td>5</td>
<td>1.5</td>
<td>1</td>
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<tr>
<td>Aero/Def Quals</td>
<td>2+</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2</td>
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</table>
Thermoplastic Composite Driveshafts

33% weight reduction
150% better post ballistic impact torque retention
TP Tape Processing Characteristics are Important

- Cost is dependent upon **Manufacturing** process and speed, **Manufacturing** buy-to-fly ratio, **Manufacturing** cost of labor and **Manufacturing** capital investment needs.
- Automation can significantly reduce **Manufacturing** labor cost and buy-to-fly ratio but generally increases front end capital investment.
- **Manufacturing** speed and part performance are dependent on TP tapes’ compatibility with the process, heat source and equipment.
  - The faster you go, the more dependent the process becomes on the quality and processing performance of the tape in thermally bonding to itself.
  - In a fast, automated process, material shortcomings are not improved.
  - As processes become more automated, material cost becomes a bigger percentage of the recurring part cost, so the tape must bring added value.
Thermoplastic Composite Tape Attributes

- Key Tape Attributes for high speed processing
  - Completely wet out at up to 60% fiber volume
  - <1% voids
  - Excellent fiber resin distribution and dimensional uniformity
  - Excellent fiber resin interface using un-sized carbon fiber
    - New TP sized fibers are under evaluation
    - Interface is impregnation process dependent
  - Very long lengths for ATP and FW
  - No curl, splits, defects or non-linearity
  - Appropriately priced
  - Tailored for:
    - High speed AFP processing
    - OOA lamination, stamping of laminates and compression molding of chopped tape
    - Enhanced handling, seaming and welding
TenCate Tape

Competitor Tape
Part Fabrication Processes Using TP Tape

- Thermoplastic Composite Processing
  - Autoclave, press and OOA consolidation
  - Thermoforming / Stamping consolidated flat laminates and pre-forms
  - AFP/ATL: partial in-situ followed by OOA or complete in-situ consolidation eliminates hand layup
    - OOA eliminates the autoclave
    - Complete in-situ consolidation lowers tooling and assembly costs and eliminates the autoclave
  - Continuous fabrication of flat laminates and shaped parts
    - Continuous fabrication of flat and shaped parts by continuous compression molding (CCM)
    - Belt consolidation of flat laminates
  - Injection overmolding onto composite shapes (PEEK onto PAEK)
  - Tension and AFP winding of pipe, tubes and cylinders
Automated Continuous Processing is Essential for TP Composites Acceptance

• TP AFP machine builders:
  • Automated Dynamics (ADC) – in-situ – N2 torch, laser
  • Accudyne – in-situ – torch with conformable shoe, infrared
  • AFPT – in-situ - laser
  • Coriolis – partial in-situ - laser
  • MTorres – in-situ - laser
  • Electroimpact - under development
  • Mikrosam - recently introduced
  • Magnum Venus – pipe wrapping machine

• Process automation companies:
  • Accudyne
  • Globe Machine
  • Diffenbacher
  • Teubert Machinenbau
  • Automated Dynamics (ADC)
High Volume- Low Cost UD Tape
High Volume- Low Cost UD Tape

- E-Glass with HDPE matrix
- Tailored tape width for full coverage at specified wrap angle
- Multiple heat source types and locations for tape and substrate
- In-situ consolidation of 800 lbs/hour
Tailored Blank
Trim scrap = 11%

Comparison
Trim scrap = 33%
Continuous Compression Molding (CCM) at Cutting Dynamics Inc.
CDI - Prototype and Series Production of CCM Parts
G650 Induction Welded Tail Elevator
Cobonded Structures

Cobonded, skin stiffened structures
- No adhesives
- No fasteners
AM Wash Out Tooling  TPC AFP Structure