Compound Benefits of Hybrid Composites

Maximising Thermosets and Thermoplastics

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Global Director Product and Market Strategy

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Organization Overview

› TenCate Advanced Composites
  › Total Employees: 750; Sales - $200+ MM
  › Manufacturing in North America, Europe, and China

› Toray Group
  › Total Employees: 46,000; Sales - $20 BN
  › Manufacturing in North America, Europe, and Asia

› Markets Served
  › Aerospace - Aerostructures, Aircraft Interiors, Radomes, Satellite/Launch
  › High Performance Industrial - Consumer Electronics, Footwear/Orthotics, F1 Racing, Tooling

› Key Product Lines
  › Thermoset Prepregs
  › Thermoplastic Prepregs and Laminates
  › Low Density Syntactic Films
  › Film Adhesives and Surfacing Films,
  › Honeycomb core and Syntactics
  › Bulk Molding Compounds and Molded Parts
Core Competence

Vision and Values

WHO WE ARE
- We are a company that makes a difference in our industry & with customers by being responsive and dependable

OUR CORE VALUES
- Responsive
- Collaborative
- Reliable
- Partnership oriented

WHAT WE DELIVER
- Advanced Composite Material Solutions and Expert Services

WHO WE SERVE
- Customers who need and value a responsive partnership-oriented organization with broad advanced composite materials technologies

HOW WE ARE DIFFERENT
- We surround our customers with collaborative technical teams to reduce risk, speed material implementation, and then back that with outstanding customer service

In the following markets:
- Aerospace
- High Performance Industrial
Portfolio Snapshot

Advanced Composites

› Largest supplier of **ultra pure/low dielectric prepregs** for commercial aerospace SATCOM, military and shipboard **radome** structures.

› Key supplier of **epoxy prepregs** to the **general aviation, launch vehicles, helicopter programs, and UAV industries** *(Cirrus, Kestrel, ICON, General Atomics Predator/Reaper, Boeing Apache, Marenco Swisshelicopter, Erickson AirCrane, Rocket Lab)*.

› The leading supplier of **high-modulus advanced composites** for satellite structures.

› Primary supplier of **thermoplastic-based composites** for commercial aerospace structural and interior applications under the TenCate **Cetex®** Thermoplastic brand.

› Key provider of **composite tooling prepregs under TenCate AmberTool®** brand.

› Provider of chopped fiber **compression molded parts** with internal tool design and part fabrication capabilities.
Principle Markets

- Commercial Aircraft: T/P for primary and secondary structure
- Military Aircraft: incl. High Temp Materials
- Unmanned Systems
- Space/Satellites and Launch Vehicles
- Radomes and Antennas
- Aircraft Interiors
- General Aviation
- Industrial and Composite Tooling
High Performance Thermoset

Structural
Semi-structural
High temperature
Ultra high temperature

Impact resistant
Out of Autoclave
Variable cure
Low temperature cure

Epoxy
BMI
Cyanate ester
Polyimide

Thermal Performance

PI
CE
PEEK
PEKK
BMI
LMP
HT epoxy
PC
PEI
PPS
PA
PMMA
PE
LT epoxy
PP

Structural Performance
High Performance Thermoplastic Composites

Performance Pyramid

Our High-Performance Thermoplastic Polymers and Product Forms

- UD tape
- Fabric prepreg
- Laminate
- Laminate parts

High-performance thermoplastics:
- TC1320, PEKK
- TC1225, Engineered PAEK
- TC1220 / TC1200, PEEK
- TC1100, PPS

Engineering thermoplastics:
- TC925 FST, PC
- TC950, PMMA*
- TC940, PET*
- TC910*, PA6

Standard thermoplastics:
- TC920, PC/ABS
- TC960, PP
- TC930, HDPE

Amorphous

Semi-crystalline
TenCate Cetex® thermoplastic advanced lightweight materials offer outstanding mechanical properties, durability, and strength.

Qualified to Boeing, Airbus material specifications. Unsurpassed performance delivers proven resistance to extreme conditions and environments.

Established choice for high volume manufacturing, TenCate Cetex® family of UD tape, prepreg, and laminate (RTL) thermoplastic composite materials is available in a wide range of fiber/resin combinations and product formats.
Thermoplastic Processing

Significant Improvements for Part Consolidation and High Volume Production

TenCate Cetex® thermoplastic composite materials are suited to a diverse range of processing methodologies, thus providing design and operational efficiencies.

Welding

Welding provides a seamless joint between substrates and can be married with overmolding to add functionality and integrate additional parts, making it an ideal alternative to time-consuming and potentially weaker adhesive bonding and mechanical fixation techniques.

Thermoforming

The high quality consolidation of TenCate Cetex® thermoplastic composites in both UD tape and RTM formats allows for simple heating and forming processes that take minutes.

Overmolding

Integrating Cetex® endless fiber reinforced composites in an injection molding process combines the strength of high-end composites with the design freedom and complexity of injection molding parts.
Material Benefits

Thermosets

+ Pedigree of data
+ Broad production basis
+ Cost effective processing
+ Mechanical performance
+ Tailored characteristics
+ Adhesion performance

- Fire Performance – by resin
- Moisture tolerance*
- Cure cycle limitations – by resin
- Limited by secondary operations

Thermoplastics

+ Mechanical performance
+ High volume manufacturing
+ Moisture tolerance
+ Fire performance
+ Fatigue performance
+ Secondary operation integration

- Limited installed supplier base
- High cost to entry for equipment
- Processing limited by geometry
- Historical database of mechanical performance

* Stated in terms of moisture ingress for a sandwich panel
Material Benefits
What Are the Limiting Benefits of The Individual Technologies?

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  + Pedigree of data
  + Broad production basis
  + Cost effective processing
  + Mechanical performance
  + Tailored characteristics
  + Adhesion performance

  - Fire Performance
  - Moisture tolerance*
  - Cure cycle limitations
  - Post processing operations

› Thermoplastics
  + Mechanical performance
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Material benefits
Increasing the Performance of Installed Supplier Capability

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Hybrid Composites, Compound Benefits
Overmolding
Next Generation Part Design

Continuous fibre material
Minimised RTL/UD tape format, customised to meet mechanical needs

Short fibre injection moulding
Neat resin or short fiber molding provides mechanical performance

Final part
Integrated part design with multiple functionalities
Hybrid Composite Solutions
Unite the Best of Thermoset and Thermoplastic Composites

 › Maximise weight reduction by eliminating adhesive film weight (100-200gsm)
 › Achieve excellent surface finish with CETEX
   ▪ Secondary benefits include, color, welding
 › Mechanical performance comparable to Thermoset (peel strength)
 › Existing production equipment can be utilised.
 › FST performance OSU 35/32 for sandwich panel with PVC foam core.
   ▪ 1-ply CETEX TC1000 – Design (Carbon)
   ▪ 1-ply E721-FR – (Carbon)
Target for Hybridization

Process Screening across Amorphous and Semi-crystalline Chemistry

- Epoxy
- BMI
- Cyanate ester
- Polyimide

Structural
- Semi-structural
- High temperature
- Ultra high temperature

Impact resistant
- Out of Autoclave
- Variable cure
- Low temperature cure

Thermal Performance

- PI
- CE
- PEEK
- BMI
- LMP
- PEKK

- HT Epoxy
- PC
- PPS
- PEI
- PMMA
- PA
- PE
- PP
- LT Epoxy
Amorphous Hybrid Benchmark

› Fire Performance
  - FAR25-853 (OSU 29/24)*
  - Smoke – PASS (<50)
  - 60-second vertical = 4.3” (6” limit)
  - 12-second vertical = 0” (8” limit)

› Mechanical Performance
  - Drum peel = 25.1 lb/3” wide sample
  - 4-point bending – 58.3 ksi

› Functional Performance
  - No dimpling (surface flatness)
  - Established cure cycles (existing epoxy cure)

* Based on 2-ply skin combination (1-ply CETEX, 1-ply Epoxy BT250E-1FR)
Semi-crystalline Hybrid Baseline

- Included **tie layer** preferably during laminate consolidation
- Balance between material compatibility and processing parameter
Tie Layer
Facilitate Joining and Coating Technologies

-Origin from coextrusion technology to promote adhesion between different layers with different constituents.

-Mechanism for TenCate Cetex® materials
  - Surface treatment forms an intermediate layer that bonds well to PPS and PEEK and various other materials such as adhesives and coatings

-Applications:
  - Coating of exterior parts
  - (Adhesive) bonding using various epoxy adhesives for joining with (thermoset) composites and metals
  - Welding at lower temperatures (repair)
### Coating of C-PPS with Tie Layer

<table>
<thead>
<tr>
<th></th>
<th>Requirements</th>
<th>C-PPS</th>
<th>Tie layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm squares</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry*</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wet**</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2 mm squares</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry*</td>
<td>0</td>
<td>2-4</td>
<td>0</td>
</tr>
<tr>
<td>Wet**</td>
<td>1</td>
<td>1-2</td>
<td>0</td>
</tr>
</tbody>
</table>

- Tested at Akzo Nobel Aerospace coatings (ISO 2409)
  - Rating (0 = good adhesion, 5 = complete delamination of coating)
- Primer
  - Low solids composite primer, isocyanate cured, with epoxy functionality
- Surface treatment
  - Cleaning with IPA
- Results: **Tie layer is a good adhesion promoter between PPS substrate and coating for dry as well as conditioned samples**

* Not conditioned
** Immersed in water for two weeks
## Bonding and Welding of C/PPS with Tie Layer

### Lap Shear Testing

<table>
<thead>
<tr>
<th>Set</th>
<th>$\sigma_L$(Mpa)</th>
<th>Failure Mode</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding of C/PPS with tie layer below $T_m$</td>
<td>9.31 (±0.53)</td>
<td>Predominantly at fiber surface</td>
<td>Very thin bondline*** (~0mm)</td>
</tr>
<tr>
<td>of PPS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C/PPS with tie layer + FM300</td>
<td>19.40 (±0.61)*</td>
<td>Cohesive failure</td>
<td>Very thin bondline*** (~0mm)</td>
</tr>
<tr>
<td>3. C/PPS no surface treatment + FM300</td>
<td>0**</td>
<td>100% adhesive</td>
<td>Tested manually</td>
</tr>
</tbody>
</table>

* ref value from datasheet 36.8 MPa

** could be separated from hand relatively easy

*** Planned to be tested according to specification with increased bond thickness

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Sample set 1

Sample set 2

Sample set 3

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![Sample set 1](image1)

![Sample set 2](image2)

![Sample set 3](image3)
Processability of C/PPS Including Tie layer

Production Results

Laminates with tie layer were thermoformed, treated, and coated at Daher.

Coating trials with tie layer were performed on part.

Cross hatch test showed good adhesion between coating and substrate.

<table>
<thead>
<tr>
<th></th>
<th>Requirements</th>
<th>Results with tie layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosshatch test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2 mm</td>
<td>Dry*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Wet**</td>
<td>1</td>
</tr>
</tbody>
</table>

* Not conditioned
** Immersed in water for two weeks
Tie layer adhesion

Tie Layer

Consolidation

Coating/Adhesive

Fracture Surface

CETEX 1100

CETEX 1100

CETEX 1100
Key Market Applications
Potential Market Adoption of Hybrid Technology

› Aerospace
   - Wing control services and access panels – chemical resistance, moisture ingress, impact performance
   - Aircraft flooring – fatigue performance, moisture resistance
   - Galleys and lavatories – surface quality (dimpling), impact performance
   - Engine casing – fatigue performance, acoustic performance
   - Galley trolleys – welding and fatigue performance
   - Cargo lining systems – in-color, impact performance, fatigue performance

› Rail
   - Train bodies – lightweighting and FR performance
   - Train flooring – impact performance and FR performance

› Mass transportation
   - Trailer bodies – FR performance for high use in tunnels
Any Questions?

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