Fortron® PPS for Thermoplastic Composites

November 2012
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Broad Portfolio of Engineering and High-Performance Polymers

Price for performance

High-Performance Polymers (HPP) (TI¹ > 150 °C)

Engineering Polymers (ETP) (TI¹ > 90 °C)

Amorphous

Partially crystalline

TI¹ = Temperature Index

Ticona Engineering Polymers

- LCP – Vectra®/Zenite®
- PPS – Fortron®
- PCT – Thermx®
- PET – Impet®
- PBT – Celanex®
- PBT Alloy – Vandar®
- TPC-ET – Riteflex®
- POM – Hostaform®
- LFRT – Celstran®, Factor®, Compel®
- CFR-TP – Celstran®
- UHMW-PE – GUR®
Fortron® PPS
Summary – Structure and Properties

- **Semicrystalline**
  - $T_g$ 85°C, $T_M$ 285°C
  - Density 1.35 g/cm$^3$

- **Inherently Flame Retardant:**
  - UL94-V0, LOI > 45

- **Chemical Resistance – Dimensional Stability**
  - Fuels, oils, solvents
  - Water-glycol

- **Easy to Process**
  - Injection molding
  - Extrusion

**Polyphenylenesulfide (PPS)**
Poly(thio – 1,4 - phenylene)
Fortron® PPS

Semi-crystalline thermoplastic polymer, perfectly suited for parts that have to withstand the high mechanical and thermal requirements which require…

- A high melting point range between 280° and 290°C
- Inherently flame resistant
- Excellent resistance to chemicals, oils and fluids
- An ideal alternative to conventional materials such as thermosetting polymers and metals
- High hardness and stiffness and superb long-term creep under load properties
- Ease to injection mold, blow mold and machine
- Weight reduction combined with high dimensional stability
Fortron® PPS Has No Known Solvent Below 200°C

- Chemical resistance with minimal attack or swelling even at elevated temperatures
  - Resists: acids/bases pH 2 to 12
  - Resists: strong bleaches
  - Resists: auto fluids – coolants, transmission & brake
  - Resists: gas & alternate fuels (methanol, ethanol)
  - Resists: hydrolysis
Fortron® PPS 0214C1 – Matrix Material for Composites

- Linear, unmodified PPS polymer
- High molecular weight / high viscosity: 140 pa·s
  - For extrusion and injection molding applications
- Specified for aircraft applications
  - In use at Airbus and Boeing
  - VIAM qualification
  - Federal state unitary enterprise “All Russian Scientific Research Institute of Aviation Materials”
- Tested in regards to flammability, smoke density and smoke toxicity:
  - ABD0031
  - FAR/JAR 25.853
  - New: DIN 5510 and ISO 5659
Fortron® PPS 0214C1 – Smoke Density Tested with 2 mm Plaques

- Smoke density according to Airbus Standard ABD0031
  - Non-flaming – Max. Value: 0, Average: 0
    - DS max. @ 4 min: 0; ABD and FAR Passed
  - Flaming – Max. Value: 32 (6 min.), Average: 23 (6 min)
    - DS max. @ 4 min: 15; ABD and FAR Passed

- Tox-Test (ABD0031):
  ABD / FAR passed

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Max. Value in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Cyanide HCN:</td>
<td>NF: 0 – F: 0</td>
<td>150</td>
</tr>
<tr>
<td>Carbon Monoxide CO:</td>
<td>NF: 0 – F: 10</td>
<td>1000</td>
</tr>
<tr>
<td>Nitrous Gases NO-NO₂:</td>
<td>NF: 0 – F: 0</td>
<td>100</td>
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<tr>
<td>Sulfur Dioxide/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hy. Sulfide SO₂ - H₂S:</td>
<td>NF: 0 – F: 10</td>
<td>100</td>
</tr>
<tr>
<td>Hydrofluoric Acid HF:</td>
<td>NF: 0 – F: 0</td>
<td>100</td>
</tr>
<tr>
<td>Hydrochloric Acid HCl:</td>
<td>NF: 0 – F: 0</td>
<td>150</td>
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</table>
Fortron® PPS 0214C1 – Flammability Tested With 2 mm Plaque

- **Vertical Burning Test 12 s ABD0031**
  - Total burn time: 12 s
  - Flame extinguish time: 0 s
  - No. of particles: 0
  - Ignited particles: 0
  - Total burn length: 5 mm

- **Vertical Burning Test 60 s ABD0031**
  - Total burn time: 60 s
  - Flame extinguish time: 0.6 s
  - No. of particles: 2.4
  - Ignited particles: 1.4
  - Total burn length: 44 mm
## Internal UL Flammability Testing

<table>
<thead>
<tr>
<th>Material</th>
<th>Part Thickness</th>
<th>Unaged Sample Rating</th>
<th>Aged Sample Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfilled Fortron PPS</td>
<td>3.0mm (0.12”)</td>
<td>V-0*</td>
<td>V-0*</td>
</tr>
<tr>
<td>Control</td>
<td>1/32”</td>
<td>V-0</td>
<td>V-2</td>
</tr>
<tr>
<td></td>
<td>1/64”</td>
<td>V-2</td>
<td>V-2</td>
</tr>
<tr>
<td>Unfilled PEEK</td>
<td>3.0mm (0.12”)</td>
<td>V-0*</td>
<td>V-0*</td>
</tr>
<tr>
<td>Control</td>
<td>1.5mm (0.059”)</td>
<td>V-0*</td>
<td>V-0*</td>
</tr>
<tr>
<td></td>
<td>1/32”</td>
<td>No V-Rating</td>
<td>V-2</td>
</tr>
<tr>
<td></td>
<td>1/64”</td>
<td>No V-Rating</td>
<td>No V-Rating</td>
</tr>
</tbody>
</table>

- Thin PEEK samples failed to achieve a V-Rating because of long burn times and cotton ignition.
- Thin PPS parts have V-0 equivalent burn times but molten polymer drips can ignite the cotton = V-2 Rating

*Data as reported by Underwriters Laboratory*
Fortron® PPS Dimensional Stability

- Extremely low moisture absorption – 0.02%
- Minimal effect of temperature
- CLTE – $19 \times 10^{-6} /°C$ (6165A4)
- Precision molding
- Low shrinkage - 0.3% (6165A4)
- Creep resistance

For Precision Parts Even at Elevated Temperatures
Low PPS Water Absorption Results in Dimensional Stability

![Bar chart showing water absorption rates for PPS, PEI, and PEEK]
Top Fortron® PPS Segments

- Semicon
- Industrial
- EE & Sensors
- Fibers
- Automotive
- Composites
Fortron® PPS
Extrusion: Film, Fiber, Netting, etc.

- Aircraft Composite
- High Tenacity Monofilament
- Filter Netting
- Stock Shapes
- CPI Filter
Fortron® PPS for Thermoplastic Composites

May 2012
Why Thermoplastic PPS Composites vs. Thermoset Composites?

Improved Properties
- Tougher, good fatigue performance
  - 4x tougher than toughened epoxies
- Damage tolerant
- Insensitive to moisture
- High-temperature performance
- Very low flammability, smoke, toxicity
- Low residual stress in molded parts
- Excellent chemical resistance

Improved Processing
- Eliminate bagging materials and labor
  - May also eliminate kitting and debulking steps and equipment
- Eliminate autoclave possible
  - Cost, space and bottleneck issues
- Rapid processing vs. thermosets
- Can be reformed
- Simple, longer lasting tool
- Fusion bonding eliminates fasteners and adhesives
  - Reduces cost and weight

Green processing
- Recyclable
- No VOCs in processing
- Less process scrap
- Fewer process energy requirements
Thermoplastic Composite Matrix Cost Advantage

- The material cost for a thermoplastic matrix might be equal or even higher.
- Lower cost for handling, processing, and assembly can lead to a substantial advantage in total cost.

Even the High Cost Thermoplastic Polymers Offer Improved Cost Savings vs. Epoxy Based Composites
Example for Value Chain in Aircraft Industries

- Plastic Pellets
- Film Producer
- Producer of Composites
- Thermo-Forming-Process
- Assembling
- Aircraft
Station 1: Film Production

Starting Product:

PPS Pellets
- Temperature stability
- High level of hardness and impact strength
- Excellent resistance to chemicals
- Broad temperature range
- Inherent flame resistance

Film Production

Station 1 – Lipp-Terler GmbH in Gaflenz near Linz, Austria. The pellets are converted into films with a thickness of 50 to 200 µm. The film leaves the special plant in rolls of 100 kg in a flawless state, crystal clear and with the required characteristics with regard to strength and dimensional stability.
Station 2: Composite Production

Starting Product:
Basic Matrix of PPS / Carbon Fiber Fabric

Laminate Production
Station 2 – Ten Cate Advanced Composites BV, Nijverdal, Netherlands. The carbon fiber fabric and PPS film are bonded together in a press, under high pressure and high temperature, into high-strength, dimensionally stable and resistant composites in the desired layer thickness.

Fortron PPS Film

e. g. Carbon Fiber

© Ticona PPS-014R1 5/12 US EN
Station 3: Thermoforming

Starting Product:
Composite plates in the required size

Shaping
Station 3 – Fokker Special Products, Hoogeveen, Netherlands.
The composite plates are pre-heated and subsequently shaped into the desired form under pressure and high temperature.
Station 4: Assembly

Starting Product:

Front wing portion
(Weight of the parts is 20 percent less than aluminum)

Assembly
Station 4 – Airbus
The completed construction element is mounted at the intended location.
Technology Breakthrough: Fixed Wing Leading Edge Airbus

- Welded structure
- Low weight and low cost monolithic design
Fortron® PPS
Success in the Aviation Industry

- Safe, efficient, environmentally friendly
- Modern design
- Licensed for aircraft construction
- New applications from Fortron® PPS
Reduced Process Energy Example for TP vs TS Composites

Thermosets
- Assemble part in tool
- Match Mold Process Cycle (1+ hours)
- Cool, removal

Thermoplastics
- Assemble part in tool
- Stamp /Thermoform Cycle (minutes)
- Subsequent part can be stamped immediately

Energy Required Per Part can be less than a factor of 10 for TP vs TS with Match Metal Molding of Simple Parts

Additional Savings:
- No Need for Prepreg Freezers
- Reduced Facility HVAC Costs
Reduced VOC’s and Toxic Products

**Thermosets**
- Prepregs usually Contain Solvents (VOC’s) for Tackiness
- Cure By-Products can be Complex Organic Compounds
- Halogenated Additives Are Typically Used to Reduce Flammability
  - But Toxicity is Increased

**Thermoplastics**
- Prepregs Do Not Contain Solvents
- No Cure By-Products
- No Halogenation Necessary for Most High Performance Thermoplastics
  - Excellent FST Performance
T300 3K Carbon Fabric/Fortron® PPS Composite Property Data*

- Values are in ksi
- Warp direction data
- Average values - Tested per Mil-R-17

Steady and Stable Across Use Temperature

* TenCate CETEX Data
T300 3K Carbon Fabric/
Fortron® PPS Composite Property Data*

- Values are in msi
- Warp direction data
- Average values - Tested per Mil-R-17

Steady and Stable Across Use Temperature

* TenCate CETEX Data
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Working Together in the Aviation Industry
Technology Validation – Carbon/PPS: Fokker 50 Undercarriage Door

- Final step in a dedicated 10-year program
- Press-formed ribs and spars
- Welded assembly
- Qualified carbon / PPS material
- Certified by the Airworthiness Authorities
- Flown on a KLM aircraft for 3.5 years
Technology Breakthrough: Fixed Wing Leading Edge Airbus A340-500/600

- Welded structure
- Low weight and low cost monolithic design
- Strong partnering with Airbus UK and TenCate
- Technology is now state of the art
  - current application Airbus A380
Metal Substitution with Linear PPS Composite Resulted in 20–50% Lighter Components

Keel Beam Application

- Multi-technology concept
  - Panels and spars
- Thermoset Prepreg lay-up
  - TP ribs and angles
  - Aluminum and titanium brackets

KB WP: 18m, 2.5 tons
Main Ribs (L&R)
A330/340 Family: Common Aileron

A318
A319
A320
A321
A330-200
A330-300
A340-300
A340-500
A340-600
A380-800

240 Parts per Airframe
Airbus A340 500/600 Aileron
Thermoplastic Composite Parts

Edge Ribs

Main Ribs

Leading Edge Ribs, Angles & Panels
Airbus A340 500/600
Thermoplastic Composite Components

**Part Description:** Panel of the Pylon Forward Second Structure - 22 per Aircraft

**Dimensions:**
- L = 700 – 1400 mm
- W = 200 – 400 mm
- Thickness 2.8 mm
- Double-Curvature Shape

**Material:**
- PPS / Carbon Fiber
- Bronze Mesh Top-layer for EMI Shielding
Leading Edge Airbus A380

- 8 assemblies / wing
- Wing length: 26 meters
- 16 segments, 52-meter length
- 400 kg total weight
Weight Reduction – The Vision

Fortron® PPS in Aircraft Interior

46% Lighter Seat Parts Due to Metal Substitution

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Aluminum</td>
<td>280 g</td>
</tr>
<tr>
<td>Fortron</td>
<td>150 g</td>
</tr>
</tbody>
</table>

Product innovations for Composites
Weight Reduction – The Vision
Linear PPS for Aircraft Interiors

- Fortron® PPS is the prime candidate for several aircraft interior efforts
- Applications include seat frames, brackets, beams, ducts
- Lower cost vs. PEI and PEKK
240 CETEX® Parts in Ailerons

Common Aileron for A330-340 Family
Summary

- Fortron® PPS is a demonstrated, producible, low-cost, high-performance thermoplastic for composite applications
  - Aircraft interior and exterior applications
  - Down hole applications
  - Corrosion resistant environments
  - High-temperature usage
  - The low-cost, green alternative

- Industrial thermoplastics composites manufacturing is a demonstrated production process
  - Proven success in aerospace

- Ticona technical personnel will work with you to meet your composites needs
Fortron® PPS
for Thermoplastic Composites

For more information on Ticona Performance Driven Solutions.™
www.ticona.com/composites

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