Linear Polyphenylene Sulfide (PPS) for Thermoplastic Composites

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  - Chemistry
  - Properties
- Long Fiber Molding Compounds
- Fortron® PPS Continuous Fiber Thermoplastic Composites
  - Processes and Applications
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Fortron® PPS
Summary – Structure and Properties

- Linear, semicrystalline
  - Tg 85°C, TM 285°C
  - Density 1.35 g/cm³
- Inherently flame resistant
  - 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 Has No Known Solvent

- 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 Dimensional Stability

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

For Precision Parts Even at Elevated Temperatures
Water Absorption

<table>
<thead>
<tr>
<th>Material</th>
<th>Water Absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPS</td>
<td>0.02</td>
</tr>
<tr>
<td>PEI</td>
<td>1.25</td>
</tr>
<tr>
<td>PEEK</td>
<td>0.12</td>
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</tbody>
</table>
Top Fortron® PPS Segments

- Semiconductor
- Industrial
- EE & Sensors
- Automotive
- Fibers
- Composites
Fortron® PPS
Automotive: Under the Hood

- Throttle Body – 1140L4
- Inlet Tank for CAC 1140L4
- Crankshaft Flange – 4332L6
- Water Pump 6165A6, 1140L6
- Water Pump Impeller – 1140L4
Fortron® PPS
Automotive: Fuel Applications

Fortron PPS was selected for:

- Resistance to all sorts of fuels including auto-oxidized fuels up to 120°C
- Excellent mechanical and impact strength at elevated temperatures
- Inherently flame resistant (UL 94 V-0 down to 0.4 mm thickness)
- Lower specific gravity than metal
- Simplified fabrication by eliminating secondary operations
Fortron® PPS 1140L4
Water Pump Impellers

- The challenge:
  - Improve pump efficiency
  - Decrease water pump cost
  - Improve fuel efficiency (Lower HP requirements)

- The innovation:
  - Exotic blade shapes improve pump efficiency by 10-20% vs. sheet metal
  - Fortron PPS has required chemical / hydrolysis resistance to OAT coolants
  - Excellent fatigue properties withstand pressure cycles
  - Excellent erosion resistance
Fortron® PPS
Injection Blow Molded Applications

Hot Air and Corrosive Fluid Applications

Diesel Engine Charge Air Duct
15% Glass Fiber Reinforced Linear PPS
Long Fiber Molding Compounds
Celstran® LFT Compared to Other Common Processes

Advantages of Celstran Long Fiber Pellets vs. Short Fiber

- Higher mechanical properties combined with significantly higher impact strength
- Reduced creep tendency
- Lower warpage and better dimensional stability

Advantages of Celstran Long Fiber Pellets vs. Wire Coated Long Fibers

- More homogeneous fiber distribution
- Higher impact strength
- Better surface / part appearance
- Lower wear on cylinder and tool

Celstran Granule Schematic

Note the uniform fiber distribution surrounded by polymer matrix throughout the whole pellet.
Pellet Cross Section
# Celstran® Glass Fiber
## PPS Material Properties

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Resin</th>
<th>Fiber %</th>
<th>Specific Gravity</th>
<th>ASTM Method:</th>
<th>Tensile</th>
<th>Flexural</th>
<th>Notched Izod</th>
<th>Comp. Strength</th>
<th>DTUL °F @ 264 psi</th>
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<tbody>
<tr>
<td>PPS-GF30-01</td>
<td>Polyphenylene Sulfide</td>
<td>30%</td>
<td>1.52</td>
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<td>PPS-GF40-01</td>
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<td>PPS-GF50-01</td>
<td>Polyphenylene Sulfide</td>
<td>50%</td>
<td>1.72</td>
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</table>
Fortron® PPS for Continuous Fiber Thermoplastic Composites
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
- Eliminating 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
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.
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
Thermoplastic Composite Processing Technologies

- Pultrusion
- Continuous laminating
- Compression molding
- Thermoforming
- Automated tape laying/fiber placement
- Bladder molding
Process Cost vs. Part Complexity for Continuous Fiber Reinforced Parts

Source: Composite Market Reports
Additional Thermoplastic Composite Manufacturing Processes

Automated Dynamics – Fiber Placement

Lingol – Thermoforming

FiberForge – Compression Molding
Advantages of Thermoplastic Composite Automation Processes

- Accurate fiber placement at any angle
- Material savings
- Labor savings
- Quality improvement
- Automatic debulking
- Reduced manufacturing space
- Reduced assembly costs
Airbus A340/A380
Leading Edge Process

Example for Thermoplastic Composite Value Chain in Aircraft Industries
Station 1: Film Production

Starting product:

Linear 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 Linear PPS / Carbon Fiber Fabric

Laminate production

Station 2 – Ten Cate Advanced Composites BV, Nijverdal, Netherlands. The carbon fiber fabric and linear 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.
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 A340 and A380

- Welded structure
- Low weight and low cost monolithic design
  - 200 kg weight reduction on A380
Technology Validation – Carbon/PPS: Fokker 50 Undercarriage Door

- Press-formed ribs and spars
- Welded assembly
- Qualified carbon / PPS material
- Certified by the Airworthiness Authorities
- Flown on KLM aircraft
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
- Alu. and Titanium Brackets
Airbus A340 500/600 Aileron
Thermoplastic Composite Parts

Edge Ribs
Main Ribs
Leading Edge Ribs, Angles & Panels
Weight Reduction – The Vision
Fortron® PPS in Aircraft Interior

Supporting Various Interior Applications

- Seat frames
- Ducting
- Panels
- Brackets
- Ribs
- Fasteners

46% Lighter Seat Parts Due to Metal Substitution
Summary

- Fortron® Linear PPS is a demonstrated, producible, low-cost, high-performance thermoplastic for aerospace composite applications
  - Aircraft interior and exterior applications
  - Flammability, Smoke, and Toxicity Performance (FST)
  - Corrosion resistant environments
  - High temperature usage
  - Wide variety of forms available

- Industrial thermoplastics composites manufacturing is a proven production process
  - Used in production of critical aerospace structures
Fortron® PPS
for
Thermoplastic Composites

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Backup slides
Fortron® PPS
Extrusion: Film, Fiber, Netting, etc.

Aircraft Composite

High Tenacity Monofilament

Filter Netting

Stock Shapes

CPI Filter
Applications: Sensors
ABS Sensor Components

- Dimensional stability
- Creep resistance
- Corrosion resistance within the required temperature range