Ticona
Engineering Polymers
Performance Driven Solutions™

Advanced Composite Polymer for the Automotive Market

Long Fiber Reinforced Linear Polyphenylene Sulfide (PPS)

SPE ACCE Conference
September 11 - 13, 2007

Presented by:
Walt Maruszczak, HEV Global Platform Leader
Ticona Engineering Polymers

Celanese
Ticona – A Business of Celanese

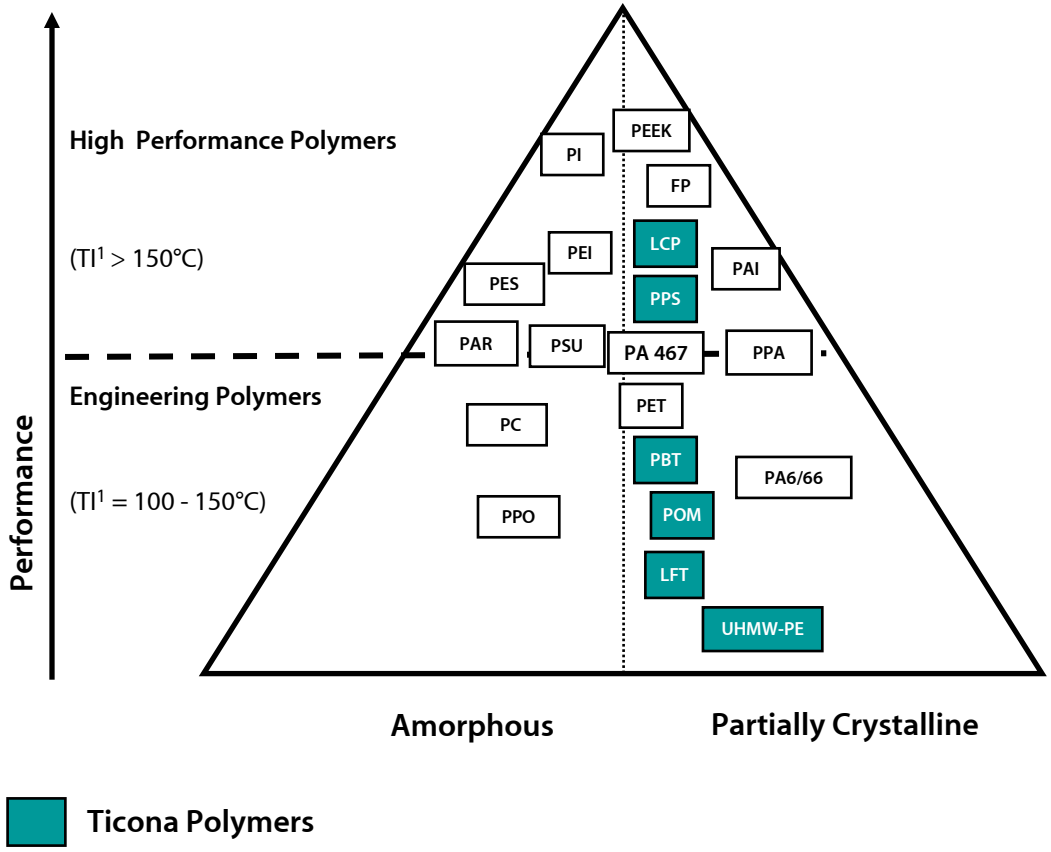
Long Fiber Reinforced
Linear Polyphenylene Sulfide (PPS)

- **Introduction**
- Properties & Requirements
- Processing
- Applications

Ticona: Polymers and Solutions

- Global Supplier - Production facilities in Americas, Europe and Asia
- Global Presence - Leading market position in most products / regions
- Significant Sales - $915 million in 2006
- Diverse Portfolio - High quality engineering plastics
- Added Value - Solutions provider and technology enabler

Broad Portfolio of Engineering and High Performance Polymers



[1] Temperature Index

Source: Market Information, Celanese

High Performance Polymers (HPPs) are:

- PPS: Polyphenylenesulfide
- LCP: Liquid Crystal Polymers
- PES: Polyarylether Sulfones
- PEI: Polyetherimides
- PSU: Polysulfones

Engineering Polymers (ETPs) are:

- POM: Polyacetals
- PC: Polycarbonate
- PA: Polyamide
- PBT: Polybutyleneterephthalate
- PET : Polyethylenterephthalate
- UHMW-PE: Ultra High Molecular Weight Polyethylene
- PEEK: Polyetherketone
- PI: Polyimide
- FP: Fluoropolymers
- PAI: Polyamide Imide
- PAR: Polyarylate
- PPA: Polyphthalamide
- PPO: Polyphenylene Oxide
- LFT: Long Fiber Thermoplastics

Composition of Typical Composites

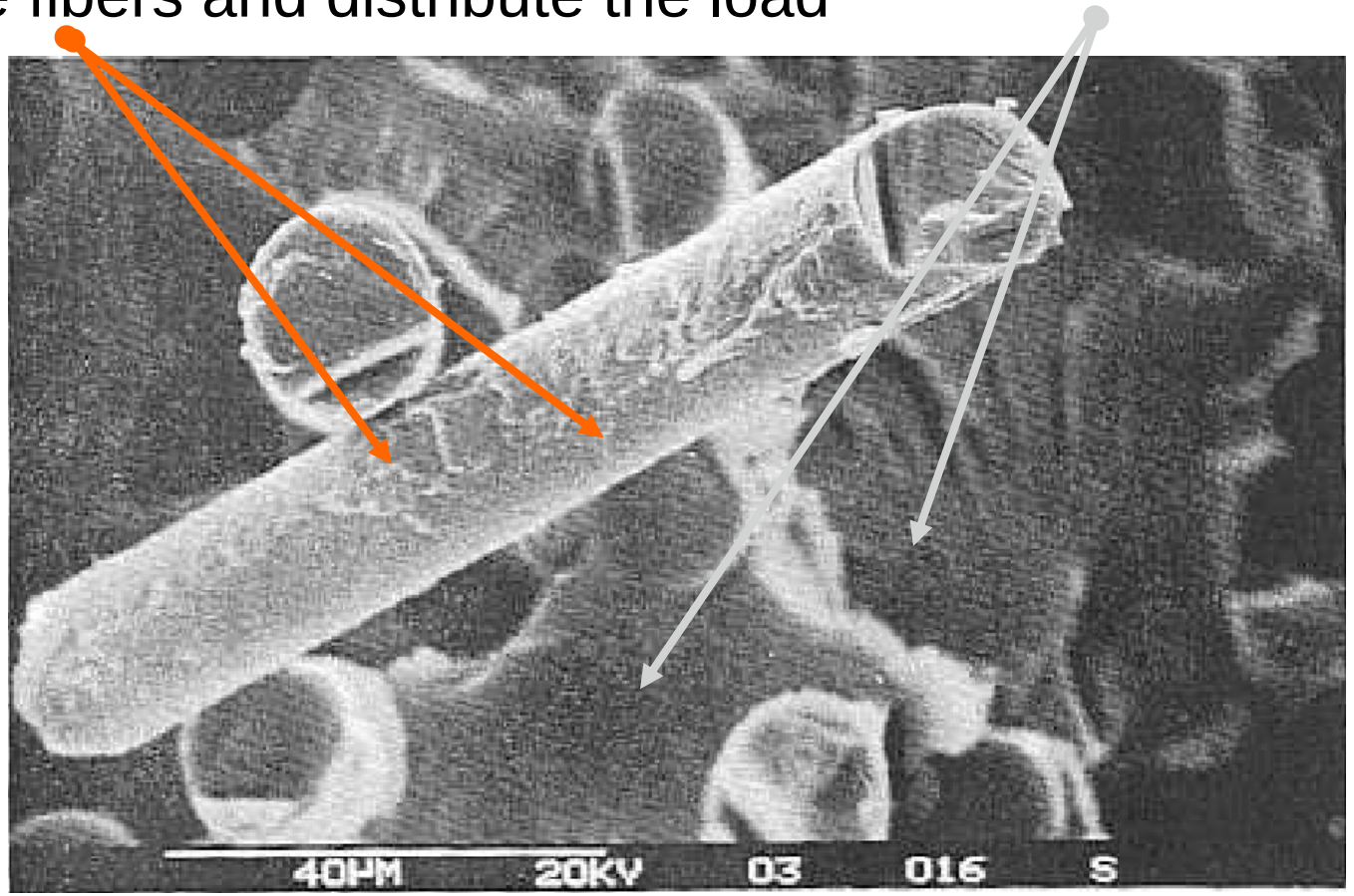
- Short-glass-fiber-reinforced compounds
  - e.g., Fortron® PPS 40% glass fiber (d50 = 200 µm)
    - Typical injection molding material
- Long-glass-fiber-reinforced compounds
  - e.g., Fortron® PPS 40% glass fiber (d50 = 400 µm)
    - For high-strength components
- Carbon fabric (CF) plus polymer matrix
  - e.g., Cetex® (d50 = component size)
    - Suitable for extremely high stresses

Cetex is a registered trademark of Ten Cate Advanced Composites BV.

What are Composites?

Composites are construction materials composed of:

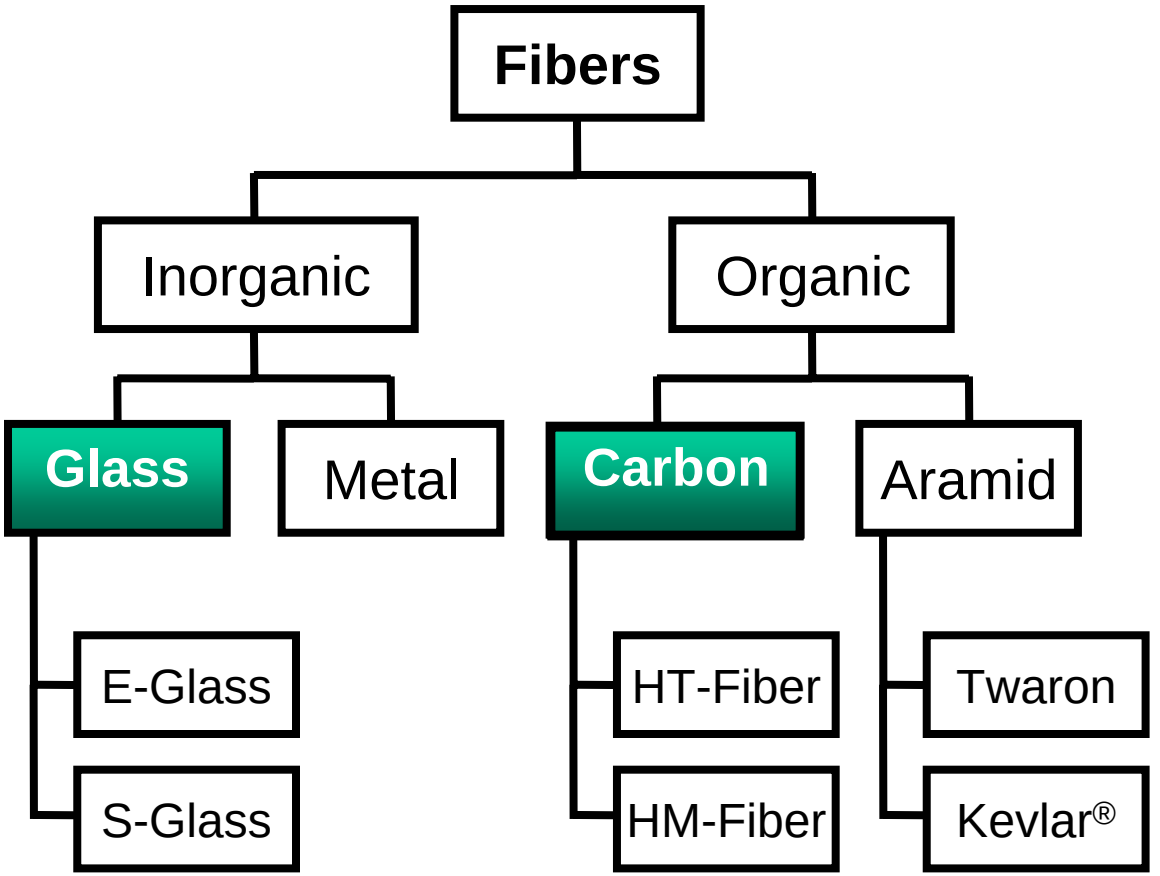
Fibers to carry the load embedded in a **Matrix** to protect the fibers and distribute the load



Reinforcing Fibers – Main Categories

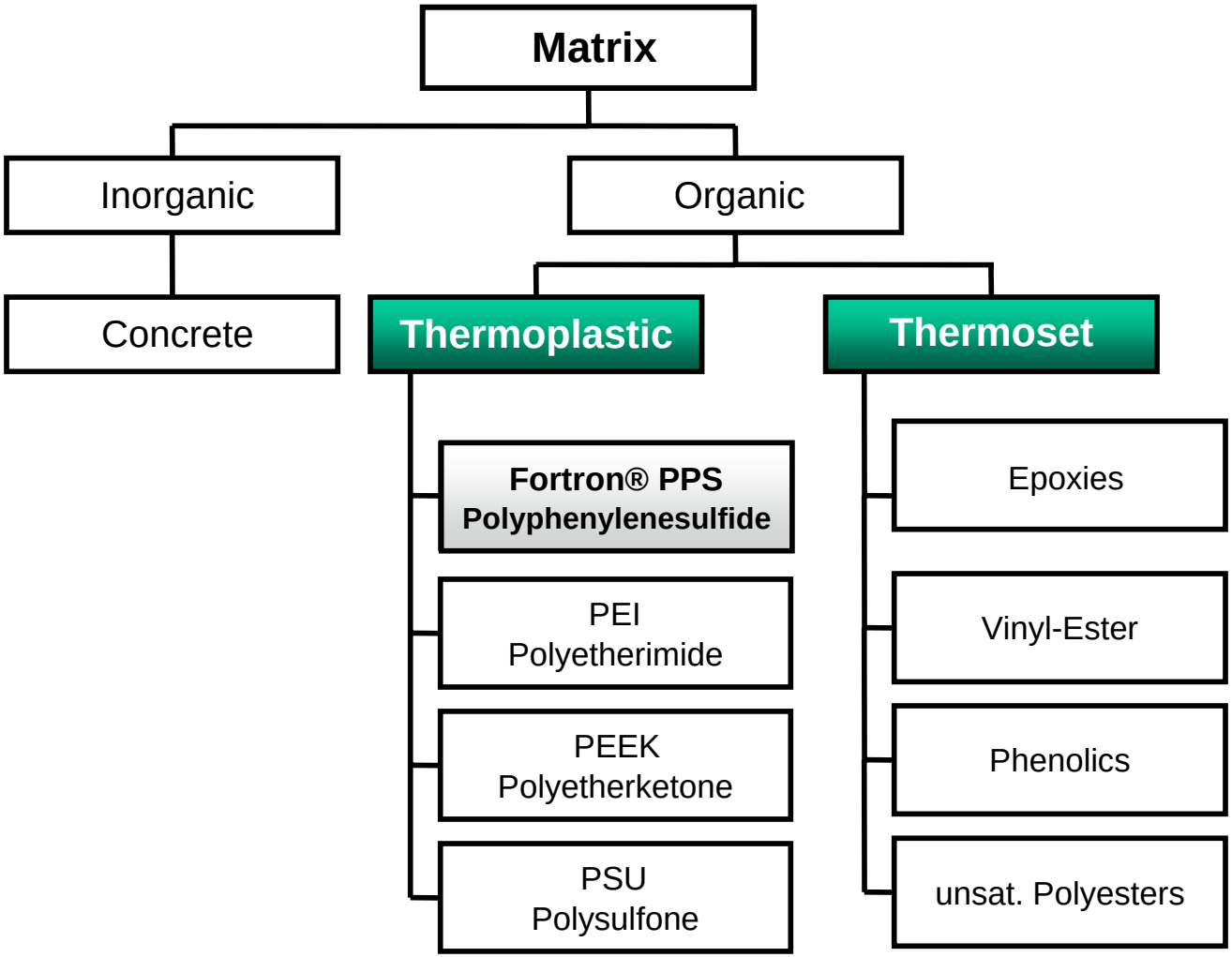
A wide variety of fibers can be used:

Most common Glass and Carbon



Other Fibers used: Ceramic, Boron, Basalt, Silicon-Carbide, Alumina.
Kevlar is a registered trademark of E.I. du Pont de Nemours and Company.

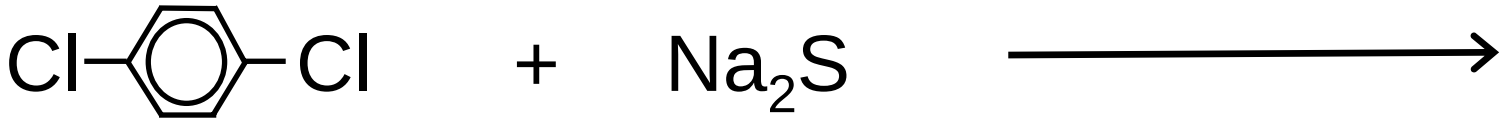
Matrix Materials – Main Categories



Long Fiber Reinforced
Linear Polyphenylene Sulfide (PPS)

- Introduction
- **Properties & Requirements**
- Processing
- Applications

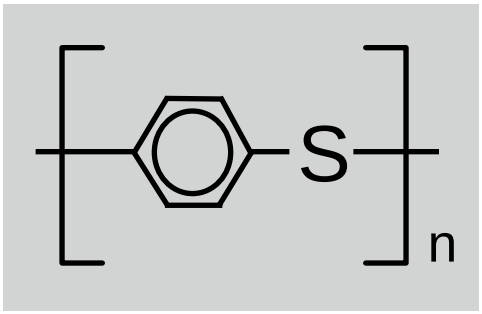
From Monomer to Polymer (The Chemistry)



p - Dichloro Benzene

Sodium Sulfide

Polycondensation

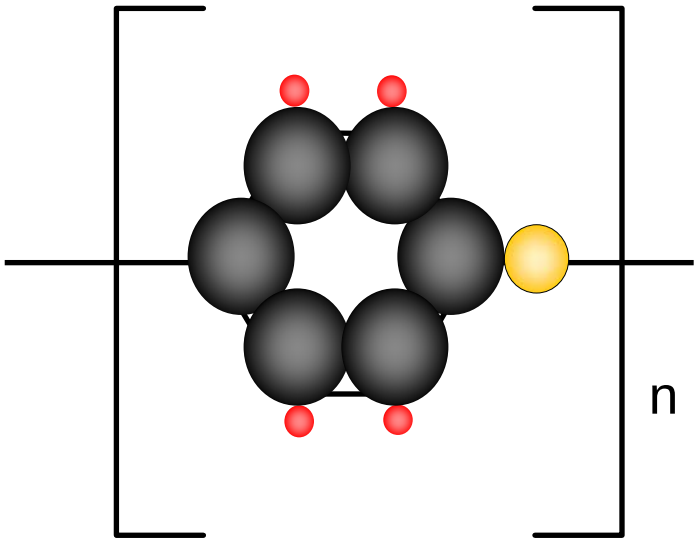


+ 2 NaCl

Polyphenylene Sulfide

Sodium Chloride

Linear PPS
Summary – Structure and Properties



Polyphenylenesulfide (PPS)

Poly(thio – 1,4 - phenylene)

- **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

Linear PPS

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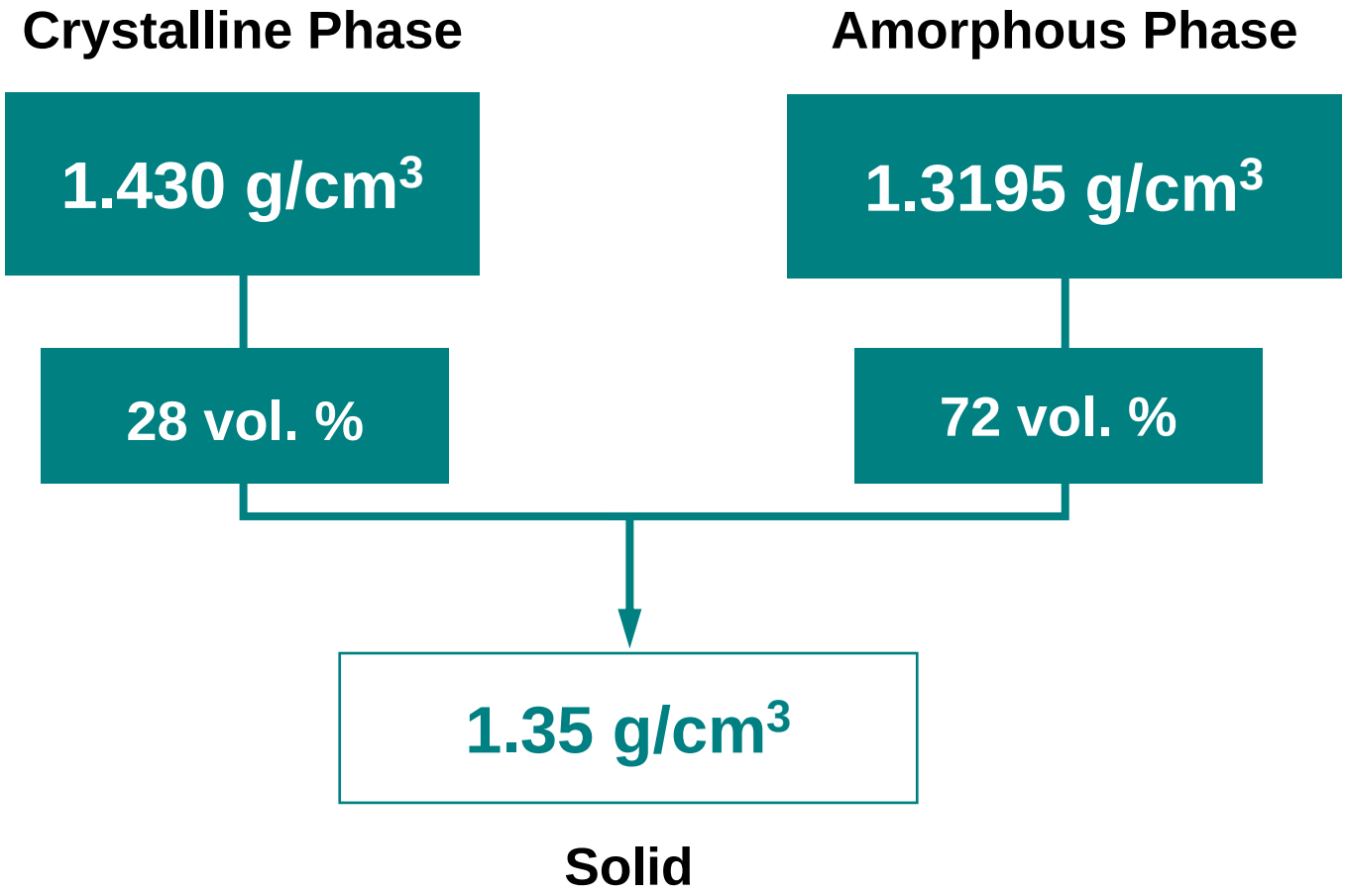
Semi-crystalline thermoplastic polymer, perfectly suited for parts that have to withstand the high mechanical and thermal requirements which require…

- A high melting point range between 280 and 290°C
- Inherently flame retardant
- 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

Linear PPS Characterization – Crystallinity

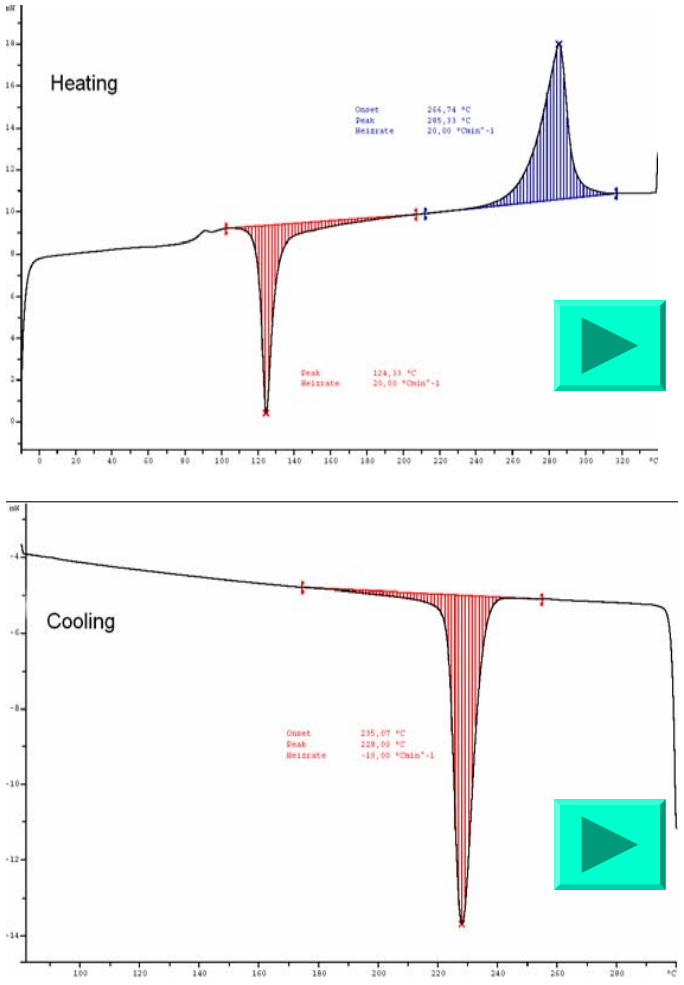
Semi-Crystalline Material



Linear PPS – Crystallization Properties

Phase Transitions
DSC Measurements

Transitions		Temperature in °C
Glass	T_g	85 – 95
Crystallization on Heating	T_{ch}	120 – 140
Melting Point Range	T_M	280 – 288
Recrystallization on Cooling	T_{CC}	255 – 220



Linear PPS – Chemical Properties

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Flammability

- Loss On Ignition (LOI): > 45
- UL94: V0 or V5A
- ABD0031: passed
- FAR/JAR 25.853: passed

Chemical Resistance

Excellent:

- Fuels, synthetic oils, water, solvents, salts, kerosene

Limited:

- Hydrochloric acid, strong oxidizing agents

Reasons to Use Linear PPS as Base Polymer for High Performance Composites

Excellent Chemical Resistance	Resistant to acids & alkali Resistant to lubricants Resistant to anti-freeze agents
Lower Density than Aluminum	Parts are lighter and have improved properties
New Process Techniques Reduce Time for Installation	Components may be induction-welded, linear vibrationally welded
Excellent Property Profile	High stiffness and flexibility Improved ductility

Matrix Materials
Thermosets vs. Thermoplastics

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Thermoset

- Chemical crosslinking reaction for part manufacture
- Irreversible
- Limited shelf time
- Part assembly
  - Conventional
    Nuts – Bolts – Screws

Thermoplastic

- Part manufacture by physical phase transition
  Solid – Liquid – Solid
- Repeatable
- Unlimited storage @ room temperatures
- Part assembly
  - Conventional
    Nuts – Bolts – Screws
  - Welding

PPS-GF40-01 (40% Long Glass Fiber)

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Composition

- High temperature polyphenylene sulfide matrix
- 40 wt% glass fibers; other wt% available

Standard Availability

- Dust-free pellets ca. 3 x 11 mm
- 55 to 40,000 lbs. shipments (25 to 20,000 kg)

PPS-GF40-01 (40% Long Glass Fiber)

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Chemical & Thermal Resistance

- Outstanding thermal resistance
- Good moisture and chemical resistance
- Does not corrode
- Inherent flame resistance

PPS-GF40-01 (40% Long Glass Fiber)

Ticona Engineering Polymers
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Wear Resistance, Strength & Rigidity

- Excellent wear resistance; passed automotive "gravelometer" test
- Superior impact strength

Regulatory Listings

- Underwriters Labs. V0 rating; file E113269

Cost Savings

- Eliminates metal fabrication, painting and later corrosion costs

PPS-GF40-01 (40% Long Glass Fiber)

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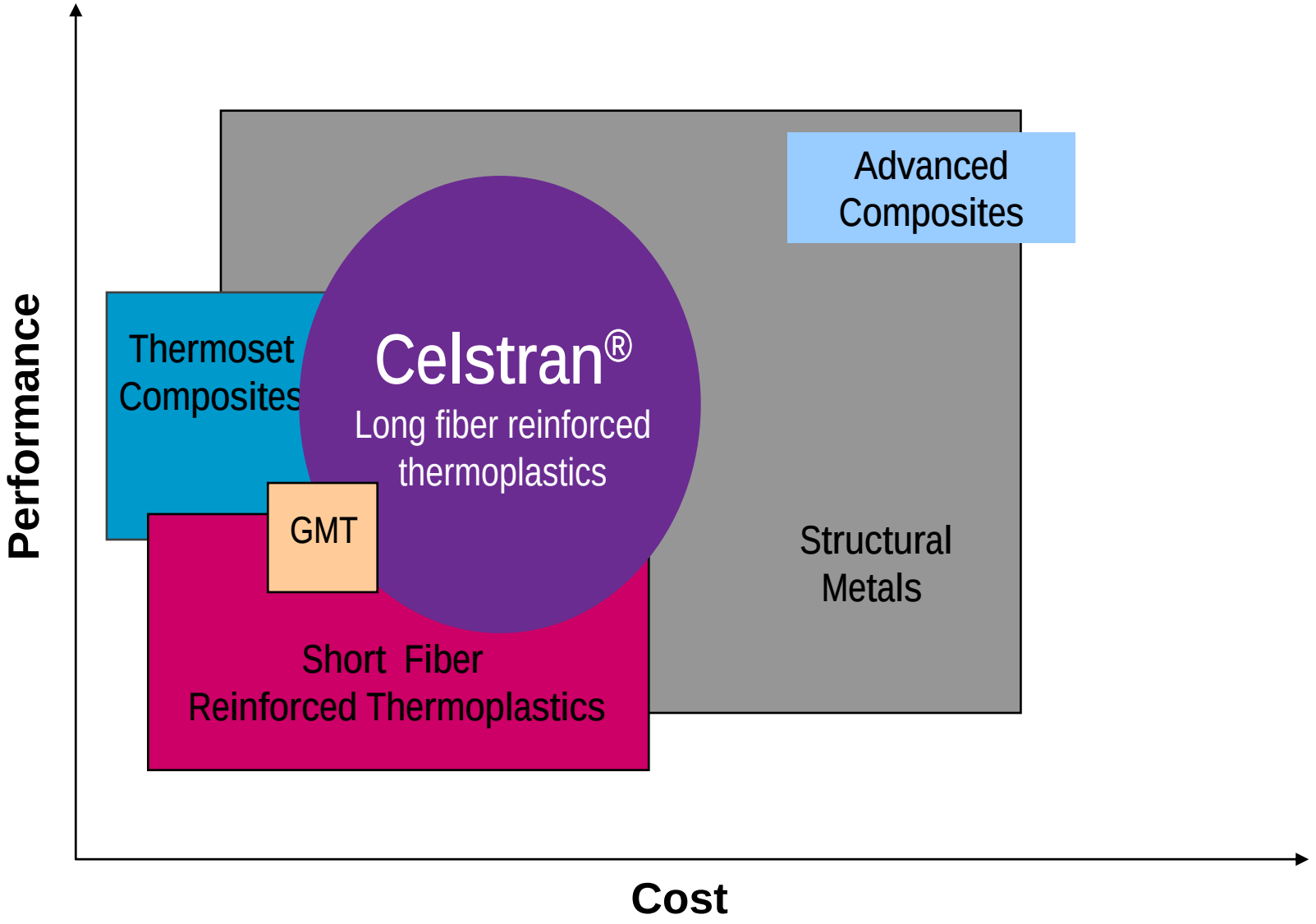

PPS-GF40-01 (40% Long Glass Fiber)

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Applications

- Electrical connectors & switches
- Pump housings & water fittings
- Parts exposed to high temperature & corrosive environments

PPS-GF40-01 (40% Long Glass Fiber)

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Typical Properties	ASTM Method	English System			International System		
		Units	°F	Value	Units	°C	Value
Density	D-792	g/cm^3	72°	1.62	g/cm^3	23°	1.62
Tensile Strength at Break	D-638	psi x 10^3	-40° 72° 300° 400°	26.0 25.5 12.2 8.6	MPa	-40° 23° 150° 204°	180 180 80 60
Tensile Modulus	D-638	psi x 10^3	-40° 72° 300° 400°	2,580 2,430 1,250 1,150	MPa	-40° 23° 150° 204°	17,800 16,800 8,600 7,900
Elongation at Break	D-638	%	-40° 72° 300° 400°	1.16 1.20 1.35 1.25	%	-40° 23° 150° 204°	1.16 1.20 1.35 1.25
Flexural Strength at Break	D-790	psi x 10^3	-40° 72° 300° 400°	37.2 36.0 23.0 18.4	MPa	-40° 23° 150° 204°	260 250 160 130
Flexural Modulus	D-790	psi x 10^3	-40° 72° 300° 400°	2,170 2,040 1,100 900	MPa	-40° 23° 150° 204°	15,000 14,100 7,600 6,200
Notched Impact, Izod	D-256	ft-lb/inch	-40° 72°	6.4 6.4	J/m	-40° 23°	340 340
Deflection Temperature @ 264 psi (1.8 MPa)	D-648	°F	n.a.	535	°C	n.a.	279
Poisson's Ratio (+/- 0.05)	D-638	Inch/inch	72°	0.35	mm/mm	23°	0.35
Shrinkage, flow direction **Shrinkage, cross-flow**	D-955	Inch/inch	72° 72°	0.002-0.003 0.004-0.005	%	23° 23°	0.2-0.3 0.4-0.5

PPS-GF40-01 (40% Long Glass Fiber)

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- **Stiff *and* Tough**
- Dynamic mechanical analysis (DMA) measures the flexural modulus (stiffness) of samples molded from Celstran® LFRT materials vs. temperature.
- Long fiber reinforcements provide stiffness over a wide temperature range.
- Increased fiber loadings increase stiffness.
- Stiffness with good impact, tensile and flexural strengths – stiff and tough, ***the long fiber advantage.***

PPS-GF40-01 (40% Long Glass Fiber)

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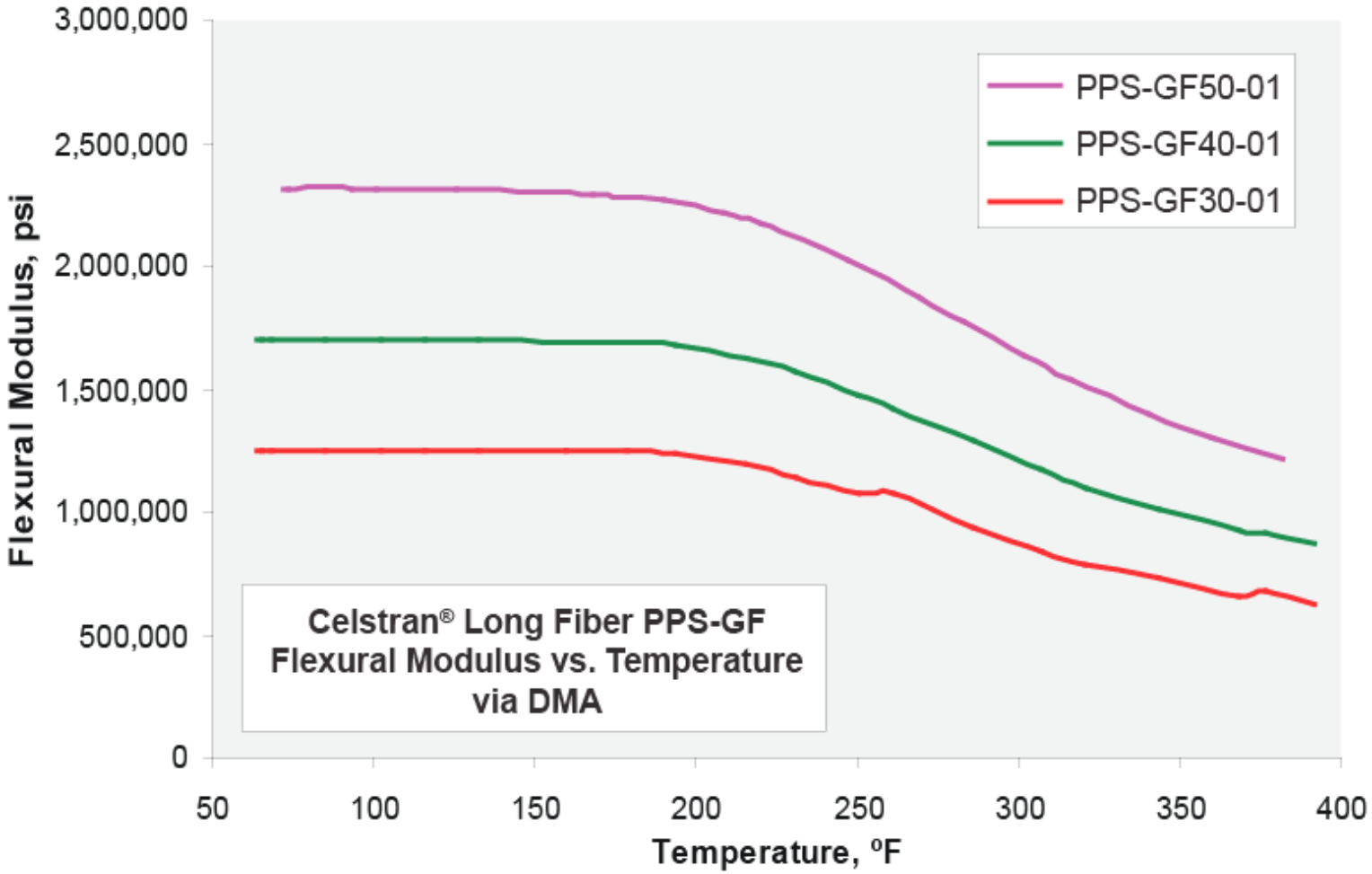

PPS-GF40-01 (40% Long Glass Fiber)

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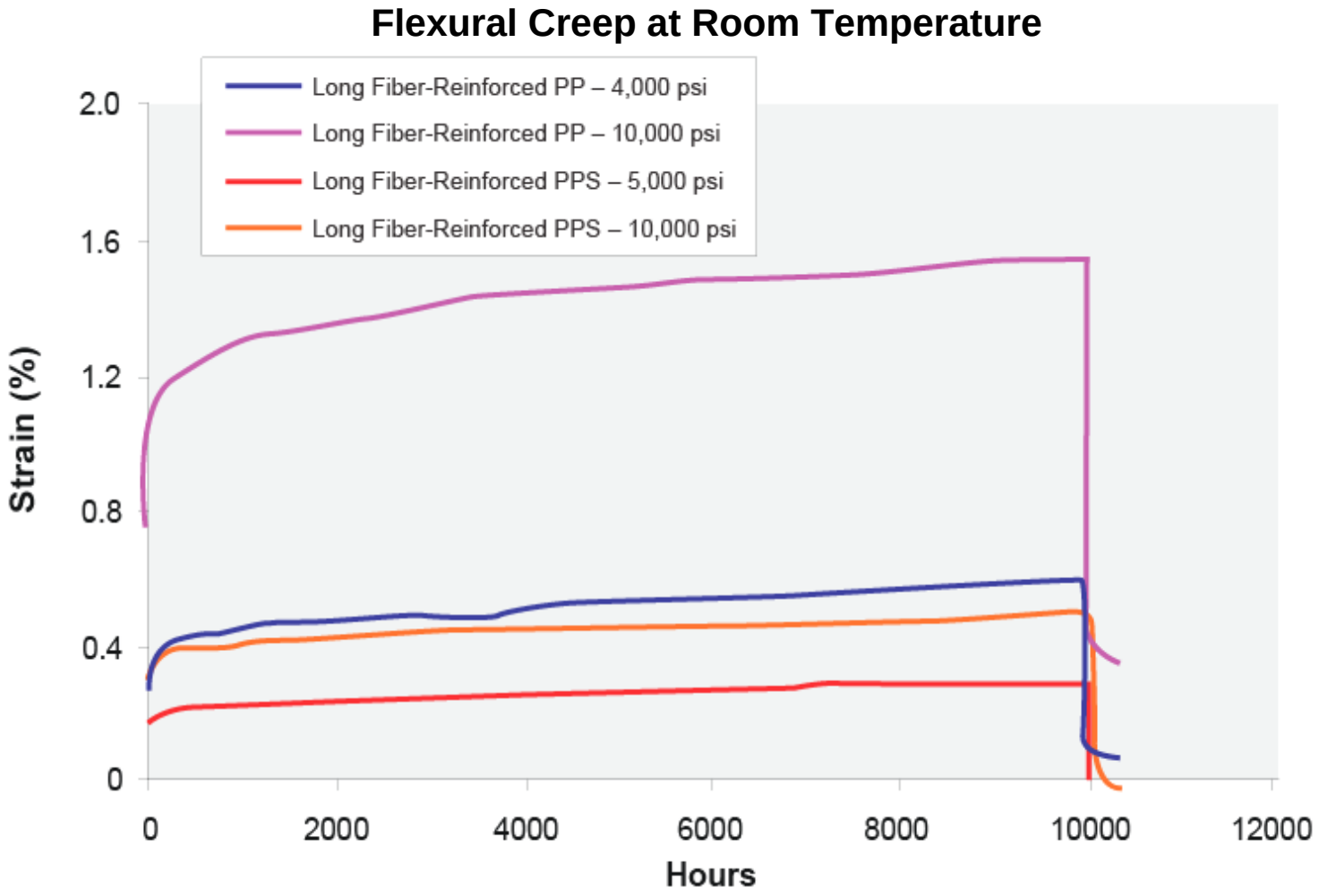

PPS-GF50-01 (50% Long Glass Fiber)

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Typical Properties[a]	ASTM Method	English System			International System		
		Units	°F	Value	Units	°C	Value
Density	D-792	g/cm^3	72°	1.72	g/cm^3	23°	1.72
Tensile Strength at Break	D-638	psi x 10^3	-40° 72°	26.1 25.6	MPa	-40° 23°	180 180
Tensile Modulus	D-638	psi x 10^3	-40° 72°	3,110 2,930	MPa	-40° 23°	21,400 20,200
Elongation at Break	D-638	%	-40° 72°	0.95 1.00	%	-40° 23°	0.95 1.00
Flexural Strength at Break	D-790	psi x 10^3	-40° 72°	39.1 38.4	MPa	-40° 23°	270 260
Flexural Modulus	D-790	psi x 10^3	-40° 72°	2,710 2,510	MPa	-40° 23°	18,700 17.300
Notched Impact, Izod	D-256	ft-lb/inch	-40° 72°	7.0 6.9	J/m	-40° 23°	370 370
Deflection Temperature @ 264 psi (1.8 MPa)	D-648	°F	n.a.	540	°C	n.a.	282
Poisson's Ratio[b]	D-638[c]	Inch/inch	72°	0.35	mm/mm	23°	0.35
Shrinkage, flow direction **Shrinkage, cross-flow**	D-955	%	72° 72°	0.1-0.2 0.3-0.4	%	23° 23°	0.1-0.2 0.3-0.4

a) Unless otherwise noted, samples were molded from natural colored Celstran® materials and tested per ASTM methods. The data, while believed to be accurate, are for information purposes only. The values shown fall within the normal ranges of properties for these materials. The suitability of these materials for any use is the user's responsibility, who must assure himself/herself the material as subsequently processed meets the requirements of that use. Sales of these products are governed by the terms of the agreement under which they are sold.

b) Poisson's ratio (±0.05) calculated from tensile bar elongation vs. width change.

Long Fiber Reinforced
Linear Polyphenylene Sulfide (PPS)

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Manufacturing Supply Chain

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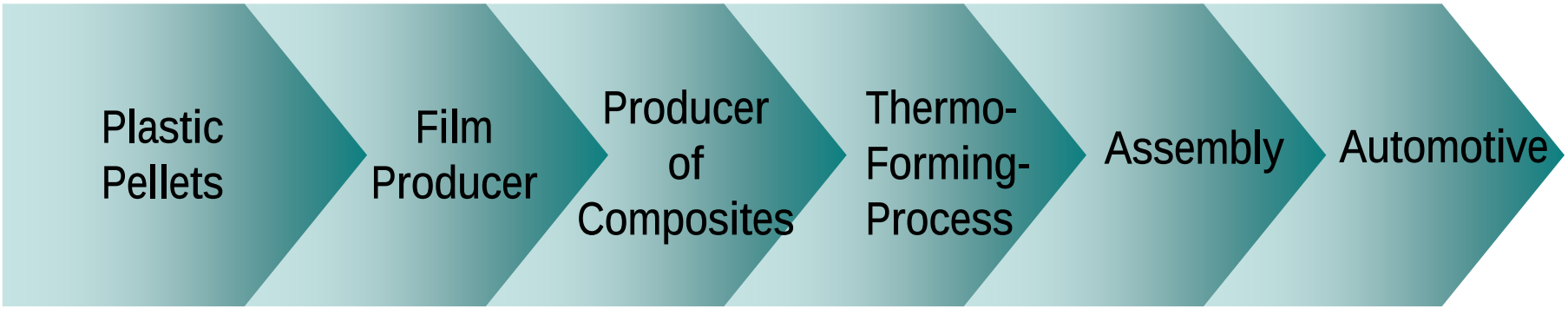

Station 1: Film Production

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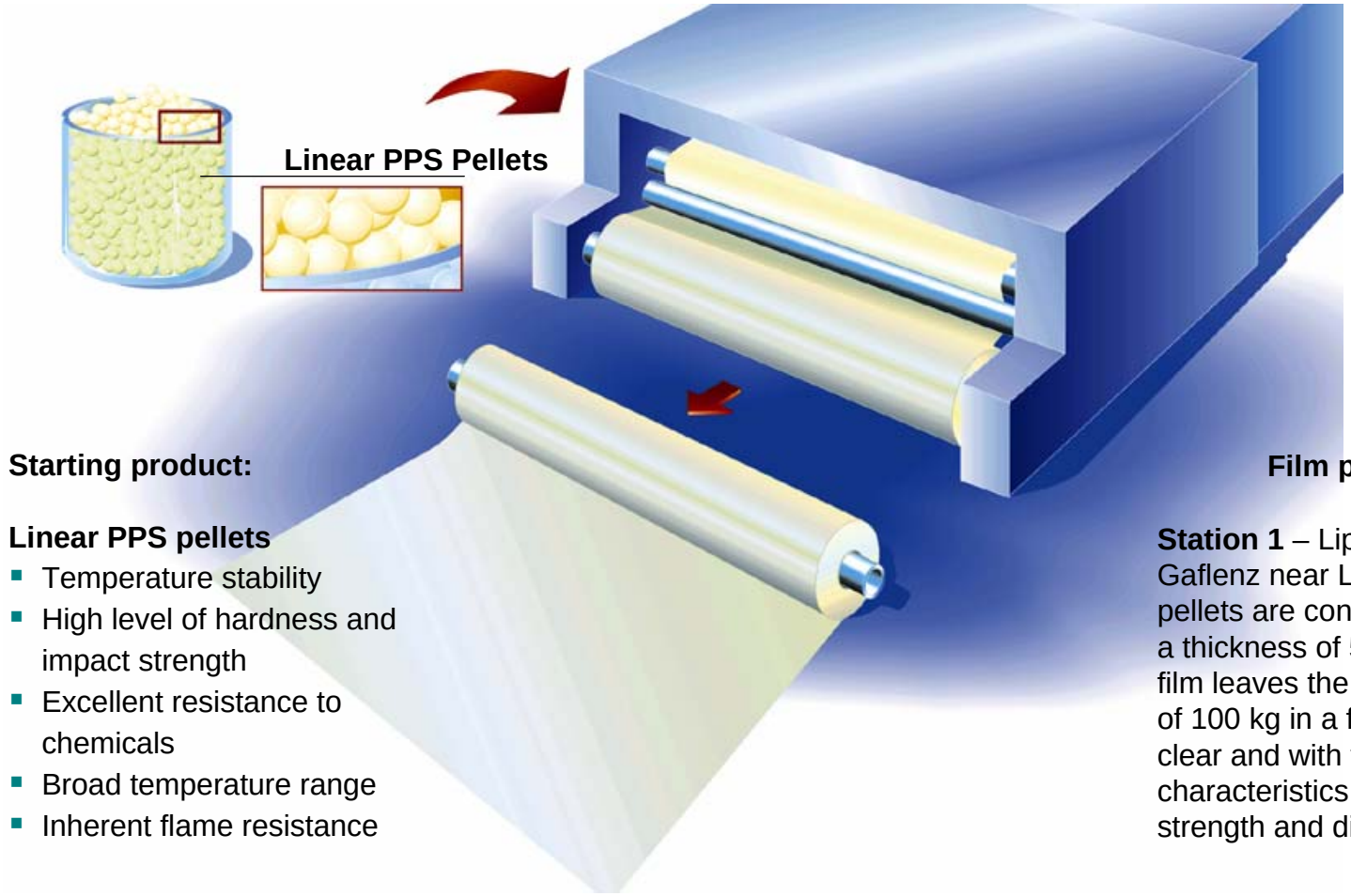


Starting product:

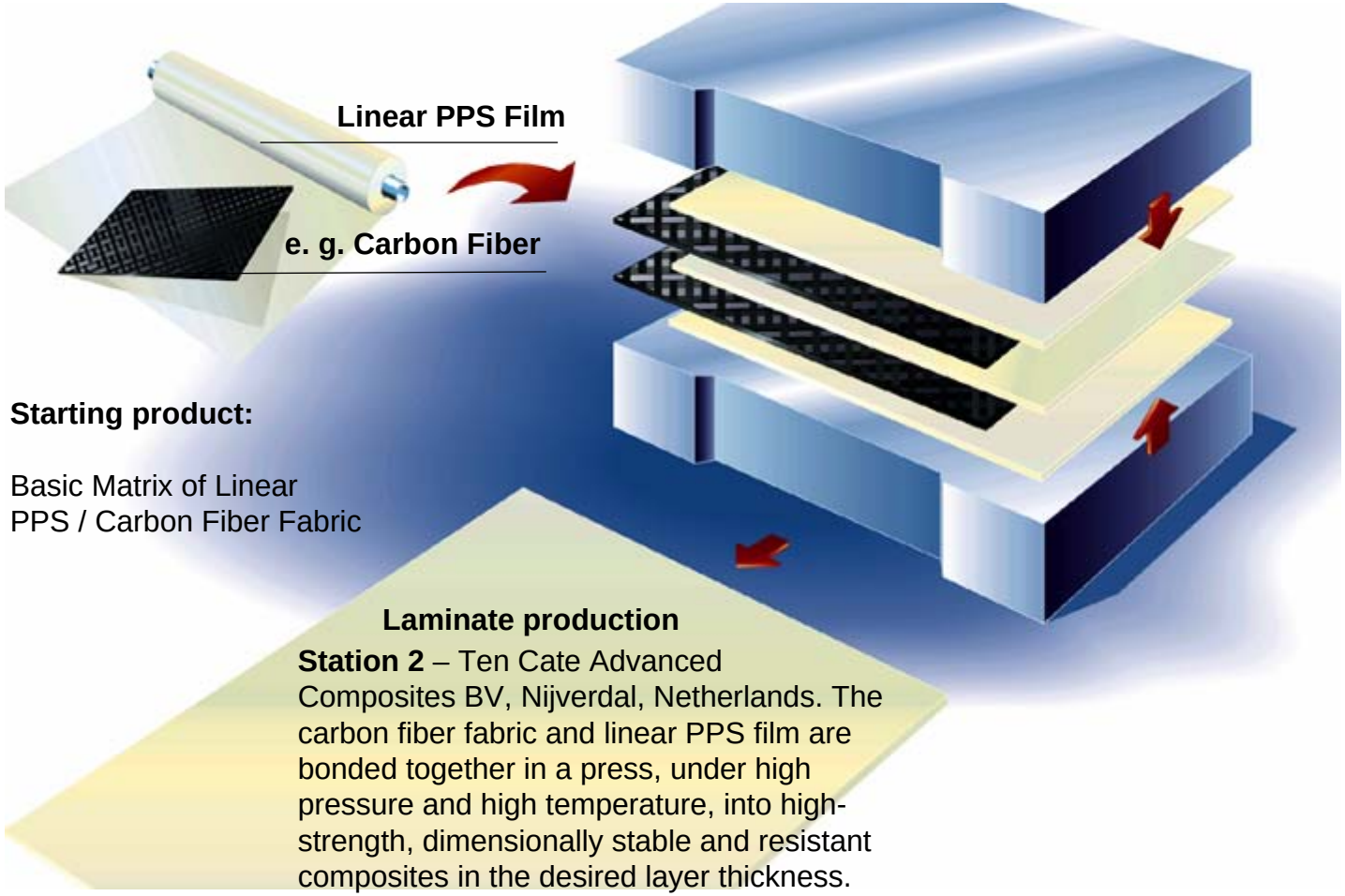
Linear PPS pellets

- 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



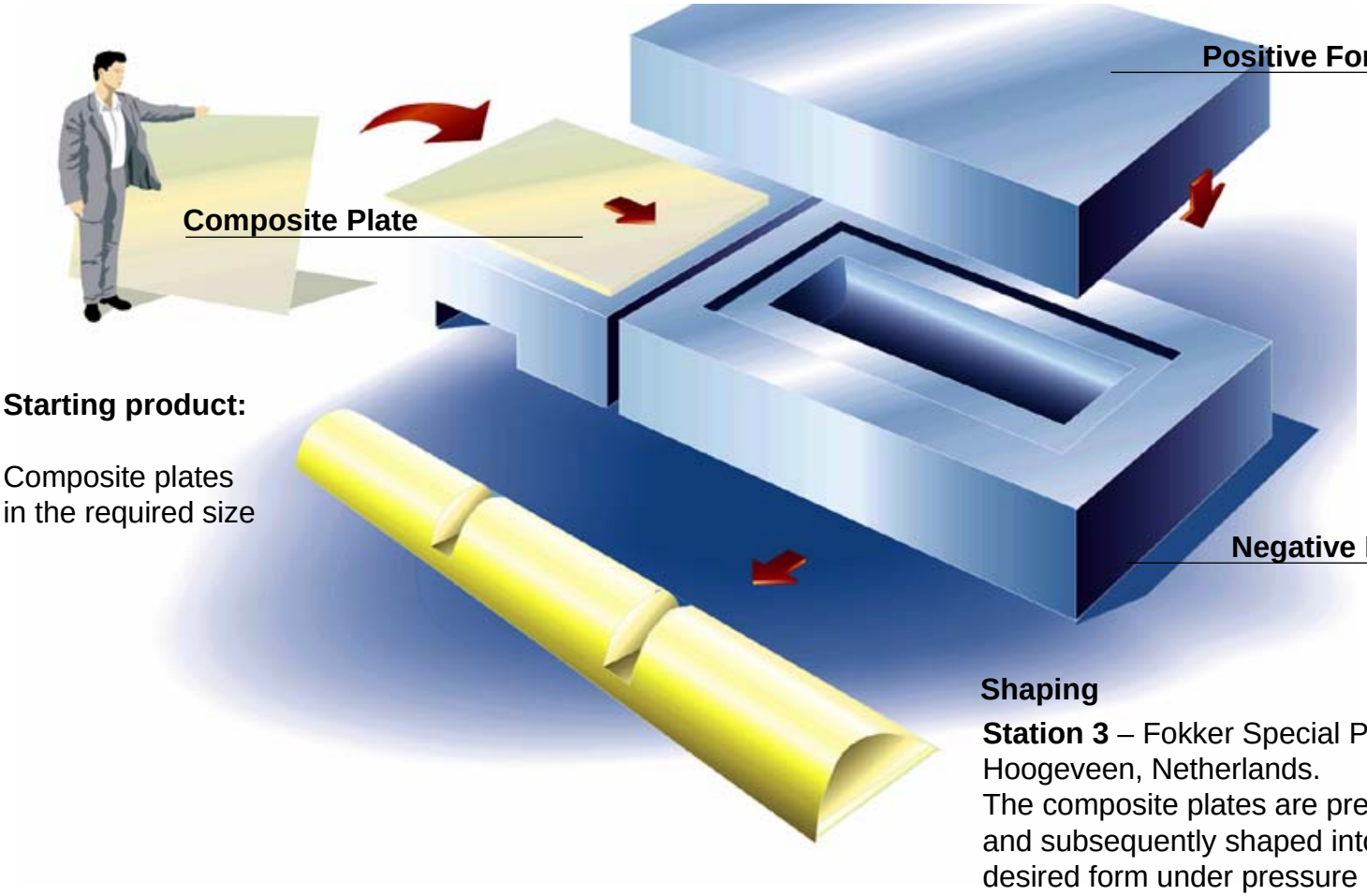
Starting product:

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



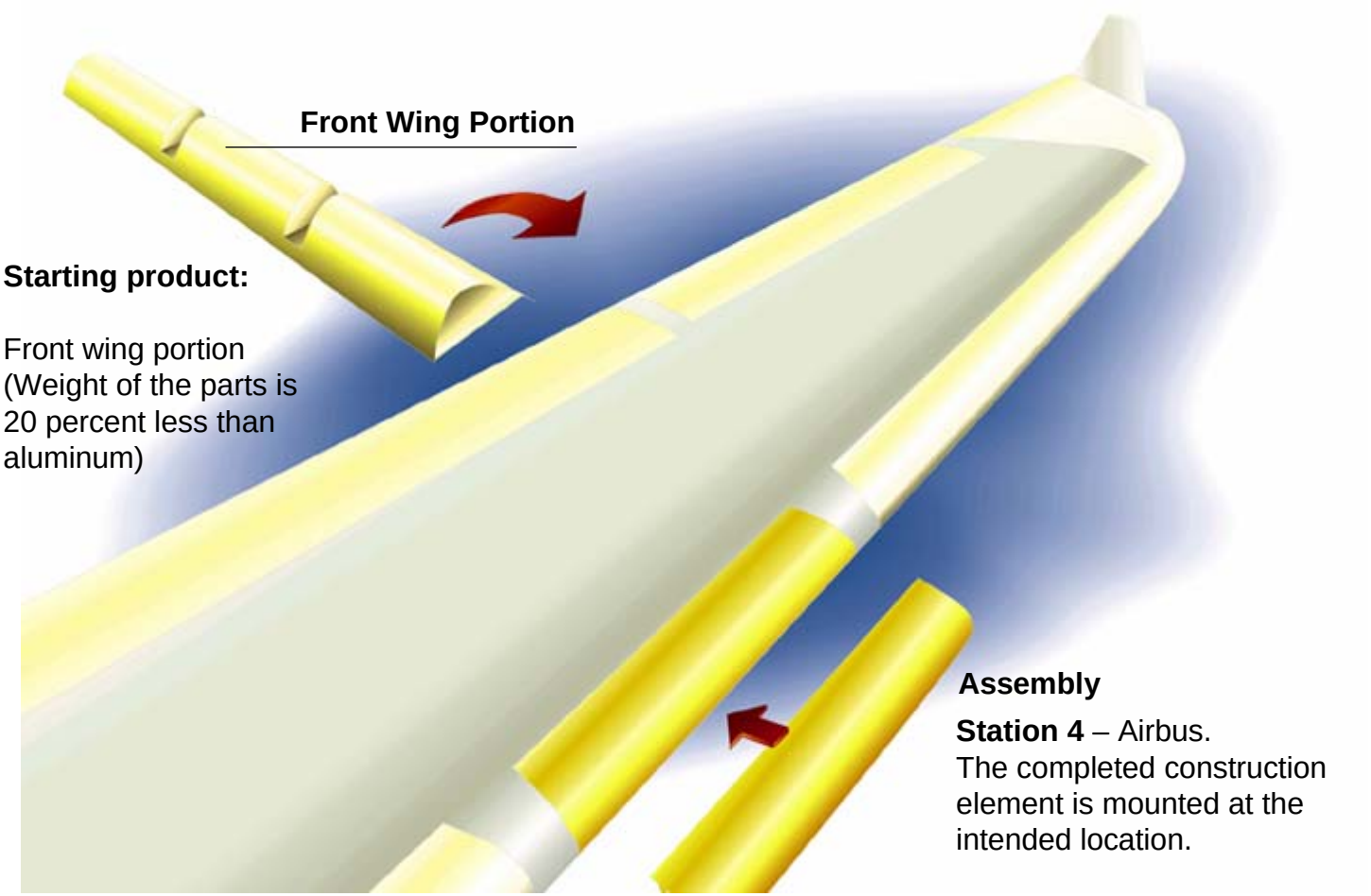
Starting product:

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.

Processing of Pre-pregs

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- Production of composite components (pre-pregs)
- Cutting
- Laser projection
- Large thermoplastics press
- High temperature autoclaves
- Ultrasonic and resistance welding
- Controlled 5-axis machining




Fortron® PPS – Success in the Aviation Industry

Ticona Engineering Polymers
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- Safe, efficient, environmentally friendly
- Modern design
- Licensed for aircraft construction

Why Use Thermoplastics?

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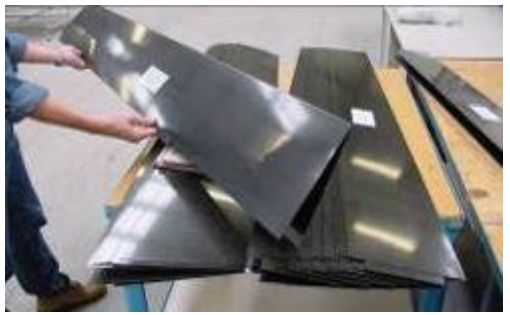
Answer: Low-cost manufacturing

1. Press-forming of ribs
2. Folding of trailing edges
3. Resistance welding of assemblies



STORK Fokker

Long Fiber Reinforced
Linear Polyphenylene Sulfide (PPS)

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- **Applications**

Technology Penetration in Aircraft Industry

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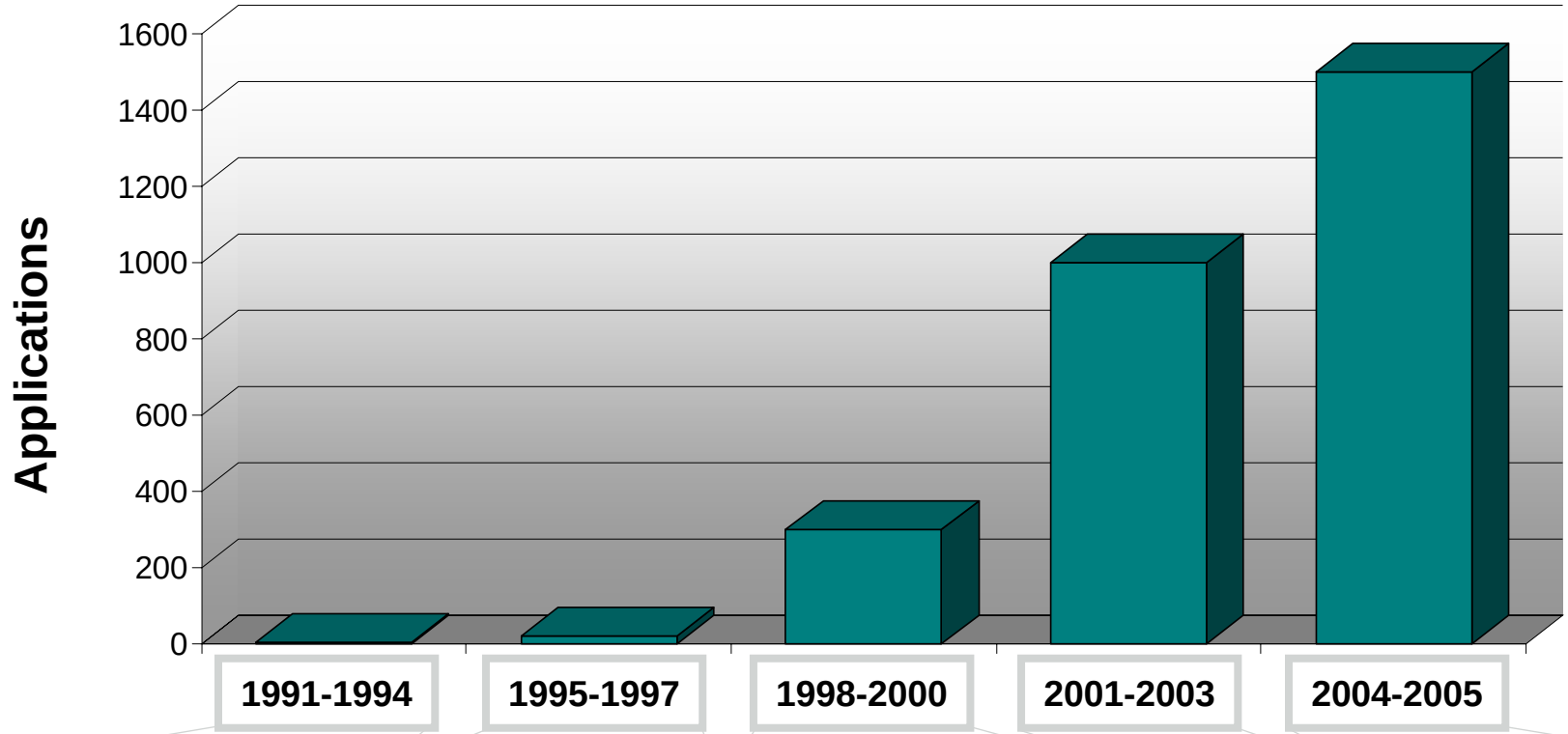

Mid ‘90’s:
Need for Chemically Resistant Material

Linear PPS Chosen for:

- Excellent chemical resistance
- Ease of processing
- Permits complex component geometry

STORK Fokker

Technology Validation Carbon Fiber/PPS: Fokker 50 Undercarriage Door

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- Final step in 10-year program
- Press-formed ribs and spars
- Welded assembly
- Qualified carbon fiber / PPS Material
- 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 Ten Cate
- Technology now state-of-the-art: newest application Airbus A380

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Metal Substitution with Linear PPS Composite Resulted in 20–50% Lighter Components

- KB WP : 18 m, 2.5 tons -

- Main Ribs (L&R) -

Multi-Technology Concept :
- Panels and Spars :
Thermoset Prepreg Lay-Up,
- TP Ribs and Angles
- Alu. and Titanium Brackets

Keel Beam Application

Airbus A340 500/600 Aileron

Thermoplastic Composite Components

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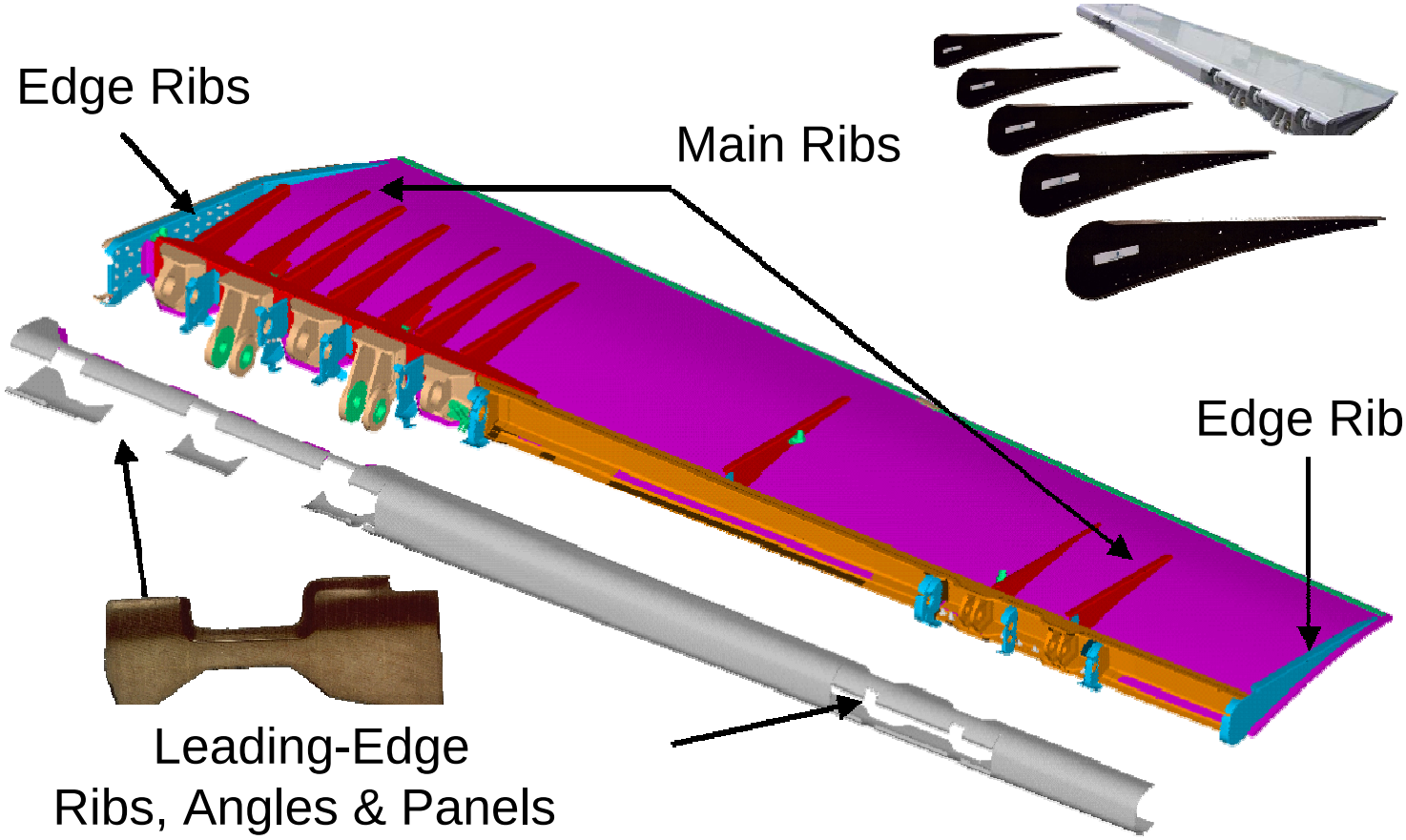

Airbus A340 500/600

Thermoplastic Composite Components

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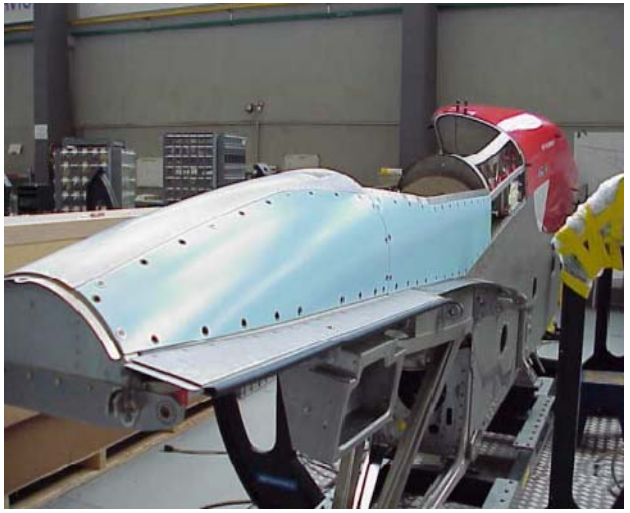
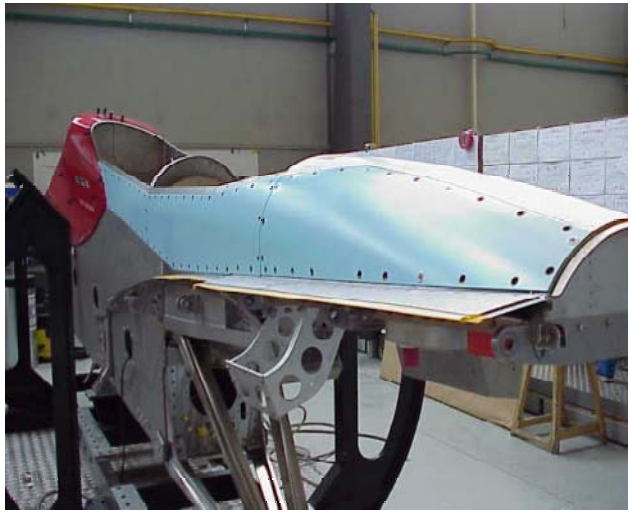
Part Description: Panel of the Pylon Forward Second Structure – 22 per Aircraft

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

Material: Linear PPS / Carbon Fiber Bronze Mesh Top-layer for EMI Shielding





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ABS Brake Sensor Housing

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Material: PPS-GF50-01

Company: Delphi Chassis

Benefits:

- Impact strength (6.9 ft-lb/in)
- Compressive strength (33.6 psi x 103)
- Dimensional stability
- Chemical resistance
- Dimensional tolerance for outside diameter (59.71mm): 0.2mm
- The molded housing has to withstand tight press-fitting (0.38mm) into the bearing housing (shear force 600 pound-force)
- No leakages at a pressure of 15 psi (before alternating temperature stress test). 3 x alternating temperature test between -40°F and 250°F, in which the mounted unit must withstand a shear force of 100 psi.
- Impact strength test with gravelometer
- Road salt resistance (standard requirement of General Motors)

Connector Body and Sleeve

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Material: PPS-GF40-01

Company: Titeflex Corporation

Benefits:

- Tensile strength (25.5 psi x 103)
- Excellent dimensional stability
- High rigidity and low creep
- Withstands corrosion and attack by petroleum fluids
- Low warpage and shrinkage to provide fittings to specification
- Excellent impact strength

Leading Edge Airbus A380

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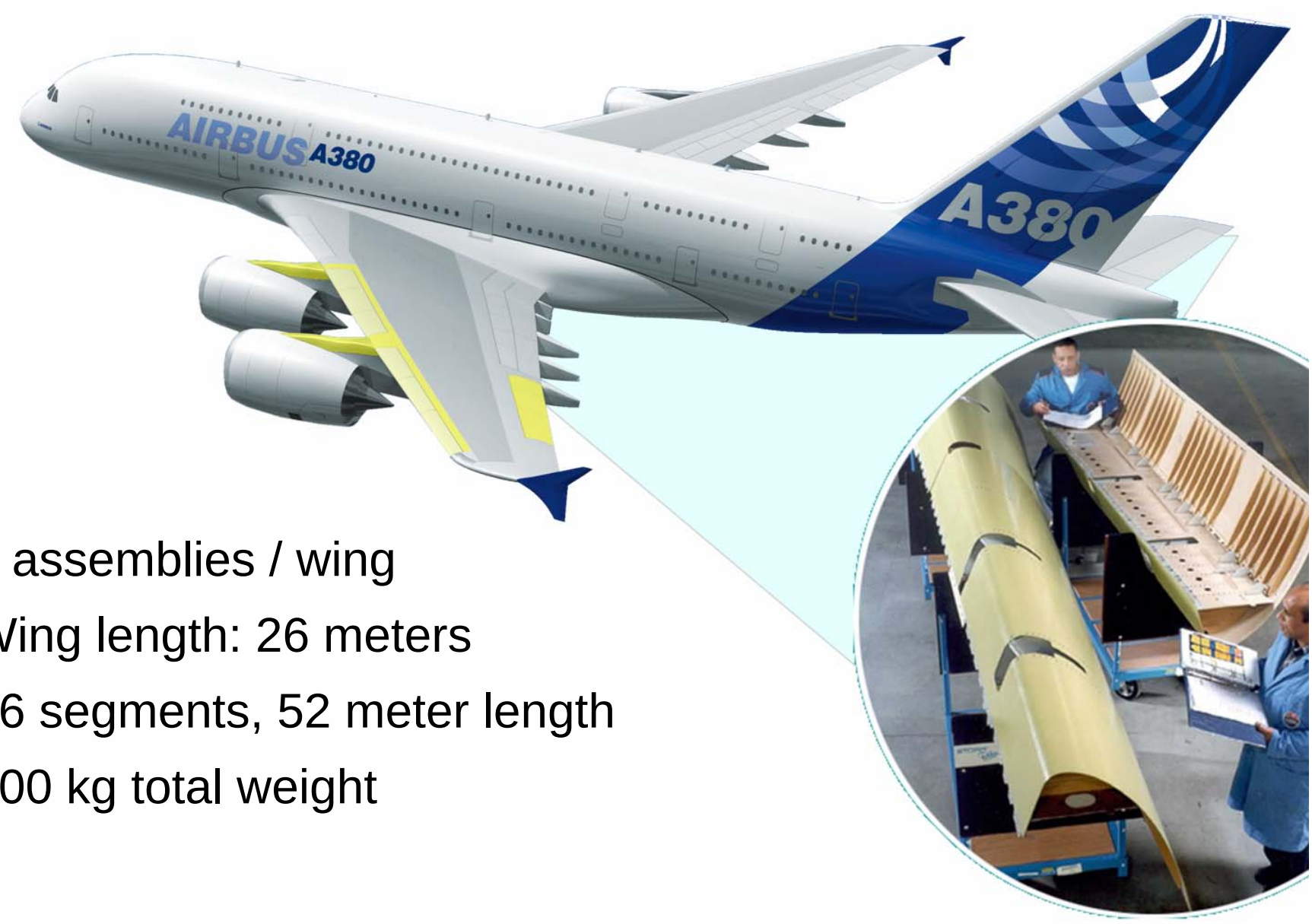

- 8 assemblies / wing
- Wing length: 26 meters
- 16 segments, 52 meter length
- 400 kg total weight

First Wing Airbus A380

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Advanced Composite Polymer for the Automotive Market

Long Fiber Reinforced Linear Polyphenylene Sulfide (PPS)

Thank you.

For more information, please contact:
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Any determination of the suitability of a particular material and part design for any use contemplated by the user is the sole responsibility of the user. We strongly recommend that users seek and adhere to the manufacturer's current instructions for handling each material they use.

Any existing intellectual property rights must be observed.