PRODUCT DATASHEET

TENCATE

TENCATE ADVANCED COMPOSITES

TenCate Cetex® TC1100 PPS Resin System

PRODUCT TYPE

Polyphenylene Sulfide Thermoplastic Resin System

SERVICE TEMPERATURE

100°C (212°F) Continuous

TYPICAL APPLICATIONS

- Primary Aircraft Structures
- Secondary Aircraft Structures
- Engine Nacelles
- Radomes

PRODUCT DESCRIPTION

TenCate Cetex® TC1100 is a semicrystalline polyphenylene sulfide thermoplastic composite offering outstanding toughness and excellent chemical and solvent resistance. The material is inherently flame resistant with low smoke emission. It exceeds 35/35 OSU and is qualified at Airbus and Boeing for multiple structural applications. This material is typically supplied in 3,660mm by 1,220mm (12 ft by 4 ft) preconsolidated laminates using the customer's designated ply count and orientation. Unitape versions are offered in a standard 6 inch (152 mm width) or alternative 12 inch widths (305 mm). Alternative narrower slit widths for ATL processing may be available through secondary slitting.

In addition, lightning strike material can be incorporated on laminates and the laminates can be textured. By utilizing preconsolidated sheets and avoiding hand lamination, the customer can significantly reduce the cycle time required to produce a finished part. In addition, thermoplastics have the unique capability of allowing parts to be welded, folded, etc., to facilitate lower part count structures.

TYPICAL PROPERTIES OF NEAT RESIN

Specific gravity	1.35 g/cc
Tg	90°C (194°F)
Melt temp	280°C (536°F)
Dielectric constant	3.20 at 1MHz
Loss tangent	0.0013 at 1MHz
Moisture absorption	0.02%
Flammability	V-0
Tensile strength	90.3 MPa (13.1 ksi)
Tensile modulus	3,800 MPa (0.551 Msi)
Elongation at yield	3%
Poisson's ratio	0.36
Compression strength	148 MPa (21.5 ksi)
Compression modulus	2,965 MPa (0.43 Msi)
Flexural strength	125 MPa (18.1 ksi)
Flexural modulus	3,725 MPa (0.54Msi)
Izod unnotched	199kJ/m^2 (94.6ft-lb/in^2)
Izod notched	15.6kJ/m^2 (7.4ft-lb/in^2)
CTE	52.2ppm/°C (29ppm/°F)
Thermal conductivity	0.19 W/m-°K
Outgassing TML	0.04%
Outgassing CVCM	0.00%
WVR	0.00%
Fluid resistance	Excellent

TenCate Cetex® TC1100 PPS Resin System

MECHANICAL PROPERTIES - TENCATE CETEX TC1100 AS-4 UNITAPE

Data delivered on AS-4, 150 gsm FAW, resin content of 34% by weight, 59% fiber by volume. Prepreg areal weight 218 gsm.

Property	Condition	Test Method	Result	
Tensile Strength (0°)	RTD	ASTM D 3039	313 ksi	2160 MPa
Tensile Modulus (0°)	RTD	ASTM D 3039	18 Msi	124 GPa
Poisson's Ratio	RTD	ASTM D 3039	0.33	
Tensile Strength (90°)	RTD	ASTM D 3039	5.7 ksi	39 MPa
Tensile Modulus (90°)	RTD	ASTM D 3039	1.4 Msi	10 GPa
Compressive Strength (0°)	RTD	ASTM D 6641	160 ksi	1100 MPa
Compressive Modulus (0°)	RTD	ASTM D 6641	17 Msi	117 GPa
In Plane Shear Strength (±45° Tension)	RTD	ASTM D 3518	11.9 ksi	82 MPa
In Plane Shear Modulus (±45° Tension)	RTD	ASTM D 3518	.50 Msi	3.5 GPa
Flexural Strength (90°)	RTD	ASTM D 790	9.9 ksi	68 MPa
Open Hole Compressive Strength	RTD	ASTM D 6484	38.7 ksi	267 MPa
Compression After Impact after 270 in-lb impact (30.5 J)	RTD	ASTM D 7137	31.4 ksi	216 MPa

(1) Consolidated ply thickness average is .0056" (0.14 mm). (2) Density is 0.058 lb/in^3 (1.6 g/cm^3).

MECHANICAL PROPERTIES - TENCATE CETEX TC1100 IM-7 UNITAPE

Data delivered on IM-7, 146 gsm FAW, resin content of 34% by weight, 59% fiber by volume. Prepreg areal weight 218 gsm.

Property	Condition	Test Method	Result	
Tensile Strength (0°)	RTD	ASTM D 3039	400 ksi	2760 MPa
Tensile Modulus (0°)	RTD	ASTM D 3039	22.1 Msi	152 GPa
Tensile Strength (90°)	RTD	ASTM D 3039	5.7 ksi	39 MPa
Tensile Modulus (90°)	RTD	ASTM D 3039	1.4 Msi	10 GPa
Compressive Strength (0°)	RTD	ASTM D 6641	186 ksi	1280 MPa
Compressive Modulus (0°)	RTD	ASTM D 6641	18 Msi	124 GPa
Flexural Strength (90°)	RTD	ASTM D 790	9.5 ksi	65 MPa

TENCATE ADVANCED COMPOSITES

TenCate Cetex® TC1100 PPS Resin System

LAMINATE DATA USED 7781 FG, 300 FAW, 37%RC (47.5% BY VOLUME)

Specific gravity 1.92 g/cc. Tg amorphous 90°C, Tg crystalline 120°C, Tm 280°C.

Property	Condition/Result		Condition/Result		Condition/Result		Condition/Result		Condition/Result	
Tensile Strength 0°	CTD	65.6 ksi (452 MPa)	RTD	49.3 ksi (339 MPa)	ETD	40.5 ksi (279 MPa)	ETW	41.9 ksi (289 MPa)	ETW (2)	35.7 ksi (246 MPa)
Tensile Strength 90°	CTD	64.8 ksi (447 MPa)	RTD	48.3 ksi (333 MPa)	ETD	40.7 ksi (281 MPa)	ETW	41.8 ksi (288 MPa)	ETW (2)	39.6 ksi (273 MPa)
Tensile Modulus 0°	CTD	3.2 Msi (22.1 GPa)	RTD	3.1 Msi (21.4 GPa)	ETD	2.9 Msi (20.0 GPa)	ETW	3 Msi (20.7 GPa)	ETW (2)	2.8 Msi (19.3 GPa)
Tensile Modulus 90°	CTD	3 Msi (20.7 GPa)	RTD	2.9 Msi (20.0 GPa)	ETD	2.7 Msi (18.6 GPa)	ETW	2.8 Msi (19.3 GPa)	ETW (2)	2.6 Msi (17.9 GPa)
Compressive Strength 0°	CTD	82.1 ksi (566 MPa)	RTD	61.6 ksi (425 MPa)	ETD	43 ksi (297 MPa)	ETW	33.4 ksi (230 MPa)	ETW (2)	24.4 ksi (168 MPa)
Compressive Strength 90°	CTD	55.7 ksi (384 MPa)	RTD	42.8 ksi (295 MPa)	ETD	29.4 ksi (203 MPa)	ETW	22.6 ksi (156 MPa)	ETW (2)	16.9 ksi (117 MPa)
Compressive Modulus 0°	CTD	3.8 Msi (26.2 GPa)	RTD	3.7 Msi (25.5 GPa)	ETD	3.2 Msi (22.1 GPa)	ETW	3.1 Msi (21.4 GPa)	ETW (2)	2.9 Msi (20.0 GPa)
Compressive Modulus 90°	CTD	3.6 Msi (24.8 GPa)	RTD	3.5 Msi (24.1 GPa)	ETD	2.9 Msi (20.0 GPa)	ETW	2.9 Msi (20.0 GPa)	ETW (2)	2.5 Msi (17.2 GPa)
In-Plane Shear Strength	CTD	15.8 ksi (109 MPa)	RTD	11.6 ksi (80.0 MPa)	ETD	8.6 ksi (59.3 MPa)	ETW	9.8 ksi (67.6 MPa)	ETW (2)	9.1 ksi (62.7 MPa)
In-Plane Shear Modulus	CTD	0.712 Msi (4.91 GPa)	RTD	0.539 Msi (3.71 GPa)	ETD	0.247 Msi (1.71 GPa)	ETW	0.208 Msi (1.44 GPa)	ETW (2)	0.109 Msi (0.752 GPa)
Flexural Strength 0°			RTD	74.2 ksi (512 MPa)						
Flexural Strength 90°			RTD	56.6 ksi (390 MPa)						
Flexural Modulus 0°			RTD	3.3 Msi (22.8 GPa)						
Flexural Modulus 90°			RTD	2.9 Msi (20.0 GPa)						
Open Hole Tensile Strength			RTD	23 ksi (159 MPa)			ETW	19.6 ksi (135 MPa)		
Open Hole Compressive Strength			RTD	26.5 ksi (183 MPa)			ETW	16 ksi (110 MPa)		
Bearing Strength Yield			RTD	46.1 ksi (318 MPa)			ETW	26.7 ksi (184 MPa)		
Bearing Strength Ultimate			RTD	74.8 ksi (516 MPa)			ETW	55.6 ksi (383 MPa)		
Compression After Impact			RTD	24.8 ksi (171 MPa)						

CTD = 55°C/67°F
ETD = 23°C/73°F at 50% RHETD = 80°C/176°F
ETW = 80°C/176°F conditioned at 70°C/158°F at 85% RH
ETW(2) = 100°C/212°F conditioned at 70°C/158°F at 85% RH

Average results according to Mil-R-17; test methods vary

FLAMMABILITY PROPERTIES

	OSU		Flammability			SMOKE (4 min)		TOXICITY						
	Heat Release	Release Rate	Burn Length	After Flame	Drip Flame	Non-flaming	Flaming	HCN	CO	NOx	SO2	HF	HCl	HBr
5 plies of 7781/PEI	14	21	1.9 mm	0sec	N/D									
4 plies of 3k PW/PPS								9.03	9		1	17	1	1

Flammability & Heat Release - FAR 25.853.
Smoke Density & Toxicity - ATS 1000.001

PRODUCT DATASHEET

TENCATE

TENCATE ADVANCED COMPOSITES

TenCate Cetex® TC1100
PPS Resin System

LAMINATE DATA USED 5HS 3K T300
280 FAW, 43% RC (50% BY VOLUME). Double sided Amcor foil

Property	Condition/Result		Condition/Result		Condition/Result		Condition/Result		Condition/Result	
Tensile Strength 0°	CTD	115 ksi (790 MPa)	RTD	110 ksi (757 MPa)	ETD	106 ksi (730 MPa)	ETW	110 ksi (756 MPa)	ETW(2)	35.7 ksi (246 MPa)
Tensile Strength 90°	CTD	109 ksi (750 MPa)	RTD	109 ksi (754 MPa)	ETD	93.6 ksi (645 MPa)	ETW	101 ksi (698 MPa)	ETW(2)	39.6 ksi (273 MPa)
Tensile Modulus 0°	CTD	7.7 Msi (53.1 GPa)	RTD	8.1 Msi (55.8 GPa)	ETD	8.2 Msi (56.5 GPa)	ETW	8.2 Msi (56.5 GPa)	ETW(2)	2.8 Msi (19.3 GPa)
Tensile Modulus 90°	CTD	7.6 Msi (52.4 GPa)	RTD	7.8 Msi (53.8 GPa)	ETD	7.6 Msi (52.4 GPa)	ETW	7.6 Msi (52.4 GPa)	ETW(2)	2.6 Msi (17.9 GPa)
Compressive Strength 0°	CTD	98 ksi (676 MPa)	RTD	93.3 ksi (643 MPa)	ETD	80.9 ksi (558 MPa)	ETW	83.8 ksi (577 MPa)		
Compressive Strength 90°	CTD	101 ksi (698 MPa)	RTD	92.4 ksi (637 MPa)	ETD	76.3 ksi (526 MPa)	ETW	77.5 ksi (534 MPa)		
Compressive Modulus 0°	CTD	7.2 Msi (49.6 GPa)	RTD	7.5 Msi (51.7 GPa)	ETD	7.5 ksi (51.7 GPa)	ETW	7.5 Msi (51.7 GPa)		
Compressive Modulus 90°	CTD	7.2 Msi (49.6 GPa)	RTD	7.5 Msi (51.7 GPa)	ETD	7.4 ksi (51.0 GPa)	ETW	7.4 Msi (51.0 GPa)		
In-Plane Shear Strength	CTD	19 ksi (131 MPa)	RTD	17.2 ksi (119 MPa)	ETD	15.7 ksi (108 MPa)	ETW	15.1 ksi (104 MPa)		
In-Plane Shear Modulus	CTD	0.642 Msi (4.43 GPa)	RTD	0.586 Msi (4.04 GPa)	ETD	0.384 Msi (2.65 GPa)	ETW	0.435 Msi (3.00 GPa)		
Flexural Strength 0°	CTD	151 ksi (1043 MPa)	RTD	149 ksi (1027 MPa)	ETD	138 ksi (954 MPa)	ETW	142 ksi (977 MPa)		
Flexural Strength 90°	CTD	121 ksi (834 MPa)	RTD	121 ksi (831 MPa)	ETD	115 ksi (794 MPa)	ETW	107 ksi (739 MPa)		
Flexural Modulus 0°	CTD	8.6 Msi (59.3 GPa)	RTD	8.7 Msi (60.0 GPa)	ETD	8.4 Msi (57.9 GPa)	ETW	8.7 Msi (60.0 GPa)		
Flexural Modulus 90°	CTD	6.3 Msi (43.4 GPa)	RTD	6.5 Msi (44.8 GPa)	ETD	6.5 Msi (44.8 GPa)	ETW	6.4 Msi (44.1 GPa)		
Open Hole Tensile Strength	CTD	41.4 ksi (285 MPa)	RTD	40.4 ksi (279 MPa)			ETW	39.1 ksi (270 MPa)		
Open Hole Compressive Strength	CTD	39.5 ksi (272 MPa)	RTD	37.1 ksi (256 MPa)			ETW	33.7 ksi (232 MPa)		
Bearing Strength Yield	CTD	71.2 ksi (491 MPa)	RTD	65.8 ksi (454 MPa)			ETW	59.9 ksi (413 MPa)		
Bearing Strength Ultimate	CTD	122 ksi (838 MPa)	RTD	122 ksi (844 MPa)			ETW	122 ksi (838 MPa)		
Compression After Impact	CTD	32.3 ksi (223 MPa)	RTD	31.2 ksi (215 MPa)			ETW	31.6 ksi (218 MPa)		

CTD = 55°C/67°F
ETD = 23°C/73°F at 50% RH
ETD = 80°C/176°F
ETW = 80°C/176°F conditioned at 70°C/158°F at 85% RH
ETW(2) = 100°C/212°F conditioned at 70°C/158°F at 85% RH

TenCate Cetex® TC1100 PPS Resin System

Processing Guidelines for TenCate Cetex® TC1100 Thermoplastic Composite Materials

TenCate Cetex® TC1100 thermoplastic composite materials from TenCate are processed by heating the material above the PPS melting point and molding it and cooling it under pressure to the desired shape. Because no chemical change occurs to the PPS matrix, processing is very rapid. The quick easy processing of TenCate Cetex materials is also made possible because of the rapid crystallization rate of the PPS matrix. The key thermal processing parameters are:

Melt Temperature .... 560°F (293°C)
Typical Processing Temperature .... 625°F (330°C)

TenCate can also produce TenCate Cetex towpregs & simple profiles (round rods, ovals, rectangles, etc.). TenCate also has the capability to chop the towpregs & simple profiles into discrete length long fiber thermoplastic type materials for injection or compression molding type processes.

Automated Processes
Below are several examples of automated processes that are utilized and available in the market today. Both processes utilize similar premises in that they eliminate the need for autoclave consolidation of thermoplastic composite parts, thereby dramatically reducing the cost of producing continuous fiber composite structures.

1. Fiber Placement with In Situ Consolidation
   This process utilizes narrow width tapes typically 0.25 – 1 inches (6 – 25 mm) as its composite material medium and lays down, heats via hot gas, laser, or other heating methods and consolidates the composite material onto the tool, in situ, without the need for further consolidation processes.

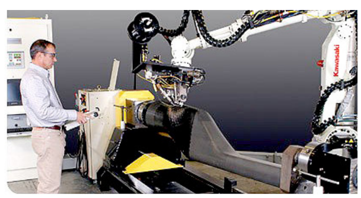

Photo courtesy of Automated Dynamics
www.automateddynamics.com

Photo courtesy of AFPT
www.afpt.biz/

2. Rapid Lamination / Forming
   This process uses wider UD tapes typically ≥ 2 inches (50 mm) width to rapidly lay down and consolidate the thermoplastic composite material into an engineered laminate structure that can then be transformed into parts via a secondary compression thermoforming process.

Automated tape laying of tailored blank followed by consolidation.

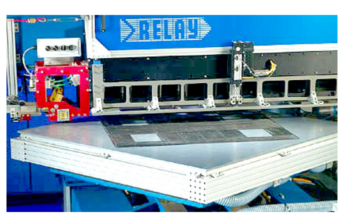

Photo Courtesy of FiberForge
www.fiberforge.com

The consolidated flat laminate is then thermoformed to a 3-D final shape.

Photo courtesy of TenCate

TenCate Cetex® TC1100
PPS Resin System

3. Continuous Compression Molding
In this multi-step process, multiple plies of thermoplastic unitape is heated in a mold and pressed into a laminate. This laminate is then pressed into a mold and thermoformed to the desired profile. A final step then molds with heat and gentle pressure into the curved profile through a process called continuous compression molding. Items such as clips, rails, beams and profile are manufactured in this type of process.

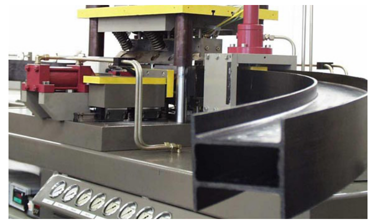

Photo Courtesy of ACM/Xperion Aerospace
www.acm-fn.de

Press Lamination: A laminate can be press molded from any TenCate Cetex prepreg by stacking two or more plies in the desired orientation into a picture frame mold, transferring the assembly to a heated platen press where it is brought to approximately 610°F (320°C) at contact pressure until the material reaches temperature. The pressure should then be increased to 100-400 psi (7-21 bar) and held for approximately 15-30 minutes.

Autoclave Lamination: Autoclave Consolidation is used for fabricating laminates from any TenCate Cetex prepreg tape. Individual layers are stacked in the desired orientation and vacuum bagged (vacuum should be maintained throughout the entire process). A high temperature bagging material, such as Kapton polyimide should be used. The assembly should then be placed in the autoclave and brought to approximately 610°F (320°C), at which time the pressure is increased from ambient to 100-150 psi (7-10 bar) and maintained for around 20-30 minutes. The part should then be cooled to room temperature at a 5-20°C cool down rate to maintain crystallinity.

Thermoforming Laminates into Shapes: Thermoforming is used to convert a flat consolidated continuous fiber reinforced laminate into a complex shape with no change in starting laminate thickness. The laminate should be heated to around 610°F (320°C) in an infrared or similar oven and then quickly transferred to a matched core/cavity mold where it can be formed at 150-600 psi (10-40 bar). For optimum properties and formability, heating of the composite laminate should take no longer than 8 minutes. Overall part production cycle times are between 2-10 minutes, depending on material thickness and part geometry. Production tooling consists of machined aluminum halves, one that has a compliant layer of cast silicone, and an associated laminate tensioning system to prevent wrinkling within the part being thermoformed.

Cutting and Machining: Thermoplastic composite laminates and thermoformed parts can be machined with feed rates and tip speeds similar to those used when machining brass. The following are some general guidelines:

Circular Saw:	Diamond-grit-edge blade of 220 grit. Blade speed: 6000 fpm (1830 mpm) with water or soap solution as coolant. Feed rates depend on thickness.
Turning Operations:	Cutting Speed: 350-400 fpm (105-120 mpm) for high speed tools, 1500-2500 fpm (180-455 mpm) for Stellite or carbide tools, and 2000-4000 fpm (600-1200 mpm) for diamond tools
Milling Operations:	Tip speed: 250-450 fpm (75-135 mpm) for carbide and diamond tools Plunge feed rate: 0.5-1 fpm (0.15-0.30 mpm)

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Drilling Operations:	Feed Rate: 0.008-0.016 in/rev (0.2-0.4 mm/rev) Drill speed: 150-300 fpm (45-90 mpm) Drill point angles: 60° for thin parts, 90° for thick parts Clearance angle: 15°
Tapping:	Tool rake of 0° to 5° negative
Shearing:	Thicknesses up to 0.125 inch (3.2 mm)

Joining: Thermoplastic composites can be joined via mechanical fasteners, adhesive bonding, or fusion welding.

Strong adhesive bonds are possible with epoxy adhesives when PPS surfaces are cleaned with a suitable degreasing solvent (i.e. MEK), abrasive treatment (i.e., abrasion wheels, sand paper, or grit blasted with #100 or #200 Aluminum Oxide). The surface energy may also be enhanced by flame/corona treatment, chromic acid etching, laser treatment, or plasma techniques. Epoxy films or pastes with cure temperatures up to 350°F (177°C), anaerobics, silicone sealers, and cyanoacrylates are effective adhesives depending on specific requirements.

TenCate Cetex® TC1100 based composites may also be bonded using conventional thermoplastic welding techniques. PPS based materials have very high melt temperatures and considerable amounts of energy must be put into the interface to achieve a good bond. Satisfactory results have also been obtained using induction or resistance welding.

Painting: TenCate Cetex® TC1100 composite surfaces can be painted with a variety of products. It is recommended that a paintable (non-silicone) mold release be used, if possible, during the molding of all surfaces to be painted. If a silicone or Teflon mold release is used during molding, laminate and part surfaces may require abrasion prior to painting. In all cases, surfaces must be wiped with a suitable solvent (e.g. MEK, DuPont 3919S) to remove oils, release agents, or other impurities.

Health & Safety: Health and safety information on handling and processing TenCate composite materials is described in a Material Safety Data Sheet available from TenCate Advanced Composites USA, Inc. To obtain this or any other information about TenCate PPS thermoplastic composite materials, contact: TenCate Advanced Composites USA, Inc. at the addresses and telephone numbers below.

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TENCATE ADVANCED COMPOSITES

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