VERSION 1.0 _ REVISION DATE 30/05/2022

TECHNICAL DATA SHEET

Roboze ToolingX CF

Overview

PPS CF is a semi-crystalline polymer consisting of a polyphenylene sulfide matrix reinforced with 12% of chopped carbon fibers.

Among the main properties of PPS there are thermal and chemical resistance.

PPS is resistant to strong acids (e.g., phosphoric and sulfuric acids), sodium hypochlorite, alcohols, ethyl acetate, butyl ether, gasoline, phenol, and cresyldiphenyl-phosphate. Nearly no solvent can dissolve it under 200°C, making it suitable in applications with aggressive environments. PPS is also inherently self-extinguishing, which makes it earn the UL94 V0 rating.

Thanks to carbon fiber reinforcement, this lightweight composite shows great stiffness, remaining dimensionally stable even at high temperatures. The PPS CF filament also has excellent tribological properties.

All these properties contribute to making it a versatile solution for the most demanding industries such as Manufacturing, Mobility and Aerospace.

Applications

Carbon fiber filled polyphenylene sulfide has wide applications in various industries, mostly because of its excellent thermal stability and great mechanical properties even when exposed to high temperatures.

These properties make the material an excellent candidate to produce components for the manufacturing of tooling. For instance, it is widely use to manufacture paper-pulp molds, thermoforming molds and calibration jigs due to its high elastic modulus.

Due to the high mechanical properties and the excellent chemical resistance, PPS CF can also be used in harsh environments and in contact with aggressive chemicals. For this reason, it is utilized in the chemical industry and automotive industry (insulators, throttle bodies, ducts). It is also ideal for electronics and electrical devices (e.g., burn-in test sockets, connectors and housings) due to the low surface resistivity that makes it fall under the ESD range of polymers.

Design phase

The preparation of the samples and the execution of the individual tests followed the guidelines imposed by the associated regulations.[1]

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[1] Although data measured in a controlled environment can provide an indication of the chemical/physical and mechanical properties of the material and thus enable comparison between different materials, the results of these tests may not be the same as those observed in the final component.

This phenomenon may be caused by the presence of geometric features or manufacturing conditions that may contribute to modifying the material behaviour. Furthermore, the properties of polymeric materials are a function of both temperature and environmental factors (solar radiation, humidity, etc.), which is why the effect of these variables should also be considered during the design phase, both in the case of short-term and long-term exposure.

In view of the above, it is recommended that a prototype be made in advance during the design phase to empirically verify its properties in the operating conditions required by the specific application.

TECHNICAL DATA SHEET

Roboze ToolingX CF

Manufacturing Process

Specimen were manufactured on a Roboze Plus PRO fed with a filament with a diameter of 1.75 ± 0.05 mm. This thermoplastic filament was subsequently extruded through a 0.6 mm diameter nozzle. Before starting the printing process, in order to minimize the concentration of water molecules adsorbed and absorbed by the filament due to exposure to the atmospheric environment, ToolingX CF spools were subjected to a drying cycle at a temperature of 100°C for 12 hours in HT Dryer.

The temperature of the print bed was set to 100°C. Before starting the printing process, 15 minutes of thermal equilibration were allowed.

The printing parameters for the following data are:

- Buildplate Temperature = 100°C
- Extrusion Temperature = 350°C
- Printing Speed = 3000 mm/min
- Layer Height = 0.22 mm
- Infill Percentage = 100%
- 2 Shells

At the end of the printing process the samples were subjected to the phase of manual removal of the support structures.

The additive manufacturing technology produces intrinsically anisotropic components. As the orientation of the component on the printing plate changes, it will be possible to observe variations in terms of both the properties of the final printed part and the productivity of the printing process. Keeping in mind what has been written above, it is possible to identify three different orientations on the building plate that are named as follows:

- Flat (or XY)
- On Edge (or XZ)
- Upright (or ZX)

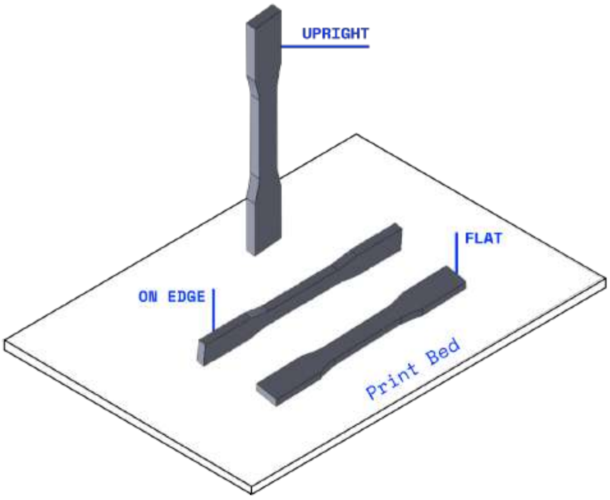

Figure 1 Example of On Edge, Upright and Flat orientation on the building plate

TECHNICAL DATA SHEET

Roboze ToolingX CF

Summary of the ToolingX CF properties

MECHANICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION			TEST METHOD
			XZ	XY ±45°	ZX	
Tensile Strength	25°C	MPa	82	66	21	ASTM D638
Young Modulus	25°C	GPa	9.1	5.4	2.0	ASTM D638
Elongation at Tensile Strength	25°C	%	1.1	1.7	1.4	ASTM D638
Flexural strength	25°C	MPa	87	66	38	ASTM D695
Flexural modulus	25°C	GPa	6.9	4.0	2.1	ASTM D695
Compressive strength	25°C	MPa	82		119	ASTM D790

PHYSICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION	TEST METHOD
Specific gravity		g/cm^3	1.33	ISO 1183
Water Absorption	23 °C/24h	%	<0.05	ISO 62
Continuous service temperature*	20.000h	°C	220	IEC 60216
Service temperature*	Lifetime max. 200h	°C	240	
Surface Resistance*		Ω	$< 10^6$	DIN IEC 60093
Flammability			Flame Resistance	
Auto Ignition Temperature		°C	540	
Radiation Resistance			Good	
Color			Dark Grey	

*The information may come from the raw material, the semi-finisshed product or an estimate.
Specific individual tests are recommended according to the applicationsconditions required for final implementation.

TECHNICAL DATA SHEET

Roboze ToolingX CF

Mechanical Properties

Tensile Properties

The tensile test is a destructive test useful to characterize the properties of materials when subjected to uniaxial tensile loads. A specimen of standard dimensions, having a "dogbone" geometry, is clamped by means of appropriate clamps to two crossbeams.

The movable crossbeam can move upwards, thus bringing the specimen into a tensile state. Once the displacement speed of the crossbar has been set, the load applied and the deformation undergone by the sample are monitored during the test.

In output the system is able to provide a Cartesian graph where on the ordinates is represented the stress (σ), i.e. the ratio between the force applied to move the mobile crosshead at constant speed and the minimum section of the "dogbone" test specimen; while the abscissae report the strain (ε), i.e. the percentage ratio between the variation of length of the test specimen with respect to its initial dimensions $(\Delta\ell)$ and its nominal length before the start of the test (ℓ_0).

The stress-strain curve will be a function of the nature of the material. The characteristic parameters that can be derived from this curve are: tensile strength (σ_M), Young's modulus (E) and strain at tensile strength (ε_M).

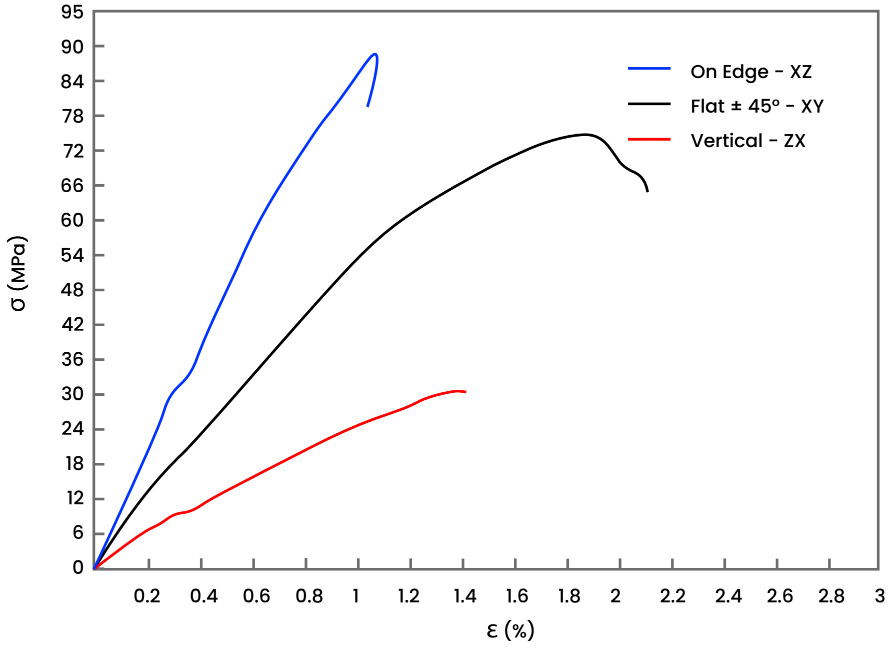

Figure 2 Comparison between tensile test behaviour of ToolingX CF samples built in different orientations

The initial section of the curve shows a region of linear elastic deformation. In this region (also called the Hookean region of the material), the material undergoes an instantaneous and reversible strain linearly dependent on the applied stress

TECHNICAL DATA SHEET

Roboze ToolingX CF

The angular coefficient of the tangent line to the linear elastic region is defined as Young's Modulus, which is the constant of proportionality between the strain undergone by the material and the applied stress. Young's modulus is generally measured from the stresses at 0.05% and 0.25% strain.Components manufactured by additive manufacturing show anisotropic mechanical properties. Since the aim of the additive manufacturing process is often to create parts of arbitrarily complex geometry, it is very difficult to align the sample in the direction that maximizes its mechanical properties.For the above reason, the mechanical properties of samples printed with different orientations on the printing plate were analyzed. The ASTM D638 standard was followed to perform the characterization of the samples. ZX-oriented specimens were milled from a 120x3.2x60 mm plate in order to evaluate inter-layer adhesion properties with minimal interference from spurious phenomena. A speed of 1 mm/min was used to calculate the tensile modulus, thereafter, the speed was increased up to 50 mm/min until the specimen failed. It should be remembered that the results of the tensile test are a function of the set test speed, which is why for a proper comparison between different materials it is important to know in advance the speed at which the test was performed.

Table 1 Tensile properties of ToolingX CF measured at 25°C for different specimen orientations

TENSILE TEST ASTM D638	UNITS	ORIENTATION		
		XZ	XY ±45°	ZX
Tensile Strength	MPa	82	66	21
Elongation at maximum load	%	1.1	1.7	1.4
Young’s Modulus	GPa	9.1	5.4	2.0

Flexural Properties

During the design phase, the knowledge of the bending behaviour of a material is crucial for the correct structural dimensioning of the component.

As shown in Figure 3, considering a bar of material fixed at both ends, and with a vertical load applied to its middle point, it is possible to demonstrate how the stresses originating inside the body present a linear axial distribution: the stress σ reaches maximum absolute values , although opposite in sign, at the extremes of the section, while it is zero at the neutral axis.

The reason for this is that the points below the neutral axis (therefore below the surface on which the load is applied load) will be in a state of compression, while the points above the neutral axis (therefore belonging to the surface free from the action of the load) will present a state of traction.

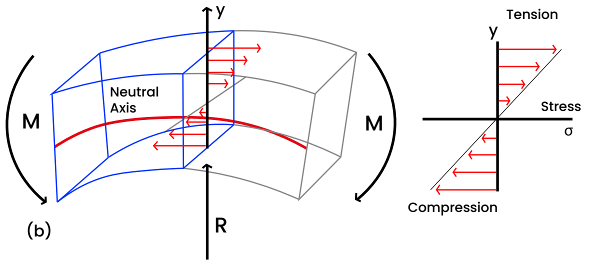

Figure 3 Stress variation along cross section of a beam subjected to flexural loads

TECHNICAL DATA SHEET

Roboze ToolingX CF

The flexural behavior of ToolingX CF was evaluated according to ASTM D790. The samples are bars with dimensions 12.7mm x 127mm x 3.2mm.

The testing speed was set to 1.35 mm/min and the support span was 50.8 mm.

Table 2 ToolingX CF Flexural Properties

ORIENTATION	E_F (MPa)	σ_F(MPa)
XY ±45°	4	66
XZ	6.9	87
ZX	2.1	38

The stress-strain curve for different printing orientations is shown below.

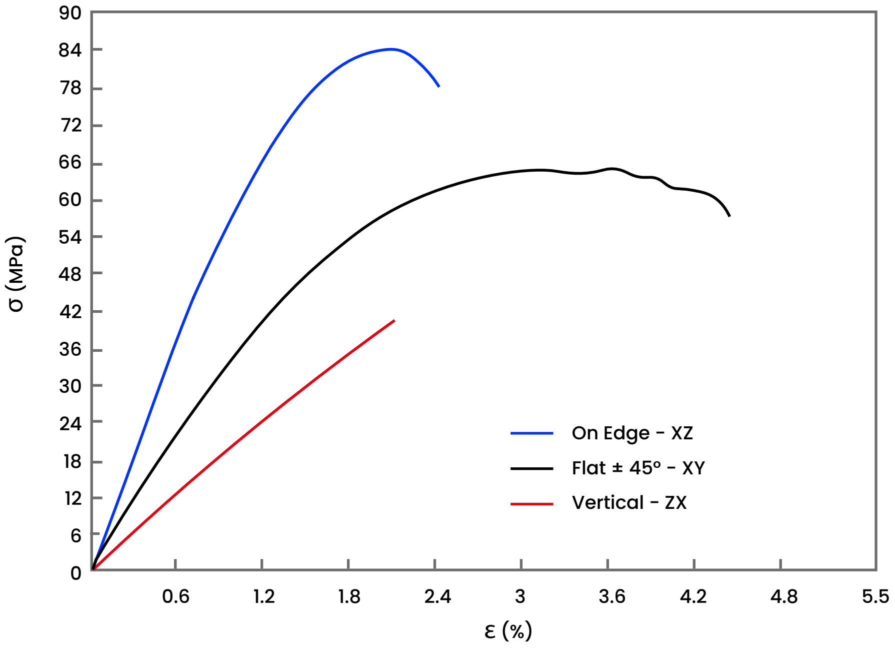

Figure 4 Stress-strain curves for ToolingX CF subjected to bending tests

Compression Properties

Compressive stresses are inherently present in many engineering systems either due to the application of a compressive load directly on the component or due to the application of impact or bending loads. Another phenomenon directly related to compressive loads is buckling, which severely limits the efficiency of systems leading to an underutilization of the real properties of the material. The ASTM D695 standard was used for the determination of the compression properties of ToolingX CF. Dimensions of cylindrical specimens are as follows:

- Diameter: 12.7mm
- Height: 25.4mm

The testing speed was set at 1.3 mm/min

TECHNICAL DATA SHEET

Roboze ToolingX CF

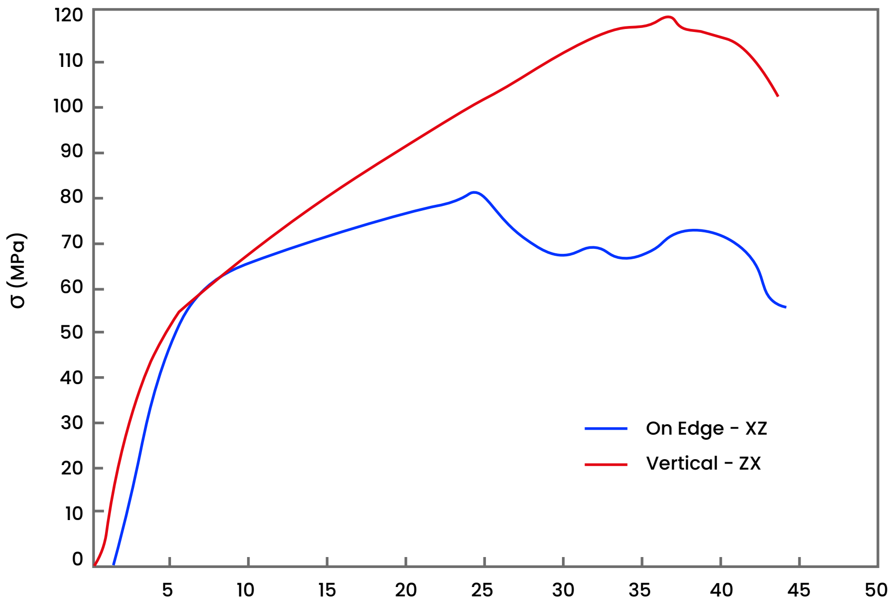

Figure 5 Stress strain curve for ToolingX CF samples subjected to compression test

Table 3 Compressive strength values of ToolingX CF at 25°C

ORIENTATION	σ_M(MPa)
XZ	82
ZX	119

Chemical Compatibility

Hostile environments for polymers generally refer to high temperatures and corrosive chemicals. As high performance plastics take on an growing role in metal replacement, it is important to understand the behavior of these polymers under hostile conditions. Regarding ToolingX CF filament, the unique aromatic sulfide backbone of the polyphenylene sulfide molecule is responsible for its heat and chemical resistance. Not surprisingly, its resistance to various organic and inorganic compounds and reagents, compared to other polymers, is excellent. Polyphenylene sulfide has very good resistance to acids and bases. Resistance to alcohols and glycols is excellent too.

An example of application of reinforced plastics for metal replacement is the automotive industry, where the key point is to cut weight and cost. Automotive environments are often incompatible to plastics. High temperatures coupled with exposure to oil, fuel, and coolants will permit only the most resistant of plastic compositions to be used. The good heat and chemical resistance of ToolingX CF makes it a leading candidate for such cases. However, the list of chemicals causing significant deterioration includes aqua regia, chlorosulfonic acid, concentrated chromic acid, concentrated sulfuric acid, some chlorinated compounds, and some amines. The following table refers to injection molded specimens of PPS containing no fillers or reinforcing agents.

TECHNICAL DATA SHEET

Roboze ToolingX CF

CHART CODES
A = Excellent. (1. Satisfactory 22° C ; 2. Satisfactory to 48° C)
B = Good -Minor Effect, slight corrosion or discoloration.
C = Fair - Moderate Effect, not recommended for continuous use. Softening, loss of strength, swelling may occur
D = Severe Effect, not recommended for ANY use

CHEMICAL	RESISTANCE
Acetaldehyde	A- Excellent
Acetone	A- Excellent
Acetylene	A- Excellent
Acetyl Chloride (dry)	A- Excellent
Alcohols	A- Excellent
Aluminum Fluoride	A- Excellent
Ammonia, aqueous	A1- Excellent
Aqua Regia (80% HCl, 20% HNO3)	D- Severe Effect
Benzene	D- Severe Effect
Carbonic acid	A- Excellent
Chlorine	D- Severe Effect
Chlorobenzene	A- Excellent
Copper salts (most)	A- Excellent
Cyclohexane	A- Excellent
Detergents, synthetic	A- Excellent
Ether	A- Excellent
Ethylene Oxide	D- Severe Effect
Ferric chloride	A- Excellent
Formaldehyde (40%)	A- Excellent
Glycol, ethylene	A- Excellent
Hydrochloric acid (20%)	D- Severe Effect
Hydrochloric acid (100%)	D- Severe Effect
Hydrocyanic acid	B- Good
Hydrogen peroxide (30%)	A1- Excellent
Hydrogen peroxide (100%	C- Fair
Hydrogen sulphide	A- Excellent
Iodine	D- Severe Effect

TECHNICAL DATA SHEET

Roboze ToolingX CF

Lactic acid	A- Excellent
Mercuric Cyanide	A- Excellent
Methanol	A- Excellent
Methyl Chloride	B- Good
Motor oil	A- Excellent
Napthalene	A- Excellent
Nickel salts	A- Excellent
Nitric acid (5-10%)	B1- Good
Nitric acid (20%)	C- Fair
Nitric acid (50%)	C- Fair
Nitrobenzene	A- Excellent
Oils, diesel fuel (20, 30, 40, 50)	A- Excellent
Oils, Hydraulic Oil (Petro)	D- Severe Effect
Oils, Linseed	B- Good
Oils, Silicone	A1- Excellent
Ozone	max 100 pppm
Phosphoric acid (<40%)	A- Excellent
Phosphoric acid (>40%)	A- Excellent
Phosphoric Anhydride	D- Severe Effect
Sea water	A- Excellent
Silicone fluids	A1- Excellent
Silver nitrate	A- Excellent
Sodium carbonate	A- Excellent
Sulphates (Na, K, Mg, Ca)	A- Excellent
Sulphites	A- Excellent
Sulphuric acid (<75%)	A- Excellent
Sulphuric acid (75-100%)	A1- Excellent
Sulphuric acid (hot concentrated)	D- Severe Effect
Urea	A- Excellent
Water, distilled	A- Excellent
Water, soft	A- Excellent
Water, hard	A- Excellent

TECHNICAL DATA SHEET

Roboze ToolingX CF

Physical Properties

Continuous Service Temperature

One of the main degradation mechanisms of polymers is the chain scission. This is due to free radicals which cause breakages in the polymer backbone chain over time. This process is accelerated by heat, moisture, light, radiation and mechanical stress. It results in reduction of mechanical performance (reduced flexibility, deterioration of the materials' elongation at break, hardening, cracking) and variation in chemical-physical properties of the material (decreasing dielectric performance). A test method to establish ageing performance for polymeric materials is IEC 60216. This standard uses accelerated heat ageing of test samples, evaluates the aged elongation at break (EAB) performance against un-aged samples, organizes the results on an Arrhenius plot and extrapolates to predict extended life performance. IEC 60216 defines the temperature rating given to a polymer material as that temperature which reduces the material's elongation at break to 50% in a period of 20,000 hours."

Table 5 Continuous Service Temperature of ToolingX CF

PROPERTIES	TEST CONDITIONS	TEMPERATURE (°C)	TEST METHOD
CONTINUOUS SERVICE TEMP.	20.000h	220	IEC 60216

Flammability

Its aromatic chemical structure and intrinsic ability to char when exposed to an external flame, provide inherent flame resistance to ToolingX CF. In addition PPS provides a low flame spread index and shows self-extinguishing and non-dripping properties. Unlike other aromatic polymers such as polystyrene and inherently flame resistant structures such as polyvinyl chloride, PPS does not produce large amounts of smoke in either the smoldering or flaming states . Auto-ignition temperature of PPS was estimated at 540°C.

Water Absorption

ISO 62 defines a method for determining the moisture absorption properties in the “through-the-thickness” direction of solid polymers. It also illustrates methods for determining the amount of water absorbed by polymers specimens of defined sizes, when immersed in water or when subjected to humid air under controlled conditions.

For single-phase materials, the diffusion coefficient is determined assuming Fickian diffusion behaviour with constant moisture absorption properties through the thickness of the test specimen.

Table 6 Water absorption of ToolingX CF

PROPERTY	OPERATION CONDITIONS	UNITS	VALUE	TEST METHOD
WATER ABSORPTION	23°C/24 H	%	<0,05	ISO 62

TECHNICAL DATA SHEET

Roboze ToolingX CF

Radiation resistance

Depending on the application, plastics can come into contact with different types of radiation, which under certain circumstances can trigger degradation of the polymer. The main degradation mechanisms induced by exposure of plastic materials to electromagnetic radiation (photolysis) include:

1) chain crosslinking: effecting an increase in molecular weight and formation of a macroscopic network (polymer solubility decreases with increased radiation dose);

2) chain scission effecting a decrease in molecular weight and, thus, substantially changing a polymer materials properties (decrease in strength, tensile and flexural performances, increase of the rate of dissolution in a given solvent).

In addition to these changes, irradiation of polymers will frequently give rise to small molecule products, resulting from bond scission followed by abstraction or combination reactions.
The effects of radiation on polymers is an area of rapidly increasing interest. Several high technology industries require specialty polymers that exhibit a specific response upon exposure to radiation. Exposure to high-energy radiations such as alpha and beta particles, Xray or gamma (γ) ray electromagnetic radiation, or neutron particles is often encountered in a wide range of industries that includes nuclear power plants, healthcare industry, and aerospace.
PPS shows good radiation resistance properties. It was found that relatively high exposures of γ radiation ($3x10^8$ rad) have no significant effect on the mechanical properties of carbon fiber filled PPS. While neutron radiation has only a slight effect on these compounds.