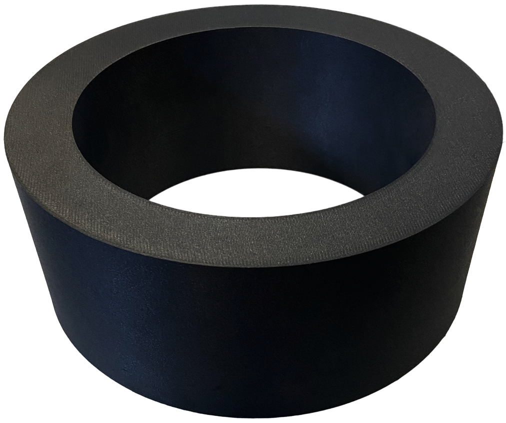
TECHNICAL DATA SHEET

Roboze Carbon PEEK



Overview

Carbon PEEK is a carbon-fiber-reinforced PEEK. The reinforcement done with 10% chopped carbon fibers improves the compressive strength, stiffness, and load capacity of PEEK.

Carbon PEEK is considered among the strongest of all thermoplastics at room temperature because it offers superlative properties that, together with its optimal wear and abrasion resistance, make it ideal for the substitution of metals in more extreme environments.

It is very resistant to hydrolysis in boiling water and superheated steam, as well as to organics, acids, and bases.

Applications

Carbon PEEK can be used both for functional prototypes and for functional parts, thanks to its very high mechanical properties. It is used in a wide range of industries like Aerospace and Defense, Automotive, Oil & Gas, Manufacturing and Motorsport. Its substantial durability makes it a common choice for harsh environments.

Typical applications include bearing retainers, bushings, oil and gas processing equipment, seals, thrust washers, pump and compressor components, aircraft hardware and fasteners, and aircraft mechanical components.

Design phase

The preparation of the samples and the execution of the individual tests followed the guidelines imposed by the associated regulations. Analyses on the relevant samples were carried out by an accredited, independent and impartial third party laboratory.[1]

[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.

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Manufacturing Process

Specimen were manufactured on a Roboze ARGO 500 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. To minimize the concentration of water molecules adsorbed and absorbed by the filament due to exposure to the atmospheric environment, before starting the printing process, Carbon PEEK spools were subjected to a drying cycle at a temperature of 100°C for 12 hours in the HT Dryer.

The temperature of the working chamber was set to 160°C. To allow isothermal conditions within the hot chamber, a 2 hour wait transpired before starting the printing process.

Printing conditions for following data tables were:

- Chamber Temperature = 160°C
- Extrusion Temperature = 470°C
- Printing speed = 1200 mm/min
- Layer height = 0,2 mm
- Infill percentage= 100%
- 2 Shells

At the end of the printing process the samples are subjected to the phase of manual removal of the supports.

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 article 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)

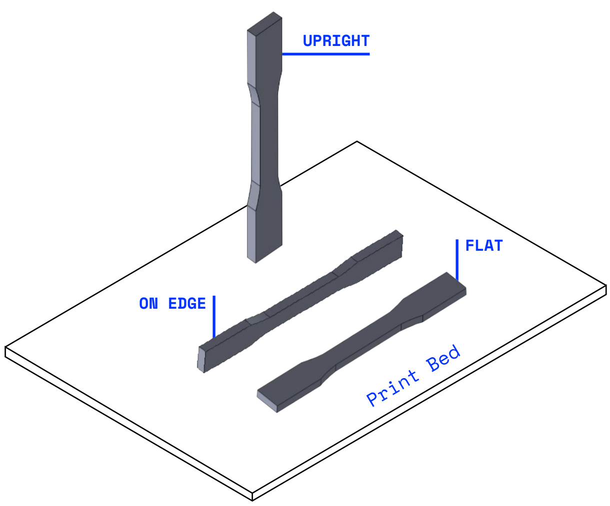

Figure 1 Example of On Edge, Upright and Flat orientation on the building plate

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Carbon PEEK properties Summary

MECHANICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION				TEST METHOD
			XZ	XY 0°	XY 45°	ZX	
Tensile Strength	25°C	MPa	139,0	136,0	125,8	28,2	ASTM D638
Young Modulus	25°C	GPa	10,7	9,1	8,1	4,0	ASTM D638
Elongation at break	25°C	%	1,6	2,2	2,2	0,7	ASTM D638
Tensile Strength	-40°C	MPa		144,0	123,5		ASTM D638
Young Modulus	-40°C	GPa		7,9	7,4		ASTM D638
Elongation at break	-40°C	%		2,0	1,8		ASTM D638
Tensile Strength	80°C	MPa		89,0	89,0		ASTM D638
Young Modulus	80°C	GPa		7,5	6,9		ASTM D638
Elongation at break	80°C	%		1,3	1,6		ASTM D638
Tensile Strength	120°C	MPa		68,9	66,9		ASTM D638
Young Modulus	120°C	GPa		8,5	6,9		ASTM D638
Elongation at break	120°C	%		0,8	1,4		ASTM D638
Tensile Strength	200°C	MPa		37,5	33,0		ASTM D638
Young Modulus	200°C	GPa		2,0	1,7		ASTM D638
Elongation at break	200°C	%		9,3	9,2		ASTM D638
Tensile Strength	250°C	MPa		28,8	28,1		ASTM D638
Young Modulus	250°C	GPa		1,3	1,3		ASTM D638
Elongation at break	250°C	%		19,0	33,7		ASTM D638
Flexural strength	25°C	MPa			144,0	48,0	ASTM D695
Flexural modulus	25°C	GPa			5,1	3,7	ASTM D695
Flexural strain at break	25°C	%			3,4	1,3	ASTM D695
Compressive strength	25°C	MPa				208,0	ASTM D790
Compressive Modulus	25°C	GPa				4,8	ASTM D790
Compressive Strength	100°C	MPa				139,0	ASTM D790
Compressive Strength	150°C	MPa				118,0	ASTM D790
Izod impact, notched	25°C	J/m	89,0				ASTM D256
Shore Hardness	D scale				84,7		ASTM D2240
Coefficient of Friction	10 N				0,24		Pin on Disk
Poisson’s ratio	25°C				0,48		ASTM D638

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Roboze Carbon PEEK

Carbon PEEK properties Summary

PHYISICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION				TEST METHOD
			XZ	XY 0°	XY 45°	ZX	
Melting Temperature		°C	345				DSC
Glass transition temperature		°C	138				DSC
Heat Deflection Temperature	1.82 MPa	°C			249		ASTM D648
Coefficient of Thermal Expansion	25°C - 50°C	10^{-6} K^{-1}			40	60	ASTM E228 ASTM E831
Coefficient of Thermal Expansion	25°C - 100°C	10^{-6} K^{-1}			36	65	ASTM E228 ASTM E831
Coefficient of Thermal Expansion	25°C - 150°C	10^{-6} K^{-1}			37	81	ASTM E228 ASTM E831
Thermal conductivity	250°C	W/m-K			0,32		
Surface Resistivity	Voltage=150 V Electrification time=60 s	Ω			> 10^{12}		ASTM D257
Surface Resistivity	Voltage=100 V Electrification time=60 s	Ω			> 10^{12}		ASTM D257

GENERAL

PROPERTY	OPERATING CONDITIONS	UNITS	VALUE	TEST METHOD
Specific gravity		g/cm^3	1,33	ASTM D792
Water Absorption		%	<0.45	ASTM D570
Moisture Absorption		%	<0.10	ASTM D570
UL 94 Flame Class Rating*			V0	UL 94
Glow Wire Flammability Index*	Thickness 2.00 mm	°C	960	IEC-60695-2-12
Reinforcing Phase			10% By Weight Carbon Fiber	
Color			Black	

*Test performed on a polymer matrix sample without rinforcing face manufactured by injection moulding.

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Mechanical Properties

Poisson's Ratio

Poisson's ratio, also known as transverse contraction coefficient, is a parameter that expresses the ability of the material to contract or expand along the transverse direction when the component is subjected to a one-way longitudinal stress. In the case of homogeneous, isotropic materials in a linear elastic field, the Poisson's coefficient (ν) can be defined as the negative ratio between the strain in transverse direction (ε_{trasv}) and that in longitudinal direction (ε_{long}).

$$\nu = -\frac{\varepsilon_{\text{trasv}}}{\varepsilon_{\text{long}}}$$

The Poisson's coefficient can assume values between -1 (auxetic materials) and 0.5 (materials that do not undergo volume change under uniaxial tensile loading). In most cases, polymeric materials have Poisson's coefficient of about 0.4, a higher value than that of ceramics (about 0.2) and metals (about 0.3). In the case of materials with ν between 0 and 0.5, tensile stress will observe a small volume contraction in the direction transverse to the load. However, this volume contraction is not able to compensate for the volume change given by the elongation, thus causing an increase in volume and therefore a reduction in density. The smaller the Poisson's coefficient, the smaller the transverse contraction and consequently the greater the volume change. ASTM D638 type 1 specimens were used to determine the Poisson's ratio. The orientation of the specimen is in the XY direction while the infill is at ±45°. The values obtained are shown in Table 1.

Table 1 Carbon PEEK Poisson's Ratio

ORIENTATION	INFILL DIRECTION	VALUE
XY	± 45°	0,48

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 test specimen "dogbone", while on the abscissae is reported 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 break (ε_B).

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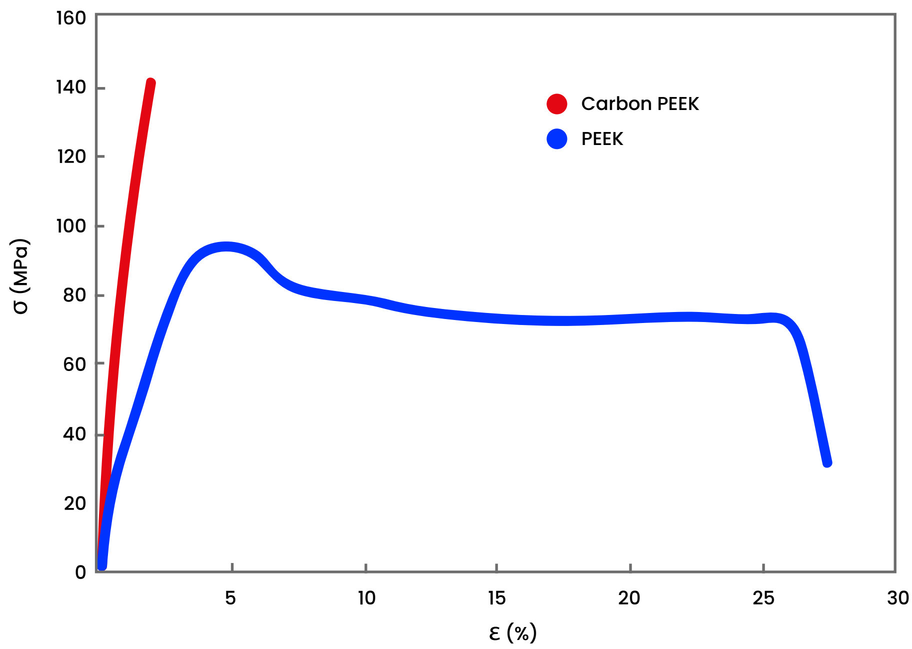

Figure 2 Comparison between tensile test behaviour of PEEK and Carbon PEEK

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.

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.

The addition of 10% by weight of short carbon fiber to the PEEK thermoplastic matrix gives the material a brittle nature. In fact, as it is possible to deduce from the σ-ε curve, the reinforcing phase gives to the material more properties in terms of maximum load and a higher stiffness, against a lower ductility.

The standard followed to perform the characterization of the samples was ASTM D638. 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 2 Tensile properties of Carbon PEEK measured at 25°C for different specimen orientations

TENSILE TEST ASTM D638		ORIENTATION			
	UNIT OF MEASURE	XZ	XY 0°	XY ±45°	ZX
Tensile Strength	MPa	139,0	136,0	125,8	28,2
Elongation at Break	%	1,6	2,2	2,2	0,7
Young Modulus	GPa	10,7	9,1	8,1	4,0

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Stress-Strain behaviour at different temperature

Carbon PEEK is a composite material composed of a thermoplastic matrix (PEEK) reinforced by a second phase (chopped carbon fiber). Thermoplastic polymers, by their nature, undergo a progressive reduction of their viscosity with increasing temperature. This leads to a progressive softening of the material until it reaches complete melting.

Obviously, as it is possible to guess, the mechanical properties of the final product will depend on the working temperature: the higher the temperature, the lower the performance of the material. However, semi-crystalline thermoplastic polymers such as PEEK, thanks to the presence of crystalline domains, can maintain high mechanical properties even at temperatures above the glass transition temperature.

The presence of the short carbon fibers dispersed in the matrix, moreover, contribute to reduce the decay of the properties as the temperature increases. The variation of the mechanical properties as a function of temperature can be analyzed by performing tensile tests in a heated chamber at the desired temperature.

Table 3 Tensile properties of Carbon PEEK measured at -40°C for different raster angle

TENSILE TEST ASTM D638				
TEMPERATURE		UNIT OF MEASURE	XY 0°	XY ±45°
-40°C	Tensile Strength	MPa	144,0	123,5
	Young Modulus	GPa	7,9	7,4
	Elongation at break	%	2,0	1,8

Table 4 Tensile properties of Carbon PEEK measured at 80°C for different raster angle

TENSILE TEST ASTM D638				
TEMPERATURE		UNIT OF MEASURE	XY 0°	XY ±45°
80°C	Tensile Strength	MPa	89,0	89,0
	Young Modulus	GPa	7,5	6,9
	Elongation at break	%	1,3	1,6

Table 5 Tensile properties of Carbon PEEK measured at 120°C for different raster angle

TENSILE TEST ASTM D638				
TEMPERATURE		UNIT OF MEASURE	XY 0°	XY ±45°
120°C	Tensile Strength	MPa	68,9	66,9
	Young Modulus	GPa	8,5	6,9
	Elongation at break	%	0,8	1,4

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Table 6 Tensile properties of Carbon PEEK measured at 200°C for different raster angle

TENSILE TEST ASTM D638				
TEMPERATURE		UNIT OF MEASURE	XY 0°	XY ±45°
200°C	Tensile Strength	MPa	37,5	33,0
	Strength at break	MPa	11,2	16,4
	Elongation at tensile strength	%	7,2	7,3
	Elongation at break	%	9,3	9,2
	Young Modulus	GPa	2,0	1,7

Table 7 Tensile properties of Carbon PEEK measured at 250°C for different raster angle

TENSILE TEST ASTM D638				
TEMPERATURE		UNIT OF MEASURE	XY 0°	XY ±45°
250°C	Tensile Strength	MPa	28,8	28,1
	Strength at break	MPa	17,2	7,6
	Elongation at tensile strength	%	9,1	9,5
	Elongation at break	%	19,0	33,7
	Young Modulus	GPa	1,3	1,3

The variation of tensile strength as a function of temperature for XY ±45° specimens is plotted below.

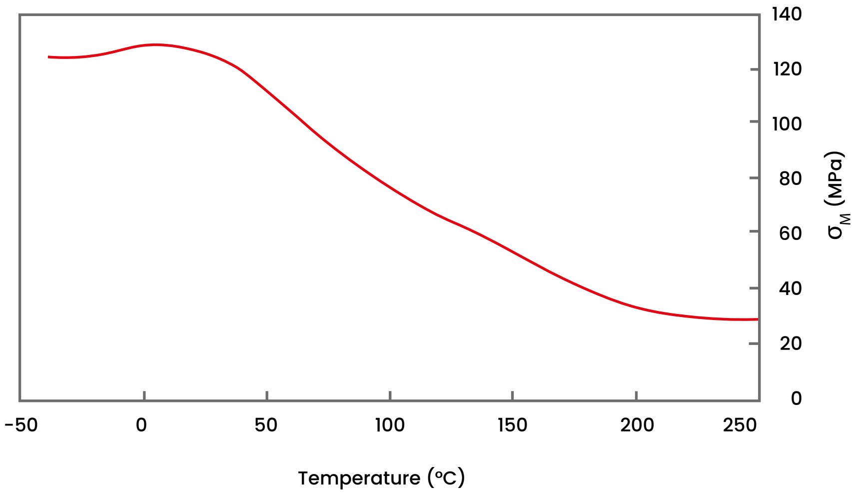

Figure 3 Variation of tensile strength as a function of temperature from -45°C to 250°C

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Analysis of the σ-ε curves show that the empirical data are in line with theoretical expectations. In fact, as the test temperature increases, the slope of the linear section and the maximum load tend to decrease, however an increase in the material toughness is observed.

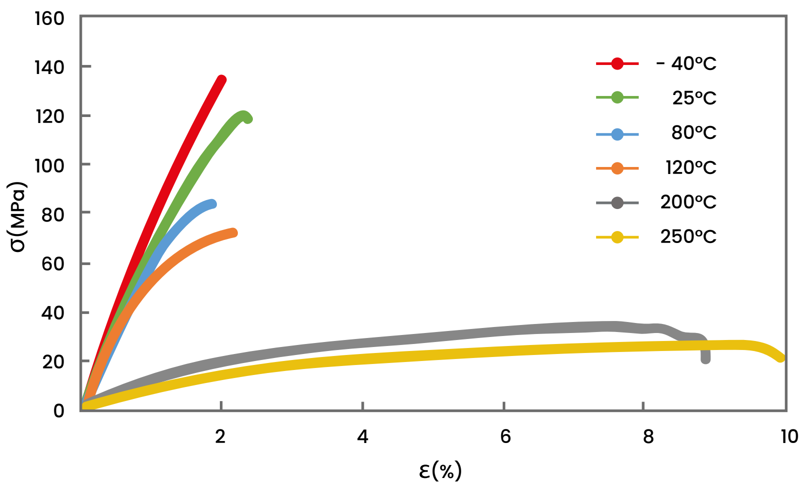

Figure 3 σ-ε curves of Carbon PEEK dogbones recorded at different temperatures

Flexural Properties

During the design phase, the knowledge of the bending behaviour of a material, results to be an essential key parameter for the correct structural dimensioning of the component.

Assuming to consider a bar of material supported at two points at the end and loaded with a load in a direction perpendicular to the centre, it is possible to demonstrate how the stresses originating inside the body present an axial stress distribution of linear type: the stress σ reaches maximum values in modulus and opposite in sign at the extremes of the section and is zero at the neutral axis.

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

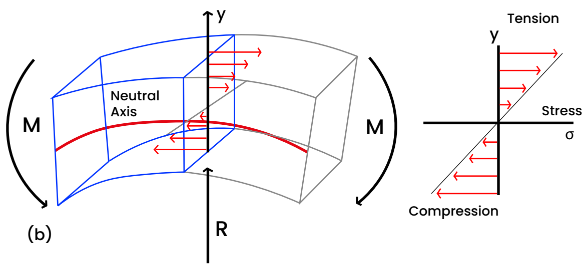

Figure 4 Stress variation along cross section of a beam subjected to flexural loads

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The flexural behavior of Carbon PEEK 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.
The strength is determined by the stress at break while the modulus is calculated by the tangent method.

Table 8 Carbon PEEK Flexural Properties

ORIENTATION	E_F (MPa)	σ_F(MPa)	ε_F(%)
XY ±45°	5	144	3,4
ZX	3,7	48,0	1,3

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 reference standard used for the determination of the compression properties of Carbon PEEK was ASTM D695. The specimens used are square-based prisms with different heights depending on whether you want to measure: the modulus or the stress.

The characteristic dimensions of the specimens are as follows:

- Compressive strength: (b) 12.7mm x (h) 12.7mm x (ℓ) 25.4mm
- Modulus of Compression: (b) 12.7mm x (h) 12.7mm x (ℓ) 50.8mm

For both tests, a testing speed of 13 mm/min was set.

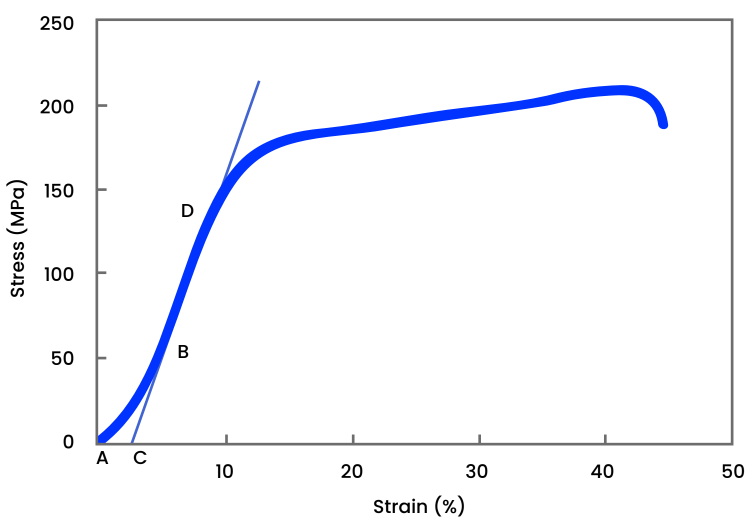

Figure 5 Stress strain curve for a Carbon PEEK sample subjected to compression test

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Except for the initial toe region AC (typical measurement artifact not representing a property of the material), Carbon PEEK shows Hookeian (linear) behavior. The point of intersection (C) between the x-axis and the extension of the linear section (BD) is the corrected point of origin on the x-axis from which all strain were measured.

Table 9 Compressive strength and modulus values of Carbon PEEK at 25°C

E_C (GPa)	σ_M(MPa)
4,8	207

The data reported in the table represent the average value of the values measured on samples placed in 15 different spatial coordinates inside the working chamber[2]

Analisys were also carry out to asses the compressive strength of the material under high temperature working conditions. The results are summarised below:

Table 10 Compressive strength values of Carbon PEEK at 100°C - 150°C

	TEMPERATURE	UNIT OF MEASURES	VALUE
COMPRESSIVE STRENGTH	100°C	MPa	139
COMPRESSIVE STRENGTH	150°C	MPa	118

Impact test

Determination of the notch toughness of a given material can be performed by an Izod impact test. It is carried out by releasing a pendulum from a given height and making it impact the material specimen, to bring it to breakage.

Table 11 Notched Izod Impact values of Carbon PEEK

NOTCHED IZOD IMPACT	ASTM D256	J/m	89

Hardness Test

The hardness is a numerical value that indicates the characteristics of plastic deformability of a material and allow to determine the resistance offered by a material to be penetrated by another (penetrator). The test of hardness used to characterize the behaviour of carbon PEEK is the ASTM D2240 Shore D test method. In this test, the specimen is first placed on a hard flat surface. Then the indenter is pressed into the specimen making sure that it is parallel to the surface and finally the hardness is read within a certain amount of time of firm contact with the specimen.

Table 12 Shore D Hardness values of Carbon PEEK

SHORE D HARDNESS	ASTM D2240	85

2 See https://bit.ly/2ZFVM9v for more details about the operating procedure.

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Coefficient of friction

Both under boundary lubricating, mixed and hydrodynamic lubricating conditions wear characteristics of PEEK improves by adding carbon fibers. The presence of carbon fibers dispersed within the polymer matrix not only minimizes the wear rate of the material but also allows a reduction in the coefficient of friction.

The debris that originates from the wear process generates a film at the interface between the surface of the sample under examination and the counterpart, which allows to reduce the friction coefficient and facilitate the sliding. Study on tribological properties of Carbon PEEK were performed on a pin-on-disc tribometer.

The methodology of the test consists in fixing the Carbon PEEK disc on a rotating plate and the steel pin (counterpart) is pushed against the disc with 10 N load. The pin stays on the disc with two degrees of freedom: one vertical, which allows its direct contact with the surface of the disc, and the other horizontal, which is responsible for the friction contact. The counterpart is a 100Cr6 steel sphere with a diameter of 6 mm. Before each test, the sphere was washed with acetone to remove any residue and contamination

The test conditions were as follows:

- Applied load: 10 N
- Track radius: 15 mm
- Sliding speed: 20 cm/s
- Sliding distance: 500 m

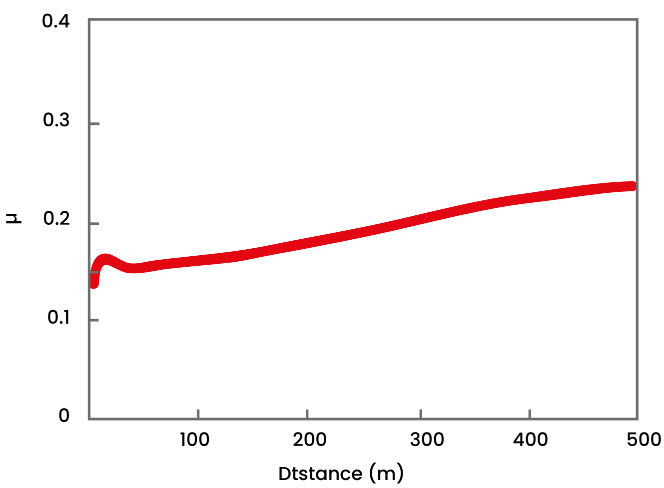

Figure 6 Variation in coefficient of friction as a function of sliding distance

The evolution of the friction coefficient can be observed for two samples. Initially, an increase in friction coefficient associated with the initial running-in period was observed.

The friction coefficient initially grows until it stabilizes (after 10 - 20 m) around values of 0.15 - 0.17, and then starts to grow further after 100 m of sliding, tending to values around 0.24. The friction curve does not completely stabilize within the distance of 500 m; however, since the friction coefficient grows quite slowly in the last 50 m or so of the test, this stretch was used to calculate the average value of the steady-state friction coefficient.

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Table 13 Synthesis of experimental data for pin on disc test

PIN ON DISC TEST CONDITION	VALUE
• Applied load: 10 N • Track radius: 15 mm • Speed: 20 cm/s • Distance: 500 m • Pin : Steel 100Cr6	0,24

Chemical Compatibility

Carbon PEEK is a PEEK matrix composite material reinforced with short carbon fiber. PEEK is known for its excellent chemical resistance to many organic and inorganic chemicals and for its exceptionally good resistance to hydrolysis in hot water. The aryl rings in PEEK are linked via ketone and ether groups in “para” position (i.e. placed at opposite ends of the ring).

The resonance-stabilized chemical structure of PEEK results in delocalization of higher orbital electrons along the entire macromolecule, making it exceptionally unreactive and intrinsically resistant to chemical degradation.

CHART CODES
R - Resistant
LR - Limited Resistance
NR - Not Recommended
ND - No Data

CHEMICAL	RESISTANCE		
	20°C/68°F	60°C/140°F	100°C/212°F
Acetaldehyde	NR	NR	R
Acetone	R	R	R
Acetylene	R	R	R
Acid fumes	R	R	R
Alcohols	R	R	R
Aliphatic esters	R	R	R
Ammonia, aqueous	R	R	R
Aromatic solvents	R	R	R
Benzene	R	R	R
Carbonic acid	R	R	R
Caustic soda & potash	R	R	R
Chlorobenzene	R	R	R

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Copper salts (most)	R	R	R
Cyclohexane	R	R	R
Detergents, synthetic	R	R	R
Ether	R	R	R
Fatty acids (>C6)	R	R	R
Ferric chloride	R	R	R
Formaldehyde (40%)	R	R	R
Glycol, ethylene	R	R	R
Hydrochloric acid (10%)	R	R	R
Hydrochloric acid (conc.)	R	R	ND
Hydrocyanic acid	R	R	R
Hydrogen peroxide (30%)	R	R	R
Hydrogen peroxide (30 - 90%)	R	R	ND
Hydrogen sulphide	R	R	R
Hypochlorites (Na 12-14%)	NR	NR	NR
Lactic acid (90%)	R	R	R
Mercury	R	R	R
Methanol	R	R	R
Milk products	R	R	R
Moist air	R	R	R
Napthalene	R	R	R
Nickel salts	R	R	R
Nitric acid (<25%)	R	R	R
Nitric acid (50%)	R	R	R
Nitric acid (90%)	NR	NR	NR
Nitric acid (fuming)	NR	NR	NR
Oils, diesel	R	R	R
Oils, essential	R	R	R
Oils, mineral	R	R	R
Oils, vegetable and animal	R	R	R
Ozone	R	R	R
Phosphoric acid (20%)	R	R	R
Phosphoric acid (50%)	R	R	R
Phosphoric acid (95%)	R	R	R
Sea water	R	R	R
Silicone fluids	R	R	R
Silver nitrate	R	R	R
Sodium carbonate	R	R	R
Sulphates (Na, K, Mg, Ca)	R	R	R
Sulphites	R	R	R
Sulphuric acid (<50%)	R	ND	ND
Sulphuric acid (70%)	R	R	R
Sulphuric acid (95%)	NR	NR	NR
Urea (30%)	R	R	R
Water, distilled	R	R	R
Water, soft	R	R	R
Water, hard	R	R	R

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Thermal Properties

Glass Transition and melting temperature

Unlike thermosetting polymers, when heated thermoplastic polymers undergo a progressive softening process until they reach complete melting. The energy supplied through heat irradiation can weaken and progressively break the Van der Walls bonds between the various polymer chains.

This phenomenon involves a reduction in the stiffness of the polymer, which ends behaving as an elastic solid and begins to assume the typical behaviour of a viscoelastic material.

The higher the temperature, the greater the viscous component will be compared to the elastic one. Glass transition temperature (T_g) is described as the temperature at which 30-50 carbon chains of the amorphous region start to move. As the temperature rises, the energy supplied to the system increases, allowing the progressive dissolution of the crystalline domains. The temperature at which this phenomenon occurs is called melting temperature (T_m).

The technique that allows to determine the T_g and the T_m is the Differential scanning calorimetry (DSC).

DSC analyses were performed according to the following cycle: heating up from 0 to 400 °C at 10 °C/m, 3 min isothermal step at 400 C, cooling down to 0°C at 10°C/min, 5 min isothermal step at 0 °C, final heating up from 0 to 400°C at 10 °C/min. Test was performed in nitrogen atmosphere. The glass transition temperature (T_g) and melting temperature (T_m) were determined:

Table 14 Glass transition temperature (Tg) and melting temperature (Tm) of a sample of Carbon PEEK

T_g	T_m
138°C	345°C

Coefficient of Thermal Expansion (α_T)

When a material in the solid state is subjected to cooling and/or heating cycles it has a tendency to contract/dilate. The phenomenon of expansion of bodies is directly related to the atomic bond force. In fact, by supplying heat to the System, the increase of the vibration amplitude of the atomic bond is favored, thus causing the dilation of the body. The greater the bond force, the lesser the expansion of the material.

The linear coefficient of thermal expansivity (α_T) is the length change for an infinitesimally narrow temperature range, at any temperature T, and is defined as follows:

$$\alpha_T = \frac{1}{L_0}\left(\frac{dL}{dT}\right)_T$$

Where L is the length of the sample, T its temperature, and L_0 its initial length. The coefficient of thermal expansion therefore represents the correlation coefficient between the deformation undergone by the material and the temperature variation.

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Info about coefficient of thermal expansivity provides quantitative characterization of expansion properties, which is an important designing index of the composite structure. The smaller α_T gives an advantage of stability during the printing phase or using process in high temperature environments.

Materials shows temperature dependence in their coefficient of thermal expansivity, especially above T_g. Therefore, a single reported number for CLTE will not accurately reflect the expansion behaviour, except below T_g where α changes little. Nonetheless, it is customary to select a representative value of CLTE for comparison purposes.

Table 15 Coefficient of Thermal Expansivity at different temperatures

PROPERTY	TEMPERATURE RANGE	UNIT OF MEASURE	ORIENTATION	
			XY	ZX
CLTE	25°C - 50°C	10^{-6} K^{-1}	40	60
CLTE	25°C - 100°C	10^{-6} K^{-1}	36	65
CLTE	25°C - 150°C	10^{-6} K^{-1}	37	81

The coefficient of thermal expansion is a function of the orientation of the charge within the matrix. In fact, the carbon fiber has a lower thermal expansion coefficient than the polymer matrix, which is why a non-homogeneous dispersion of the reinforcing phase could alter the thermal expansion coefficient of the composite.
For this reason, appropriate tolerances should be considered in the design phase.

Heat Deflection Temperature

Heat Deflection Temperature (HDT) allows to empirically define the ability of a material to resist a constant stress when exposed to a heated environment.

The reference standard used for this analysis is ASTM D648. This standard requires the use of a rectangular geometry sample (127 mm x 13 mm x 3.2 mm) positioned edgewise on two supports 101.6 mm apart (Method A)

The specimen is subsequently loaded with a constant stress of 1.8 MPa.

The heating of the specimen is done by immersing it inside a heated fluid bath according to a temperature range fixed at 120°C/h. The temperature at which a deflection of 0.25 mm occurs is defined as HDT.

Table 16 Deflection Temperature

DEFLECTION TEMPERATURE AT 1.8 MPa	ASTMD648	°C	249

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Thermal diffusivity

Among the main thermophysical parameters to characterize the heat transfer properties of a material we find Thermal Conductivity and Thermal Diffusivity.

Thermal conductivity was measured by laser flash method. Laser heat pulse was irradiated on the front side of cylindrical specimen (Ø12.5 × 3 mm), the heat is transmitted through the sample thickness direction and the resulting temperature rise at the sample's rear face is recorded as a function of time.

The higher the thermal diffusivity of the sample, the shorter the time needed to heat the opposite side of the sample.

Heat diffusivity with temperature at ambient temperature and 250°C was measured on Carbon PEEK. Specific heat was measured by differential scanning calorimeter Thermal conductivity and can be obtained from following equation:

$$k = \alpha C_p \rho$$

where k is thermal conductivity, α is thermal diffusivity, C_p is heat capacity and ρ is density.

Partial percolation of highly conductive carbon fibers in the PEEK matrix may induce thermal conductivity increase. The increase in thermal diffusivity is a function of the orientation of the carbon fibres within the matrix. The more carbon fibres are oriented in a direction parallel to the heat flow, the higher the thermal conductivity of the material.

Table 17 Thermal Conductivity at different temperatures

THERMAL CONDUCTIVITY @ 250°C	W/m-K	0,32

Electrical Properties

Surface Resistivity

Surface resistivity (ρS) is defined as the electrical resistance of the surface of an insulating material. Since the length of the surface is fixed, the measurement is independent of the physical dimensions (thickness and diameter) of the specimen.

Surface resistivity is measured by applying a known voltage across the surface of the insulating specimen and measuring the resulting current.

ASTM D257 test method is used. Materials with surface resistivities above 10^{11} ohm are considered insulators.

Table 18 Surface resistivity of Carbon PEEK recorded at different voltage

VOLTAGE = 150 V ELECTRIFICATION TIME =60 s	ASTM D257	Ω	$1.35 \cdot 10^{12}$
VOLTAGE = 100 V ELECTRIFICATION TIME =60 s	ASTM D257	Ω	$1.64 \cdot 10^{12}$