VERSION 1.0 _ REVISION DATE 30/05/2022

TECHNICAL DATA SHEET

Roboze PEKK

Overview

Polyetherketoneketone (PEKK) is a polymer that belongs to the polyaryletherketone (PAEK) family, known for its excellent mechanical properties, high use temperatures, and superior chemical resistance. PEKK is a super polymer with slow crystallization kinetics that can be printed in its amorphous phase. In fact, PEKK is much easier to process than other members of the PAEK family. This is due not only to the improved flow properties during extrusion, but also to the lower shrink rate and warping.
PEKK has two ketone bonds and one ether bond in the main chain structure, making it highly thermally stable. Like PEEK, PEKK has good tribological properties and excellent chemical and thermal resistance, being able to withstand mechanical loads up to 150°C.
Its amorphous nature provides it with better inter-layer adhesion and greater dimensional stability, enabling the printing of larger components. Like other members of the PAEK family, PEKK also exhibits excellent flame and combustion resistance: when forced to burn, it produces very few toxic gases. PEKK also passes the UL94 vertical burn test of a V0 rating.
Other features that make PEKK valuable include impact resistance and translucency for thin wall thicknesses. Due to its excellent chemical-physical and mechanical properties, PEKK has applications in a variety of fields, such as aerospace (radomes, fuel tank manhole covers, cabin interior panels, window surrounds, seats components, conduit interconnections devices, impellers), energy (Tubes, pipes,channel,seal rings, backup rings,electrical connectors, compressor components,sensor housing,...) and motorsport (high temperature parts, complex tubes and air ducts, bearing, gearwheels, fuel manifold, thrust washers...).

Applications

Due to its excellent chemical-physical and mechanical properties, PEKK has applications in a variety of fields. Thanks to its chemical resistance to the harshest environments, it can be widely used in the energy industry for the manufacturing of impellers, ducts, channels, sealings and connectors. It is widely common in the chemical industry as well, thanks to the extreme corrosion-resistance, for the production of agitators and manifolds.

Due to the flammability properties, it is used in the aerospace industry for the production of air ducts, covers and interior parts.In the motorsport industry, PEKK is appreciated for the high strength-to-weight ratio for the production of high-temperature parts, such as under the hood components, such as complex tubes, air ducts, fuel manifolds and thrust washers.

Design phase

The preparation of the samples and the execution of the individual tests followed the guidelines imposed by the associated regulations.[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 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, Roboze PEKK 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 = 150°C
- Extrusion Temperature = 425°C
- Printing Speed = 1800 mm/min
- Layer Height = 0.35 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)

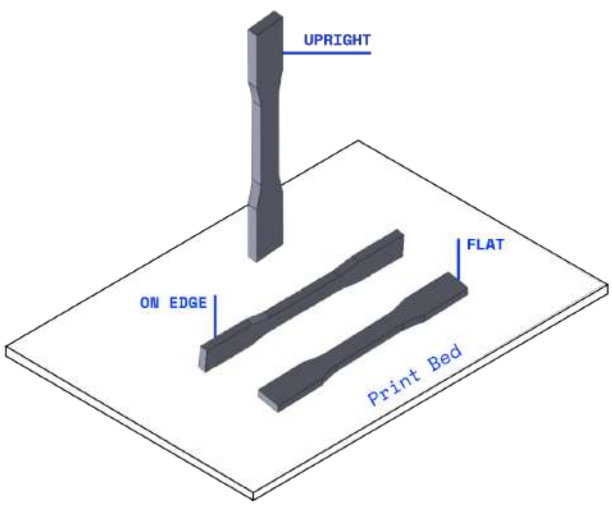

Figure 1 Example of On Edge, Upright and Flat orientation on the building plate

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Summary of the Roboze PEKK properties

MECHANICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION			TEST METHOD
			XZ	XY ±45°	ZX	
Tensile Strength	25°C	MPa	86	89	66	ASTM D638
Young Modulus	25°C	GPa	3.2	2.9	2.5	ASTM D638
Elongation at Tensile Strength	25°C	%	4.0	5.1	3.7	ASTM D638
Flexural strength	25°C	MPa	67	60	65	ASTM D695
Flexural modulus	25°C	GPa	2.4	2	2.2	ASTM D695
Compressive strength	25°C	MPa	99		100	ASTM D790
Charpy Impact Strength*	Unnotched		NB			ISO 179/1eA

PHYSICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION	TEST METHOD
Specific gravity		g/cm³	1.27	ISO 1183
Water Absorption	23 °C/24h	%	<0.1	ISO 62
Melt Volume Rate	MVR 380 °C/2,16 kg	cm³/10min	20	ISO 1133
Flammability Behaviour			V0	UL94
Continuous Service Temp	23 °C/50% rh	°C	255	IEC 60216
Service temperature	Lifetime max. 200h	°C	300	
Color			Traslucent Brown	

*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.

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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).

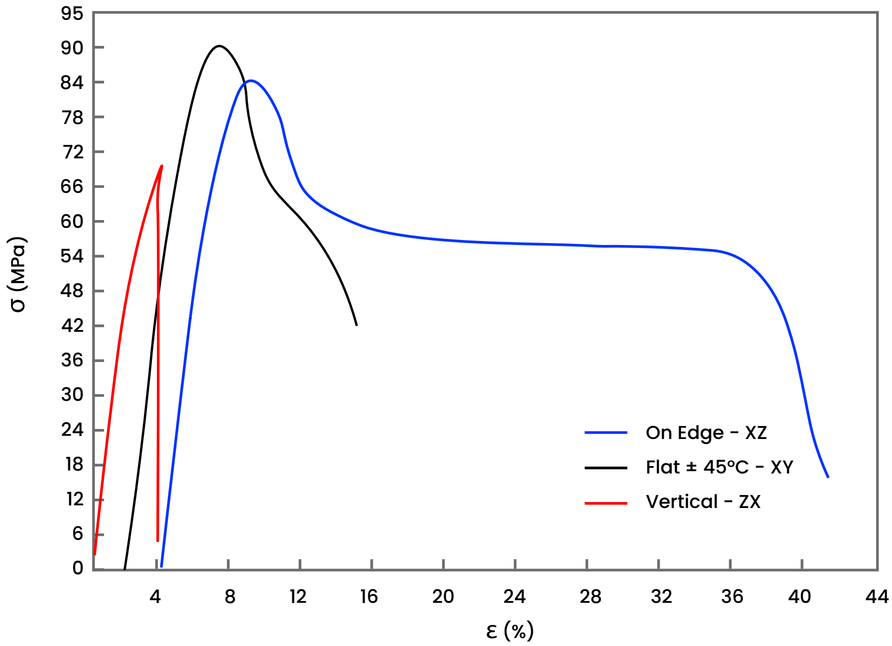

Figure 2 Comparison between tensile test behaviour of PEKK samples built in different orientations

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

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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.

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 Roboze PEKK measured at 25°C for different specimen orientations

TENSILE TEST ASTM D638	UNITS	ORIENTATION		
		XZ	XY ±45°	ZX
Tensile Strength	MPa	86	89	66
Elongation at maximum load	%	4.0	5.1	3.7
Young's Modulus	GPa	3.2	2.9	2.5

Flexural Properties

During the design phase, the knowledge of the bending behaviour of a material, results to be a key parameter 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.

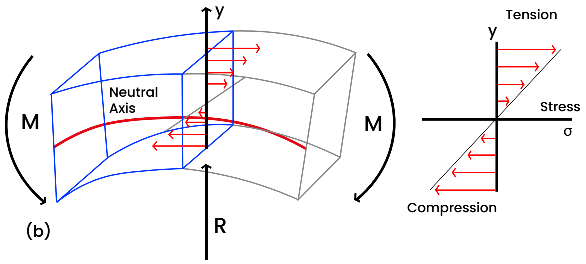

Figure 3 Stress variation along cross section of a beam subjected to flexural loads

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The flexural behavior of Roboze PEKK 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 Roboze PEKK Flexural Properties

ORIENTATION	E_F (MPa)	σ_F(MPa)
XY ±45°	2	60
XZ	2.2	67
ZX	2.2	65

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

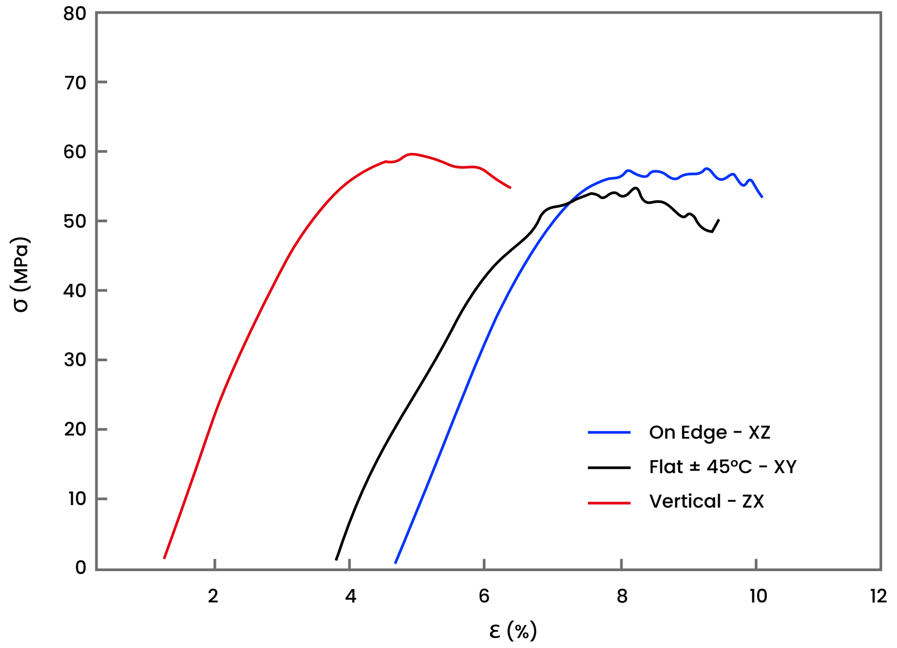

Figure 4 Stress-strain curves for Roboze PEKK subjected to bending tests

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 Roboze PEKK. Dimensions of cylindrical specimens are as follows:

- Diameter: 12.7mm
- Height: 25.4mm

The testing speed was set at 1.3 mm/min

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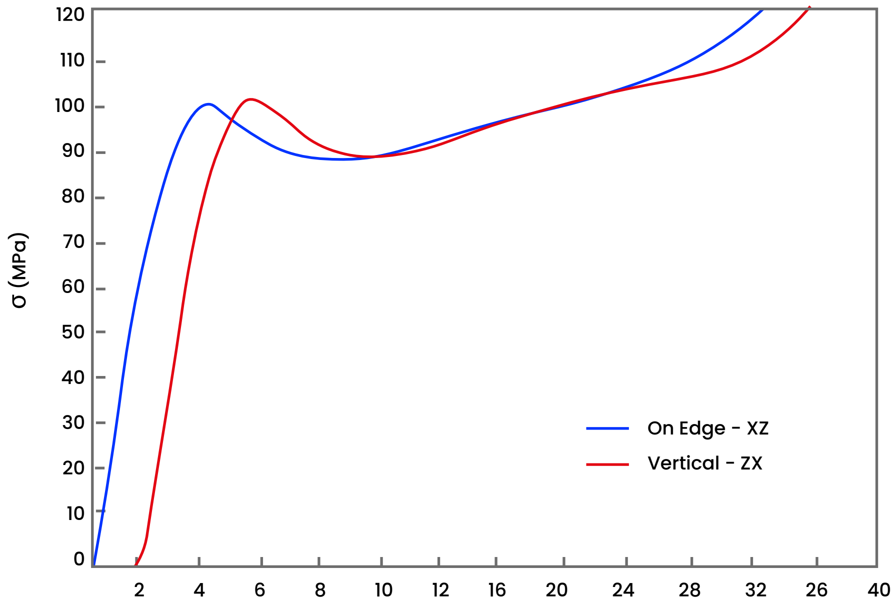

Figure 5 Stress strain curve for Roboze PEKK samples subjected to compression test

Table 3 Compressive strength values of Roboze PEKK at 25°C

ORIENTATION	σ_M (MPa)
XZ	99
ZX	100

Impact Test

The Charpy impact test measures the energy absorbed by a standard specimen while breaking under an impact load. ISO 179/1eA specifies a procedure for defining the Charpy impact strength of polymers. Charpy Impact test can be applied for valuing the brittleness or toughness of different materials when subjected to impulsive forces.

This test consists of striking with a hammer on a pendulum arm a suitable specimen consisting of a notched horizontal beam supported by its ends. The hammer strikes opposite to the notch and the energy absorbed by the sample is evaluated by the reduction in motion of the pendulum arm. Data reported in the following table refer to samples manufactured by injection molding.

Table 4 Impact strength values of Roboze PEKK at 25°C

PROPERTY	OPERATING CONDITIONS	UNIT	VALUE	TEST METHOD
Impact strength	23°C , notched	kJ/m^2	NB	ISO 179 1eA

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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. These 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 Melting temperature of Roboze PEKK

PROPERTIES	TEST CONDITIONS	TEMPERATURE (°C)	TEST METHOD
CONTINUOUS SERVICE TEMP.	23 °C/50% rh	225	IEC 60216

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 Roboze PEKK

PROPERTY	UNIT	VALUE	TEST METHOD
DENSITY	g/cm^3	1.27	ISO 1183-3

Flammability UL94

UL is a flammability tests for determining flammability behavior of polymers. It measures the ability of plastic component to extinguish the flame after ignition and its dripping behavior when exposed to an open flame or radiant heat source under controlled laboratory conditions. In order to reach the highest flame resistance rating (V0), the sample should be able to extinguish the flame two times after ignition and avoid the ignition of cotton with the drip of melted plastic.

Table 7 UL Flammability behaviour of Roboze PEKK

PROPERTY	VALUE	TEST METHOD
FLAMMABILITY BEHAVIOUR	V-0	UL 94