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TECHNICAL DATA SHEET

Roboze Carbon PA PRO

Overview

Polyamides (PA) are polymers characterized by repeating units (monomers) linked by amide bonds (CO-NH), on which many properties of this type of compound depend. PAs belong to the category of semi-crystalline polymers, i.e., polymers in which the macromolecular chains in the solid state tend to arrange themselves in crystalline regions known as "crystallites". The orderly distribution of the polymer chains is ensured by interactions between the amino group of one chain and the carboxyl group of the adjacent macromolecule.

Roboze's Carbon PA PRO is based on a PA 6 reinforced with carbon fibers (15 % by weight). The matrix has been engineered to minimize the melting temperature (234 °C) of the crystalline phase and thus reduce the extrusion temperature, enabling easier material processing.
The addition of chopped carbon fibers results in a composite material with high mechanical strength, stiffness, and thermal resistance. Furthermore, the polyamide matrix offers high toughness at low temperatures as well as easy processing.

Carbon PA PRO has low moisture absorption rate, as well as low-warpage and high dimensional stability. In addition, it offers good resistance to a variety of hydrocarbons, such as gasoline, diesel, ethers, and esters.

Roboze's Carbon PA PRO is ideal for metal replacement applications thanks to its high tensile strength (Table 1). Significant weight reductions are also possible because of its low density (1.232 g/cm^3) and it is possible to achieve an excellent surface smoothness and appearance. Using a spray plasticizer will waterproof parts printed with Carbon PA PRO, also decreasing surface roughness, and making components more resistant to UV light.

Applications

Carbon PA PRO performs best in high mechanical stress applications such as motorsport where it has been successfully used in spoilers and other aerodynamic parts. Its outstanding properties also make it an excellent material for manufacturing structural components in aviation such as frames for drones. Furthermore, it finds many uses in the manufacturing industry, for example for support frames in robotic production lines and, particularly when combined with the design freedom of 3D printing, for the manufacturing of tooling such as centering devices and gripping fingers.

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

Specimens were manufactured on a Roboze Plus PRO fed with a 1.75 ± 0.05 mm diameter filament. This thermoplastic filament was subsequently extruded through a 0.6 mm diameter nozzle. Before starting the printing process, in order to minimize the amount of water molecules adsorbed and absorbed by the filament due to exposure to the atmospheric environment, Roboze Carbon PA PRO spools were subjected to a drying cycle at a temperature of 90 °C for 12 hours in HT Dryer

The temperature of the printing chamber was set to 90 °C. Before starting the printing process, 30 minutes of thermal equilibration were allowed.

The printing parameters for the following data are:

- Chamber Temperature = 90 °C
- Extrusion Temperature = 270 °C
- Printing speed = 3600 mm/min
- Layer height = 0.27 mm
- Infill percentage= 100%

At the end of the printing process the support structures were manually removed.

The additive manufacturing technology produces intrinsically anisotropic components. As the orientation of the component on the printing plate changes, so do 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)

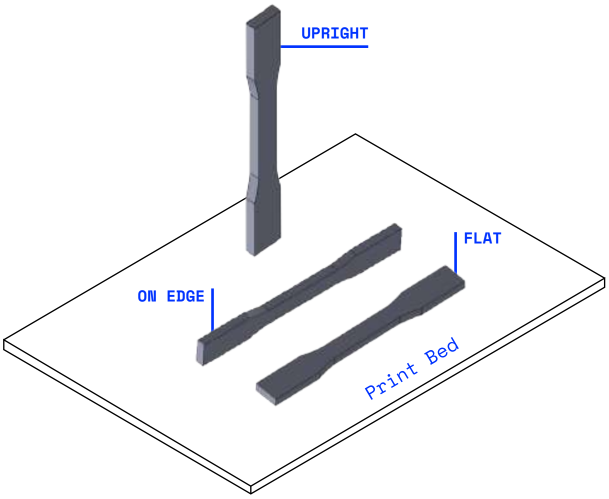

Figure 1 Example of On Edge, Upright and Flat orientation on the building plate

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Summary of Roboze Carbon PA PRO properties

MECHANICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION			TEST METHOD
			XZ	XY ± 45°	ZX	
Tensile Strength	25 °C	MPa	171	141	32	ASTM D638, type IV
Young's Modulus	25 °C	GPa	13.1	8.8	2.6	ASTM D638, type IV
Elongation at break	25 °C	%	1.58	2	1.48	ASTM D638, type IV

PHYSICAL PROPERTIES

PROPERTY	OPERATING CONDITIONS	UNITS	VALUE	TEST METHOD
Specific gravity		g/cm^3	1.232	ISO 1183-1
Glass transition temperature (T_g)	20 °C/min heating and cooling rate, in air	°C	70	ISO 11357-2 DSC
Crystallization temperature (T_c)	20 °C/min heating and cooling rate, in air	°C	180	ISO 11357-3 DSC
Melting point (T_m)	20 °C/min heating and cooling rate, in air	°C	234	ISO 11357-3 DSC
Melt volume flow rate	275 °C, 5 kg	cm^3/10 min	42.2	ISO 1133
Reinforcing phase (carbon fibers)		% by weight	15	
Colour			Black	

The information may come from the raw material, the semi-finished product, or an estimate.
Specific individual tests are recommended according to the conditions 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 (Δℓ) 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 elongation at break (ε_0).

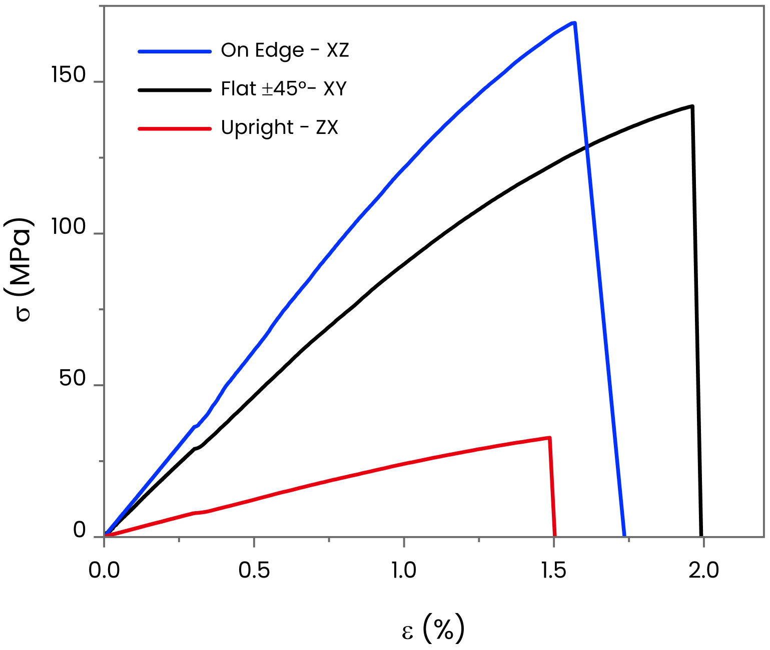

Figure 2: Comparison between tensile test behavior of Carbon PA PRO samples built in different orientations

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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 that is 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. It should be noted that components manufactured by additive manufacturing have anisotropic mechanical properties therefore, particularly with very complex geometries, it can be difficult to maximize the mechanical response. Typically the best practice is to identify the main load direction and orient the part in relation to this.

After drying in oven at 90 °C, the samples were tested using the ASTM D638 standard (Type IV). ZX-oriented specimens were milled from a 120x3.2x60 mm plate 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 noted that results of tensile testing are a function of test speed, therefore 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 Carbon PA PRO measured at 25 °C for different specimen orientations

PROPERTY	OPERATING CONDITIONS	UNITS	ORIENTATION			TEST METHOD
			XZ	XY ±45°	ZX	
Tensile Strength	25 °C	MPa	171	141	32	ASTM D638, type IV
Young’s modulus	25 °C	GPa	13.1	8.8	2.6	ASTM D638, type IV
Elongation at break	25 °C	%	1.58	2	1.48	ASTM D638, type IV

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Physical properties

Water and moisture absorption

Carbon PA PRO filament should be stored at 15 - 25 °C in its originally sealed package in a clean and dry environment. If the recommended storage conditions are observed the products will have a minimum shelf life of 12 months. Since residual moisture in the filament can lead to several problems during the printing process, it is recommended to dry it for at least 4 hours (and a maximum of 16 hours) at 90 °C before printing. The water molecules adsorbed and absorbed by the material may trigger hydrolysis phenomena during extrusion due to the high temperature of the process. Moreover, it is good practice to keep the printed parts in a dry environment. The reason being that since water behaves as a plasticizer with PAs, technically relevant mechanical parameters (e.g., Young's modulus) of printed parts can be negatively affected by absorbed moisture.

Melting and glass transition temperatures

Unlike thermosets, 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 Waals bonds between the various polymer chains.

This phenomenon involves a reduction in the stiffness of the polymer, which stops behaving as an elastic solid and begins to assume the typical behavior of a viscoelastic material. The higher the temperature, the greater the viscous component will be compared to the elastic one.

As the temperature rises, the energy supplied to the system increases, causing the carbon chains to start moving. This changes the material from a hard and relatively brittle "glassy" state into a viscous or "rubbery" one, this happens at a temperature known as the glass transition temperature (T_g). Further heating allows the progressive dissolution of the crystalline domains, which happens at the melting temperature (T_m). The crystalline domains are generated during the cooling of the material, and this happens to a temperature known as crystallization temperature (T_c). The characteristic temperatures of Carbon PA PRO are given in the following table.

Table 2: Glass transition temperature (T_g), melting temperature (T_m), and crystallization temperature (T_c) of Carbon PA PRO

PROPERTY	UNIT	VALUE	TEST METHOD
GLASS TRANSITION TEMPERATURE (T_g)	°C	70	DSC
CRYSTALLIZATION TEMPERATURE (T_c)	°C	180	DSC
MELTING POINT (T_m)	°C	234	DSC