APPLICATION **NOTE**

Why Knowledge About Anisotropy Is Crucial When Designing High-Performance Composite Parts

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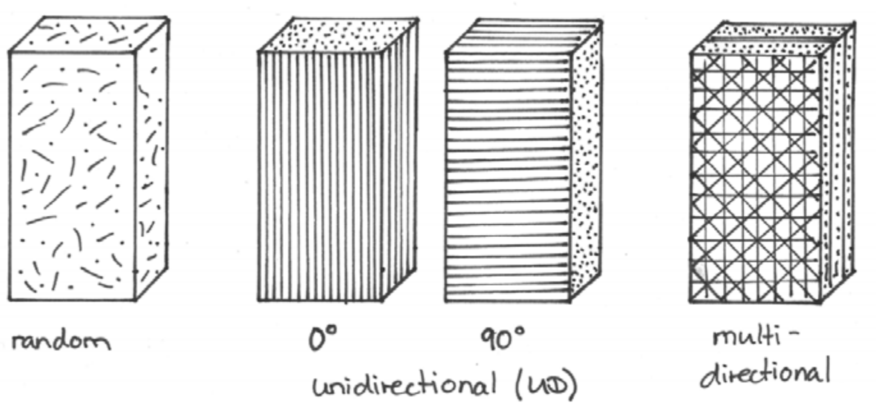
Introduction

Fiber-reinforced composite materials, which combine the properties of fibers and a polymer matrix, have been around for decades. Fiber-matrix composites are stiffer, have a great strength-to-weight performance and have a much lower density than their metal counterparts. This makes them up to 60% lighter than, for example, steel; a very desirable characteristic when it comes to components for the mobility sector and in particular the automotive industry, where the reduction of weight is important for improving fuel efficiency or extending the range of electric cars. Another advantage of makes fiber matrix composites that makes them of high interest in the automotive industry is their resistance to corrosion.

Thermoplastic matrix composites reinforced with glass fibers have a higher density and a lower modulus than carbon fiber-reinforced composites but come at a much lower cost, which is an important factor for the automotive industry. Polypropylene (PP) as a neat material, but also with short and continuous fiber reinforcement, is widely used for automotive parts due to its outstanding mechanical properties, moldability and low cost. Applications include casins and compartments, bumpers, fender liners, interior trim, instrumental panels and door trims. Other positive characteristics of PP are high chemical resistance, good weatherability, processability and impact/stiffness balance, which explains why it is one of the most widely used polymers on the market.

Quasi-Isotropic and Anisotropic Composites

There are different ways to incorporate the fiber into the thermoplastic matrix – randomly oriented fibers, unidirectional continuous fibers or multi-directional fabric; see Figure 1. The orientation of the added fibers plays an important role when it comes to part properties.



1 Schematics of different fiber orientations

NGB · Application Note 198 · EN · 1120 · Technical specifications are subject to change.

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While randomly oriented fibers increase the strength and stiffness over that of the neat polymer to a certain extent, the addition of oriented fibers in a preferential direction significantly increases the performance in this direction of the part. This preferential orientation gives the composite anisotropic properties, i.e. the properties in the fiber orientation are dominated by the fiber properties and perpendicular to that, the matrix properties are more pronounced. Knowledge about this anisotropic behavior is a prerequisite for the design and production of these composite components. Although the anisotropy of the mechanical properties is the first thing that everyone thinks of, the material's expansion behavior also differs depending on the fiber direction.

When the anisotropy of a material is overlooked, or is not known, this can cause major problems in the final product. For example, plane surfaces can buckle, or even worse, cracks or breaks can form.

2 TMA 402 ***F3*** *Hyperion® Polymer Edition* and the new expansion sample holder on the right

Thermomechanical Analysis – A Method for Determining Anisotropy in Composites

Using the method of Thermomechanical Analysis (TMA), dimensional changes and therefore the CTE of fiber-reinforced polymers can be determined in different material directions. For this study, samples were prepared at Neue Materialien Bayreuth. Three layers of a PP-GF UD tape were stacked on top of each other and pre-consolidated in a double belt press in three heating zones from 180-190°C. The blank was then preheated in a convection oven for 10 min and transferred to a hot press with a mold temperature of 80°C. There, a pressure of 10 bar was applied for 5 min during solidification. The resulting thickness was 1 mm. While the tape has an average fiber volume content of 45 vol%, the local variations in the plate were measured at between 40-50 vol% GF.

For the TMA measurements at NETZSCH Analyzing & Testing, samples of 25 x 5 mm were cut from the plate in two different directions: 0° to the fiber direction and 90° to the fiber direction.

The samples were measured with the new TMA 402 ***F3*** *Hyperion® Polymer Edition* (figure 2). After an initial cooling step, the temperature was increased from -70°C to 140°C at a heating rate of 5 K/min. The thermal expansion coefficient was calculated using the mean CTE analysis (m. CTE in the NETZSCH analysis software), which computes the slope between two data points. All measurement conditions are summarized in table 1.

Tab 1. Measurement conditions

Sample holder	Expansion, made of SiO_2
Sample load	50 mN
Atmosphere	N_2
Gas flow rate	50 ml/min
Temperature range	-70°C ... 140°C at a heating rate of 5 K/min

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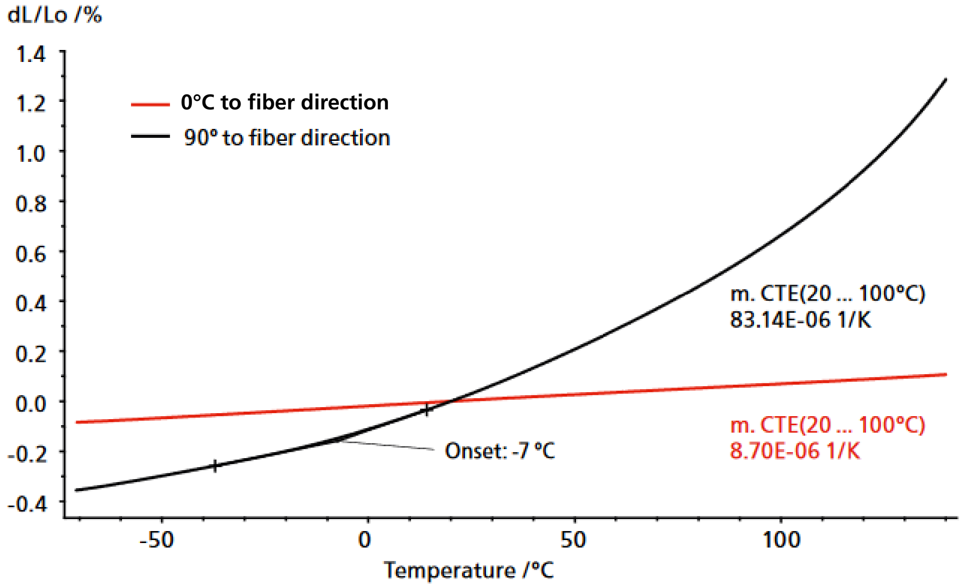

3 Measurement on a PP-GF-UD composite material. Sample size: 25 mm, heating rate: 5 K/min from -70°C to 140°C, atmosphere: N_2, sample holder for measurements in the expansion mode made of fused silica

Example: Anisotropy in PP-GF-UD

This material exhibits different CTEs depending on the direction the material is measured. The CTE of these kinds of composites is a combinaiton between that of the matrix and that of the fibers contained in it. This is why the CTE of such materials differs considerably depending on direction. The measurement results for the CTE for the PP-GF in the two different fiber directions are shown in figure 3. The red curve depicts the measurement in the fiber direction 0°. The low CTE value is in the range of the CTE of glass and shows that this measurement direction is dominated by the low thermal expansion of the glass fibers. The same material measured 90° to the fiber direction (black curve) is dominated by the polypropylene matrix. It shows a much higher CTE and exhibits the known glass transition (T_g) of polypropylene at -7°C, which is not observable in the red curve.

In the matrix, the dominating direction of the CTE of a composite follows the rule of mixture:

$$\alpha_c = v_f \cdot \alpha_f + \left(1 - v_f\right) \cdot \alpha_m$$

Where α is the linear thermal expansion coefficient (CTE), v is the volume fraction and the indices f and m denote the fibers and matrix, respectively. Assuming that the measured CTE in the 0° fiber direction is the same as α_f, and the CTE of the polypropylene matrix corresponds to $\alpha_m = 1.6 \cdot 10^{-4} K^{-1}$ (not measured here), the glass fiber volume fraction in the measured composite is calculated as:

$$v_f = \frac{\alpha_c - \alpha_m}{\alpha_f - \alpha_m} = \frac{83.14 \cdot 10^{-6} K^{-1} - 1.6 \cdot 10^{-4} K^{-1}}{8.7 \cdot 10^{-6} K^{-1} - 1.6 \cdot 10^{-4} K^{-1}} \cdot 100\% = 50.8\% \,.$$

Summary

The study showed the importance of analyzing the coefficient of thermal expansion for high-performance composite materials based on the fiber direction.

If you are interested in finding out more about Thermomechanical Analysis and its areas of application, visit www.netzsch.com/tmapolymeredition

Acknowldgement

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About Neue Materialien Bayreuth GmbH

Neue Materialien Bayreuth GmbH is a non-academic research company developing various novel materials for lightweight constructions, from polymers and fiber-reinforced composites to metals including also the processing. They provide application-oriented solutions by optimizing available materials and production processes (https://www.nmbgmbh.de/en/).

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