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Analysis of Fibers, Pores, and Mechanical Properties in µCT-scan of a Long Fiber-Reinforced Thermoplastic

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Fiber-reinforced composites play an increasingly important role in lightweight applications. Among these composites, short and long fiber-reinforced thermoplastics are highly popular as they combine comparably low material cost, efficient production processes, e.g. injection molding, and good mechanical properties, especially if long fibers are used.

These materials present a complex microstructure with two material phases (fibers and polymer) and usually, an unwanted third phase (pores). Additionally, the manufacturing process itself influences the microstructure e. g. by changing the fiber orientation or the fiber length. In injection molding, the filling of the mold leads to a characteristic layer structure, which in the simplest case, consist of two outer regions and a core. In the outer regions, high shear velocities lead to an alignment along the flow direction. The slower, laminar flow in the core region causes a transverse to random orientation of the fibers. This effect produces complex fiber orientations in the composite. Using µCT-scans , the fibers and pores in the resulting microstructure can be analyzed thoroughly to better understand the microstructure of injection molded materials.

In this study, a µCT-scan of a glass fiber reinforced polypropylene made by the Leibniz-Institut für Verbundwerkstoffe GmbH (IVW) was analyzed. It has a fiber volume content of 13%, a tensile modulus of 6 GPa, and an elongation at break of 2.5% [1]. The specimen was an injection molded type 1A shouldered test bar and mechanical testing was performed according to DIN EN ISO 527-1 to -5 [1].

In a first step, the gray-value images of the scan were imported in the GeoDict® software for segmentation. A non-local means filter was applied (patch radius: 1, search radius: 3, filter strength: 0.2) to improve the image quality. The segmentation led to a fiber volume content of 13.2% and a significant number of pores, namely 1.3%. The resulting model has a size of 1500x1500x800 voxels. Figure [1] shows the gray-value image and the segmented fibers.

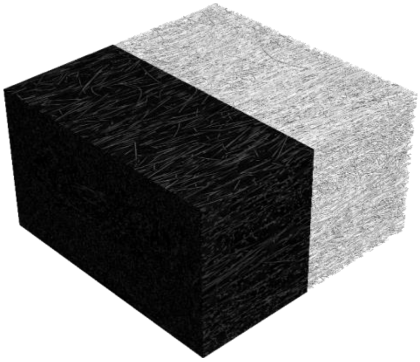

Figure 1. Gray-value image and segmented fibers

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In a second step, the fibers in the segmented scan were identified using a self-trained neural network. For technical details see [2]. The fiber analysis delivers -among others- fiber diameter and fiber orientation. The fiber orientation was also analyzed through the thickness of the scan. This showed the typical three-layer structure of injection molded materials, as shown in Figure 2. All fibers with an angle to the x-direction larger than 25° were labeled in red color.

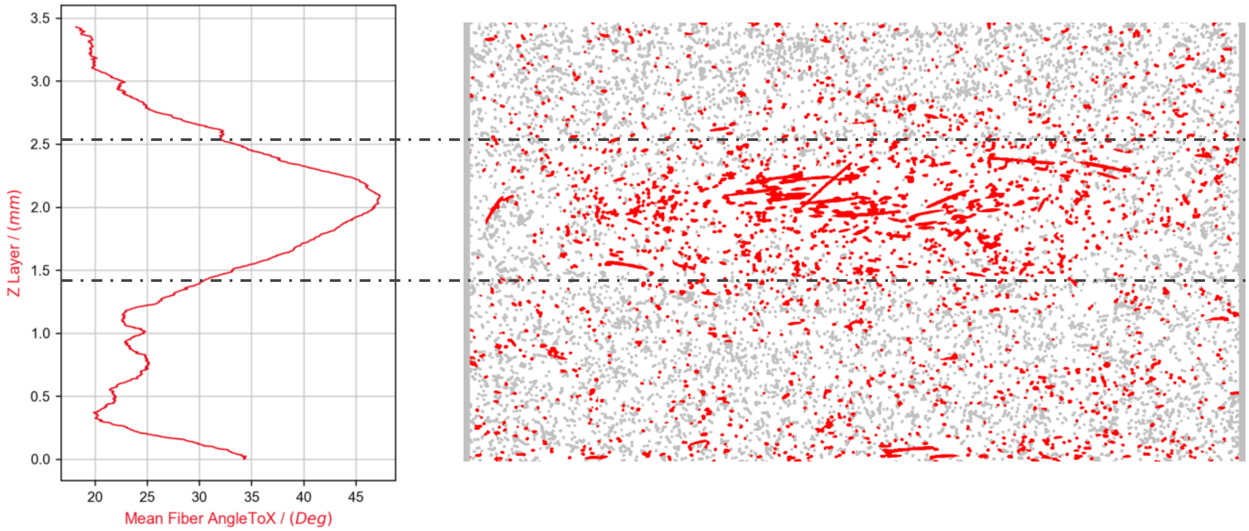

Figure 2. Fiber angle to x-direction along the thickness of the scan (left) and cross-section of the structure with two fiber types (right): white, with an angle to x smaller than 25° and red, with an angle to x larger than 25°.

Third, pores were identified using a watershed-based algorithm. Their shape, diameter, and location was analyzed. The voids are mainly located in the inner region in which the fibers are not aligned to the flow direction and have a mean diameter (diameter of volume-equivalent sphere) of 237.367 µm with a standard deviation of 97.4617 µm. The pores are displayed in Figure 3:

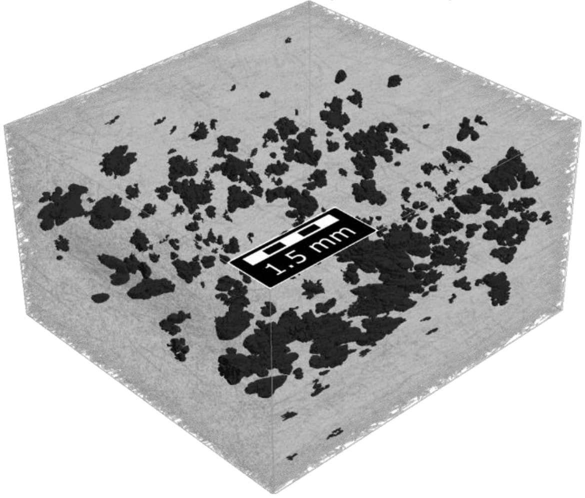

Figure 3. Pores in the core layer of the segmented scan

As last step, we analyzed the mechanical properties of the scan and compared the result to the tensile tests performed at IVW. To do that, we used the finite-differences-based voxel-solver FeelMath

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developed by Fraunhofer ITWM which is incorporated in the GeoDict® software. For comparison, the elastic moduli in the direction of the injection was used. This is also the main fiber direction in the outer layers. The elastic moduli of the constituent materials (used for the simulation), of the specimen tested by IVW, and of the segmented scan simulated in GeoDict are listed in the following table.

	Elastic modulus
Glass fibers	72 GPa
Polypropylene	
From mechanical test	5.99 GPa ± 0.19 GPa
From simulation	5.80 GPa

In addition, the influence of the voids in the stiffness was analyzed. To do that, the pores in the segmented scan were filled with polypropylene as well. The elastic modulus with pores was 5.80 GPa and the elastic modulus without pores 5.88 GPa. This minimal increase shows that the pores have no significant influence on the elastic modulus, although they appear quite large. However, they are mainly found in the core layer, in which the misaligned fibers do not contribute to the elastic modulus to the same extend as the rather straight fibers in the outer layers

Those exemplary analyses show that the investigation of a µCT-scan of an injection molded material delivers valuable insights into the influence of its microstructure. Material and process developers may use this knowledge for optimization. Moreover, this workflow is suitable for quality control for components with high requirements regarding pores or fiber orientation.

References:

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[2] A. Grießer et al., Identification of Fiber Characteristics of a Filter Media based on Artificial Intelligence (AI) with GeoDict©. Downloaded from https://www.geodict.com/Showroom/Technical-Reports/M2M-2020-01_TechReport_Math2Market.pdf, https://doi.org/10.30423/report.m2m-2020-0, 2020.

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