Analysis of the Fibre Orientation of Fibre-Reinforced Thermoplastics Parts for the Improvement of the 3d Fibre Spraying Process

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Aims

Fibre-reinforced thermoplastics (FRTP) are composite materials consisting of two components. Fibres with a high tensile strength, e.g. glass or carbon fibres, are embedded in a matrix made of thermoplastic polymers. The fibre alignment defines the mechanical properties of the structure like stiffness or strength. The polymer matrix keeps the final workpiece in its form and protects the fibres.

Besides the advantage of an endless storability, FRTP offer outstanding mechanical properties such as a high elongation at break and a high impact resistance [1]. Furthermore, they can be easily recycled [2]. Because of these advantages their importance on the market is increasing and they are becoming more and more attractive as material for the substitution of steel parts in the automobile industry [3,4].

Typically, FRTP with continuous fibres and defined fibre orientation are made of pre-impregnated textile fabrics. These are often cut and draped manually. The high proportion of manual work and the cut of the pre-impregnated textile fabrics cause high production costs. To reduce the manufacturing costs the Institute of Plastics Processing (IKV) develops the novel three-dimensional (3d) Fibre Spraying Process. It allows to manufacture three-dimensional near net shaped preforms from a glass-/ polypropylene hybrid yarn.

Within the 3d Fibre Spraying Process, the hybrid yarn is chopped into defined fibre length, is put on a permeable tool and is consolidated on the near net shape tool afterwards. A fibre deflector realigns the chopped fibres. This provides the possibility of achieving a defined fibre orientation in the spraying process. The fibre orientation is crucial for the mechanical properties of the part.

a.) hybrid yarn b.) fibre spraying facility (photo: P. Winandy) c.) FRTP part

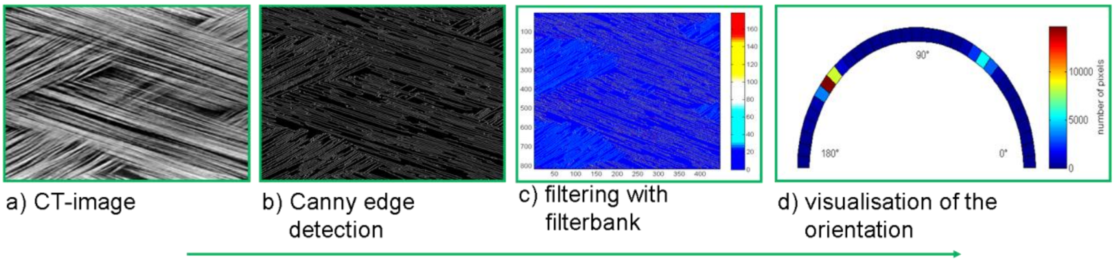
Figure 1: Hybrid yarn, fibre spraying facility at the IKV and typical part made of fibre reinforced thermoplastics (FRTP)

To investigate the influence of the process parameters on the fibre orientation, it is necessary to determine the fibre orientation. X-ray microtomography (micro-CT) allows the non-destructive, three-dimensional (3d) image acquisition of the internal structure of a FRTP part at high resolutions. In this project, an algorithm for the estimation of the fibre orientation distribution is developed. It is applied to virtual sections through data volumes acquired using micro-ct. Two-dimensional virtual sections are analyzed, because methods that allow the analysis of the fibres in all three dimensions are computationally highly intensive due to the large 3d data volumes. Furthermore, the thickness of the parts analysed in this project is small compared to the length of the fibres. Thus, information on the orientation of the fibres in the x-y plane is sufficient.

Method

To estimate the fibre orientation in fibre-reinforced composites, several approaches have been proposed in literature with application to various materials such as wood-fibre-reinforced composites [5], injection moulded parts filled with short glass fibres [6], fibre-reinforced concrete [7], carbon-fibre-reinforced polymers [8] and glass-fibre-reinforced polymers [9, 10].

In this project, 2d anisotropic Gaussian filters [8,10] are applied to virtual sections through volume data acquired using micro-CT. Anisotropic Gaussian filter kernels are two-dimensional elliptical Gaussian functions, rotated in an arbitrary direction. The filters can be directly applied to the grayscale images. No fibre segmentation from the polymer matrix is needed. Therefore, the algorithm can be used on data where the fibres are only a few pixels wide, which allows a larger field of view or faster scanning times repectively. Furthermore, they can be easily implemented and their extension from 2d to 3d is straightforward. Efficient implementation schemes have been proposed in [11] and [12]. By arranging a defined number of these filters to a filter bank and filtering the image with each filter kernel, the local fibre orientation can be detected for every fibre pixel. Figure 2 displays the structure of the algorithm schematically.



a) CT-image

b) Canny edge detection

c) filtering with filterbank

d) visualisation of the orientation

Figure 2: Overview of the structure of the proposed algorithm

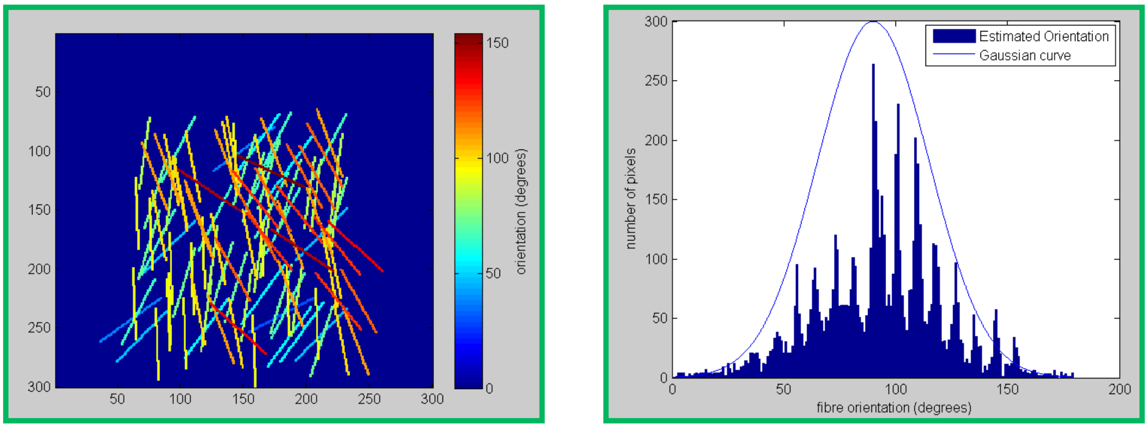
Firstly, the image is pre-processed with a Canny edge detector [13]. This operator reduces objects to their boundaries and at the same time smoothes the image to remove noise (see fig. 2b). This greatly reduces the number of pixels to be processed while preserving fibre orientation information. This way, the variance parameters of the anisotropic Gaussian filter can be fixed to detect objects of one pixel thickness independent from the actual image.

The image is filtered with each filter kernel of the filter bank. After each filtering step, the current filter response is compared pixel by pixel to the previous one and only the highest values are stored along with the corresponding orientation angle. This results in two datasets: one containing the maximum filter response and one containing the orientation for each image pixel. The orientations are only estimated for positions belonging to the fibre boundaries generated using the Canny filter, excluding the background and any distortions.

The ct-scans are performed with a Skyscan 1172 microtomography system (Skyscan N.V., Kontich, Belgium) and the algorithms have been integrated into the software framework “Ozella3D”, which has been written in Matlab and C in the course of this and previous projects [14].

Results

To validate the proposed method, test images containing straight fibres with a defined orientation are generated. The fibre distribution follows a Gaussian distribution with a mean value of 90° and standard deviation $\sigma = 25°$ (fig. 3). Figure 3a displays the generated image. The color of the fibres encodes the orientation. Figure 3b shows the real Gaussian curve used to create the fibres (in continuous line) and the number of pixels of a certain orientation (as a histogram). As can be seen the measured distribution resembles the model very well.

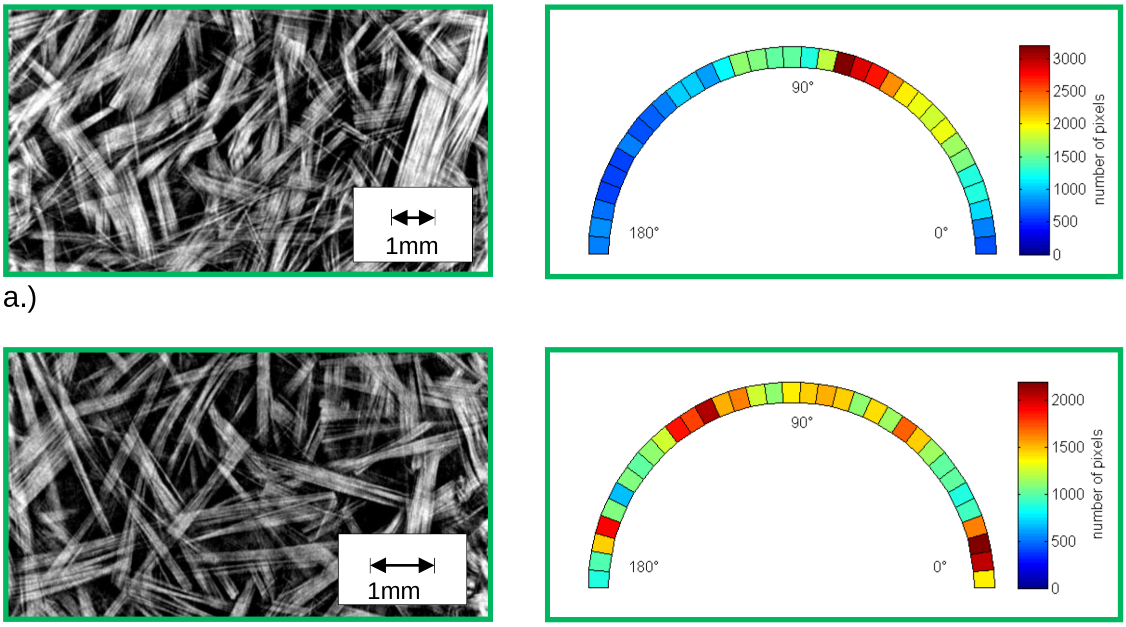


a.) Test image, orientation is distributed following a Gaussian curve with mean 90° and $\sigma = 25°$.

b.) Real model distribution curve and the estimated orientation using the proposed method.

Figure 3: Validation of the proposed algorithms

Figures 4 displays virtual sections through typical FRTP samples together with their estimated fibre orientation distribution. The samples have been produced using different process parameters. As can be seen, the fibres in figure 4a show a higher degree of orientation than the fibres in figure 4b. This information can be utilised to optimise the fibre spraying process.



a.)

b.)

Figure 4: virtual sections through typical FRTP samples together with their estimated fibre distribution.

Conclusion

The orientation of the fibres in fibre reinforced thermoplastic (FRTP) parts has strong influence on the mechanical properties of the parts. Therefore, detailed information on the fibre orientation allows the improvement and optimisation of the production process.

X-ray micro-ct provides a good utility for imaging the internal structure of FRTP parts. In this paper, an algorithm for the two dimensional analysis of the fibre orientation in virtual sections through the volume data is presented. The algorithm has been applied to various samples and has shown good results. For the future, more detailed research and the expansion to the three-dimensional analysis of the data is planned.

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