RESEARCH PAPERS
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

2014 Volume 22, Special Number

WAYS OF COMPARATION OF THE FIBRE ORIENTATION IN INJECTION MOULDING PARTS

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ABSTRACT

The fibre orientation in short fibre reinforced thermoplastics depends on injection moulding technology parameters. The aim of this paper is to propose possibilities for comparing fibre orientation of the real sample and the result from simulation software. Fibre orientation of selected injection moulding part is simulated. In some selected points second-order tensor of orientation was estimated. Stereological metallography was used for possibility of comparison these results with experimental ones. An experimental result of estimation of degree of fibre orientation is described. The use of stereological metallography allows very simple and effective experimental estimation of short glass fibre orientation, which can be used for experimental verification of numerical simulation model, which can be optimized to obtained coincidence with experiments.

KEY WORDS

Injection moulding, fibre orientation, stereology, numeric simulation

INTRODUCTION

It is very important to propose a method for comparing the fibre orientation of the real sample and the result from simulation software. The software Moldex3D was used, which belongs to the top of software for injection moulding simulation. Rate of its success can only be measured when compared to the actual situation. There are many ways to measure different results, but deal with fibre orientation is very interesting, because many of not only mechanical properties are depending on them. To achieve this objective, is needed to compile tensor orientation by means of simulation program and find out how to verify this tensor.

FIBRE ORIENTATION

The orientation of simple fibre may be defined by the two angles θ and Φ illustrated in Figure 1. In a Short Fibre Reinforced Thermoplastic (SFRT) component there are frequently

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millions of fibres, therefore each individual fibre orientation specifying is very impractical [1]. The fibres orientation in space can be described by the probability distribution function (PDF), *Ψ(θ, Φ)* [2].

Orientation of a single fibre may be defined by the Cartesian components of a vector *p*, also. The components of p_i are described with the angles *θ* and *Φ,* as follows:

$$p_1=\sin\theta.\ \cos\Phi$$
$$p_2=\sin\theta.\sin\Phi \qquad [1]$$
$$p_3=\cos\theta$$

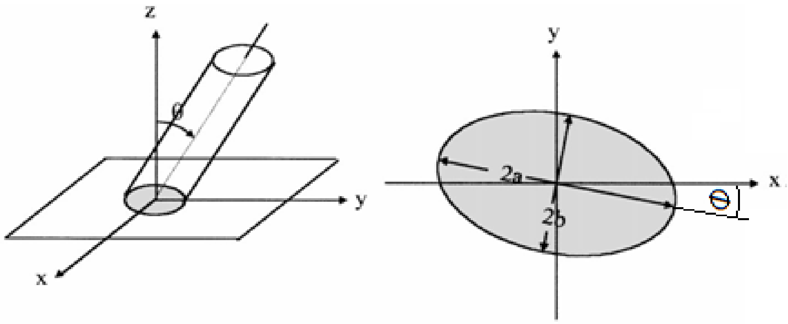

Fig. 1 *The orientation of a single fibre can be expressed in polar coordinates by the two angles (θ,Φ)*

The PDF function describes the fibre orientation direction (FOD) which in complete form holds a lot of information, making any numerical calculations based on these data highly computationally intensive. In some applications where there exists a simplified FOD distribution, the density function, *Ψ(p)* may in turn be simplified. But in many applications, it is not possible to make such a simplification [3]. The tensor description of FOD has become the most used system of characterization [4]. This tensor gets a concise description of the FOD, without the need for any a priori assumption of a simplified orientation. For the second-order tensor, it has nine components but only six of these are independent because of the symmetry condition. The components of the second-order tensor for a group of *n* fibres are calculated as follows:

$$a_{ij} = \frac{1}{n}\left(\sum_{k=1}^{n} p_i^k p_j^k\right) = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \quad i,j = 1,2,3 \qquad [2]$$

Six independent components for an individual fibre are as follows:

$$a_{11} = sin^2\theta.cos^2\Phi$$
$$a_{22} = cos^2\theta.cos^2\Phi$$
$$a_{33} = cos^2\theta$$
$$a_{12} = a_{21} = sin^2\theta.cos^2\Phi.\sin\Phi \qquad [3]$$
$$a_{13} = a_{31} = \sin\theta.\cos\theta.\cos\Phi$$
$$a_{23} = a_{32} = \sin\theta.\cos\theta.\sin\Phi$$

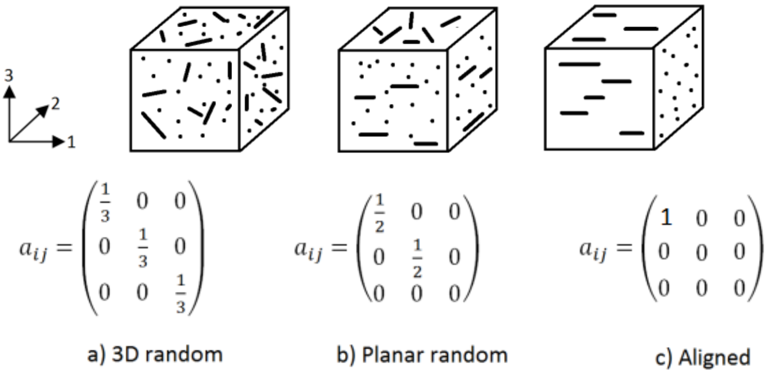

Fig. 2 *Example of different orientation states and corresponding orientation tensors*

Orientation tensor components have a physical interpretation. Figure 2(a) shows isotropic state, with equal orientation distribution in all directions. If all the fibres lie in the 1-2 plane (see Figure 2(b)), it corresponds to 2D isotropic (planar random) orientation state. Perfectly aligned orientation in 1 direction is shown in Figure 2(c).

RESULTS OF SIMULATION SOFTWARE

Good simulation software, for example Moldex3D in this case, allows to view results of fibre orientation as an orientation of the *X* direction, *Y* direction, *Z* direction, the total orientation and orientation at surface. These first three orientations are relevant for the establishment of second-order orientation tensor. They belong to tensor´s values a_{11}, a_{22} and a_{33}, which are shown in Figures 3, 4 and 5.

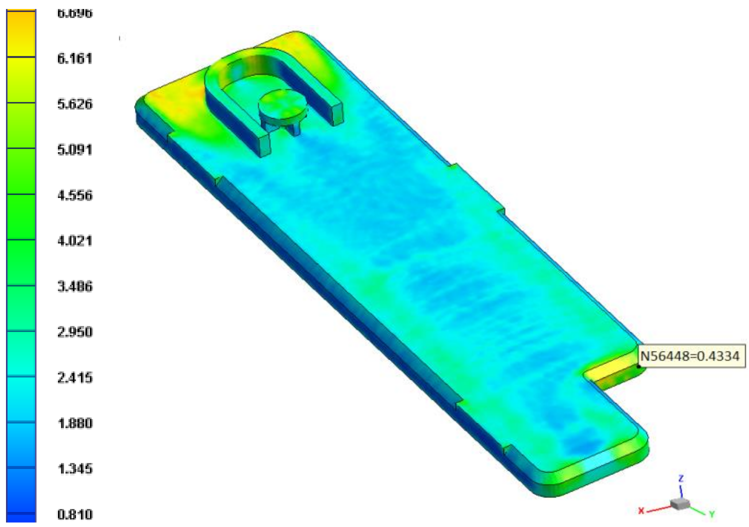

Fig. 3 *Fibre orientation in X direction*

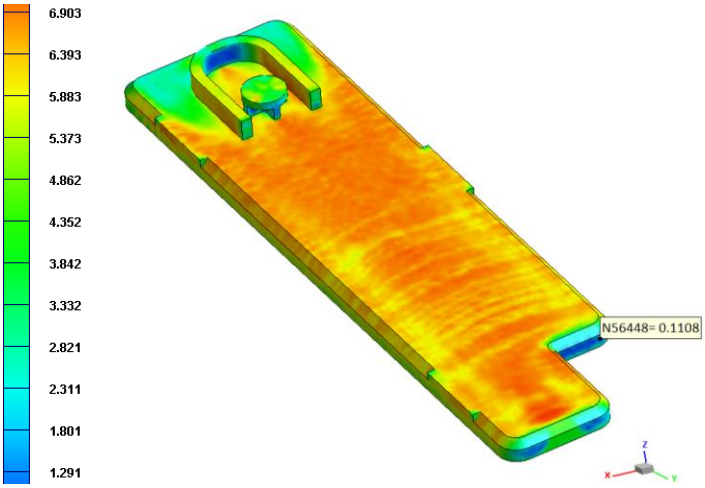

Fig. 4 *Fibre orientation in Y direction*

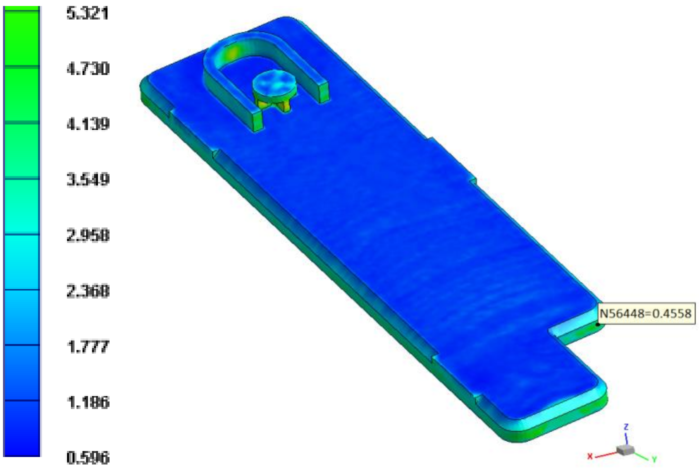

Fig. 5 *Fibre orientation in Z direction*

Orientation tensor can be compiled for any point, for example N56448 point:

$$a_{ij} = \begin{pmatrix} 0.4334 & 0 & 0 \\ 0 & 0.1108 & 0 \\ 0 & 0 & 0.4558 \end{pmatrix} \qquad [4]$$

Degree of orientation, which can be compared to orientation evaluated using stereological metallography (see below), can be calculated as:

$$O = \frac{a_{ii} - a_{jj}}{a_{ii} + a_{jj}} \qquad [5]$$

QUANTITATIVE ANALYSIS OF COMPOSITE STRUCTURES

Only total examination of the structure and properties of materials carried out in the production and processing conditions should be related with macroscopic properties of the material. In the isometric structures microparticles are randomly oriented in all directions. In oriented structures, microparticles have a preferential orientation.

In the case of short glass fibres reinforced thermoplastics it's structure consist of thermoplastic matrix and reinforcing fibres, which has some preferred orientation in most of cases – the structure is anisotropy. The way of scalar measurement of structure anisotropy is determination of degree of orientation. The anisotropic microstructure is decomposed into isotropic, planar or linear oriented components using stereology methods.

Length of oriented fibres can be divided to isometric and oriented parts and degree of orientation is ratio of oriented part of length to total length. Oriented test plane method can be used. Test planes are placed perpendicular and parallel to the orientation direction [5]. The equations refer to the oriented $(Lv)_{OR}$ portion of the system of lines and to the total $(Lo)_{CE}$ length per unit volume [6]. They are [7]:

$$(L_V)_{OR} = (P_A)_O - (P_A)_P \quad [6]$$

$$(L_V)_{CE} = (P_A)_O + (P_A)_P, \quad [7]$$

where:
$(P_A)_O$ is number of cross-sections between test perpendicular plane and fibres per unit test area,
$(P_A)_P$ is number of cross-sections between test parallel plane and fibres per unit test area.
Degree of linear orientation O is:

$$O = (L_V)_{OR} / (L_V)_{CE}. \quad [8]$$

EXPERIMENT

For an example, an analysis of injection moulding part gear from lathe gear set was made. The gear material is Silamid 13.01 ESV 30-301. It is a PA 6 polyamide with 30% volume fraction of glass fibres. The diameter of the fibre was 0.02 mm, length about 0.5 mm. From the gear-teeth a specimen was taken away. The probe was metallographic prepared and observed on a light microscope. In the middle of the tooth two metallographic cuts were made: one perpendicular to main tooth axis (Figure 5) and parallel to main tooth axis (Figure 6). Degree of fibre orientation estimation according [6], [7] and /8/ was - 0.32. It means, that fibre orientation is perpendicular to main tooth axis.

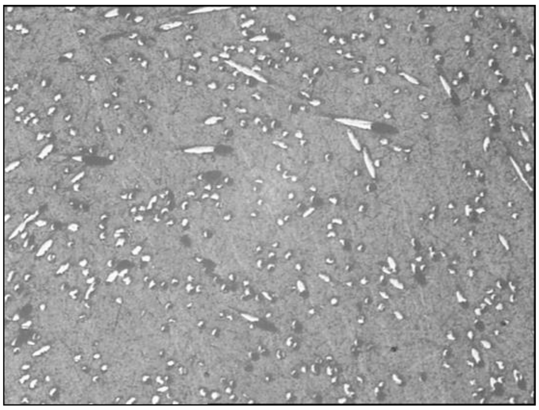

Fig. 5 *Structure of tooth, parallel to main axis, mag. 110x*

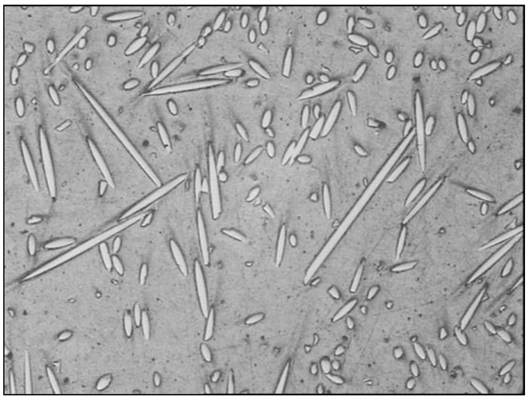

Fig. 6 *Structure of tooth, perpendicular to main axis, mag. 110x*

CONCLUSION

The fibre orientation can be controlled by injection parameters. For option of parameters of process analysis of fibre orientation is necessary. The utilization of stereological metallography allows very simple and effective experimental estimation of short glass fibre orientation by measuring the relative length of fibres orientation in various places of injection moulding parts. These results can be compared with the results obtained from numerical simulation using equation /5/. It leads to experimental verification of numerical simulation model, which can be optimized to obtained coincidence with experiments.

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