J. Mater. Environ. Sci. 8 (1) (2017) 44-49 *Modhaffar et al.*
ISSN : 2028-2508
CODEN: JMESCN

Simulation of Short Fiber Orientation in Thermoplastic Matrix

I. Modhaffar, K. Gueraoui*, S. Men-la-yakhaf, H. El tourroug

Team of modeling and simulation in mechanics and energetic, Faculty of sciences, Mohammed V University, Rabat B.P. 1014, Rabat, Morocco

Received 08 Jun 2016, Revised 01 Nov 2016, Accepted 03 Nov 2016
**For correspondence: Email: Kgueraoui@yahoo.fr (K. Gueraoui)*

Abstract
The Polypropylene polymer mixed with curved fibers was injected into rectangular mold in order to improve its thermoplastic properties. The aim of this study is to investigate the effect of fibers orientation. The prediction of the orientation of short fibers within the polymer matrix was obtained by image processing method based on the method that determines ellipses orientation and size of fibers from a scanned image and then the results obtained were validated by ImageJ.

Keywords: injection, composites, short-fiber reinforced, thermoplastics, fiber orientation, ellipses method.

1. Introduction
Due to economic and technological interests, reinforced polymer composites with short matrix fibers constitute an important class of engineering materials. In particular, these composites with non-aligned reinforcements are of considerable importance because of their good thermal-elastic properties. Although both the matrix and the fibers are isotropic, anisotropic composite is usually due to non-random fiber orientations: it is more rigid and stronger along the direction of the dominant orientation. This research project is devoted to the evaluation and measurements of both elastic and thermal properties of polypropylene composite fibers, obtained by injection molding.
Injection molded composites contain mostly partially short fibers, oriented in complex and highly non-ideal grounds. Furthermore, extrusion compounding, of the classical pathway of preparation of these compounds has a practical limit of the maximum processing fiber content in the range of 40 to 45% by weight of fibers. Accordingly, the applications for these composite materials cannot be achieved, where strength and stiffness criteria may be fulfilled with volume fractions of fibers of 0.2 or less. This is low fibers load compared to the application that need high performance where the volume fractions of 0.5 or more of aligned continuous fibers can be used, usually at the cost of accepting a lower level of processing efficiency.
To describe the rheological behavior of suspensions of different fibers transversely isotropic fluid models (TIF) have been widely proposed and utilized. These models represent a variant of the original continuum model developed by Ericksen [1] and hand. [2]. Their microstructure origins were recognized by Doi and Edwards [3], Hinch and Leal [4], Dinh and Armstrong [5], Lipscomb et al. [6] and Phan-Thien and Graham [8]. In some stydies, authors use numerical methods such as finite volume method and finite differences method [12-32] to describe the orientations of fibers and the flow.
In dilute systems, where the volume fraction of the time aspect ratio squared $\mathbf{a_r=L/d}$ (length/diameter) is less than unity; the fiber-fiber interactions can be ignored. In non-diluted systems, fiber-optic interactions cannot be

neglected. Folgar and Tucker [7] modeled the fiber-fiber interactions due to random collisions resulting in a distribution of fibers in their special configuration.
The aim of this study consists on the quantification of the fiber orientation state from polished cross-section rectangular mold, where by a computer-aided image analysis is used to measure the contour of the fibers. In order to ensure sufficient contrast for different matrix materials in reflected scan, a special specimen preparation treatment was preceded.

2. **Materials and Methodology**

2.1. *Description of Fiber Orientation in Composites*

A short fiber is assumed as cylindrical, rigid and straight rod. Therefore, its spatial orientation can be described using spherical coordinates with the azimuthal φ and zenith θ angles as is shown in Figure 1. These angles are used to construct an orientation unit vector p parallel to the backbone of the particle defined as:

$$p = p_1\delta_1 + p_2\delta_2 + p_3\delta_3 \quad (1)$$

Where the components are defined as follows:

$$\begin{cases} P_1 = \sin\theta\cos\varphi \\ P_2 = \sin\theta\sin\varphi \\ P_3 = \cos\theta \end{cases} \quad (2)$$

In our study $\varphi = \frac{\pi}{2}$
Or the equations (2) become:

$$\begin{cases} P_1 = 0 \\ P_2 = \sin\theta \\ P_3 = \cos\theta \end{cases} \quad (3)$$

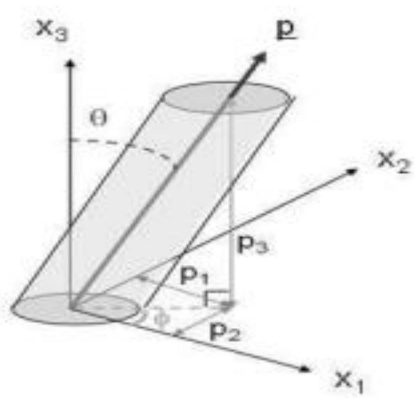

Figure 1: Geometrical representation of fiber spatial orientation.

The orientation of a population of fibers can be described using orientation tensors, as proposed by Advani [10] and Tucker [9].

2.2 *Determination of Orientation in Short Fiber in Composites using the Method of Ellipses*

The ellipse method is simple procedure used to characterize the orientation in 2D short fibers based composite. A sample taken from a region of interest in a composite is mounted and polished using common metallographic technique. The sample is scanned to acquire images of the sample surface. The resulting image contains several elliptical imprints representing fiber cut by the surface plane of the polished sample [11].

Five geometrical parameters are usually measured from each ellipse and then used to construct the vector of orientation. Figure 2 can help to visualize the settings directly measured from each ellipse. The position of the fiber is determined from the horizontal and vertical center of mass (xc, yc), of the ellipse. The other parameters are the minor (m) and large (M) axis of the ellipse and the azimuth angle (φ) is commonly referred as the in-plane angle while the angle from the plane was commonly used to refer to θ.
Using geometrical principles, the out-of-plane angle is determined by:

$$\theta_f = \cos^{-1}\left(\frac{m}{M}\right) \qquad (4)$$

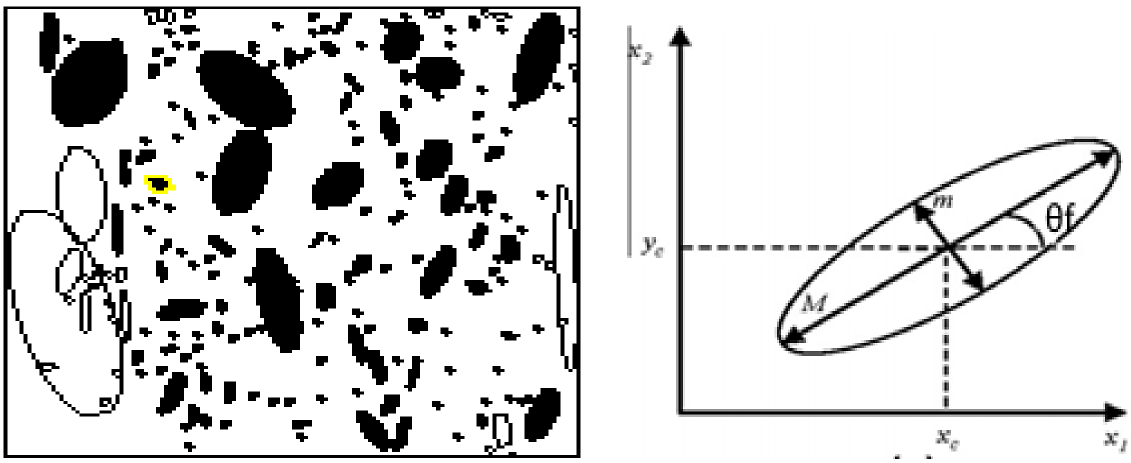

Figure 2: Definition of geometrical parameters measured using the ellipses method: coordinates of the center of the ellipse (xc, yc), minor axis (m), major axis (M), and in-plane angle (θ_f)

3. Image Processing Methodology

3.1 Matlab Analysis

For images analysis, the sample was moved in a scanner laser jet photographer. In this paper, three samples having dimensions of 10 cm width and 4 cm length are investigated.

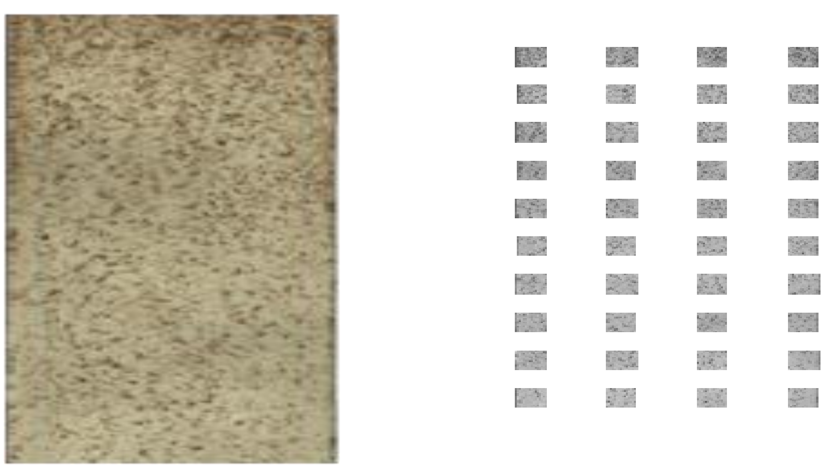

Figure 3: Rectangular sample containing polypropylene mixed with short fibers.

Image processing and image analysis were performed using an internal program developed with Matlab and image processing toolbox (IPT). A detection system based on a manual or semi manual selection has been established to measure the elliptical footprint rather elliptical. The algorithm implemented included the following general steps: selection, discretization and characterization of footprints, the correction angles in the plane, and calculation of the average fiber orientation.

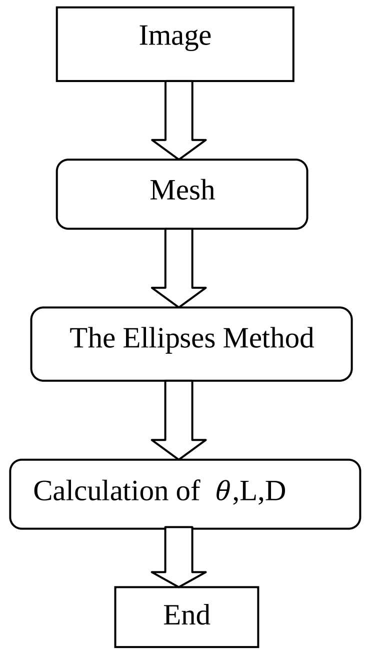

Figure 4: Chart for the procedure for the determination of fibers orientation, width and length.

3.2 *ImageJ analysis*

The principle of ImageJ is to manipulate, view, edit and analyze images after manual discretization. After processing, orientation, length and width for each fiber, can be obtained.

4. Results and discussion

The Figures above show the mean angles as function as position for difference section.
We note for the figures (B) and (C) the section i=3, i=4 that the fluctuation of mean angles and position is very strong at the entrance of the sample until the middle position, after that the stabilization of the fluctuation becomes moderate. This result can be explained by the fact at the entrance the flow is strogly influenced by the boundary conditions, it is why this fluctuation.
In the figure (A) the section i=1, i=2 we Remarque the fluctuation of the mean angles and position for the section i=3 is very important than the two other sections, this result can be explain as effect of the boundary of the simple. The sction i=3 is adjacent to the wall, so an immediate influence by the boundary conditions is translated by this fluctuation.
Last figure (D) shows the comparison between the result obtain using Matlab and imageJ. It is clear from this figure the two techniques give comparable result. This result shows the important of our code to predict the orientation of the fibers.

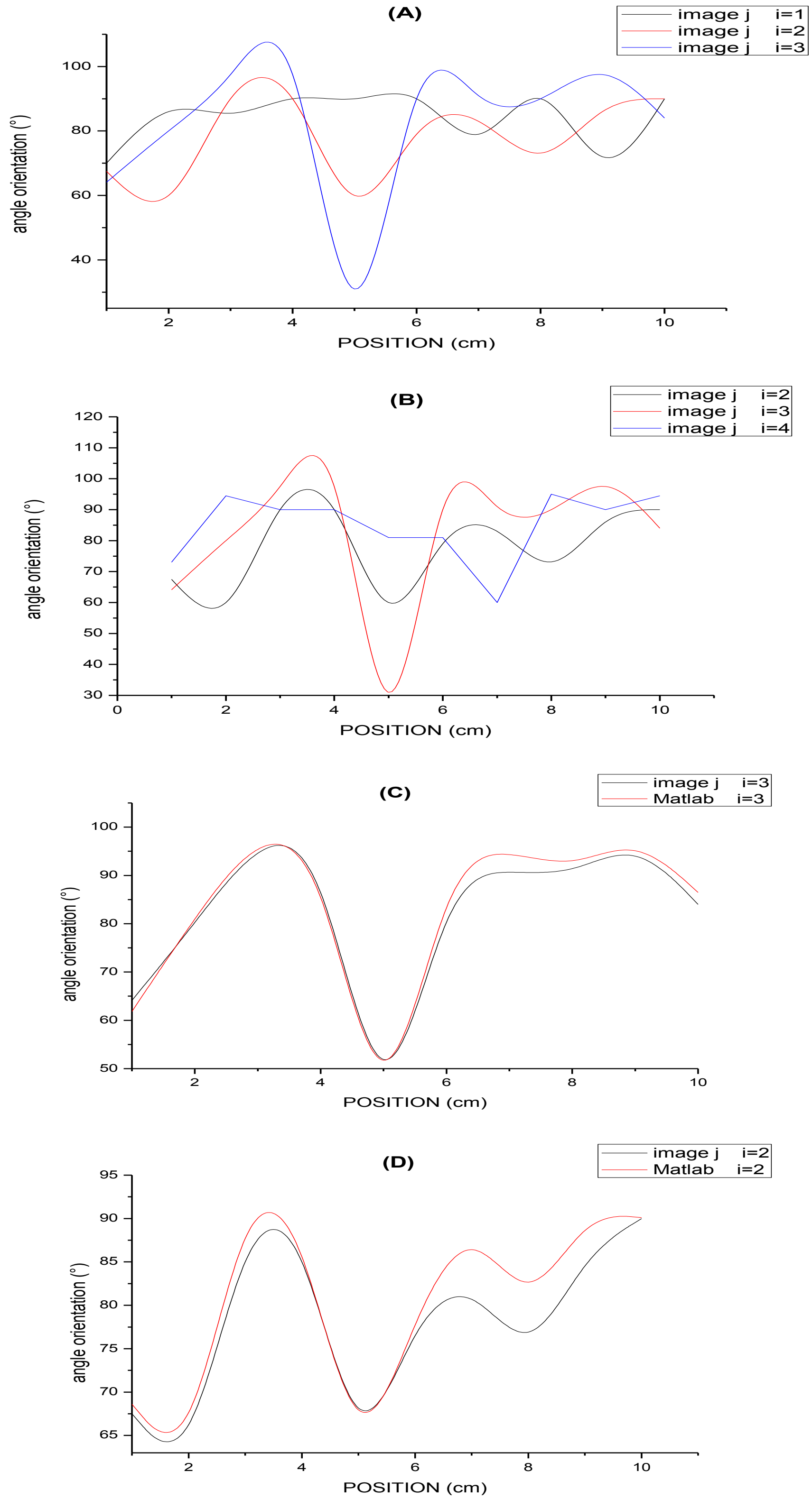

Figure 5: Mean angles profile depending on the width j and length I the polypropylene

Conclusions

A comparative investigation of short fibers orientation within thermoplastic polymer matrix (polypropylene) by using two methods: Matlab simulation and ImageJ processing was developed. It was found that the results obtained with Matlab simulation are more accurate. This can be explained by the fact it can easily handle the guidelines for any sample in order to use them with an algorithm. As application to the developed method, it can be extended for a non Newtonian fluid to simulate the flow of molten polymers as short fibers. These types of short fibers are the most used in the industry.

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