Composites Science and Technology 91 (2014) 45–49

Contents lists available at ScienceDirect

Composites Science and Technology

journal homepage: www.elsevier.com/locate/compscitech

Predicting the elastic properties of sisal fiber reinforced polypropylene composites by a new method based on generalized method of cells and laminate analogy approach

Zhanying Sun, Xiongyan Zhao *, Xin Wang, Jinsong Ma

College of Material Science and Engineering, Hebei University of Science and Technology, Shijiazhuang 050018, China

ARTICLE INFO

Article history:
Received 5 August 2013
Received in revised form 14 November 2013
Accepted 23 November 2013
Available online 8 December 2013

Keywords:
A. Short-fiber composites
C. Anisotropy
C. Elastic properties
C. Modeling
Natural fiber composites

ABSTRACT

In this paper, a new method based on generalized method of cells and laminate analogy approach was used to predict the elastic properties of short sisal fiber reinforced polypropylene composites. The effects of fiber volume fractions and fiber aspect ratios on the elastic properties of composites were studied by the new model and other models. Continuous fiber composite and layered composite, as two special cases were analyzed in detail by this new model. The results show that both fiber volume fraction and fiber aspect ratio have significant effects on the axial Young's modulus. However, the fiber volume fraction has very small effects on the transverse Young's modulus, axial shear modulus and axial Poisson's ratio. The new model agrees better than other models with the experimental data. The elastic properties of composites with complex microstructures can be predicted efficiently by this new model.

1. Introduction

Owing to the time-consuming and costly testing in experiments, the predictions for the mechanical properties of composites have been developed rapidly. Compared to conventional synthetic fibers, natural fibers show inherent variability of the geometrical and mechanical properties. Thus the principal difficulty arising in the testing of conventional composites will appear more commonly in testing natural fiber composites [1]. Therefore, predicting the mechanical properties of these materials is becoming increasingly nessesary and important.

So far the predictions for the mechanical properties of natural fiber composites have mainly focused on Rule of Mixtures (ROM), Halpin-Tsai, Cox shear-lag and Kelly-Tyson semi-empirical equations [2–5]. These predictions were all based on an assumption that the fibers were isotropic; no attention was paid to the anisotropy of natural fibers. However, the highly anisotropic nature has great effect on the mechanical properties of natural fibers and their composites. For most natural fibers, the axial properties are greatly larger than the transverse properties [6–8]. Therefore, for the accuracy of modeling, the anisotropy of fiber properties should be taken into account. Owing to the variations in diameters and shapes, the axial and transverse moduli of natural fibers show large distributions. The accuracy for measuring these data requires the detailed sizes of the fiber diameters and shapes. Recently, Thomason et al. [9] and Summerscales et al. [10] studied the natural fibers' cross-sections in detail. To the authors' knowledge, the values obtained by Thomason et al. are the most reasonable. Therefore, the data for the axial, transverse Young's and axial shear moduli of sisal fiber in this paper are adopted from Thomason et al.'s studies, which can be found in Refs. [9] and [11].

For predicting the mechanical properties of composites, Paley and Aboudi [12,13] put forward an important method called generalized method of cells (GMC), which is a micromechanics model for multi-phased composites with complex microstructures. Thereafter, in order to study the short fiber composites, Aboudi [13] proposed a three-dimensional generalized method of cells (GMC-3D). Based on GMC-3D, Bednarcyk and Pindera [14] developed an analytical micromechanics model for studying the effects of yarn porosity on the properties of woven carbon/copper composites. Recently, Aboudi, Arnold and Bednarcyk [15] summarized many works which modeled the mechanical properties using GMC and GMC-3D. Owing to the highly anisotropy of natural fibers, GMC and GMC-3D are fit for predicting the mechanical properties of natural fiber composites.

The predictions for mechanical properties of short fiber reinforced thermoplastics can be performed by laminate analogy approach (LAA). This can be found in the researches of Chin, Xia and Fu [16–19]. Currently, GMC and GMC-3D model mainly focus on the unidirectional and woven metal matrix composites and fiber reinforced thermoset composites. There are very few studies

* Corresponding author. Tel.: +86 311 88632425; fax: +86 311 88613206.
E-mail address: zhaoxy66@126.com (X. Zhao).

0266-3538/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compscitech.2013.11.022

on short fiber reinforced thermoplastics. The aim of this paper is to predict the elastic properties of short sisal fiber reinforced polypropylene composites based on the combination of GMC-3D and LAA. This new method is abbreviated GMCL in this paper.

2. Model

Short fiber reinforced thermoplastics can be considered as a laminate consisted of many layers. Each layer of the laminate had different fiber length and fiber orientation from other layers. The predictions can be performed based on fiber length distribution and 2D planar fiber orientation distribution [18]. Fig. 1a is a sketch of short fiber composite; Fig. 1b is a sketch of the same fiber length layers, where l_1, l_2, l_n etc. stand for different fiber lengths. Fig. 1c is a sketch of the same fiber orientation layers, where θ_1, θ_2, θ_n etc. represent different fiber orientations. In Fig. 1c, each layer has the same fiber length and orientation, thus the properties of each layer can be easily calculated by GMC-3D. Fig. 2 shows a sketch of GMC-3D method for the zero orientation layer of Fig. 1c. The coordinate x_1 presents the axial direction of fibers. The dark and light color components stand for fibers and matrix, respectively. For the sake of simplicity, the fibers are considered to be square-shaped in cross-section, transverse isotropic and linearly elastic. The matrix is assumed to be isotropic and linearly elastic. It is also supposed that the interfacial bonding between fiber and matrix is perfect. Each layer of Fig. 1c is assumed to be an aligned short fiber composite with a periodic microstructure whose repeating unit cell consisted of $2 \times 2 \times 2$ rectangular parallelepiped subcells. The details of GMC-3D method can be seen in Refs. [13] and [14].

It can be seen in Fig. 1, for predicting the properties of composites, the fiber length distribution and fiber orientation distribution must be clear. The fiber length probability density function $f(l)$ can be written by [18]

$$f(l) = abl^{b-1}\exp(-al^b), \quad l > 0 \tag{1}$$

The cumulative distribution fuction $F(l)$ of fiber length can be given by

$$F(l) = 1 - \exp(-al^b), \quad l > 0 \tag{2}$$

where a and b are scale and shape parameters, l is the fiber length.

The fiber orientation distribution function $g(\theta)$ can be expressed as [16]

$$g(\theta) = \frac{\lambda \exp(-\lambda\theta)}{1 - \exp(-\lambda\pi/2)} \tag{3}$$

The cumulative distribution fuction $G(\theta)$ of fiber orientation can be written by

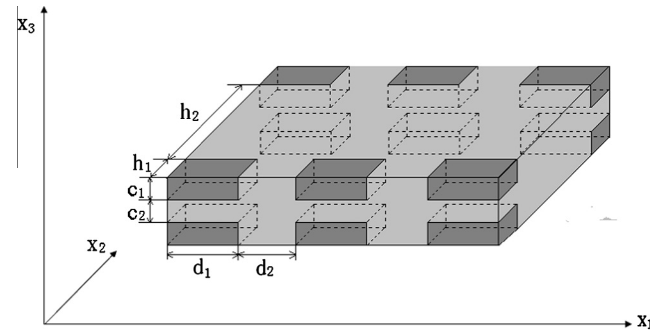

Fig. 2. The sketch of GMC-3D method. d_1, h_1, c_1 denote the fiber dimensions; d_2, h_2, c_2 denote the matrix dimensions. $d_1 + d_2$, $h_1 + h_2$, $c_1 + c_2$ denote the dimensions of a representative cell.

$$G(\theta) = \frac{1 - \exp(-\lambda\theta)}{1 - \exp(-\lambda\pi/2)} \tag{4}$$

where λ is the shape parameter, θ is the fiber orientation.

The stiffness matrix of the uniaxial ply can be calculated by GMC-3D. Then the stiffness matrix in the off-axis ply and engineering tensile constants of composites can be given by LAA [18].

3. Experimental procedures

3.1. Materials

Polypropylene Y1600 was purchased from the plastics of Shanghai Petrochemical Complex, China, with a melt flow index of 16 g/10 min. Coupling agent A018 used in the study is a maleated polypropylene (MAPP) supplied by Shanghai Zhongzhen Material Technology Co., Ltd., China. The amount of grafting is 1.1 wt% and the melt flow index is above 70 g/10 min. Sisal fiber rovings were obtained from Dongfang Sisal Group Co., Ltd., China.

3.2. Processing

Polypropylene, MAPP and dried sisal fiber rovings were compounded in a twin-screw extruder (model GE2.8.30-41, Gauder Group, Luxembourg) at 190 °C. The fiber weight fraction was controlled by the extruder speed and the matrix adding. The extrudates exiting from the twin-screw extruder were cooled by water immediately and cut into pellets by a pelletizer. Then these pellets were dried at 80 °C for over 10 h and molded into standard ASTM specimens at 190 °C using a TTI-80 plastic injection machine (Dong Hua Machinery Co., Ltd., China). The mold temperature was

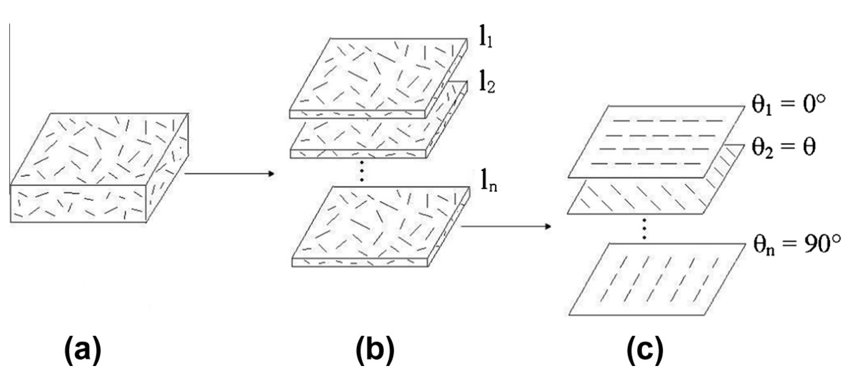

Fig. 1. The sketch of laminate analogy approach (l = fiber length; θ = fiber orientation).