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Procedia Structural Integrity 8 (2018) 517–525

Structural Integrity Procedia

www.elsevier.com/locate/procedia

AIAS 2017 International Conference on Stress Analysis, AIAS 2017, 6-9 September 2017, Pisa, Italy

Numerical model for the characterization of biocomposites reinforced by sisal fibres

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Abstract

Although several works have been recently published in literature about biocomposites, i.e. on innovative and ecofriendly polymer matrix composites reinforced by natural fibers, there are not studies on the influence of the waviness that various natural fiber present after their extraction. In order to give a contribution to the knowledge of the effects of the fiber waviness on the main mechanical properties of biocomposites, as the longitudinal Young modulus, in the present study a systematic numerical analysis has been carried out by using parametric models properly developed, that let the user to consider the effects of the key influence parameters as the fiber concentrations and the fiber curvature. Successive experimental studies have allowed to corroborate the accuracy of the numerical results, as well as to highlight the local effects due to the fiber waviness, that in some cases can become more significant than the global effects analyzed by the numerical approach.

Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis

Keywords: biocomposites; agave; sisal fibres; finite element method;

1. Introduction

Increasing attention to environmental protection from industrial pollution has raised interest in biomaterials, and in particular towards biocomposites, materials obtained usually by reinforcing renewable (biopolymeric) matrices by

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2452-3216
Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis
10.1016/j.prostr.2017.12.051

means of natural fibers, (refer to Murherjee and Satyananrayana (1984), Furqan et al. (2015), Yan et al. (2015), Omrani et al. (2015), Koronis et al. (2013)). Although there are several works in literature on this subject, there are no models which are able to accurately predict the mechanical behavior of these materials as the fiber concentration and their orientation change. This is probably due to the peculiar characteristics of natural fibers and their biocomposites, such as variable diameter, non-straight shape, and not-perfect alignment of fibers with load due to the lack of suitable fabrics that can guarantee such alignment. A key feature is the not-perfect straightness of the natural fibers and in particular the natural wavy form taken by various natural fibers, such as agave, following the extraction process. The effects of this wavy form could be limited by the manufacture of special unidirectional fabrics obtained after stretching and aligning the fibers. Unfortunately, for different natural fibers, such as for agave, these fabrics are not yet available and the production of long-fiber biocomposites for semi-structural and structural applications is commonly done by direct lamination of wavy fibers. Obviously, the performance of such biocomposites is affected by this key feature but the experimenter or the designer usually overlook this effect since simple tools able to evaluate its effects on the main mechanical properties of the biocomposite are not available. In order to limit the effects of the waviness of the fibers on the biocomposite, a practice carried out by some experimenters is to manufacture the laminates by trying to counteract the fiber waves relative to adjacent laminae, thus obtaining laminates which are globally orthotropic.

There are studies in the literature on the effects of fiber misalignment in polymer matrix composites, (refer to Berthelot (1982), Knibbs and Morris (1984), Bednarcykb et al. (2014), Lia et al. (2016), Khatibzadeh and Piggot (1996)), but such approaches are generally unfit to be applied to wavy natural fibers.

The case of wavy fibers has in some cases already been treated in literature in the particular case of carbon nanotubes (CNTs) reinforced composites. Many of these studies are based on micromechanical models, as atomic models are computationally too expensive to simulate the behavior of even a small portion of the composite. In detail, Fisher et al. (2003) analyzed the effect of curvature and waveform of carbon nanotubes on their ability to reinforce a composite. A representative value was sought that quantifies the stiffness due to the curvature of the CNTs, with respect to the elastic modulus determined by the presence of the straight nanotubes. The wavy fibers represented by the CNTs were studied using a finite element model. The wavy form of the CNT is introduced by assuming for the nanotube a sinusoidal shape. In another article, Bradshaw, Fisher and colleagues (2003) used an alternative approach in which the CNT was modeled as an infinitely long sine fiber. Pantano and colleagues, (refer to Pantano and Cappello (2008), Pantano and Cappello (2006), Pantano et al. (2008)), using micromechanical models investigated the effects of CNT curvature, single wall (SWNTs), (refer to Pantano and Cappello (2008), Pantano and Cappello (2006)), and multi-walled nanotubes (MWNTs) (refer to Pantano et al. (2008)), and interaction at the interface between CNTs and matrix on the rigidity of the nanocomposite. Numerical models (refer to Pantano and Cappello (2008), Pantano and Cappello (2006), Pantano et al. (2008)) show that the improvement in the mechanical properties strongly depends on the characteristics of the inclusions; in particular from the aspect ratio, volume fraction, curvature, relationship between the mechanical properties of the particles and those of the matrix, and by the nature of the matrix/particle interface. Although there is a close similarity between the wavy form of natural fibers and that of nanotubes, the results reported in the literature on the effects of waviness on the mechanical properties of the nanotubes reinforced composite are by no means extensible to the case of biocomposites as they have values of the key parameters that are quite different. Totally dissimilar are not just the size of the fibers, which differ from several orders of magnitude, but also the volume fraction, the stiffness and so on.

In order to make a contribution to the development of a relatively simple tool that allows the experimenter to evaluate the effects of the wavy form of natural fibers on the longitudinal rigidity of a unidirectional biocomposite with long fibers, a numerical model based on the finite elements method was developed that, approximating the fiber form with a sinusoidal shape, allows to evaluate the influence of the waviness on the stiffness of the biocomposite. Later experimental tests carried out considering a biocomposite reinforced with long fibers of sisalan agave, confirmed the accuracy of the numerical predictions for different values of the key parameters such as volume concentration and waviness.