Materials and Design 76 (2015) 55–63

Contents lists available at ScienceDirect

Materials and Design

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

Determination of in-plane elastic properties of rice husk composite

Petch Jearanaisilawong [a,*], Shayanin Eahkanong [a], Bundit Phungsara [a], Anchalee Manonukul [b]

[a] Department of Mechanical and Aerospace Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok, 1518 Pracharat 1 Rd., Wongsawang, Bangsue, Bangkok 10800, Thailand
[b] National Metal and Materials Technology Center, National Science and Technology Development Agency, 114 Thailand Science Park, Paholyothin Rd., Klong 1, Klong Luang, Pathumthani 12120, Thailand

ARTICLE INFO

Article history:
Received 2 July 2014
Revised 16 March 2015
Accepted 22 March 2015
Available online 24 March 2015

Keywords:
Short fiber composite
Rice husk
Fiber orientation distribution
Mori–Tanaka model

ABSTRACT

An approach to evaluate macroscopic elastic properties of rice husk composite from its morphology is demonstrated. Hard shells of rice husks were used as a low-cost reinforcing agent in thin polypropylene sheet. Composite samples containing 5–20% mass fractions of rice husks were formed by compression molding, and the orientation distributions of rice husks in the samples were evaluated from micrographs of the composite structure. Effective elastic properties of the composite were calculated from the Mori–Tanaka model that includes the effect of reinforcement orientation. The homogeneous Mori–Tanaka model was benchmarked against an equivalent composite model using explicit modeling of the reinforcements in a finite element simulation; good agreement between the in-plane moduli of the two models was confirmed. Predictive capabilities of the Mori–Tanaka model were demonstrated by matching the model responses to the composite response under uniaxial tensile tests and four-point bending tests. Predicted effective axial moduli compared favorably with the experimental values. However, discrepancy exists in the predicted flexural moduli due to the shortcoming of the Mori–Tanaka model in capturing the out-of-plane response. The comparisons show that the proposed approach is adaptable to predict the in-plane anisotropic elastic properties of compression-molded rice husk reinforced polypropylene composite.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Rice husks are hard empty shells of rice grains available as a byproduct from rice milling. They are currently utilized in a wide range of applications such as animal feeds, an ingredient in fertilizers and biofuels, and a reinforcing component in concrete and building materials. Interests have expanded to using dried rice husks as a reinforcing agent in polymer composites [1–8]. Manufacturing of rice husk polymer composite consists of mixing raw rice husks and coupling agent with polymers, such as polypropylene [1–6], epoxy resin [7], or elastomers [8], and forming the mixture into products using standard forming techniques such as extrusion, injection and compression molding. Current literature is focused on evaluation of effective properties of rice husk composite using standard techniques such as tension, flexure and fracture tests. Parameters that can influence composite properties, including volume fraction of rice husks [1,3], temperature during deformation [3], compatibilizing agents [4], manufacturing processes [5], type of filler [2,6], and matrices [7,8], have been analyzed.

Alternatively, properties of the rice husk composite can be analytically evaluated using constitutive models for short fiber reinforced polymer (SFRP) that take into account both the geometrical and mechanical properties of the constituents. These models employ the concept of homogenization where a non-uniform composite structure is idealized as an equivalent continuum medium. A pioneer approach by Hill [9], known as the self-consistent micromechanics model, was developed for an elastic isotropic matrix reinforced by perfectly aligned isotropic cylindrical fibers. This composite exhibited a transversely isotropic response along the fiber direction, and its elastic constants were derived from the volume fraction and arrangement of the fibers. Bonding between the fibers and the matrix was assumed to be rigid, and any interactions between fibers were neglected. For the special cases of spheroidal or ellipsoidal fibers, the self-consistent model could be expressed in a closed form in accordance with the analysis of Eshelby's inclusion [10]. Following the framework of the self-consistent model, Mori and Tanaka [11] introduced a fourth-order texture tensor that related an averaged strain of the ellipsoid inclusion to that of the matrix. The coefficients in the texture tensor were

---

[*] Corresponding author.
E-mail address: petchj@kmutnb.ac.th (P. Jearanaisilawong).

http://dx.doi.org/10.1016/j.matdes.2015.03.042
0261-3069/© 2015 Elsevier Ltd. All rights reserved.

determined from the aspect ratio of the inclusion and the Poisson's ratio of the matrix. The Mori–Tanaka (MT) model had been shown to accurately predict the effective properties of the composite particularly when reinforcing fibers are either randomly aligned or in perfect alignment along one preferential direction.

Ferrari and Johnson [12] proposed an expansion of the MT model that included the effect of fiber orientation by a weighted average integration of the composite stiffness with respect to a spherical harmonics of the orientation distribution function (ODF). Ferrari and Johnson demonstrated that this model yielded an isotropic response for isotropic fibers embedded in an isotropic matrix regardless of the fiber shapes and orientation distributions. Ferrari [13] further proved that the MT model will result in physically unacceptable predictions if the contribution of the matrix was neglected. The MT model would yield a symmetric stiffness tensor for certain combinations of matrix and fibers, namely (1) a random orientation distribution of the fibers, (2) unidirectional alignment of the fibers, (3) isotropic fibers, and (4) spherical fibers. For anisotropic fiber orientation distributions, Ferrari showed that the MT model would have a non-symmetrical stiffness tensor that led to instability in the model response. Marzari and Ferrari [14] analyzed the dependence of effective moduli of textured composites on the geometry and orientation distribution of fibers. In particular, the Ferrari and Johnson model was used to predict the elastic properties of an ideal composite with disk-shaped and cylindrical fibers at fixed concentration levels. Nadeau and Ferrari [15] provided a set of theoretical boundaries on the coefficients of the texture tensor as well as a necessary and sufficient condition for the normalization of the ODF. Schjødt-Thomsen and Pyrz [16] derived an alternative Mori–Tanaka-based model with a symmetric stiffness tensor. Their approach utilized a direct integration of the stiffness tensor with respect to an orientation distribution of fibers instead of an integration of the texture tensor as employed by Ferrari [13]. The model capability was demonstrated for a two dimensional ODF represented by a two-parameter probability distribution function.

Incorporation of material anisotropy from the orientation distribution of material texture into the constitutive models has been demonstrated in a number of applications, including modeling mono-crystals in metallic matrices [17,18], short fiber reinforced polymers [19], clay particle composite [20], and biological materials such as bones [21] and skins [22]. However, such approach has not been applied to rice husk reinforced composite due to its recent emergence to the industry.

Challenges in the property evaluation of rice husk composite still remain. The mechanical response of this composite can depend on geometrical and mechanical properties of reinforcing agents, properties of the matrix, and morphological properties such as volume or mass fraction and orientation distribution of the reinforcing agents. For the processes with known flow characteristics of the composite melts, such as extrusion and injection molding, the alignment of the reinforcements are determinable from the preferential flow direction. However, the rice husks reinforced composites produced by compression molding do not have a predefined flow pattern, leading to an indeterminate scattering pattern of the reinforcements. Consequently, the effective properties of the composite are measureable after the forming process.

The objective of this work is to develop an approach to evaluate anisotropic effective elastic properties of compression-molded rice husk polypropylene composite from the properties of the constituents and the orientation of the reinforcements. The properties are evaluated from the homogeneous Mori–Tanaka model with an incorporation of orientation distribution of reinforcements. All input data for the model are obtained via a set of standard measurements, such as uniaxial testing on the composite constituents, and characterization of composite structure using an in-house image processing code. The calculated effective properties from the homogeneous Mori–Tanaka model are benchmarked with the values obtained from finite element models with explicit modeling of reinforcements. The theoretical predictions of the elastic properties of the composite, particularly in-plane axial moduli and flexural moduli, are validated with the experimentally measured values.

2. Material preparation and characterization

2.1. Characterization of rice husks

Rice husks are short hollowed shells of rice grains. After the milling process, the rice husks were sun-dried in an open field before storage. The Thai Jasmine rice husks obtained from a local mill were further dried in an oven at 100 °C for 24 h prior to measurements and stored in a desiccant in a sealed container. Under close inspection, a number of rice husks appeared cracked or clipped from the milling process. Fig. 1 shows an example of a full shell, partially cracked rice husk. The dimensions of Thai Jasmine rice husks were measured by image processing software. The averaged length (l) and the averaged width (w) of 264 randomly selected husks are 7.14 ± 1.68 mm and 1.24 ± 0.27 mm, respectively. The averaged aspect ratio (l/w) of the undamaged rice husks is 5.76. The morphology and dimensions of the Thai Jasmine rice husks are in line with similar data of intact rice husks in [1].

Even though rice husks are used as filler in a number of composites, data remains limited for key mechanical properties of rice husks, such as tensile modulus and tensile strength. Here, tensile properties of rice husks were measured by performing uniaxial loading tests along the grain of the rice husks. A tensile test sample was prepared by gluing both ends of a damage-free rice husk with a high strength epoxy to extension pieces that fitted the tensile grips. The thickness and the end-to-end initial length of the rice husk sample were measured using a micrometer. The sample was then loaded in a universal testing machine with a 10 N load cell at a speed of 0.5 mm/s until failure. Stress–strain curves of the rice husks are plotted against the average of all tests in Fig. 2. Because the husks exhibit a linear response to failure, they are modeled by a linear isotropic material with an average Young's modulus of 2525.33 MPa. Noted difference in Young's modulus and tensile strength of rice husks can be attributed to natural variations in the microstructure of rice husks and possible internal damage from the sample preparation process.

2.2. Characterizations of rice husks reinforced composite

The rice husks were blended with polypropylene pallets and a compatibilizing agent, Polypropylene-graft-maleic anhydride, in a

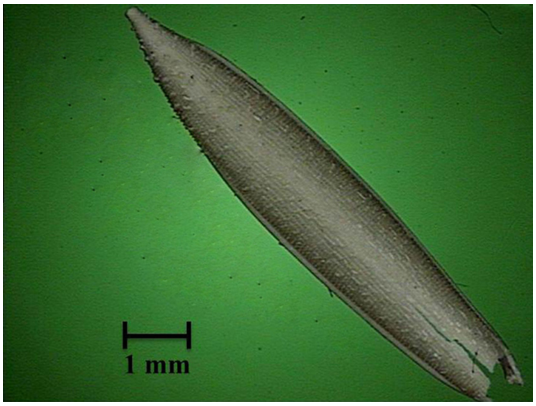

Fig. 1. A rice husk sample.

Download English Version:

https://daneshyari.com/en/article/828605

Download Persian Version:

https://daneshyari.com/article/828605

Daneshyari.com