Computational Materials Science 79 (2013) 25–30

Contents lists available at SciVerse ScienceDirect

Computational Materials Science

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

A virtual frame work for predication of effect of voids on transverse elasticity of a unidirectionally reinforced composite

H. Nikopour *

Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, QC H3A 2K6, Canada

ARTICLE INFO

Article history:
Received 4 April 2013
Received in revised form 15 May 2013
Accepted 27 May 2013
Available online 28 June 2013

Keywords:
Elasticity
Representative area element
Composites
Air void

ABSTRACT

This paper introduces a powerful computational technique to study micro-mechanics of composites, particularly, it examines effect of air voids in evaluation of the effective transverse elasticity properties of a unidirectionally reinforced composite. A computational Representative Area Element (RAE) simulation of patterned fibre and void arrangement is used to derive the effective transverse elasticity properties of a transversely isotropic composite. The computational estimates for the elastic constants are found to be in reasonable agreement with typical theoretical estimates for multiphase materials.

1. Introduction

Fibre reinforced polymer (FRP) materials are extensively used in various engineering applications [1–4]. The transverse mechanical behaviour of a unidirectionally reinforced element represents the weakest link in the load transfer capabilities of the composite and thus merits detailed attention, in terms of the evaluation of its deformability, damage initiation and fracture [5–7]. The mechanics of fibre reinforced materials under conditions of damage is less well understood in comparison to the significant progress that has been made in the modelling and experiments involving defect free composite materials [8]. Damage in fibre-reinforced composites can take place at various scales ranging from matrix cracking, matrix yield, fibre fracture and interface debonding depending upon the types of mechanical and environmental loads that can be applied to the composite during use (Fig. 1). The importance of damage to the structural integrity of fibre-reinforced materials was discussed several decades ago by a number of researchers including [9–11].

In this paper, we estimate the transverse elasticity properties of a unidirectionally reinforced polyester–carbon fibre composite with a constant fibre volume fraction and with/without air void. The computational modelling is performed using the general purpose finite element code ABAQUS™. The Representative Area Element (RAE) is subjected to various modes of homogeneous straining and the computational estimates for the strain energy are used to compute the effective elasticity properties of the composite with a patterned fibre and air void arrangement.

2. Theoretical estimates

Several theoretical models have been proposed in the literature for estimating the elasticity properties of unidirectionally reinforced multiphase composites. Extensive accounts of these developments can be found in the texts and articles by Hill [12], Hashin and Rosen [13], Halpin and Tsai [14], Whitney and Riley [15], Sideridis [16], Sun and Vaidya [17], Afonso and Ranalli [18], and Cohen and Ishai [19]. In this paper, computational results were compared with Hashin and Rosen [13] theoretical estimates which are based on variational approach. It should be noted that the model for the composite used by Hashin and Rosen [13] assumes that the fibres are surrounded by a matrix material, thereby ensuring non-contiguity between adjacent fibres. It should also be noted that when the axis of symmetry of the transversely isotropic elastic material is aligned with the fibre direction, five independent elastic constants are necessary and sufficient to characterise the complete linear elastic behaviour. Other elasticity properties can be related to these five independent parameters using theory of transversely isotropic materials [20,21].

3. Computational modelling

The main objective of the research was to develop a geometric model of the fibre and air voids arrangement in the composite to computationally estimate the effective transverse elasticity properties.

* Tel.: +1 514 398 2424; fax: +1 514 398 7361.
E-mail address: hasan.nikopourdeilami@mail.mcgill.ca

0927-0256/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.commatsci.2013.05.049

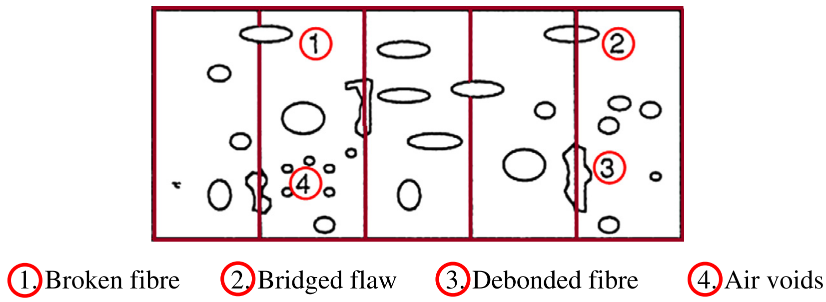

Fig. 1. Possible manufacturing flaws in composite materials.

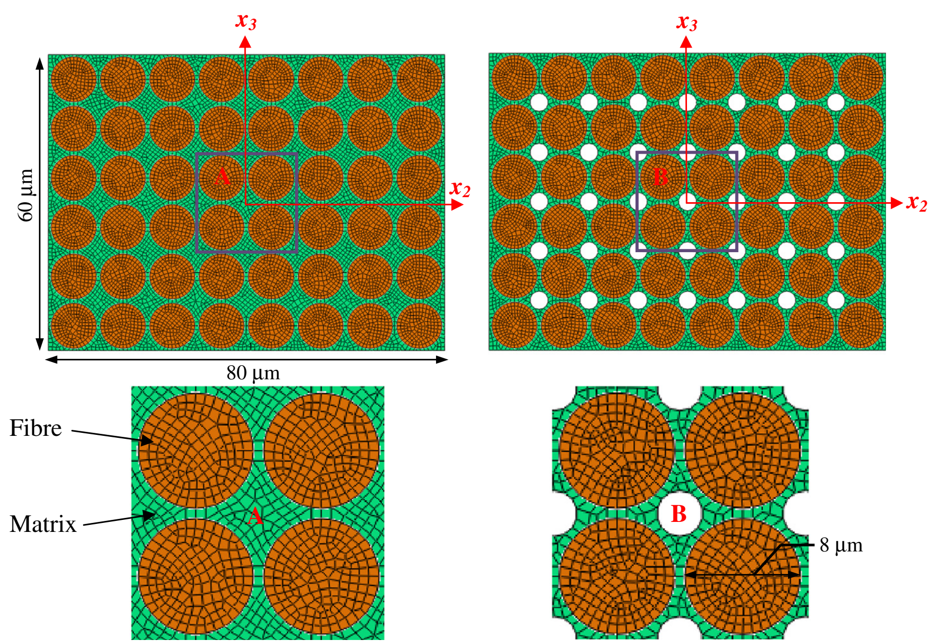

Fig. 2. FEM computational models for identification of transverse properties of (a) RAE with no void [number of elements: 3231, element type: 4-node bilinear quadrilateral], (b) RAE with air voids [number of elements: 2973, element type: 4-node bilinear quadrilateral], (c) finite element mesh detail at A and (d) finite element mesh detail at B.

3.1. Finite element models

The computational modelling was performed using the ABAQUS™ software. Finite element models of the representative area elements were constructed (Fig. 2) and these elemental regions were subjected to appropriate states of homogeneous strain to estimate, through energy equivalence, the effective elasticity properties of the composite. These computational estimates for the effective elasticity properties for unidirectionally fibre-reinforced composites with patterned fibre and void arrangement were then compared with Hashin and Rosen analytical estimates [13]. RAEs considered in this study had an identical fibre area fraction of 66% and different air void ratio of 0% and 8%, respectively.

Transverse properties, including the plane strain bulk modulus, K_{23}; the plane strain shear modulus, G_{23}; the transverse Young's modulus, E_{22}, and Poisson's ratio, ν_{23}, were identified using two-dimensional plane strain models. Discretizations of two-dimensional models were performed using the standard 4-node bilinear quadrilateral element available in ABAQUS™ (CPS4R). A convergence study was conducted to determine if the mesh size of the final model provided accurate results and whether or not there should be continued mesh refinement, or coarser meshes to reduce the computing time during analysis. The focus of the research was on the effect of air voids, hence, perfect bonding between the matrix and fibres was assumed and other damage effects that can result from matrix cracking, debonding at the fibre–matrix interface, and transverse cracking of fibres were not considered in these models. The fibres and the matrix were modelled as isotropic materials having elastic constants indicated in Table 1. Details of boundary conditions and constraints for identification of each transverse elasticity property, along with the energy density equation for a homogenous transversely isotropic section under the same boundary conditions and constraints, are presented in the following sections. Stress and strain distributions were achieved and the strain energy density of the Representative Area Element (RAE) was calculated using the general equation for arbitrary heterogeneous isotropic materials [22].

Table 1
Mechanical properties of resin matrix and fibre.

Property	Specific gravity	Tensile strength (MPa)	Tensile Young's modulus (GPa)	Ultimate tensile strain (%)	Poisson's ratio
Resin	1.20	78.6	3.1	3.4	0.35
Fibre	1.81	2450.4	224.4	1.6	0.20