Computational Materials Science 138 (2017) 77–91

Contents lists available at ScienceDirect

Computational Materials Science

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

Numerical analysis of thermal expansion behaviors and interfacial thermal stress of 3D braided composite materials

Hailou Wang, Miao Cao, Amna Siddique, Baozhong Sun, Bohong Gu *

College of Textiles, Donghua University, Shanghai 201620, China

ARTICLE INFO

Article history:
Received 6 April 2017
Received in revised form 14 June 2017
Accepted 19 June 2017

Keywords:
3D braided composite materials
Thermal expansion
Interfacial stress
Finite element method (FEM)

ABSTRACT

The objective of this investigation is to analyze the thermal expansion behaviors and interfacial thermal stress of 3D braided carbon/epoxy composite materials in various temperature fields ranging from −100 °C to 140 °C. Two geometrical structure models, microstructure model and multi-unit cell model were established to investigate the thermo-mechanical behaviors of the 3D braided composites. The microstructure model has revealed the effect of braiding angle on the thermal expansion behaviors, interfacial stress and distribution. The multi-unit cell model was developed to analyze the nonlinear change of axial coefficient of thermal expansion (CTE) with braiding angle. We found that the interfacial normal thermal stress between braided yarns and resin increases with the braiding angle. The axial thermal strain exhibits thermal shrinkage for a small braiding angle and thermal expansion for a large braiding angle at high temperature. The critical braiding angle was found at which the axial CTE transited from negative to positive, i.e., the zero thermal expansion coefficient braided composite materials could be designed.

1. Introduction

Three-dimensional (3D) braided composite materials exhibit better mechanical performance in terms of microstructure integrity than laminated composites [1]. 3D braided composites have received a great attention and could be used in some specific conditions such as the cryogenic environment, when they will encounter the problem of thermal expansion [2].

Some attention has been paid to investigate the temperature effect on the mechanical properties of 3D braided composites [3–8], for example, in thermo-mechanical behaviors [9–14] and also in thermal expansions [11,12]. The studies on thermal expansion behaviors of 3D braided composites are few.

Furthermore, the above mentioned studies on thermal expansion behaviors were only performed on the unit-cell level, which cannot reveal the internal mechanisms, especially the interface behaviors. The incompatibility of thermal expansion between two phases will generate thermal stress at the interface, which may cause or aggravate the interfacial failure. Therefore, the interfacial thermal stress and its distribution also need to be further studied.

In numerical studies, representative volume cell model [15], unit-cell model [16,17], multi-scale model [18] and structure model [19] were often employed to analyze the 3D braided composites. Through taking advantage of each model's strengths, the 3D braided composites' thermo-mechanical properties can be broader and deeper studied.

Here we numerically analyzed the microstructure effect of 3D braided composites on the thermal expansion and interfacial thermal stress based on microstructure model and a new multi-unit cell model. Both models were validated and the internal mechanisms for thermal expansion of 3D braided composites were found. In addition, the interfacial thermal stress and its distribution at high and low temperatures were also investigated. The changes of thermal expansion coefficient with braiding angle were also analyzed and the critical braiding angle at which the axial thermal expansion coefficient is zero was found.

2. Modeling approach

The three-dimensional braided structure can be physically produced with 4-step 1×1 braiding method in yarn array of 10×10 as shown in Fig. 1. Two modeling approaches were developed as shown in Fig. 2. Method I is the microstructure model, and method II is the multi-unit cell model (MUCM). The microstructure model was aimed to reveal the internal mechanisms for thermal expansion and the distribution of interfacial thermal stress. The microstructure model was performed by finite element method. The MUCM was aimed to obtain the relationship between thermal expansion coefficient and braiding angle. In addition, compared

* Corresponding author.
E-mail address: gubh@dhu.edu.cn (B. Gu).

http://dx.doi.org/10.1016/j.commatsci.2017.06.023
0927-0256/

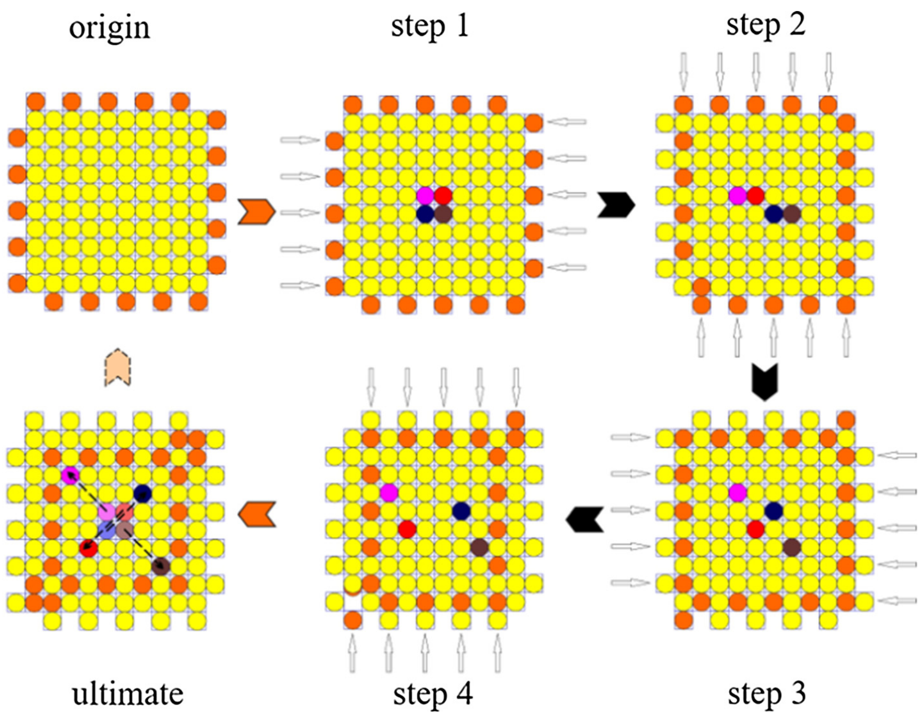

Fig. 1. Braiding process.

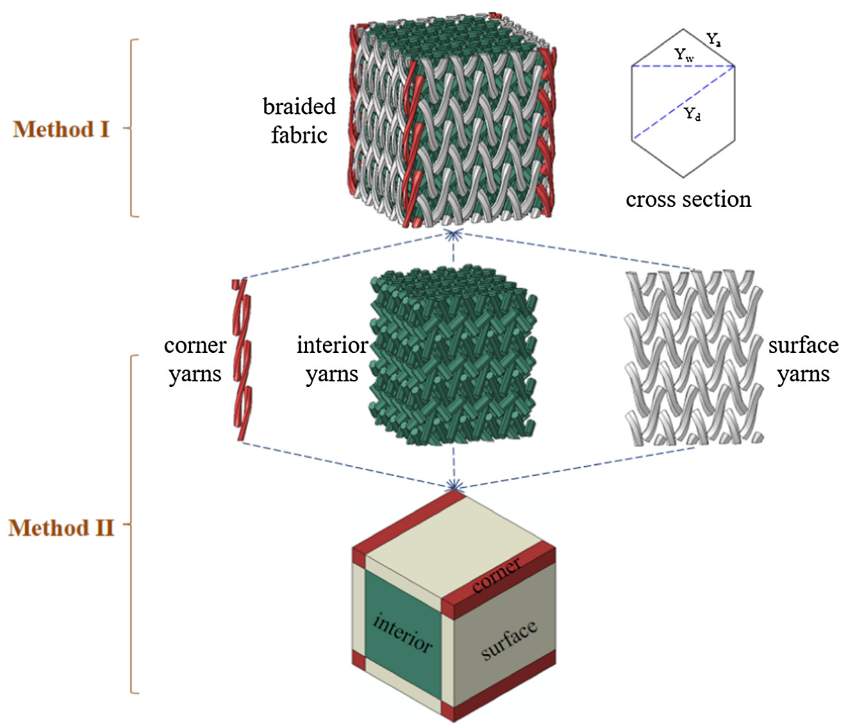

Fig. 2. Demonstration of microstructure model and MUCM approaches.

with the microstructure model, the MUCM is time-saving and more convenient to be applied in the practical applications.

2.1. Geometric model

The geometric model of 3D braided composites for the microstructure model was established based on the real structure as shown in Fig. 2. The braided preform is composed of three parts: interior yarns, surface yarns and corner yarns. The cross section shape of yarn is assumed as hexagon which can make the adjacent faces among yarns parallel. The resin matrix is cut from the geometric model of the braided preform. The geometric parameters for the hexagon section are derived as follows:

$$Y_a = V(y) \times \frac{\sqrt{1+\cot^2\alpha}}{4\sqrt{2+\cot^2\alpha}} W$$

$$Y_w = V(y) \times \frac{\sqrt{2}}{4} W$$